Cortex™-R4 and Cortex-R4F

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Technical Reference Manual

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Cortex-R4 and Cortex-R4F
Technical Reference Manual

Release Information

The following changes have been made to this book.

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Preface

This preface introduces the *Cortex-R4 and Cortex-R4F Technical Reference Manual*. It contains the following sections:

About this book

This is the *Technical Reference Manual* (TRM) for the *Cortex-R4 and Cortex-R4F* processors. In this book the generic term processor means both the Cortex-R4 and Cortex-R4F processors. Any differences between the two processors are described where necessary.

Note

The Cortex-R4F processor is a Cortex-R4 processor that includes the optional *Floating Point Unit* (FPU) extension, see *Product revision information* on page 1-24 for more information.

In this book, references to the Cortex-R4 processor also apply to the Cortex-R4F processor, unless the context makes it clear that this is not the case.

Product revision status

The r*n*p*n* identifier indicates the revision status of the product described in this book, where:

r*n* Identifies the major revision of the product.

p*n* Identifies the minor revision or modification status of the product.

Intended audience

This book is written for system designers, system integrators, and programmers who are designing or programming a *System-on-Chip* (SoC) that uses the processor.

Using this book

This book is organized into the following chapters:

Chapter 1 *Introduction*

Read this for an introduction to the processor and descriptions of the major functional blocks.

Chapter 2 *Programmer's Model*

Read this for a description of the processor registers and programming information.

Chapter 3 *Processor Initialization, Resets, and Clocking*

Read this for a description of clocking and resetting the processor, and the steps that the software must take to initialize the processor after reset.

Chapter 4 *System Control Coprocessor*

Read this for a description of the system control coprocessor registers and programming information.

Chapter 5 *Prefetch Unit*

Read this for a description of the functions of the *Prefetch Unit* (PFU), including dynamic branch prediction and the return stack.

Chapter 6 *Events and Performance Monitor*

Read this for a description of the *Performance Monitoring Unit* (PMU) and the event bus.

Chapter 7 *Memory Protection Unit*

Read this for a description of the *Memory Protection Unit* (MPU) and the access permissions process.

Chapter 8 *Level One Memory System*

Read this for a description of the Level One (L1) memory system.

Chapter 10 *Power Control*

Read this for a description of the power control facilities.

Chapter 11 *Debug*

Read this for a description of the debug support.

Chapter 12 *FPU Programmer's Model*

Read this for a description of the *Floating Point Unit* (FPU) support in the Cortex-R4F processor.

Chapter 13 *Integration Test Registers*

Read this for a description of the Integration Test Registers, and of integration testing of the processor with an ETM-R4 trace macrocell.

Chapter 15 *AC Characteristics*

Read this for a description of the timing parameters applicable to the processor.

Chapter 14 *Cycle Timings and Interlock Behavior*

Read this for a description of the instruction cycle timing and instruction interlocks.

Appendix A *Processor Signal Descriptions*

Read this for a description of the inputs and outputs of the processor.

Appendix B *ECC Schemes*

Read this for a description of how to select the *Error Checking and Correction* (ECC) scheme depending on the *Tightly-Coupled Memory* (TCM) configuration.

Appendix C *Revisions*

Read this for a description of the technical changes between released issues of this book.

Glossary Read this for definitions of terms used in this guide.

Conventions

Conventions that this book can use are described in:

- *Typographical*
- *Timing diagrams* on page xix
- *Signals* on page xix.

Typographical

The typographical conventions are:

italic Highlights important notes, introduces special terminology, denotes internal cross-references, and citations.

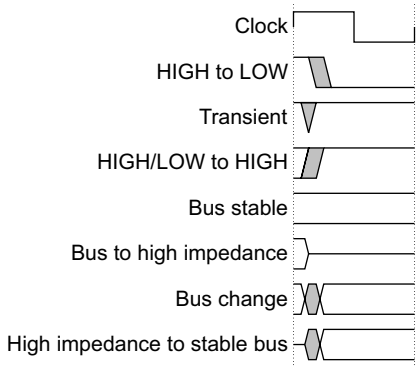
bold Highlights interface elements, such as menu names. Denotes signal names. Also used for terms in descriptive lists, where appropriate.

`monospace`	Denotes text that you can enter at the keyboard, such as commands, file and program names, and source code.
`mono`space	Denotes a permitted abbreviation for a command or option. You can enter the underlined text instead of the full command or option name.
`monospace italic`	Denotes arguments to monospace text where the argument is to be replaced by a specific value.
`monospace bold`	Denotes language keywords when used outside example code.
< and >	Enclose replaceable terms for assembler syntax where they appear in code or code fragments. For example: `MRC p15, 0 <Rd>, <CRn>, <CRm>, <Opcode_2>`

Timing diagrams

The figure named *Key to timing diagram conventions* explains the components used in timing diagrams. Variations, when they occur, have clear labels. You must not assume any timing information that is not explicit in the diagrams.

Shaded bus and signal areas are undefined, so the bus or signal can assume any value within the shaded area at that time. The actual level is unimportant and does not affect normal operation.



Key to timing diagram conventions

Signals

The signal conventions are:

Signal level	The level of an asserted signal depends on whether the signal is active-HIGH or active-LOW. Asserted means: • HIGH for active-HIGH signals • LOW for active-LOW signals.
Lower-case n	At the start or end of a signal name denotes an active-LOW signal.
Prefix A	Denotes global *Advanced eXtensible Interface* (AXI) signals.
Prefix AR	Denotes AXI read address channel signals.
Prefix AW	Denotes AXI write address channel signals.
Prefix B	Denotes AXI write response channel signals.
Prefix P	Denotes Advanced Peripheral Bus (APB) signals.

Prefix R	Denotes AXI read data channel signals.
Prefix W	Denotes AXI write data channel signals.

Further reading

This section lists publications by ARM and by third parties.

See `http://infocenter.arm.com` for access to ARM documentation.

ARM publications

This book contains information that is specific to the processor. See the following documents for other relevant information:

- *AMBA® AXI Protocol Specification* (ARM IHI 0022)
- *AMBA 3 APB Protocol Specification* (ARM IHI 0024)
- *ARM Architecture Reference Manual, ARMv7-A and ARMv7-R edition* (ARM DDI 0406)
- *ARM PrimeCell® Vectored Interrupt Controller (PL192) Technical Reference Manual* (ARM DDI 0273)
- *Cortex-R4 and Cortex-R4F Integration Manual* (ARM DII 0130)
- *Cortex-R4 and Cortex-R4F Configuration and Sign-off Guide* (ARM DII 0185)
- *CoreSight™ DAP-Lite Technical Reference Manual* (ARM DDI 0316)
- *CoreSight ETM-R4 Technical Reference Manual* (ARM DII 0367)
- *RealView™ Compilation Tools Developer Guide* (ARM DUI 0203)
- *Application Note 98, VFP Support Code* (ARM DAI 0098)
- *Application Note 204, Understanding processor memory types and access ordering* (ARM DAI 0204).

Other publications

This section lists relevant documents published by third parties:

- ANSI/IEEE Std 754-1985, *IEEE Standard for Binary Floating-Point Arithmetic*
- JEP106M, *Standard Manufacture's Identification Code, JEDEC Solid State Technology Association*.

Feedback

ARM welcomes feedback on this product and its documentation.

Feedback on this product

If you have any comments or suggestions about this product, contact your supplier and give:

- The product name.
- The product revision or version.
- An explanation with as much information as you can provide. Include symptoms if appropriate.

Feedback on this book

If you have any comments on this book, send an e-mail to `errata@arm.com`. Give:

- the title
- the number
- the relevant page number(s) to which your comments apply
- a concise explanation of your comments.

ARM also welcomes general suggestions for additions and improvements.

Chapter 1
Introduction

This chapter introduces the processor and its features. It contains the following sections:

1.1 About the processor

The processor is a mid-range CPU for use in deeply-embedded systems.

The features of the processor include:

- An integer unit with integral EmbeddedICE-RT logic.
- High-speed *Advanced Microprocessor Bus Architecture* (AMBA) *Advanced eXtensible Interfaces* (AXI) for Level two (L2) master and slave interfaces.
- Dynamic branch prediction with a global history buffer, and a 4-entry return stack.
- Low interrupt latency.
- Non-maskable interrupt.
- Optional *Floating Point Unit* (FPU). The Cortex-R4F processor is a Cortex-R4 processor that includes the FPU.
- A Harvard Level one (L1) memory system with:
  - optional *Tightly-Coupled Memory* (TCM) interfaces with support for error correction or parity checking memories
  - optional caches with support for optional error correction schemes
  - optional ARMv7-R architecture *Memory Protection Unit* (MPU)
  - optional parity and *Error Checking and Correction* (ECC) on all RAM blocks.
- The ability to implement and use redundant core logic, for example, in fault detection.
- An L2 memory interface:
  - single 64-bit master AXI interface
  - 64-bit slave AXI interface to TCM RAM blocks and cache RAM blocks.
- A debug interface to a CoreSight *Debug Access Port* (DAP).
- A trace interface to a CoreSight ETM-R4.
- A *Performance Monitoring Unit* (PMU).
- A *Vectored Interrupt Controller* (VIC) port.

1.2 About the architecture

The processor implements the ARMv7-R architecture and ARMv7 debug architecture. In addition, the Cortex-R4F processor implements the VFPv3-D16 architecture. This includes the VFPv3 instruction set.

The ARMv7-R architecture provides 32-bit ARM and 16-bit and 32-bit Thumb instruction sets, including a range of *Single Instruction, Multiple-Data* (SIMD) *Digital Signal Processing* (DSP) instructions that operate on 16-bit or 8-bit data values in 32-bit registers.

See the *ARM Architecture Reference Manual, ARMv7-A and ARMv7-R edition* for more information on the:

- ARM instruction set and Thumb instruction set
- ARMv7 debug architecture
- VFPv3 instruction set.

1.3 Components of the processor

This section describes the main components of the processor:

- *Data Processing Unit* on page 1-5
- *Load/store unit* on page 1-5
- *Prefetch unit* on page 1-5
- *L1 memory system* on page 1-5
- *L2 AXI interfaces* on page 1-7
- *Debug* on page 1-8
- *System control coprocessor* on page 1-9
- *Interrupt handling* on page 1-9.

Figure 1-1 shows the structure of the processor.

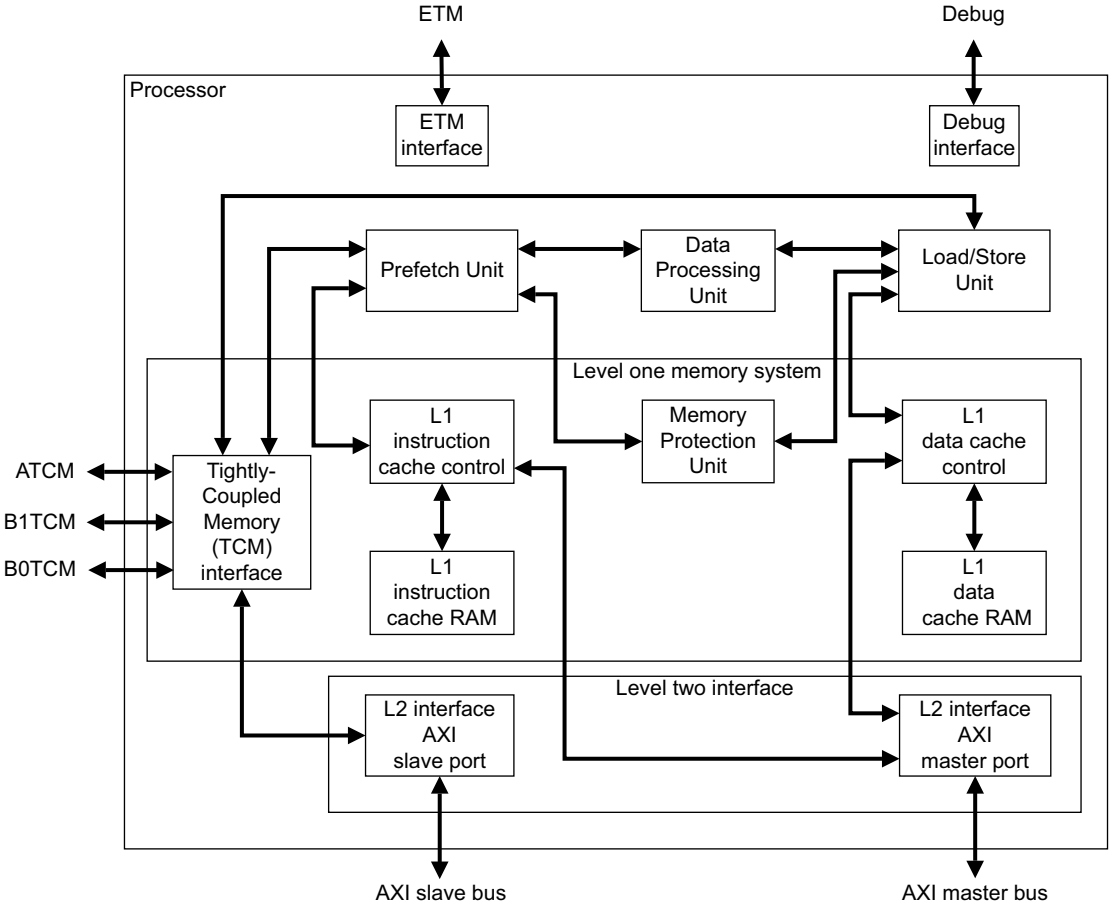


Figure 1-1 Processor block diagram

The *PreFetch Unit* (PFU) fetches instructions from the memory system, predicts branches, and passes instructions to the *Data Processing Unit* (DPU). The DPU executes all instructions and uses the *Load/Store Unit* (LSU) for data memory transfers. The PFU and LSU interface to the L1 memory system that contains L1 instruction and data caches and an interface to a L2 system. The L1 memory can also contain optional TCM interfaces.

1.3.1 Data Processing Unit

The DPU holds most of the program-visible state of the processor, such as general-purpose registers, status registers and control registers. It decodes and executes instructions, operating on data held in the registers in accordance with the ARM Architecture. Instructions are fed to the DPU from the PFU through a buffer. The DPU performs instructions that require data to be transferred to or from the memory system by interfacing to the LSU. See Chapter 2 *Programmer's Model* for more information.

Floating Point Unit

The *Floating Point Unit* (FPU) is an optional part of the DPU which includes the VFP register file and status registers. It performs floating-point operations on the data held in the VFP register file. See Chapter 12 *FPU Programmer's Model* for more information.

1.3.2 Load/store unit

The LSU manages all load and store operations, interfacing with the DPU to the TCMs, caches, and L2 memory interfaces.

1.3.3 Prefetch unit

The PFU obtains instructions from the instruction cache, the TCMs, or from external memory and predicts the outcome of branches in the instruction stream. See Chapter 5 *Prefetch Unit* for more information.

Branch prediction

The branch predictor is a global type that uses history registers and a 256-entry pattern history table.

Return stack

The PFU includes a 4-entry return stack to accelerate returns from procedure calls. For each procedure call, the return address is pushed onto a hardware stack. When a procedure return is recognized, the address held in the return stack is popped, and the prefetch unit uses it as the predicted return address.

1.3.4 L1 memory system

The processor L1 memory system includes the following features:

- separate instruction and data caches
- flexible TCM interfaces
- 64-bit datapaths throughout the memory system
- MPU that supports configurable memory region sizes
- export of memory attributes for L2 memory system
- parity or ECC supported on local memories.

For more information of the blocks in the L1 memory system, see:

- *Instruction and data caches* on page 1-6
- *Memory Protection Unit* on page 1-6
- *TCM interfaces* on page 1-6
- *Error correction and detection* on page 1-7.

Instruction and data caches

You can configure the processor to include separate instruction and data caches. The caches have the following features:

- Support for independent configuration of the instruction and data cache sizes between 4KB and 64KB.
- Pseudo-random cache replacement policy.
- 8-word cache line length. Cache lines can be either write-back or write-through, determined by MPU region.
- Ability to disable each cache independently.
- Streaming of sequential data from `LDM` and `LDRD` operations, and sequential instruction fetches.
- Critical word first filling of the cache on a cache miss.
- Implementation of all the cache RAM blocks and the associated tag and valid RAM blocks using standard ASIC RAM compilers
- Parity or ECC supported on local memories.

Memory Protection Unit

An optional MPU provides memory attributes for embedded control applications. You can configure the MPU to have eight or twelve regions, each with a minimum resolution of 32 bytes. MPU regions can overlap, and the highest numbered region has the highest priority.

The MPU checks for protection and memory attributes, and some of these can be passed to an external L2 memory system.

For more information, see Chapter 7 *Memory Protection Unit*.

TCM interfaces

Because some applications might not respond well to caching, there are two TCM interfaces that permit connection to configurable memory blocks of *Tightly-Coupled Memory* (ATCM and BTCM). These ensure high-speed access to code or data. As an option, the BTCM can have two memory ports for increased bandwidth.

An ATCM typically holds interrupt or exception code that must be accessed at high speed, without any potential delay resulting from a cache miss.

A BTCM typically holds a block of data for intensive processing, such as audio or video processing.

You can individually configure the TCM blocks at any naturally aligned address in the memory map. Permissible TCM block sizes are:

- 0KB
- 4KB
- 8KB
- 16KB
- 32KB
- 64KB
- 128KB
- 256KB

- 512KB
- 1MB
- 2MB
- 4MB
- 8MB.

The TCMs are external to the processor. This provides flexibility in optimizing the TCM subsystem for performance, power, and RAM type. The **INITRAMA** and **INITRAMB** pins enable booting from the ATCM or BTCM, respectively. Both the ATCM and BTCM support wait states.

For more information, see Chapter 8 *Level One Memory System*.

Error correction and detection

To increase the tolerance of the system to soft memory faults, you can configure the caches for either:

- parity generation and error correction/detection
- ECC code generation, single-bit error correction, and two-bit error detection.

Similarly, you can configure the TCM interfaces for:

- parity generation and error detection
- ECC code generation, single-bit error correction, and two-bit error detection.

For more information, see Chapter 8 *Level One Memory System*.

1.3.5 L2 AXI interfaces

The L2 AXI interfaces enable the L1 memory system to have access to peripherals and to external memory using an AXI master and AXI slave port.

AXI master interface

The AXI master interface provides a high bandwidth interface to second level caches, on-chip RAM, peripherals, and interfaces to external memory. It consists of a single AXI port with a 64-bit read channel and a 64-bit write channel for instruction and data fetches.

The AXI master can run at the same frequency as the processor, or at a lower synchronous frequency. If asynchronous clocking is required an external asynchronous AXI slice is required.

AXI slave interface

The AXI slave interface enables AXI masters, including the AXI master port of the processor, to access data and instruction cache RAMs and TCMs on the AXI system bus. You can use this for DMA into and out of the TCM RAMs and for software test of the TCM and cache RAMs.

The slave interface can run at the same frequency as the processor or at a lower, synchronous frequency. If asynchronous clocking is required an external asynchronous AXI slice is required.

Bits in the Auxiliary Control Register and Slave Port Control Register can control access to the AXI slave. Access to the TCM RAMs can be granted to any master, to only privileged masters, or completely disabled. Access to the cache RAMs can be separately controlled in a similar way.

1.3.6 Debug

The processor has a CoreSight compliant *Advanced Peripheral Bus version 3* (APBv3) debug interface. This permits system access to debug resources, for example, the setting of watchpoints and breakpoints.

The processor provides extensive support for real-time debug and performance profiling.

The following sections give an overview of debug:

- *System performance monitoring*
- *ETM interface*
- *Real-time debug facilities*.

System performance monitoring

This is a group of counters that you can configure to monitor the operation of the processor and memory system. For more information, see *About the PMU* on page 6-6.

ETM interface

The *Embedded Trace Macrocell* (ETM) interface enables you to connect an external ETM unit to the processor for real-time code tracing of the core in an embedded system.

The ETM interface collects various processor signals and drives these signals from the processor. The interface is unidirectional and runs at the full speed of the processor. The ETM interface connects directly to the external ETM unit without any additional glue logic. You can disable the ETM interface for power saving. For more information, see the *CoreSight ETM-R4 Technical Reference Manual*.

Real-time debug facilities

The processor contains an EmbeddedICE-RT logic unit to provide real-time debug facilities. It has:

- up to eight breakpoints
- up to eight watchpoints
- a *Debug Communications Channel* (DCC).

Note

The number of breakpoints and watchpoints is configured during implementation, see *Configurable options* on page 1-13.

The EmbeddedICE-RT logic monitors the internal address and data buses. You access the EmbeddedICE-RT logic through a memory-mapped APB interface.

The processor implements the ARMv7 Debug architecture, including the extensions of the architecture to support CoreSight.

To get full access to the processor debug capability, you can access the debug register map through the APBv3 slave port. See Chapter 11 *Debug* for more information on debug.

The EmbeddedICE-RT logic supports two modes of debug operation:

Halt mode On a debug event, such as a breakpoint or watchpoint, the debug logic stops the processor and forces it into debug state. This enables you to examine the internal state of the processor, and the external state of the system, independently from other system activity. When the debugging process completes, the processor and system state are restored, and normal program execution resumes.

Monitor debug mode

On a debug event, the processor generates a debug exception instead of entering debug state, as in halt mode. The exception entry enables a debug monitor program to debug the processor while enabling critical interrupt service routines to operate on the processor. The debug monitor program can communicate with the debug host over the DCC or any other communications interface in the system.

1.3.7 System control coprocessor

The system control coprocessor provides configuration and control of the memory system and its associated functionality. Other system-level operations, such as memory barrier instructions, are also managed through the system control coprocessor.

For more information, see *System control and configuration* on page 4-4.

1.3.8 Interrupt handling

Interrupt handling in the processor is compatible with previous ARM architectures, but has several additional features to improve interrupt performance for real-time applications.

VIC port

The core has a dedicated port that enables an external interrupt controller, such as the ARM PrimeCell *Vectored Interrupt Controller* (VIC), to supply a vector address along with an *Interrupt Request* (IRQ) signal. This provides faster interrupt entry, but you can disable it for compatibility with earlier interrupt controllers.

Note

If you do not have a VIC in your design, you must ensure the **nIRQ** and **nFIQ** signals are asserted, held LOW, and remain LOW until the exception handler clears them.

Low interrupt latency

On receipt of an interrupt, the processor abandons any pending restartable memory operations. Restartable memory operations are the multiword transfer instructions `LDM`, `LDRD`, `STRD`, `STM`, `PUSH`, and `POP` that can access Normal memory.

To minimize the interrupt latency, ARM recommends that you do not perform:

- multiple accesses to areas of memory marked as Device or Strongly Ordered
- SWP operations to slow areas of memory.

Exception processing

The ARMv7-R architecture contains exception processing instructions to reduce interrupt handler entry and exit time:

SRS Save return state to a specified stack frame.

RFE Return from exception using data from the stack.

CPS Change processor state, such as interrupt mask setting and clearing, and mode changes.

1.4 External interfaces of the processor

The processor has the following interfaces for external access:

- *APB Debug interface*
- *ETM interface*
- *Test interface*.

For more information on these interfaces and how they are integrated into the system, see the *AMBA 3 APB Protocol Specification* and the *CoreSight Architecture Specification*.

1.4.1 APB Debug interface

AMBA APBv3 is used for debugging purposes. CoreSight is the ARM architecture for multi-processor trace and debug. CoreSight defines what debug and trace components are required and how they are connected.

Note

The APB debug interface can also connect to a DAP-Lite. For more information on the DAP-Lite, see the *CoreSight DAP-Lite Technical Reference Manual*.

1.4.2 ETM interface

You can connect an ETM-R4 to the processor through the ETM interface. The ETM-R4 provides instruction and data trace for the processor. For more information on how the ETM-R4 connects to the processor, see the *CoreSight ETM-R4 Technical Reference Manual*.

All outputs are driven directly from a register unless specified otherwise. All signals are relative to **CLKIN** unless specified otherwise.

The ETM interface includes these signals:

- an instruction interface
- a data interface
- an event interface
- other connections to the ETM.

See *ETM interface signals* on page A-19 for information about the names of signals that form these interfaces. See *Event bus interface* on page 6-19 for more information about the event bus.

1.4.3 Test interface

The test interface provides support for test during manufacture of the processor using *Memory Built-In Self Test* (MBIST). For more information on the test interface, see *MBIST signals* on page A-21. See the *Cortex-R4 and Cortex-R4F Integration Manual* for information about the timings of these signals.

1.5 Power management

The processor includes several microarchitectural features to reduce energy consumption:

- Accurate branch and return prediction, reducing the number of incorrect instruction fetch and decode operations.
- The caches use sequential access information to reduce the number of accesses to the tag RAMs and to unmatched data RAMs.
- Extensive use of gated clocks and gates to disable inputs to unused functional blocks. Because of this, only the logic actively in use to perform a calculation consumes any dynamic power.

The processor uses four levels of power management:

Run mode This mode is the normal mode of operation where all of the functionality of the processor is available.

Standby mode This mode disables most of the clocks of the device, while keeping the device powered up. This reduces the power drawn to the static leakage current and the minimal clock power overhead required to enable the device to wake up from the Standby mode.

Shutdown mode This mode has the entire device powered down. All state, including cache and TCM state, must be saved externally. The assertion of reset returns the processor to the run state.

Dormant mode The processor can be implemented in such a way as to support Dormant mode. Dormant mode is a power saving mode in which the processor logic, but not the processor TCM and cache RAMs, is powered down. The processor state, apart from the cache and TCM state, is stored to memory before entry into Dormant mode, and restored after exit.

For more information on preparing the Cortex-R4 to support Dormant mode, contact ARM.

For more information on the power management features, see Chapter 10 *Power Control*.

1.6 Configurable options

Table 1-1 shows the features of the processor that can be configured using either build-configuration or pin-configuration. See *Product documentation, design flow, and architecture* on page 1-21 for information about configuration of the processor. Many of these features, if included, can also be enabled and disabled during software configuration.

Table 1-1 Configurable options

Feature	Options	Sub-options	Build-configuration or pin-configuration
Redundant core	Single-core (no redundancy)	-	Build
	Dual-core (redundant)	In-phase clocks Out-of-phase clocks	Build
Instruction cache	No i-cache	-	Build
	i-cache included	No error checking Parity error checking 64-bit ECC error checking	Build
		4KB (4x1KB ways) 8KB (4x2KB ways) 16KB (4x4KB ways) 32KB (4x8KB ways) 64KB (4x16KB ways)	Build
Data cache	No d-cache	-	Build
	d-cache included	No error checking Parity error checking 32-bit ECC error checking	Build
		4KB (4x1KB ways) 8KB (4x2KB ways) 16KB (4x4KB ways) 32KB (4x8KB ways) 64KB (4x16KB ways)	Build
ATCM	No ATCM ports	-	Build and pin
	One ATCM port	No error checking Parity error checking 32-bit ECC error checking 64-bit ECC error checking	Build
		4KB, 8KB, 16KB, 32KB, 64KB, 128KB, 256KB, 512KB, 1MB, 2MB, 4MB, or 8MB	Pin

Table 1-1 Configurable options (continued)

Feature	Options	Sub-options	Build-configuration or pin-configuration
BTCM	No BTCM ports	-	Build and pin
	One BTCM port (B0TCM)	No error checking Parity error checking 32-bit ECC error checking 64-bit ECC error checking	Build
		4KB, 8KB, 16KB, 32KB, 64KB, 128KB, 256KB, 512KB, 1MB, 2MB, 4MB, or 8MB	Pin
	Two BTCM ports (B0TCM and B1TCM)	No error checking Parity error checking 32-bit ECC error checking 64-bit ECC error checking	Build
		2x2KB, 2x4KB, 2x8KB, 2x16KB, 2x32KB, 2x64KB, 2x128KB, 2x256KB, 2x512KB, 2x1MB, 2x2MB, or 2x4MB	Pin
		Interleaved on 64-bit granularity in memory Adjacent in memory	Pin
Instruction endianness	Little-endian	-	Build
	Pin-configured	Little-endian Big-endian	Pin
Floating point (VFP)	No FPU	-	Build
	FPU included[a]	-	
MPU	No MPU	-	Build
	MPU included	8 MPU regions 12 MPU regions	Build
TCM bus parity	No TCM address and control bus parity	-	Build
	TCM address and control bus parity generated	-	
AXI bus parity	No AXI bus parity	-	Build
	AXI bus parity generated/ checked	-	
Breakpoints	2-8 breakpoint register pairs	-	Build
Watchpoints	1-8 watchpoint registers	-	Build
ATCM at reset	Disabled	-	Pin
	Enabled[b]	Base address `0x0` Base address configured	Pin and build

Table 1-1 Configurable options (continued)

Feature	Options	Sub-options	Build-configuration or pin-configuration
BTCM at reset	Disabled	-	Pin
	Enabled[b]	Base address configured Base address `0x0`	Pin and build
Peripheral ID RevAnd field	Any 4-bit value	-	Build
AXI slave interface	No AXI-slave	-	Build
	AXI-slave included	-	
TCM Hard Error Cache	No TCM Hard Error Cache	-	Build
	TCM Hard Error Cache included [c]	-	
Non-Maskable FIQ Interrupt	Disabled (FIQ can be masked by software	-	Pin
	Enabled	-	
Parity type[d]	Odd parity	-	Pin
	Even parity	-	

a. Only available with the Cortex-R4F processor.
b. Only if the relevant TCM port(s) are included.
c. Only if at least one TCM port is included and uses ECC error checking.
d. Only relevant if at least one TCM port is included and uses parity error checking, one of the caches includes parity checking, or AXI or TCM bus parity is included.

Table 1-2 describes the various features that can be pin-configured to be either enabled or disabled at reset. It also shows which CP15 register field provides software configuration of the feature when the processor is out of reset. All of these fields exist in either the system control register, or one of the auxiliary control registers.

Table 1-2 Configurable options at reset

Feature	Options	Register
Exception endianness	Little-endian/big-endian data for exception handling	EE
Exception state	ARM/Thumb state for exception handling	TE
Exception vector table	Base address for exception vectors: `0x00000000`/`0xFFFF0000`	V
TCM error checking	ATCM parity check enable[a]	ATCMPCEN
	BTCM parity check enable, for B0TCM and B1TCM independently [a]	B0TCMPCEN/ B1TCMPCEN
	ATCM ECC check enable[a]	ATCMPCEN
	BTCM ECC check enabled, for B0TCM and B1TCM together[a]	B0TCMPCEN/ B1TCMPCEN

Table 1-2 Configurable options at reset (continued)

Feature	Options	Register
TCM external errors	ATCM external error enable	ATCMECEN
	BTCM external error enable, for B0TCM and B1TCM independently	B0TCMECEN/ B1TCMECEN
TCM load/store-64 (read-modify-write) behavior	ATCM load/store-64 enable[b]	ATCMRMW
	BTCM load/store-64 enable[b]	BTCMRMW

a. Can only be enabled if the appropriate TCM is configured with the appropriate error checking scheme, and the appropriate number of ports
b. Can only be enabled if the appropriate TCM is not configured with 32-bit ECC.

1.7 Execution pipeline stages

The following stages make up the pipeline:

- the Fetch stages
- the Decode stages
- an Issue stage
- the three or four Execution stages.

Figure 1-2 shows the Fetch and Decode pipeline stages of the processor and the pipeline operations that can take place at each stage.

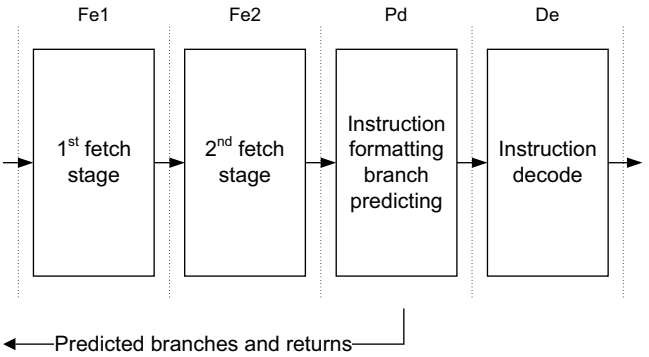


Figure 1-2 Processor Fetch and Decode pipeline stages

The names of the pipeline stages and their functions are:

Fe Instruction fetch where data is returned from instruction memory.

Pd Pre-decode where instructions are formatted and branch prediction occurs.

De Instruction decode.

Figure 1-3 shows the Issue and Execution pipeline stages for the Cortex-R4 processor.

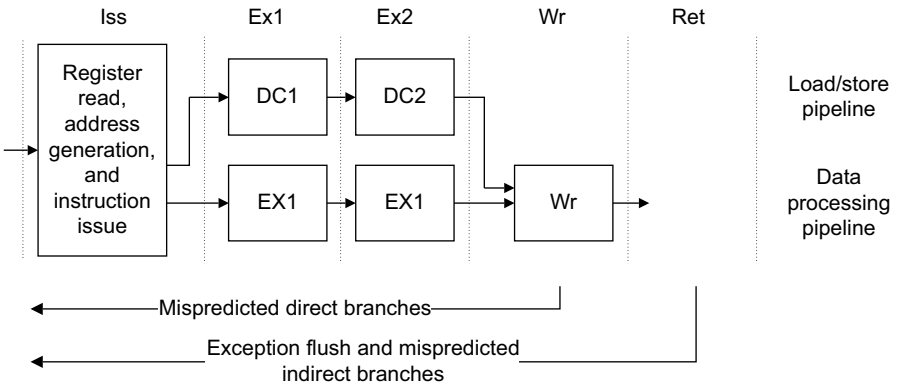


Figure 1-3 Cortex-R4 Issue and Execution pipeline stages

Figure 1-4 on page 1-18 shows the Issue and Execution pipeline stages for the Cortex-R4F processor.

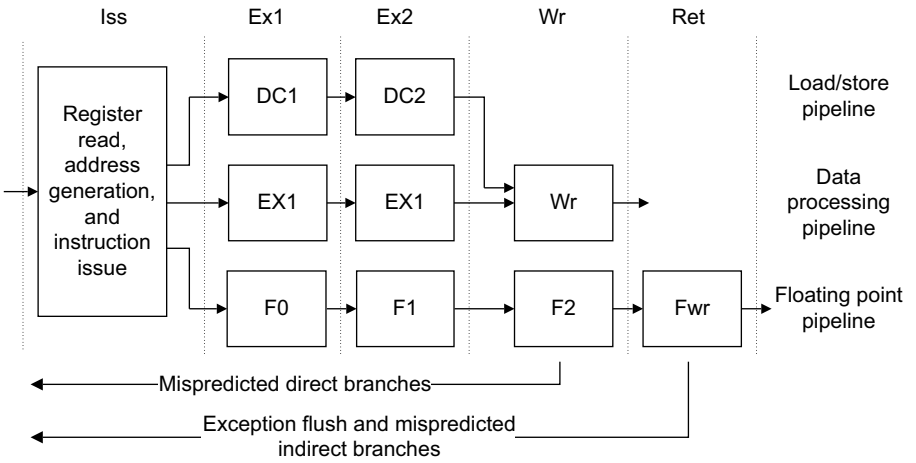


Figure 1-4 Cortex-R4F Issue and Execution pipeline stages

The names of the common pipeline stages and their functions are:

Iss Register read and instruction issue to execute stages.

Ex Execute stages.

Wr Write-back of data from the execution pipelines.

Ret Instruction retire.

The names of the load/store pipeline stages and their functions are:

DC1 First stage of data memory access.

DC2 Second stage of data memory access.

The names of the floating point pipeline stages and their functions are:

F0 Floating point register read.

F1 First stage of floating point execution.

F2 Second stage of floating point execution.

Fwr Floating point writeback.

The pipeline structure provides a pipelined 2-cycle memory access and single-cycle load-use penalty. This enables integration with slow RAM blocks and maintains good CPI at reasonable frequencies.

1.8 Redundant core comparison

The processor can be implemented with a second, redundant copy of most of the logic. This second core shares the input pins and the cache RAMs of the master core, so only one set of cache RAMs is required. The master core drives the output pins and the cache RAMs.

Comparison logic can be included during implementation which compares the outputs of the redundant core with those of the master core. If a fault occurs in the logic of either core, because of radiation or circuit failure, this is detected by the comparison logic. Used in conjunction with the RAM error detection schemes, this can help protect the system from faults. The inputs **DCCMINP[7:0]** and **DCCMINP2[7:0]** and the outputs **DCCMOUT[7:0]** and **DCCMOUT2[7:0]** enable the comparison logic inside the processor to communicate with the rest of the system.

ARM provides example comparison logic, but you can change this during implementation. If you are implementing a processor with dual-redundant cores, contact ARM for more information. If you are integrating a Cortex-R4 macrocell with dual-redundant cores, contact the implementer for more details.

1.9 Test features

The processor is delivered as fully-synthesizable RTL and is a fully-static design. Scan-chains and test wrappers for production test can be inserted into the design by the synthesis tools during implementation. See the relevant reference methodology documentation for more information.

Production test of the processor cache and TCM RAMs can be done through the dedicated, pipelined MBIST interface. This interface shares some of the multiplexing present in the processor design, which improves the potential frequency compared to adding multiplexors to the RAM modules. See the *Cortex-R4 and Cortex-R4F Integration Manual* for more information about this interface, and how to control it.

In addition, you can use the AXI slave interface to read and write the cache and TCM RAMs. You can use this feature to test the cache RAMs in a running system. This might be required in a safety-critical system. The TCM RAMs can be read and written directly by the program running on the processor. You can also use the AXI slave interface for swapping a test program in to the TCMs for the processor to execute. See *Accessing RAMs using the AXI slave interface* on page 9-24 for more information about how to access the RAMs using the AXI slave interface.

1.10 Product documentation, design flow, and architecture

This section describes the content of the product documents, how they relate to the design flow, and the relevant architectural standards and protocols.

Note

See *Further reading* on page xx for more information about the documentation described in this section.

1.10.1 Documentation

The following books describe the processor:

Technical Reference Manual

The *Technical Reference Manual* (TRM) describes the processor functionality and the effects of functional options on the behavior of the processor. It is required at all stages of the design flow. Some behavior described in the TRM might not be relevant, because of the way the processor has been implemented and integrated. If you are programming the processor, contact the implementer to determine the build configuration of the implementation, and the integrator to determine the pin configuration of the SoC that you are using.

Configuration and Sign-Off Guide

The *Configuration and Sign-Off Guide* (CSG) describes:

- the available build configuration options and related issues in selecting them
- how to configure the *Register Transfer Level* (RTL) with the build configuration options
- the processes to sign off the configured RTL and final macrocell.

The ARM product deliverables include reference scripts and information about using them to implement your design. Reference methodology documentation from your EDA tools vendor complements the CSG. The CSG is a confidential book that is only available to licensees.

Integration Manual

The *Integration Manual* (IM) describes how to integrate the processor into a SoC including describing the pins that the integrator must tie off to configure the macrocell for the required integration. Some of the integration is affected by the configuration options that were used to implement the processor. Contact the implementer of the macrocell that you are using to determine the implemented build configuration options. The IM is a confidential book that is only available to licensees.

1.10.2 Design flow

The processor is delivered as synthesizable RTL. Before it can be used in a product, it must go through the following process:

1. Implementation. The implementer configures and synthesizes the RTL to produce a hard macrocell. This includes integrating the cache RAMs into the design.
2. Integration. The integrator integrates the hard macrocell into a SoC, connecting it to a memory system and to appropriate peripherals for the intended function. This memory system includes the *Tightly Coupled Memories* (TCMs).

3. Programming. The system programmer develops the software required to configure and initialize the processor, and possibly tests the required application software on the processor.

Each of these stages can be performed by a different company. Configuration options are available at each stage. These options affect the behavior and available features at the next stage:

Build configuration

The implementer chooses the options that affect how the RTL source files are pre-processed. They usually include or exclude logic that can affect the area or maximum frequency of the resulting macrocell.

For example, the BTCM interface can be configured to have zero, one (B0TCM) or two (B0TCM and B1TCM) ports. If one port is chosen, the logic for the second port is excluded from the macrocell, although the pins remain, and the second port (B1TCM) cannot be used on that macrocell.

Configuration inputs

The integrator configures some features of the processor by tying inputs to specific values. These configurations affect the start-up behavior before any software configuration is made. They can also limit the options available to the software.

For example, if the build configuration for the macrocell includes both BTCM ports, the integrator can choose how many ports to actually use, and therefore how many RAMs must be integrated with the macrocell. If the integrator only wishes to use one BTCM port, they can connect RAM to the B0TCM port only, and tie the ENTCM1IF input to zero to indicate that the B1TCM is not available.

Software configuration

The programmer configures the processor by programming particular values into software-visible registers. This affects the behavior of the processor.

For example, the enable bit in the BTCM Region Register controls whether or not memory accesses are performed to the BTCM interface. However, the BTCM cannot, and must not, be enabled if the build configuration does not include any BTCM ports, or if the pin configuration indicates that no RAMs have been integrated onto the BTCM ports.

Note

This manual refers to *implementation-defined* features that are applicable to build configuration options. References to a feature which is *included* mean that the appropriate build and pin configuration options have been selected, while references to an *enabled* feature mean one that has also been configured by software.

1.10.3 Architectural information

The Cortex-R4 processor conforms to, or implements, the following specifications:

ARM Architecture

This describes:

- The behavior and encoding of the instructions that the processor can execute.
- The modes and states that the processor can be in.
- The various data and control registers that the processor must contain.

- The properties of memory accesses.
- The debug architecture you can use to debug the processor. The TRM gives more information about the implemented debug features.

The Cortex-R4 processor implements the ARMv7-R architecture profile.

Advanced Microcontroller Bus Architecture protocol

Advanced Microcontroller Bus Architecture (AMBA) is an open standard, on-chip bus specification that defines the interconnection and management of functional blocks that make up a *System-on-Chip* (SoC). It facilitates development of embedded processors with multiple peripherals.

IEEE 754 This is the IEEE Standard for Binary Floating Point Arithmetic.

An architecture specification typically defines a number of versions, and includes features that are either optional or partially specified. The TRM describes which architectures are used, including which version is implemented, and the architectural choices made for the implementation. The TRM does not provide detailed information about the architecture, but some architectural information is included to give an overview of the implementation or, in the case of control registers, to make the manual easier to use. See the appropriate specification for more information about the implemented architectural features.

1.11 Product revision information

This manual is for major revision 1 of the processor. At the time of release, this includes the r1p0, r1p1, r1p2, and r1p3 releases, although the vast majority of the information in this document will also be applicable to any future r1px releases. The following broadly describes the changes made in each subsequent revision of the processor:

Revision 1 Introduction of the ECC functional options and addition of the FPU options, to implement the Cortex-R4F processor.

Note

The r1p0 release was not generally available.

1.11.1 Processor identification

The Cortex-R4 processor contains a number of *IDentification* (ID) registers that enable software or a debugger to identify the processor as Cortex-R4, and the *variant* (major revision) and *revision* (minor revision) of the design. These registers are:

Main ID Register (MIDR)

This register is accessible by software and identifies the part, the variant, and the revision. See *c0, Main ID Register* on page 4-14. A copy of this register can also be read by a debugger through the debug APB interface. See *Processor ID Registers* on page 11-32.

Debug ID Register (DIDR)

This register can be read by a debugger through the debug APB interface, and by software. It identifies the variant and revision. See *CP14 c0, Debug ID Register* on page 11-10.

Peripheral ID Registers

These registers can be accessed through the debug APB interface only, and identify the revision number of the processor. See *Debug Identification Registers* on page 11-35.

Floating Point System ID Register (FPSID)

When the build-configuration includes the floating point unit, this register identifies the revision number of the floating-point unit. See *Floating-Point System ID Register, FPSID* on page 12-5.

Note

Floating point functionality is provided only with the Cortex-R4F processor.

The *revision number* of the processor, in the Peripheral ID and FPSID registers, is a single field that incorporates information about both major and minor revisions.

Table 1-3 shows the mappings between these various numbers, for all releases.

Table 1-3 ID values for different product versions

ID value	r0p0	r0p1	r0p2	r0p3	r1p0	r1p1	r1p2	r1p3
Variant field, Main ID Register	0x0	0x0	0x0	0x0	0x1	0x1	0x1	0x1
Revision field, Main ID Register	0x0	0x1	0x2	0x3	0x0	0x1	0x2	0x3
Variant field, Debug ID Register	0x0	0x0	0x0	0x0	0x1	0x1	0x1	0x1
Revision field, Debug ID Register	0x0	0x1	0x2	0x3	0x0	0x1	0x2	0x3
Revision number, Peripheral ID Registers	0x0	0x1	0x2	0x5	0x3	0x4	0x6	0x7
Revision number, FPSID Register	-	-	-	-	0x3	0x4	0x6	0x7

1.11.2 Architectural information

The ARM Architecture includes a number of registers that identify the version of the architecture and some of the architectural features that a processor implements. Chapter 4 *System Control Coprocessor* describes the values that the processor implements for the fields in these registers. For details of the possible values and their meanings for these fields, see the *ARM Architecture Reference Manual*.

Chapter 2
Programmer's Model

This chapter describes the processor registers and provides an overview for programming the microprocessor. It contains the following sections:

2.1 About the programmer's model

The processor implements the ARMv7-R architecture that provides:

- the 32-bit ARM instruction set
- the extended Thumb instruction set introduced in ARMv6T2, that uses Thumb-2 technology to provide a wide range of 32-bit instructions.

For more information on the ARM and Thumb instruction sets, see the *ARM Architecture Reference Manual*. This chapter describes some of the main features of the architecture but, for a complete description, see the *ARM Architecture Reference Manual*.

This chapter also makes reference to older versions of the ARM architecture that the processor does not implement. These references are included to contrast the behavior of the Cortex-R4 processor with other processors you might have used that implement an older version of the architecture.

2.2 Instruction set states

The processor has two instruction set states:

ARM state The processor executes 32-bit, word-aligned ARM instructions in this state.

Thumb state The processor executes 32-bit and 16-bit halfword-aligned Thumb instructions in this state.

Note

Transition between ARM state and Thumb state does not affect the processor mode or the register contents.

2.2.1 Switching state

The instruction set state of the processor can be switched between ARM state and Thumb state:

- Using the `BX` and `BLX` instructions, by a load to the PC, or with a data-processing instruction that does not set flags, with the PC as the destination register. Switching state is described in the *ARM Architecture Reference Manual*.

  Note

  When the `BXJ` instruction is used the processor invokes the `BX` instruction.

- Automatically on an exception. You can write an exception handler routine in ARM or Thumb code. For more information, see *Exceptions* on page 2-16.

2.2.2 Interworking ARM and Thumb state

The processor enables you to mix ARM and Thumb code. For more information about interworking ARM and Thumb, see the *RealView Compilation Tools Developer Guide*.

2.3 Operating modes

In each state there are seven modes of operation:

- *User* (USR) mode is the usual mode for the execution of ARM or Thumb programs. It is used for executing most application programs.
- *Fast interrupt* (FIQ) mode is entered on taking a fast interrupt.
- *Interrupt* (IRQ) mode is entered on taking a normal interrupt.
- *Supervisor* (SVC) mode is a protected mode for the operating system and is entered on taking a *Supervisor Call* (SVC), formerly SWI.
- *Abort* (ABT) mode is entered after a data or instruction abort.
- *System* (SYS) mode is a privileged user mode for the operating system.
- *Undefined* (UND) mode is entered when an Undefined instruction exception occurs.

Modes other than User mode are collectively known as Privileged modes. Privileged modes are used to service interrupts or exceptions, or access protected resources.

2.4 Data types

The processor supports these data types:

- doubleword, 64-bit
- word, 32-bit
- halfword, 16-bit
- byte, 8-bit.

Note

- When any of these types are described as unsigned, the N-bit data value represents a non-negative integer in the range 0 to $+2^N-1$, using normal binary format.
- When any of these types are described as signed, the N-bit data value represents an integer in the range -2^{N-1} to $+2^{N-1}-1$, using two's complement format.

For best performance you must align these data types in memory as follows:

- doubleword quantities aligned to 8-byte boundaries, *doubleword aligned*
- word quantities aligned to 4-byte boundaries, *word aligned*
- halfword quantities aligned to 2-byte boundaries *halfword aligned*
- byte quantities can be placed on any byte boundary.

The processor supports mixed-endian and unaligned access. For more information, see *Unaligned and mixed-endian data access support* on page 2-28.

Note

You cannot use `LDRD`, `LDM`, `STRD`, or `STM` instructions to access 32-bit quantities if they are not 32-bit aligned.

2.5 Memory formats

The processor views memory as a linear collection of bytes numbered in ascending order from zero. For example, bytes 0-3 hold the first stored word, and bytes 4-7 hold the second stored word.

The processor can treat words of data in memory as being stored in either:

- *Byte-invariant big-endian format*
- *Little-endian format*.

Additionally, the processor supports mixed-endian and unaligned data accesses. For more information, see the *ARM Architecture Reference Manual*.

2.5.1 Byte-invariant big-endian format

In byte-invariant big-endian (BE-8) format, the processor stores the most significant byte of a word at the lowest-numbered byte, and the least significant byte at the highest-numbered byte. Figure 2-1 shows byte-invariant big-endian (BE-8) format.

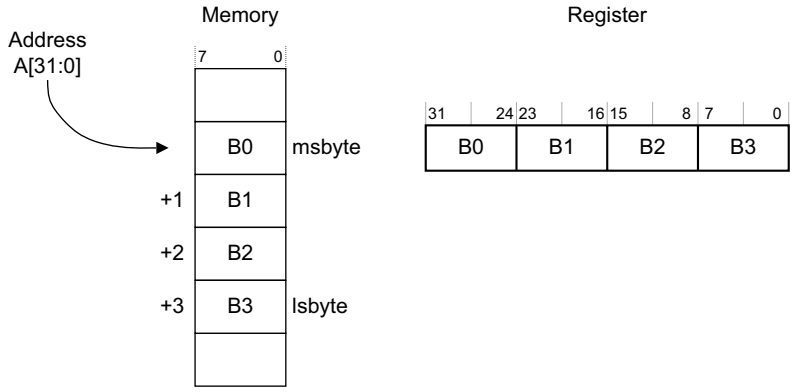


Figure 2-1 Byte-invariant big-endian (BE-8) format

2.5.2 Little-endian format

In little-endian format, the lowest-numbered byte in a word is the least significant byte of the word and the highest-numbered byte is the most significant. Figure 2-2 shows little-endian format.

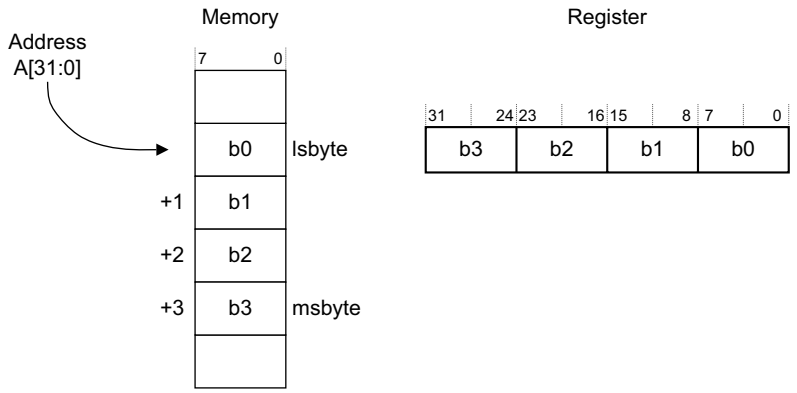


Figure 2-2 Little-endian format

2.6 Registers

The processor has a total of 37 program registers:

- 31 general-purpose 32-bit registers
- six 32-bit status registers.

These registers are not all accessible at the same time. The processor state and operating mode determine the registers that are available to the programmer.

2.6.1 The register set

In the processor the same register set is used in both the ARM and Thumb states. Sixteen general registers and one or two status registers are accessible at any time. In Privileged modes, alternative mode-specific banked registers become available. Figure 2-3 on page 2-9 shows the registers that are available in each mode.

The register set contains 16 directly-accessible registers, R0-R15. Another register, the *Current Program Status Register* (CPSR), contains condition code flags, status bits, and current mode bits. Registers R0-R12 are general-purpose registers that hold either data or address values. Registers R13, R14, R15, and the CPSR have these special functions:

Stack pointer Software normally uses register R13 as a *Stack Pointer* (SP). The `SRS` and `RFE` instructions use Register R13.

Link Register Register R14 is used as the subroutine *Link Register* (LR).

Register R14 receives the return address when a *Branch with Link* (`BL` or `BLX`) instruction is executed.

You can use R14 as a general-purpose register at all other times. The corresponding banked registers R14_svc, R14_irq, R14_fiq, R14_abt, and R14_und similarly hold the return values when interrupts and exceptions are taken, or when `BL` or `BLX` instructions are executed within interrupt or exception routines.

Program Counter Register R15 holds the PC:

- in ARM state this is word-aligned
- in Thumb state this is either word or halfword-aligned.

Note

There are special cases for reading R15:

- reading the address of the current instruction plus, either:
  - 4 in Thumb state
  - 8 in ARM state.
- reading `0x00000000` (zero).

There are special cases for writing R15:

- causing a branch to the address that was written to R15
- ignoring the value that was written to R15
- writing bits [31:28] of the value that was written to R15 to the condition flags in the CPSR, and ignoring bits [27:20] (used for the `MRC` instruction only).

You must not assume any of these special cases unless it is explicitly stated in the instruction description. Instead, you must treat instructions with register fields equal to R15 as Unpredictable.

For more information, see the *ARM Architecture Reference Manual*.

In Privileged modes, another register, the *Saved Program Status Register* (SPSR), is accessible. This contains the condition code flags, status bits, and current mode bits saved as a result of the exception that caused entry to the current mode.

Banked registers have a mode identifier that indicates which mode they relate to. Table 2-1lists these identifiers.

Table 2-1 Register mode identifiers

Mode	Mode identifier
User	usr[a]
Fast interrupt	fiq
Interrupt	irq
Supervisor	svc
Abort	abt
System	usr[a]
Undefined	und

a. The `usr` identifier is usually omitted from register names. It is only used in descriptions where the User or System mode register is specifically accessed from another operating mode.

FIQ mode has seven banked registers mapped to R8–R14 (R8_fiq–R14_fiq). As a result many FIQ handlers do not have to save any registers.

The Supervisor, Abort, IRQ, and Undefined modes each have alternative mode-specific registers mapped to R13 and R14, permitting a private stack pointer and link register for each mode.

Figure 2-3 on page 2-9 shows the register set, and those registers that are banked.

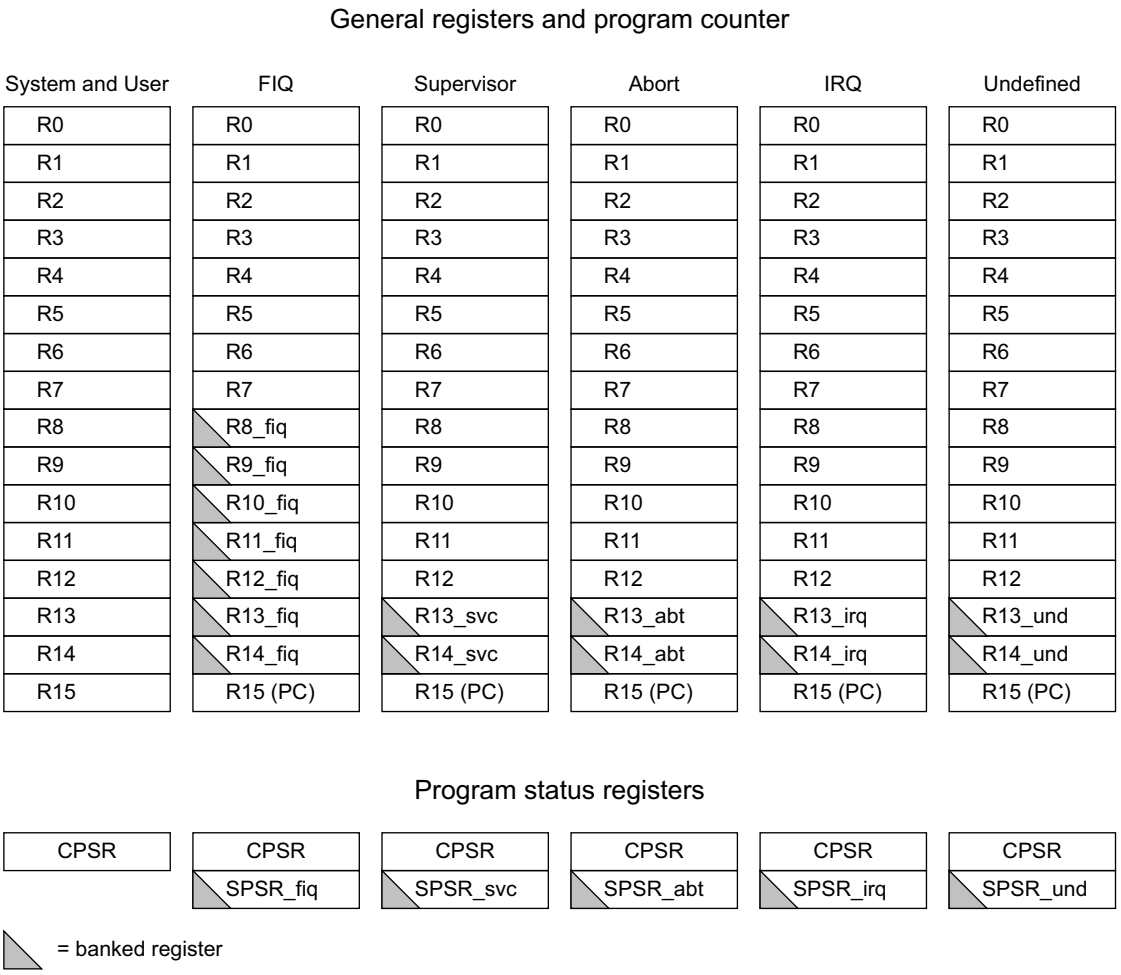


Figure 2-3 Register organization

Note

For 16-bit Thumb instructions, the high registers, R8–R15, are not part of the standard register set. You can use special variants of the `MOV` instruction to transfer a value from a low register, in the range R0–R7, to a high register, and from a high register to a low register. The `CMP` instruction enables you to compare high register values with low register values. The `ADD` instruction enables you to add high register values to low register values. For more information, see the *ARM Architecture Reference Manual*.

2.7 Program status registers

The processor contains one CPSR and five SPSRs for exception handlers to use. The program status registers:

- hold information about the most recently performed ALU operation
- control the enabling and disabling of interrupts
- set the processor operating mode.

Figure 2-4 shows the bit arrangement in the status registers.

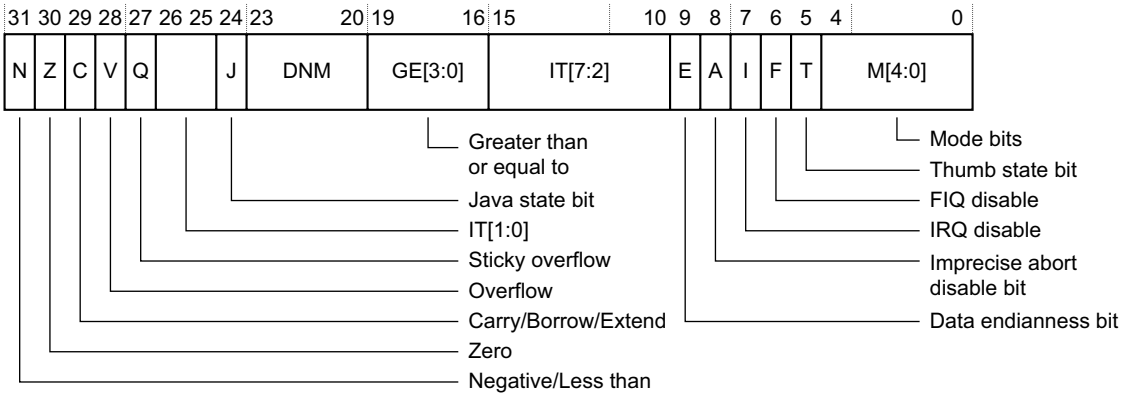


Figure 2-4 Program status register

The following sections explain the meanings of these bits:

- *The N, Z, C, and V bits*
- *The Q bit* on page 2-11
- *The IT bits* on page 2-11
- *The J bit* on page 2-12
- *The DNM bits* on page 2-12
- *The GE bits* on page 2-12
- *The E bit* on page 2-13
- *The A bit* on page 2-13
- *The I and F bits* on page 2-13
- *The T bit* on page 2-13
- *The M bits* on page 2-14

2.7.1 The N, Z, C, and V bits

The N, Z, C, and V bits are the condition code flags. You can optionally set them with arithmetic and logical operations, and also with `MSR` instructions and `MRC` instructions to R15. The processor tests these flags in accordance with an instruction's condition code to determine whether to execute that instruction.

In ARM state, most instructions can execute conditionally on the state of the N, Z, C, and V bits. The exceptions are:

- `BKPT`
- `CPS`
- `LDC2`
- `MCR2`
- `MCRR2`
- `MRC2`

- MRRC2
- PLD
- RFE
- SETEND
- SRS
- STC2.

In Thumb state, the processor can only execute the Branch instruction conditionally. Other instructions can be made conditional by placing them in the *If-Then* (IT) block. For more information about conditional execution in Thumb state, see the *ARM Architecture Reference Manual*.

2.7.2 The Q bit

Certain multiply and fractional arithmetic instructions can set the Sticky Overflow, Q, flag:

- QADD
- QDADD
- QSUB
- QDSUB
- SMLAD
- SMLAxy
- SMLAWy
- SMLSD
- SMUAD
- SSAT
- SSAT16
- USAT
- USAT16.

The Q flag is sticky in that, when an instruction sets it, this bit remains set until an MSR instruction writing to the CPSR explicitly clears it. Instructions cannot execute conditionally on the status of the Q flag.

To determine the status of the Q flag you must read the PSR into a register and extract the Q flag from this. For information of how the Q flag is set and cleared, see individual instruction definitions in the *ARM Architecture Reference Manual*.

2.7.3 The IT bits

IT[7:5] encodes the base condition code for the current IT block, if any. It contains b000 when no IT block is active.

IT[4:0] encodes the number of instructions that are to be conditionally executed, and whether the condition for each is the base condition code or the inverse of the base condition code. It contains b00000 when no IT block is active.

When an IT instruction is executed, these bits are set according to the condition in the instruction, and the *Then* and *Else* (T and E) parameters in the instruction. During execution of an IT block, IT[4:0] is shifted to:

- reduce the number of instructions to be conditionally executed by one
- move the next bit into position to form the least significant bit of the condition code.

For more information on the operation of the IT execution state bits, see the *ARM Architecture Reference Manual*.

2.7.4 The J bit

The J bit in the CPSR returns 0 when read.

Note

You cannot use an `MSR` to change the J bit in the CPSR.

2.7.5 The DNM bits

Software must not modify the *Do Not Modify* (DNM) bits. These bits are:

- Readable, to preserve the state of the processor, for example, during process context switches.
- Writable, to enable the processor to restore its state. To maintain compatibility with future ARM processors, and as good practice, use a read-modify-write strategy when you change the CPSR.

2.7.6 The GE bits

Some of the SIMD instructions set GE[3:0] as greater-than-or-equal bits for individual halfwords or bytes of the result, as Table 2-2 shows.

Table 2-2 GE[3:0] settings

Instruction	GE[3] A op B greater than or equal to C	GE[2] A op B greater than or equal to C	GE[1] A op B greater than or equal to C	GE[0] A op B greater than or equal to C
Signed				
SADD16	[31:16] + [31:16] ≥ 0	[31:16] + [31:16] ≥ 0	[15:0] + [15:0] ≥ 0	[15:0] + [15:0] ≥ 0
SSUB16	[31:16] - [31:16] ≥ 0	[31:16] - [31:16] ≥ 0	[15:0] - [15:0] ≥ 0	[15:0] - [15:0] ≥ 0
SADDSUBX	[31:16] + [15:0] ≥ 0	[31:16] + [15:0] ≥ 0	[15:0] - [31:16] ≥ 0	[15:0] - [31:16] ≥ 0
SSUBADDX	[31:16] - [15:0] ≥ 0	[31:16] - [15:0] ≥ 0	[15:0] + [31:16] ≥ 0	[15:0] + [31:16] ≥ 0
SADD8	[31:24] + [31:24] ≥ 0	[23:16] + [23:16] ≥ 0	[15:8] + [15:8] ≥ 0	[7:0] + [7:0] ≥ 0
SSUB8	[31:24] - [31:24] ≥ 0	[23:16] - [23:16] ≥ 0	[15:8] - [15:8] ≥ 0	[7:0] - [7:0] ≥ 0
Unsigned				
UADD16	[31:16] + [31:16] ≥ 2^{16}	[31:16] + [31:16] ≥ 2^{16}	[15:0] + [15:0] ≥ 2^{16}	[15:0] + [15:0] ≥ 2^{16}
USUB16	[31:16] - [31:16] ≥ 0	[31:16] - [31:16] ≥ 0	[15:0] - [15:0] ≥ 0	[15:0] - [15:0] ≥ 0
UADDSUBX	[31:16] + [15:0] ≥ 2^{16}	[31:16] + [15:0] ≥ 2^{16}	[15:0] - [31:16] ≥ 0	[15:0] - [31:16] ≥ 0
USUBADDX	[31:16] - [15:0] ≥ 0	[31:16] - [15:0] ≥ 0	[15:0] + [31:16] ≥ 2^{16}	[15:0] + [31:16] ≥2^{16}
UADD8	[31:24] + [31:24] ≥ 2^{8}	[23:16] + [23:16] ≥ 2^{8}	[15:8] + [15:8] ≥ 2^{8}	[7:0] + [7:0] ≥ 2^{8}
USUB8	[31:24] - [31:24] ≥ 0	[23:16] - [23:16] ≥ 0	[15:8] - [15:8] ≥ 0	[7:0] - [7:0] ≥ 0

Note

GE bit is 1 if A op B ≥ C, otherwise 0.

The SEL instruction uses GE[3:0] to select which source register supplies each byte of its result.

Note

- For unsigned operations, the usual ARM rules determine the GE bits for carries out of unsigned additions and subtractions, and so are carry-out bits.
- For signed operations, the rules for setting the GE bits are chosen so that they have the same sort of greater than or equal functionality as for unsigned operations.

2.7.7 The E bit

ARM and Thumb instructions are provided to set and clear the E bit. The E bit controls load/store endianness. See the *ARM Architecture Reference Manual* for information on where the E bit is used.

Architecture versions prior to ARMv6 specify this bit as SBZ. This ensures no endianness reversal on loads or stores.

2.7.8 The A bit

The A bit is set automatically. It disables imprecise Data Aborts. For more information on how to use the A bit, see *Imprecise abort masking* on page 2-23.

2.7.9 The I and F bits

The I and F bits are the interrupt disable bits:

- when the I bit is set, IRQ interrupts are disabled
- when the F bit is set, FIQ interrupts are disabled.

Software can use MSR, CPS, MOVS pc, SUBS pc, LDM ..,{..pc}^, or RFE instructions to change the values of the I and F bits.

When NMFIs are enabled, updates to the F bit are restricted. For more information see *Non-maskable fast interrupts* on page 2-19.

2.7.10 The T bit

The T bit reflects the instruction set state:

- when the T bit is set, the processor executes in Thumb state
- when the T bit is clear, the processor executes in ARM state.

Note

Never use an MSR instruction to force a change to the state of the T bit in the CPSR. The processor ignores any attempt to modify the T bit using an MSR instruction.

2.7.11 The M bits

M[4:0] are the mode bits. These bits determine the processor operating mode as Table 2-3 shows.

Table 2-3 PSR mode bit values

M[4:0]	Mode	Visible state registers	
		Thumb	ARM
b10000	User	R0–R7, R8-R12, SP, LR, PC, CPSR	R0–R14, PC, CPSR
b10001	FIQ	R0–R7, R8_fiq-R12_fiq, SP_fiq, LR_fiq PC, CPSR, SPSR_fiq	R0–R7, R8_fiq–R14_fiq, PC, CPSR, SPSR_fiq
b10010	IRQ	R0–R7, R8-R12, SP_irq, LR_irq, PC, CPSR, SPSR_irq	R0–R12, R13_irq, R14_irq, PC, CPSR, SPSR_irq
b10011	Supervisor	R0–R7, R8-R12, SP_svc, LR_svc, PC, CPSR, SPSR_svc	R0–R12, R13_svc, R14_svc, PC, CPSR, SPSR_svc
b10111	Abort	R0–R7, R8-R12, SP_abt, LR_abt, PC, CPSR, SPSR_abt	R0–R12, R13_abt, R14_abt, PC, CPSR, SPSR_abt
b11011	Undefined	R0–R7, R8-R12, SP_und, LR_und, PC, CPSR, SPSR_und	R0–R12, R13_und, R14_und, PC, CPSR, SPSR_und
b11111	System	R0–R7, R8-R12, SP, LR, PC, CPSR	R0–R14, PC, CPSR

Note

- In Privileged mode an illegal value programmed into M[4:0] causes the processor to enter System mode.
- In User mode M[4:0] can be read. Writes to M[4:0] are ignored.

2.7.12 Modification of PSR bits by MSR instructions

In architecture versions earlier than ARMv6, `MSR` instructions can modify the flags byte, bits [31:24], of the CPSR in any mode, but the other three bytes are only modifiable in Privileged modes.

In the ARMv7-R architecture each CPSR bit falls into one of these categories:

- Bits that are freely modifiable from any mode, either directly by `MSR` instructions or by other instructions whose side-effects include writing the specific bit or writing the entire CPSR.

  Bits in Figure 2-4 on page 2-10 that are in this category are N, Z, C, V, Q, GE[3:0], and E.

- Bits that an `MSR` instruction must never modify, and so must only be written as a side-effect of another instruction. If an `MSR` instruction tries to modify these bits, the results are architecturally Unpredictable. In the processor these bits are not affected.

  The bits in Figure 2-4 on page 2-10 that are in this category are the execution state bits [26:24], [15:10], and [5].

- Bits that can only be modified from Privileged modes, and that instructions completely protect from modification while the processor is in User mode. Entering a processor exception is the only way to modify these bits while the processor is in User mode, as described in *Exceptions* on page 2-16.

Bits in Figure 2-4 on page 2-10 that are in this category are A, I, F, and M[4:0].

2.8 Exceptions

Exceptions are taken whenever the normal flow of a program must temporarily halt, for example, to service an interrupt from a peripheral. Before attempting to handle an exception, the processor preserves the critical parts of the current processor state so that the original program can resume when the handler routine has finished.

This section provides information of the processor exception handling:

- *Exception entry and exit summary*
- *Reset* on page 2-18
- *Interrupts* on page 2-18
- *Aborts* on page 2-22
- *Supervisor call instruction* on page 2-24
- *Undefined instruction* on page 2-25
- *Breakpoint instruction* on page 2-25
- *Exception vectors* on page 2-26.

Note

When the processor is in debug halt state, and an exception occurs, it is handled differently to normal. See *Exceptions in debug state* on page 11-47 for more details

2.8.1 Exception entry and exit summary

Table 2-4 summarizes the PC value preserved in the relevant R14 on exception entry, and the recommended instruction for exiting the exception handler.

Table 2-4 Exception entry and exit

Exception or entry	Recommended return instruction	Previous state		Notes
		ARM R14_x	Thumb R14_x	
SVC[a]	`MOVS PC, R14_svc`	IA + 4	IA + 2	Where the IA is the address of the SVC or Undefined instruction.
UNDEF	Varies[b]	IA + 4	IA + 2	
PABT	`SUBS PC, R14_abt, #4`	IA + 4	IA + 4	Where the IA is the address of instruction that had the Prefetch Abort.
FIQ	`SUBS PC, R14_fiq, #4`	IA + 4	IA + 4	Where the IA is the address of the instruction that was not executed because the FIQ or IRQ took priority.
IRQ	`SUBS PC, R14_irq, #4`	IA + 4	IA + 4	
DABT	`SUBS PC, R14_abt, #8`	IA + 8	IA + 8	Where the IA is the address of the Load or Store instruction that generated the Data Abort.
RESET	`NA`	-	-	The value saved in R14_svc on reset is Unpredictable.
BKPT	`SUBS PC, R14_abt, #4`	IA + 4	IA + 4	Software breakpoint.

a. Formerly SWI.

b. The return instruction you must use after an UNDEF exception has been handled depends on whether you want to retry the undefined instruction or not and, if so, on the size of the undefined instruction.

Taking an exception

When taking an exception the processor:

1. Preserves the address of the next instruction in the appropriate LR. When the exception is taken from:

   ARM state

   The processor writes the address of the instruction into the LR, offset by a value (current IA + 4 or IA + 8 depending on the exception) that causes the program to resume from the correct place on return.

   Thumb state

   The processor writes the address of the instruction into the LR, offset by a value (current IA + 2, IA + 4 or IA + 8 depending on the exception) that causes the program to resume from the correct place on return.

2. Copies the CPSR into the appropriate SPSR. Depending on the exception type, the processor might modify the IT execution state bits of the CPSR prior to this operation to facilitate a return from the exception.

3. Forces the CPSR mode bits to a value that depends on the exception and clears the IT execution state bits in the CPSR.

4. Sets the E bit based on the state of the EE bit. Both these bits are contained in the System Control Register, see *c1, System Control Register* on page 4-35.

5. The T bit is set based on the state of the TE bit.

6. Forces the PC to fetch the next instruction from the relevant exception vector.

The processor can also set the interrupt disable flags to prevent otherwise unmanageable nesting of exceptions.

Leaving an exception

When an exception has completed, the exception handler must move the LR, minus an offset, to the PC. The offset varies according to the type of exception, as Table 2-4 on page 2-16 shows.

Typically the return instruction is an arithmetic or logical operation with the S bit set and Rd = R15, so the processor copies the SPSR back to the CPSR. Alternatively, an `LDM ..,{..pc}^` or `RFE` instruction can perform a similar operation if the return state has been pushed onto a stack.

Note

The action of restoring the CPSR from the SPSR:

- Automatically restores the T, E, A, I, and F bits to the value they held immediately prior to the exception.
- Normally resets the IT execution state bits to the values held immediately prior to the exception. If the exception handler wants to return to the following instruction, these bits might require to be manually advanced to avoid applying the incorrect condition codes to that instruction. For more information about the IT instruction and Undefined instruction, and an example of the exception handler code, see the *ARM Architecture Reference Manual*.

Because SVC handlers are always expected to return after the SVC instruction, the IT execution state bits are automatically advanced when an exception is taken prior to copying the CPSR into the SPSR.

2.8.2 Reset

When the **nRESET** signal is driven LOW a reset occurs, and the processor abandons the executing instruction.

When **nRESET** is driven HIGH again the processor:

1. Forces CPSR M[4:0] to b10011 (Supervisor mode) and sets the A, I, and F bits in the CPSR. The E bit is set based on the state of the **CFGEE** pin. Other bits in the CPSR are indeterminate.
2. Forces the PC to fetch the next instruction from the reset vector address.
3. Reverts to ARM state or Thumb state depending on the state of the **TEINIT** pin, and resumes execution.

After reset, all register values except the PC and CPSR are indeterminate.

See Chapter 3 *Processor Initialization, Resets, and Clocking* for more information on the reset behavior for the processor.

2.8.3 Interrupts

The processor has two interrupt inputs, for normal interrupts (**nIRQ**) and fast interrupts (**nFIQ**). Each interrupt pin, when asserted and not masked, causes the processor to take the appropriate type of interrupt exception. See *Exceptions* on page 2-16 for more information. The CPSR.F and CPSR.I bits control masking of fast and normal interrupts respectively.

A number of features exist to improve the interrupt latency, that is, the time taken between the assertion of the interrupt input and the execution of the interrupt handler. By default, the processor uses the *Low Interrupt Latency* (LIL) behaviors introduced in version 6 and later of the ARM Architecture. The processor also has a port for connection of a *Vectored Interrupt Controller* (VIC), and supports *Non-Maskable Fast Interrupts* (NMFI).

The following subsections describe interrupts:

- *Interrupt request*
- *Fast interrupt request* on page 2-19
- *Non-maskable fast interrupts* on page 2-19
- *Low interrupt latency* on page 2-19
- *Interrupt controller* on page 2-20.

Interrupt request

The IRQ exception is a normal interrupt caused by a LOW level on the **nIRQ** input. An IRQ has a lower priority than an FIQ, and is masked on entry to an FIQ sequence. You must ensure that the **nIRQ** input is held LOW until the processor acknowledges the interrupt request, either from the VIC interface or the software handler.

Irrespective of whether the exception is taken from ARM state or Thumb state, an IRQ handler returns from the interrupt by executing:

```
SUBS PC, R14_irq, #4
```

You can disable IRQ exceptions within a Privileged mode by setting the CPSR.I bit to b1. See *Program status registers* on page 2-10. IRQ interrupts are automatically disabled when an IRQ occurs, by setting the CPSR.I bit. You can use nested interrupts but it is up to you to save any corruptible registers and to re-enable IRQs by clearing the CPSR.I bit.

Fast interrupt request

The *Fast Interrupt Request* (FIQ) reduces the execution time of the exception handler relative to a normal interrupt. FIQ mode has eight private registers to reduce, or even remove the requirement for register saving (minimizing the overhead of context switching).

An FIQ is externally generated by taking the **nFIQ** input signal LOW. You must ensure that the **nFIQ** input is held LOW until the processor acknowledges the interrupt request from the software handler.

Irrespective of whether exception entry is from ARM state or Thumb state, an FIQ handler returns from the interrupt by executing:

```
SUBS PC, R14_fiq, #4
```

If *Non-Maskable Fast Interrupts* (NMFIs) are not enabled, you can mask FIQ exceptions by setting the CPSR.F bit to b1. For more information see:

- *Program status registers* on page 2-10
- *Non-maskable fast interrupts*.

FIQ and IRQ interrupts are automatically masked by setting the CPSR.F and CPSR.I bits when an FIQ occurs. You can use nested interrupts but it is up to you to save any corruptible registers and to re-enable interrupts.

Non-maskable fast interrupts

When NMFI behavior is enabled, FIQ interrupts cannot be masked by software. Enabling NMFI behavior ensures that when the FIQ mask, that is, the CPSR.F bit, has been cleared by the reset handler, fast interrupts are always taken as quickly as possible, except during handling of a fast interrupt. This makes the fast interrupt suitable for signaling critical events. NMFI behavior is controlled by a configuration input signal **CFGNMFI**, that is asserted HIGH to enable NMFI operation. There is no software control of NMFI.

Software can detect whether NMFI operation is enabled by reading the NMFI bit of the System Control Register:

NMFI == 0 Software can mask FIQs by setting the CPSR.F bit to b1.

NMFI == 1 Software cannot mask FIQs.

For more information see *c1, System Control Register* on page 4-35.

When the NMFI bit in the System Control Register is b1:

- an instruction writing b0 to the CPSR.F bit clears it to b0
- an instruction writing b1 to the CPSR.F bit leaves it unchanged
- the CPSR.F bit can be set to b1 only by an FIQ or reset exception entry.

Low interrupt latency

Low Interrupt Latency (LIL) is a set of behaviors that reduce the interrupt latency for the processor, and is enabled by default. That is, the FI bit [21] in the System Control Register is Read-as-One.

LIL behavior enables accesses to Normal memory, including multiword accesses and external accesses, to be abandoned part-way through execution so that the processor can react to a pending interrupt faster than would otherwise be the case. When an instruction is abandoned in this way, the processor behaves as if the instruction was not executed at all. If, after handling the interrupt, the interrupt handler returns to the program in the normal way using instruction `SUBS pc, r14, #4`, the abandoned instruction is re-executed. This means that some of the memory accesses generated by the instruction are performed twice.

Memory that is marked as Strongly Ordered or Device type is typically sensitive to the number of reads or writes performed. Because of this, instructions that access Strongly Ordered or Device memory are never abandoned when they have started accessing memory. These instructions always complete either all or none of their memory accesses. Therefore, to minimize the interrupt latency, you must avoid the use of multiword load/store instructions to memory locations that are marked as Strongly Ordered or Device.

Interrupt controller

The processor includes a VIC port for connection of a *Vectored Interrupt Controller* (VIC). An interrupt controller is a peripheral that handles multiple interrupt sources. Features usually found in an interrupt controller are:

- multiple interrupt request inputs, one for each interrupt source, and one or more amalgamated interrupt request outputs to the processor
- the ability to mask out particular interrupt requests
- prioritization of interrupt sources for interrupt nesting.

In a system with an interrupt controller with these features, software is still required to:

- determine from the interrupt controller which interrupt source is requesting service
- determine where the service routine for that interrupt source is loaded
- mask or clear that interrupt source, before re-enabling processor interrupts to allow another interrupt to be taken.

A VIC does all these in hardware to reduce the interrupt latency. It supplies the starting address of the service routine corresponding to the highest priority asserted interrupt source directly to the processor. When the processor has accepted this address, it masks the interrupt so that the processor can re-enable interrupts without clearing the source. The PL192 VIC is an *Advanced Microcontroller Bus Architecture* (AMBA) compliant, *System-on-Chip* (SoC) peripheral that is developed, tested, and licensed by ARM for use in Cortex-R4 designs.

You can use the VIC port to connect a PL192 VIC to the processor. See the *ARM PrimeCell Vectored Interrupt Controller (PL192) Technical Reference Manual* for more information about the PL192 VIC. You can enable the VIC port by setting the VE bit in the System Control Register. When the VIC port is enabled and an IRQ occurs, the processor performs an handshake over the VIC interface to obtain the address of the handling routine for the IRQ.

See the *Cortex-R4 and Cortex-R4F Integration Manual* for more information about the VIC port, its signals, and their timings.

Interrupt entry flowchart

Figure 2-5 on page 2-21 is a flowchart for processor interrupt recognition. It shows all the necessary decisions and actions for complete interrupt entry.

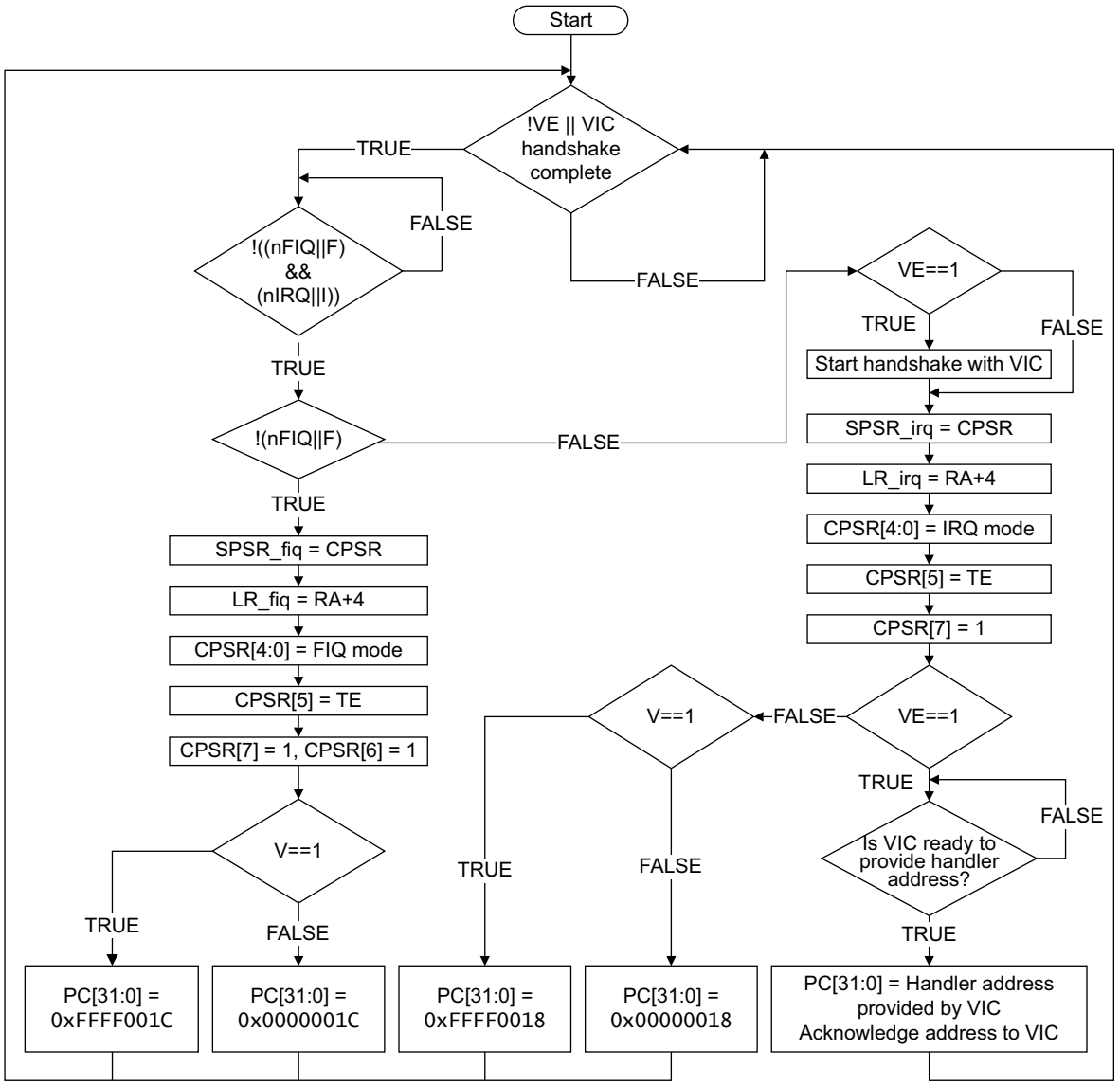


Figure 2-5 Interrupt entry sequence

For information on the I and F bits that Figure 2-5 shows, see *Program status registers* on page 2-10. For information on the V and VE bits that Figure 2-5 shows, see *c1, System Control Register* on page 4-35.

2.8.4 Aborts

When the processor's memory system cannot complete a memory access successfully, an abort is generated. Aborts can occur for a number of reasons, for example:

- a permission fault indicated by the MPU
- an error response to a transaction on the AXI memory bus
- an error detected in the data by the ECC checking logic.

An error occurring on an instruction fetch generates a *prefetch abort*. Errors occurring on data accesses generate *data aborts*. Aborts are also categorized as being either *precise* or *imprecise*.

When a prefetch or data abort occurs, the processor takes the appropriate type of exception. See *Exception entry and exit summary* on page 2-16 for more information. Additional information about the type of abort is stored in registers, and signaled as events. See *Fault handling* on page 8-7 for more details of the types of fault that can cause an abort and the information that the processor provides about these faults.

Prefetch aborts

When a *Prefetch Abort* (PABT) occurs, the processor marks the prefetched instruction as invalid, but does not take the exception until the instruction is to be executed. If the instruction is not executed, for example because a branch occurs while it is in the pipeline, the abort does not take place.

All prefetch aborts are precise.

Data aborts

An error occurring on a data memory access can generate a data abort. If the instruction generating the memory access is not executed, for example, because it fails its condition codes, or is interrupted, the data abort does not take place.

A *Data Abort* (DABT) can be either precise or imprecise, depending on the type of fault that caused it.

The processor implements the *base restored Data Abort model*, as opposed to a *base updated Data Abort model*.

With the *base restored Data Abort model*, when a Data Abort exception occurs during the execution of a memory access instruction, the processor hardware always restores the base register to the value it contained before the instruction was executed. This removes the requirement for the Data Abort handler to unwind any base register update that the aborted instruction might have specified. This simplifies the software Data Abort handler. For more information, see the *ARM Architecture Reference Manual*.

Precise aborts

A precise abort, also known as a synchronous abort, is one for which the exception is guaranteed to be taken on the instruction that generated the aborting memory access. The abort handler can use the value in the Link Register (r14_abt) to determine which instruction generated the abort, and the value in the Saved Program Status Register (SPSR_abt) to determine the state of the processor when the abort occurred.

Imprecise aborts

An imprecise abort, also known as an asynchronous abort, is one for which the exception is taken on a later instruction to the instruction that generated the aborting memory access. The abort handler cannot determine which instruction generated the abort, or the state of the processor when the abort occurred. Therefore, imprecise aborts are normally fatal.

Imprecise aborts can be generated by store instructions to normal-type or device-type memory. When the store instruction is committed, the data is normally written into a buffer that holds the data until the memory system has sufficient bandwidth to perform the write access. This gives read accesses higher priority. The write data can be held in the buffer for a long period, during which many other instructions can complete. If an error occurs when the write is finally performed, this generates an imprecise abort.

Imprecise abort masking

The nature of imprecise aborts means that they can occur while the processor is handling a different abort. If an imprecise abort generates a new exception in such a situation, the r14_abt and SPSR_abt values are overwritten. If this occurs before the data is pushed to the stack in memory, the state information about the first abort is lost. To prevent this from happening, the CPSR contains a mask bit to indicate that an imprecise abort cannot be accepted, the A-bit. When the A-bit is set, any imprecise abort that occurs is held pending by the processor until the A-bit is cleared, when the exception is actually taken. The A-bit is automatically set when abort, IRQ or FIQ exceptions are taken, and on reset. You must only clear the A-bit in an abort handler after the state information has either been stacked to memory, or is no longer required.

Only one pending imprecise abort of each imprecise abort type is supported. The processor supports the following pending imprecise aborts:

- Imprecise external abort

  If a subsequent imprecise external abort is signaled while another one is pending, the later one is ignored and only one abort is taken.

- One TCM write external error for each TCM port.

- Cache write parity or ECC error.

  If a subsequent cache parity or ECC error is signaled while another one is pending, the later one is normally ignored and only one abort is taken. However, if the pending error was correctable, and the later one is not correctable, the pending error is ignored, and one abort is taken for the error that cannot be corrected.

Memory barriers

When a store instruction, or series of instructions has been executed to normal-type or device-type memory, it is sometimes necessary to determine whether any errors occurred because of these instructions. Because most of these errors are reported imprecisely, they might not generate an abort exception until some time after the instructions are executed. To ensure that all possible errors have been reported, you must execute a `DSB` instruction. Abort exceptions are only taken because of these errors if they are not masked, that is, the CPSR A-bit is clear. If the A-bit is set, the aborts are held pending.

Aborts in Strongly Ordered and Device memory

When a memory access generates an abort, the instruction generating that access is abandoned, even if it has not completed all its memory accesses, and the abort exception is taken. The abort handler can then do one of the following:

- fix the error and return to the instruction that was abandoned, to re-execute it

- perform the appropriate data transfers on behalf of the aborted instruction and return to the instruction after the abandoned instruction
- treat the error as fatal and terminate the process.

If the abort handler returns to the abandoned instruction, some of the memory accesses generated are repeated. The effect is that multiword load/store instructions can access the same memory location twice. The first access occurs before the abort is detected, and the second when the instruction is restarted.

In Strongly Ordered or Device type memory, repeating memory accesses might have unacceptable side-effects. Therefore, if the abort handler can fix the error and re-execute the aborted instruction, you must ensure that for all memory errors on multiword load/store instructions, either:

- all side effects of repeating accesses are inconsequential
- the error must either occur on the first word accessed or not at all.

The instructions that this rule applies to are:

- All forms of ARM instructions `LDM`, and `LDRD`, all forms of `STM`, `STRD` including VFP variants, and unaligned `LDR`, `STR`, `LDRH`, and `STRH`
- Thumb instructions `LDMIA`, `LDRD`, `SDRD`, `PUSH`, `POP`, and `STMIA` including VFP variants, and unaligned `LDR`, `STR`, `LDRH`, and `STRH`.

Abort handler

If you configure the processor with parity or ECC on the caches or the TCMs, and the abort handler is in one of these memories, then it is possible for a parity or ECC error to occur in the abort handler. If the error is not recoverable, then a precise abort occurs and the processor loops until the next interrupt. The LR and SPSR values for the original abort are also lost. Therefore, you must construct software that ensures that no precise aborts occur when in the abort handler. This means the abort handler must be in external memory and not cached.

2.8.5 Supervisor call instruction

You can use the *SuperVisor Call* (SVC) instruction (formerly SWI) to enter Supervisor mode, usually to request a particular supervisor function. The SVC handler reads the opcode to extract the SVC function number. A SVC handler returns by executing the following instruction, irrespective of the processor operating state:

```
MOVS PC, R14_svc
```

This action restores the PC and CPSR, and returns to the instruction following the SVC.

IRQs are disabled when a software interrupt occurs.

The processor modifies the IT execution state bits on exception entry so that the values that the processor writes into the SPSR are correct for the instruction following the SVC. This means that the SVC handler does not have to perform any special action to accommodate the IT instruction. For more information on the IT instruction, see the *ARM Architecture Reference Manual*.

2.8.6 Undefined instruction

When an instruction is encountered which is UNDEFINED, or is for the VFP when the VFP is not enabled, the processor takes the Undefined instruction exception. Software can use this mechanism to extend the ARM instruction set by emulating UNDEFINED coprocessor instructions. UNDEFINED exceptions also occur when a `UDIV` or `SDIV` instruction is executed, the value in Rm is zero, and the DZ bit in the System Control Register is set.

If the handler is required to return after the instruction that caused the Undefined exception, it must:

- Advance the IT execution state bits in the SPSR before restoring SPSR to CPSR. This is so that the correct condition codes are applied to the next instruction on return. The pseudo-code for advancing the IT bits is:

```
Mask = SPSR[11,10,26,25];
if (Mask != 0) {
   Mask = Mask << 1;
   SPSR[12,11,10,26,25] = Mask;
   }
if (Mask[3:0] == 0) {
   SPSR[15:12] = 0;
}
```

- Obtain the instruction that caused the Undefined exception and return correctly after it. Exception handlers must also be aware of the potential for both 16-bit and 32-bit instructions in Thumb state.

  After testing the SPSR and determining the instruction was executed in Thumb state, the Undefined handler must use the following pseudo-code or equivalent to obtain this information:

```
addr = R14_undef - 2
instr = Memory[addr,2]
if (instr >> 11) > 28 { /* 32-bit instruction */
   instr = (instr << 16) | Memory[addr+2,2]
   if (emulating, so return after instruction wanted) }
   R14_undef += 2 //
} //
}
```

  After this, `instr` holds the instruction (in the range `0x0000-0xE7FF` for a 16-bit instruction, `0xE8000000-0xFFFFFFFF` for a 32-bit instruction), and the exception can be returned from using a `MOVS PC, R14` to return after it.

IRQs are disabled when an Undefined instruction trap occurs. For more information about Undefined instructions, see the *ARM Architecture Reference Manual*.

2.8.7 Breakpoint instruction

A breakpoint (BKPT) instruction operates as though the instruction causes a Prefetch Abort.

A breakpoint instruction does not cause the processor to take the Prefetch Abort exception until the instruction is to be executed. If the instruction is not executed, for example because a branch occurs while it is in the pipeline, the breakpoint does not take place.

After dealing with the breakpoint, the handler executes the following instruction irrespective of the processor operating state:

```
SUBS PC, R14_abt, #4
```

This action restores both the PC and the CPSR, and retries the breakpointed instruction.

Note

If the EmbeddedICE-RT logic is configured into Halt debug-mode, a breakpoint instruction causes the processor to enter debug state. See *Halting debug-mode debugging* on page 11-3.

2.8.8 Exception vectors

You can configure the location of the exception vector addresses by setting the V bit in CP15 c1 System Control Register to enable HIVECS, as Table 2-5 shows.

Table 2-5 Configuration of exception vector address locations

Value of V bit	Exception vector base location
0	0x00000000
1 (HIVECS)	0xFFFF0000

Table 2-6 shows the exception vector addresses and entry conditions for the different exception types.

Table 2-6 Exception vectors

Exception	Offset from vector base	Mode on entry	A bit on entry	F bit on entry	I bit on entry
Reset	0x00	Supervisor	Set	Set	Set
Undefined instruction	0x04	Undefined	Unchanged	Unchanged	Set
Software interrupt	0x08	Supervisor	Unchanged	Unchanged	Set
Abort (prefetch)	0x0C	Abort	Set	Unchanged	Set
Abort (data)	0x10	Abort	Set	Unchanged	Set
IRQ	0x18	IRQ	Set	Unchanged	Set
FIQ	0x1C	FIQ	Set	Set	Set

2.9 Acceleration of execution environments

Because the ARMv7-R architecture requires Jazelle® software compatibility, three Jazelle registers are implemented in the processor.

Table 2-7 shows the Jazelle register instruction summary and the response to the instructions.

Table 2-7 Jazelle register instruction summary

Register	Instruction	Response
Jazelle ID	`MRC p14, 7, <Rd>, c0, c0, 0`	Read as zero
	`MCR p14, 7, <Rd>, c0, c0, 0`	Ignore writes
Jazelle main configuration	`MRC p14, 7, <Rd>, c2, c0, 0`	Read as zero
	`MCR p14, 7, <Rd>, c2, c0, 0`	Ignore writes
Jazelle OS control	`MRC p14, 7, <Rd>, c1, c0, 0`	Read as zero
	`MCR p14, 7, <Rd>, c1, c0, 0`	Ignore writes

Note

Because no hardware acceleration is present in the processor, when the `BXJ` instruction is used, the `BX` instruction is invoked.

2.10 Unaligned and mixed-endian data access support

The processor supports unaligned memory accesses. Unaligned memory accesses was introduced with ARMv6. Bit [22] of c1, Control Register is always 1.

The processor supports byte-invariant big-endianness BE-8 and little-endianness LE. The processor does not support word-invariant big-endianness BE-32. Bit [7] of c1, Control Register is always 0.

For more information on unaligned and mixed-endian data access support, see the *ARM Architecture Reference Manual*.

2.11 Big-endian instruction support

The processor supports little-endian or big-endian instruction format, and is dependent on the setting of the **CFGIE** pin. This is reflected in bit [31] of the System Control Register. For more information, see *c1, System Control Register* on page 4-35.

Note

The facility to use big-endian or little-endian instruction format is an implementation option, and you can therefore remove it in specific implementations. If this facility is not present, the **CFGIE** pin is still reflected in the System Control Register but the instruction format is always little-endian.

Chapter 3
Processor Initialization, Resets, and Clocking

Before you can run application software on the processor, it must be reset and initialized, including loading the appropriate software-configuration. This chapter describes the signals for clocking and resetting the processor, and the steps that the software must take to initialize the processor after reset. It contains the following sections:

3.1 Initialization

Most of the architectural registers in the processor, such as r0-r14, and s0-s31 and d0-d15 when floating-point is included, are not reset. Because of this, you must initialize these for all modes before they are used, using an immediate-MOV instruction, or a PC-relative load instruction. The *Current Program Status Register* (CPSR) is given a known value on reset. This is described in the *ARM Architecture Reference Manual*. The reset values for the CP15 registers are described along with the registers in Chapter 4 *System Control Coprocessor*.

In addition, before you run the application, you might want to:

- program particular values into various registers, for example, stack pointers
- enable various processor features, for example, error correction
- program particular values into memory, for example, the TCMs.

Other initialization requirements are described in:

- *MPU*
- *CRS*
- *FPU*
- *Caches* on page 3-3
- *TCM* on page 3-3.

3.1.1 MPU

If the processor has been built with an MPU, before you can use it you must:

- program and enable at least one of the regions
- enable the MPU in the System Control Register.

See *c6, MPU memory region programming registers* on page 4-49. Do not enable the MPU unless at least one MPU region is programmed and active. If the MPU is enabled, before using the TCM interfaces you must program MPU regions to cover the TCM regions to give access permissions to them.

3.1.2 CRS

In processor revisions r1p2 and earlier the *Call-Return-Stack* (CRS) in the PFU is not reset. This means it contains UNPREDICTABLE data after reset. ARM recommends that you initialize the CRS before it is used. For more information on the PFU, see Chapter 5 *Prefetch Unit*,

To do this, before any return instructions are executed, such as `BX`, `LDR pc`, or `LDM pc`, execute four branch-and-link instructions, as follows:

```
; Initialise call-return-stack (CRS) with four call instructions.
        BL call1
call1   BL call2
call2   BL call3
call3   BL next
next
```

3.1.3 FPU

If the processor has been built with a *Floating Point Unit* (FPU) you must enable it before VFP instructions can be executed:

- enable access to the FPU in the coprocessor access control register, see *c1, Coprocessor Access Register* on page 4-44

- enable the FPU by setting the EN-bit in the FPEXC register, see *Floating-Point Exception Register, FPEXC* on page 12-7.

Note

Floating-point logic is only available with the Cortex-R4F processor.

3.1.4 Caches

If the processor has been built with instruction or data caches, these must be invalidated before they are enabled, otherwise UNPREDICTABLE behavior can occur. See *Cache operations* on page 4-54.

If you are using an error checking scheme in the cache, you must enable this by programming the auxiliary control register as described in *Auxiliary Control Registers* on page 4-38 before invalidating the cache, to ensure that the correct error code or parity bits are calculated when the cache is invalidated. An invalidate all operation never reports any ECC or parity errors.

3.1.5 TCM

The processor does not initialize the TCM RAMs. It is not essential to initialize all the memory attached to the TCM interface but ARM recommends that you do. In addition, you might want to preload instructions or data into the TCM for the main application to use. This section describes various ways that you can perform data preloading. You can also configure the processor to use the TCMs from reset.

Preloading TCMs

You can write data to the TCMs using either store instructions or the AXI slave interface. Depending on the method you choose, you might require:

- particular hardware on the SoC that you are using
- boot code
- a debugger connected to the processor.

Methods to preload TCMs include:

Memory copy with running boot code

The boot code includes a memory copy routine that reads data from a ROM, and writes it into the appropriate TCM. You must enable the TCM to do this, and it might be necessary to give the TCM one base address while the copy is occurring, and a different base address when the application is being run.

Copy data from the debug communications channel

The boot code includes a routine to read data from the *Debug Communications Channel* (DCC) and write it into the TCM. The debug host feeds the data for this operation into the DCC by writing to the appropriate registers on the processor APB debug port.

Execute code in debug halt state

The processor is put into debug halt state by the debug host, which then feeds instructions into the processor through the *Instruction Transfer Register* (ITR). The processor executes these instructions, which replace the boot code in either of the two methods described above.

DMA into TCM

The SoC includes a *Direct Memory Access* (DMA) device that reads data from a ROM, and writes it to the TCMs through the AXI slave interface.

Write to TCM directly from debugger

A *Debug Access Port* (DAP) in the system is used to generate AMBA transactions to write data into the TCMs through the AXI slave interface. This DAP is controlled from the debug host through a JTAG chain.

Preloading TCMs with parity or ECC

The error code or parity bits in the TCM RAM, if configured with an error scheme, are not initialized by the processor. Before a RAM location is read with ECC or parity checking enabled, the error code or parity bits must be initialized. To calculate the error code or parity bits correctly, the logic must have all the data in the data chunk that those bits protect. Therefore, when the TCM is being initialized, the writes must be of the same width and aligned to the data chunk that the error scheme protects.

You can initialize the TCM RAM with error checking turned on or off, according to the rules below see. See *Auxiliary Control Registers* on page 4-38. The error code or parity bits written to the TCM are valid even if the error checking is turned off.

If the slave port is used, write transactions must be used that write to the TCM memory as follows:

- If the error scheme is parity, any write transaction can be used.
- If the error scheme is 32-bit ECC, the write transactions must start at a 32-bit aligned addresses and write a continuous block of memory, containing a multiple of 4 bytes. All bytes in the block must be written, that is, have their byte lane strobe asserted.
- If the error scheme is 64-bit ECC, the write transactions must start at a 64-bit aligned addresses and write a continuous block of memory, containing a multiple of 8 bytes. All bytes in the block must be written, that is, have their byte lane strobe asserted.

If initialization is done by running code on the processor, this is best done by a loop of stores that write to the whole of the TCM memory as follows:

- If the error scheme is parity, or no error scheme, any store instruction can be used.
- If the scheme is 32-bit ECC, use *Store Word* (STR), *Store Two Words* (STRD), or *Store Multiple Words* (STM) instructions to 32-bit aligned addresses.
- If the scheme is 64-bit ECC, use STRD or STM, that has an even number of registers in the register list, with a 64-bit aligned starting address.

Note

You can use the alignment-checking features of the processor to help you ensure that memory accesses are 32-bit aligned, but there is no checking for 64-bit alignment. If you are using STRD or STM, an alignment fault is generated if the address is not 32-bit aligned. For the same behavior with `STR` instructions, enable strict-alignment-checking by setting the A-bit in the System Control Register. See *c1, System Control Register* on page 4-35.

If the error scheme is 64-bit ECC, a simpler way to initialize the TCM is:

- Turn off error checking.

- Turn on 64-bit store behavior using CP15. See *c15, Secondary Auxiliary Control Register* on page 4-41.
- Write to the TCM using any store instructions, or any AXI write transactions. The processor performs read-modify-write accesses to ensure that all writes are to 64-bit aligned quantities, even though error checking is turned off.

Note

You can enable error checking and 64-bit store behavior on a per-TCM interface basis. References above to these controls relate to whichever TCM is being initialized.

Using TCMs from reset

The processor can be pin-configured to enable the TCM interfaces from reset, and to select the address at which each TCM appears from reset. See *TCM initialization* on page 8-16 for more details. This enables you to configure the processor to boot from TCM but, to do this, the TCM must first be preloaded with the boot code. The **nCPUHALT** pin can be asserted while the processor is in reset to stop the processor from fetching and executing instructions after coming out of reset. While the processor is halted in this way, the TCMs can be preloaded with the appropriate data. When the **nCPUHALT** pin is deasserted, the processor starts fetching instructions from the reset vector address in the normal way.

Note

When it has been deasserted to start the processor fetching, **nCPUHALT** must not be asserted again except when the processor is under processor or power-on reset, that is, **nRESET** asserted. The processor does not halt if the **nCPUHALT** pin is asserted while the processor is running.

3.2 Resets

The processor has the following reset inputs:

nRESET This signal is the main processor reset that initializes the majority of the processor logic.

PRESETDBGn This signal resets processor debug logic and CoreSight ETM-R4.

nSYSPORESET This signal is the reset that initializes the entire processor, including CP14 debug logic and the APB debug logic. See CP14 registers reset on page 11-23 for information.

nCPUHALT This signal stops the processor from fetching instructions after reset.

All of these are active-LOW signals that reset logic in the processor. You must take care when designing the logic to drive these reset signals.

The processor synchronizes the resets to the relevant clock domains internally.

3.3 Reset modes

The reset signals in the processor enable you to reset different parts of the design independently. Table 3-1 shows the reset signals, and the combinations and possible applications that you can use them in.

Table 3-1 Reset modes

Reset mode	nRESET	PRESETDBGn	nSYSPORESET	nCPUHALT	Application
Power-on reset	0	x	0	x	Reset at power up, full system reset. Hard reset or cold reset.
Processor reset	0	x	1	x	Reset of processor only, watchdog reset. Soft reset or warm reset.
Normal	1	x	1	1	Normal run mode.
Halt	1	x	1	0	Halt mode, provided normal mode has not been entered since reset.
Debug reset	x	0	x	x	Resets all debug logic and debug APB interface.

Note

If **nRESET** is set to 1 and **nSYSPORESET** is set to 0 the behavior is architecturally Unpredictable.

This section of the manual describes:

- *Power-on reset*
- *Processor reset* on page 3-8
- *Normal operation* on page 3-8
- *Halt operation* on page 3-8.

3.3.1 Power-on reset

You must apply power-on or *cold* reset to the processor when power is first applied to the system. In the case of power-on reset, the leading, or falling, edge of the reset signals, **nRESET** and **nSYSPORESET**, does not have to be synchronous to **CLKIN**. Because the **nRESET** and **nSYSPORESET** signals are synchronized within the processor, you do not have to synchronize these signals. Figure 3-1 shows the application of power-on reset.

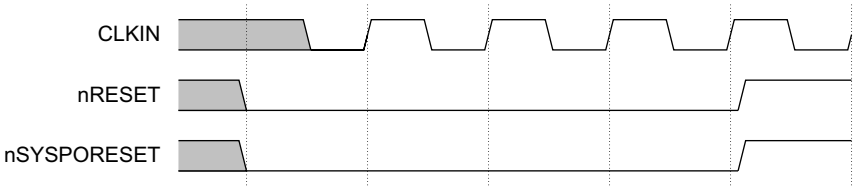


Figure 3-1 Power-on reset

ARM recommends that you assert the reset signals for at least four **CLKIN** cycles to ensure correct reset behavior.

It is not necessary to assert **PRESETDBGn** on power-up.

3.3.2 Processor reset

A processor or *warm* reset initializes the majority of the processor, excluding the EmbeddedICE-RT logic. Processor reset is typically used for resetting a system that has been operating for some time, for example, watchdog reset.

Because the **nRESET** signal is synchronized within the processor, you do not have to synchronize this signal.

3.3.3 Normal operation

During normal operation, neither processor reset nor power-on reset is asserted. If the Embedded ICE-RT is not used, the value of **PRESETDBGn** does not matter.

3.3.4 Halt operation

When **nCPUHALT** is asserted, and **nSYSPORESET** and **nRESET** deasserted, the processor is out of reset, but the PFU is inhibited from fetching instructions. For example, you can use **nCPUHALT** to enable DMA into the TCMs using the processor. You can then deassert **nCPUHALT** and the PFU starts fetching instructions from TCMs. When the processor has started fetching, **nCPUHALT** must not be asserted again except when the processor is reset.

3.4 Clocking

The processor has two functional clock inputs. Externally to the processor, you must connect together **CLKIN** and **FREECLKIN**.

In addition, there is the **PCLKDBG** clock for the debug APB bus. This is asynchronous to the main clock.

All clocks can be stopped indefinitely without loss of state.

Three additional clock inputs, **CLKIN2**, **DUALCLKIN**, and **DUALCLKIN2**, are related to the dual-redundant core functionality, if included. If you are integrating a Cortex-R4 macrocell with dual-redundant core, contact the implementer of that macrocell for information about how to connect the clock inputs.

The following is described in this section:

- *AXI interface clocking*
- *Clock gating*.

3.4.1 AXI interface clocking

The AXI master and AXI slave interfaces must be connected to AXI systems that are synchronous to the processor clock, **CLKIN**, even if this might be at a lower frequency. This means that every rising edge on the AXI system clock must be synchronous to a rising edge on **CLKIN**.

The AXI master interface clock enable signal **ACLKENM** and the AXI slave interface clock enable signal **ACLKENS** must be asserted on every **CLKIN** rising edge for which there is a simultaneous rising edge on the AXI system clock.

Figure 3-2 shows an example in which the processor is clocked at 400MHz (**CLKIN**), while the AXI system connected to the AXI master interface is clocked at 200MHz (**ACLKM**). The **ACLKENM** clock indicates the relationship between the two clocks.

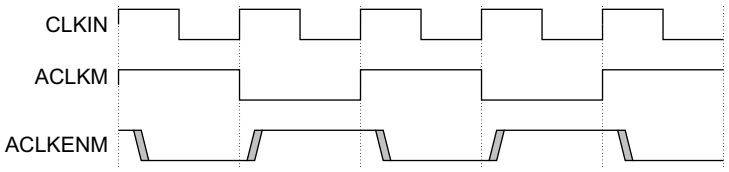


Figure 3-2 AXI interface clocking

If the AXI system connected to an interface is clocked at the same frequency as the processor, then the corresponding clock enable signal must be tied HIGH.

3.4.2 Clock gating

You can use the **STANDBYWFI** output to gate the clock to the TCMs when the processor is in Standby mode. If you do, you must design the logic so that the TCM clock starts running within four cycles of **STANDBYWFI** going LOW.

Chapter 4
System Control Coprocessor

This chapter describes the purpose of the system control coprocessor, its structure, operation, and how to use it. It contains the following sections:

4.1 About the system control coprocessor

This section gives an overview of the system control coprocessor. For more information of the registers in the system control coprocessor, see *System control coprocessor registers* on page 4-9.

The purpose of the system control coprocessor, CP15, is to control and provide status information for the functions implemented in the processor. The main functions of the system control coprocessor are:

- overall system control and configuration
- cache configuration and management
- *Memory Protection Unit* (MPU) configuration and management
- system performance monitoring.

The system control coprocessor does not exist in a distinct physical block of logic.

4.1.1 System control coprocessor functional groups

The system control coprocessor appears as a set of registers that you can write to and read from. Some of the registers permit more than one type of operation. The functional groups for the registers are:

- *System control and configuration* on page 4-4
- *MPU control and configuration* on page 4-5
- *Cache control and configuration* on page 4-5
- *TCM control and configuration* on page 4-6
- *System performance monitor* on page 4-6
- *System validation* on page 4-7.

Table 4-1 on page 4-3 shows the overall functionality for the system control coprocessor, provided through the registers. The registers are listed in their functional groups.

Table 4-2 on page 4-9 lists the registers in the system control processor, in register order, and gives the reset value for each register.

Table 4-1 System control coprocessor register functions

Function	Register/operation	Reference to description
System control and configuration	Control	*c1, System Control Register* on page 4-35
	Auxiliary control	*Auxiliary Control Registers* on page 4-38
	Coprocessor Access Control	*c1, Coprocessor Access Register* on page 4-44
	Main ID[a]	*c0, Main ID Register* on page 4-14
	Product Feature IDs	*The Processor Feature Registers* on page 4-18 *c0, Debug Feature Register 0* on page 4-20 *c0, Auxiliary Feature Register 0* on page 4-21 *Memory Model Feature Registers* on page 4-21 *Instruction Set Attributes Registers* on page 4-26
	Multiprocessor ID	*c0, Multiprocessor ID Register* on page 4-18
	Slave Port Control	*c11, Slave Port Control Register* on page 4-59
	Context ID	*c13, Context ID Register* on page 4-60
	FCSE PID	*c13, FCSE PID Register* on page 4-60
Software compatibility	Thread And Process ID	*c13, Thread and Process ID Registers* on page 4-61
MPU control and configuration	Data Fault Status	*c5, Data Fault Status Register* on page 4-45
	Auxiliary Fault Status	*c5, Auxiliary Fault Status Registers* on page 4-47
	Instruction Fault Status	*c5, Instruction Fault Status Register* on page 4-46
	Instruction Fault Address	*c6, Instruction Fault Address Register* on page 4-49
	Data Fault Address	*c6, Data Fault Address Register* on page 4-48
	MPU Type	*c0, MPU Type Register* on page 4-17
	Region Base Address	*c6, MPU Region Base Address Registers* on page 4-50
	Region Size and Enable	*c6, MPU Region Size and Enable Registers* on page 4-50
	Region Access Control	*c6, MPU Region Access Control Registers* on page 4-51
	Memory Region Number	*c6, MPU Memory Region Number Register* on page 4-53
Cache control and configuration	Cache Type	*c0, Cache Type Register* on page 4-15
	Current Cache Size Identification	*c0, Current Cache Size Identification Register* on page 4-32
	Current Cache Level	*c0, Current Cache Level ID Register* on page 4-34
	Cache Size Selection	*c0, Cache Size Selection Register* on page 4-35
	c7, Cache Operations	*Cache operations* on page 4-54
	c15, Invalidate all data cache	

Table 4-1 System control coprocessor register functions (continued)

Function	Register/operation	Reference to description
TCM control and configuration	TCM Status	*c0, TCM Type Register* on page 4-16
	Region	*c9, BTCM Region Register* on page 4-57 *c9, TCM Selection Register* on page 4-59
System performance monitoring	Performance monitoring	Chapter 6 *Events and Performance Monitor*
Validation	System validation	*Validation Registers* on page 4-62

a. Known as the ID Code Register on previous designs. Returns the device ID code.

4.1.2 System control and configuration

The system control and configuration registers provide overall management of:

- memory functionality
- interrupt behavior
- exception handling
- program flow prediction
- coprocessor access rights for CP0-CP13, including the VFP, CP10-11.

The system control and configuration registers also provide the processor ID and information on configured options.

The system control and configuration registers consist of 18 read-only registers and seven read/write registers. Figure 4-1 shows the arrangement of registers in this functional group.

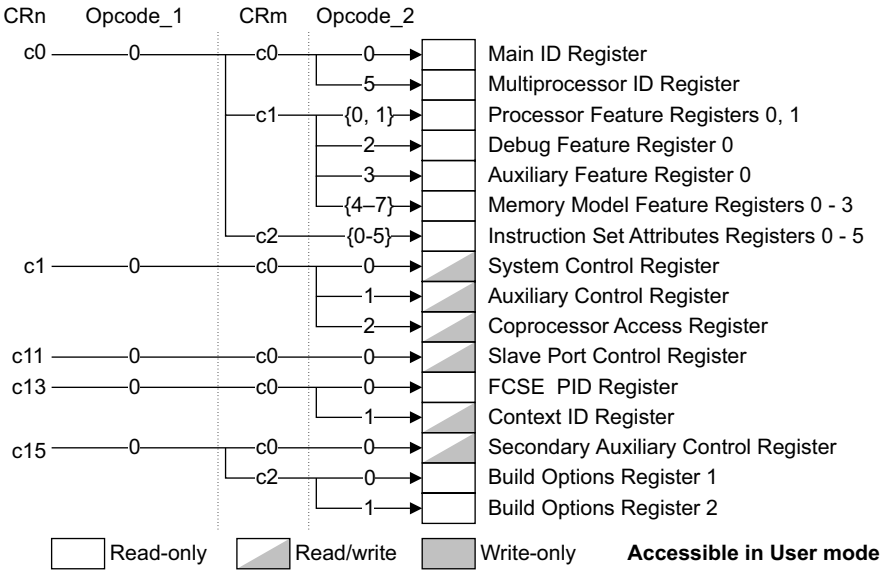


Figure 4-1 System control and configuration registers

Some of the functionality depends on how you set external signals at reset.

System control and configuration behaves in three ways:

- as a set of flags or enables for specific functionality
- as a set of numbers, with values that indicate system functionality
- as a set of addresses for processes in memory.

4.1.3 MPU control and configuration

The MPU control and configuration registers:

- control program access to memory
- designate areas of memory as either:
  - Normal, Non-cacheable
  - Normal, Cacheable
  - Device
  - Strongly Ordered.
- detect MPU faults and external aborts.

The MPU control and configuration registers consist of one read-only register and eleven read/write registers. Figure 4-2 shows the arrangement of registers in this functional group.

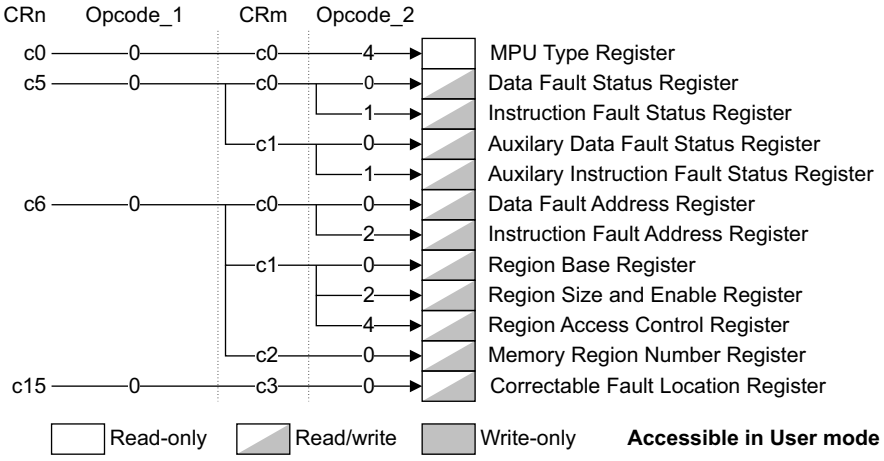


Figure 4-2 MPU control and configuration registers

MPU control and configuration can behave:

- as a set of numbers, with values that describe aspects of the MPU or indicate its current state
- as a set of operations that act on the MPU.

4.1.4 Cache control and configuration

The cache control and configuration registers:

- provide information on the size and architecture of the instruction and data caches
- control cache maintenance operations that include clean and invalidate caches, drain and flush buffers, and address translation
- override cache behavior during debug or interruptible cache operations.

The cache control and configuration registers consist of three read-only registers, one read/write register, and a number of write-only registers. Figure 4-3 on page 4-6 shows the arrangement of the registers in this functional group.

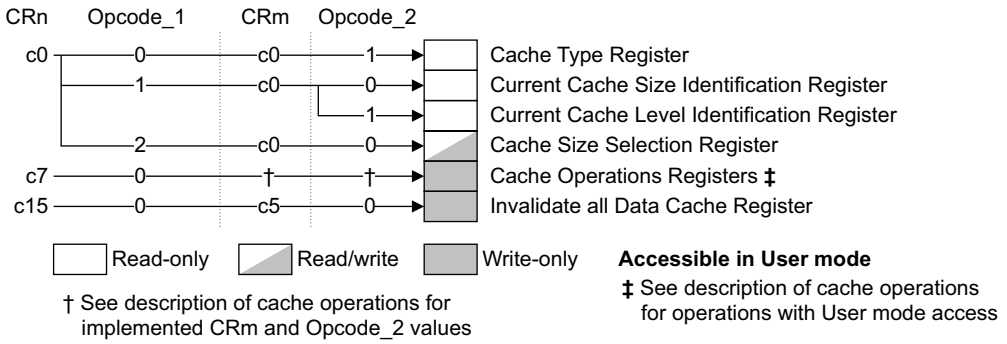


Figure 4-3 Cache control and configuration registers

Cache control and configuration registers behave as:

- a set of numbers, with values that describe aspects of the caches
- a set of bits that enable specific cache functionality
- a set of operations that act on the caches.

4.1.5 TCM control and configuration

The TCM control and configuration registers:

- inform the processor about the status of the TCM regions
- define TCM regions.

The TCM control and configuration registers consist of two read-only registers and two read/write registers. Figure 4-4 shows the arrangement of registers.

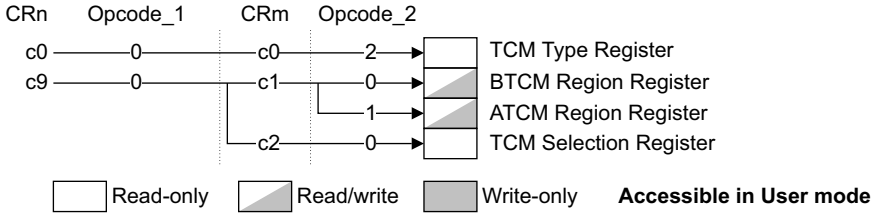


Figure 4-4 TCM control and configuration registers

TCM control and configuration behaves in three ways:

- as a set of numbers, with values that describe aspects of the TCMs
- as a set of bits that enable specific TCM functionality
- as a set of addresses that define the memory locations of data stored in the TCMs.

4.1.6 System performance monitor

The performance monitor registers:

- control the monitoring operation
- count events.

The system performance monitor consists of 12 read/write registers. Figure 4-5 on page 4-7 shows the arrangement of registers in this functional group.

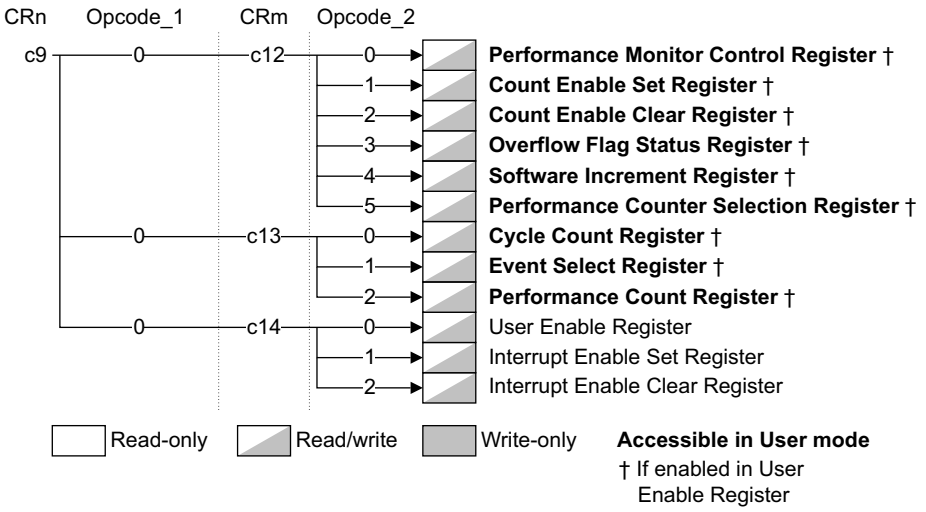


Figure 4-5 System performance monitor registers

System performance monitoring counts system events, such as cache misses, pipeline stalls, and other related features to enable system developers to profile the performance of their systems. It can generate interrupts when the number of events reaches a given value.

For more information on the programmer's model of the performance counters see the *ARM Architecture Reference Manual*.

See Chapter 6 *Events and Performance Monitor* for more information on the registers.

4.1.7 System validation

The system validation registers extend the use of the system performance monitor registers to provide some functions for validation. You must not use them for other purposes. The system validation registers schedule and clear:

- resets
- interrupts
- fast interrupts
- external debug requests.

The system validation registers consist of nine read/write registers and one write-only register. Figure 4-6 shows the arrangement of registers.

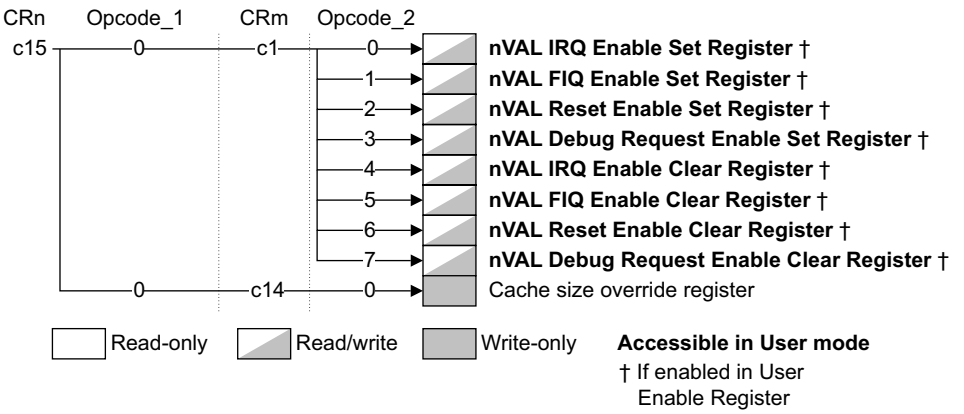


Figure 4-6 System validation registers

You can only change the cache size to a size supported by the cache RAMs implemented in your design.

4.2 System control coprocessor registers

This section describes all of the registers in the system control coprocessor. The section presents a summary of the registers and descriptions in register order of CRn, Opcode_1, CRm, Opcode_2.

For more information on using the system control coprocessor and the general method of how to access CP15 registers, see the *ARM Architecture Reference Manual*.

4.2.1 Register allocation

Table 4-2 shows a summary of address allocation and reset values for the registers in the system control coprocessor where:

- CRn is the register number within CP15
- Op1 is the Opcode_1 value for the register
- CRm is the operational register
- Op2 is the Opcode_2 value for the register.

Table 4-2 Summary of CP15 registers and operations

CRn	Op1	CRm	Op2	Register or operation	Type	Reset value	Page
c0	0	c0	{0, 3, 6-7}	Main ID	Read-only	0x41xFC14x[a]	page 4-14
			1	Cache Type	Read-only	0x8003C003	page 4-15
			2	TCM Type	Read-only	0x00010001	page 4-16
			4	MPU Type	Read-only	0x00000000[b]	page 4-17
			5	Multiprocessor ID	Read-only	0x00000000	page 4-18
		c1	0	Processor Feature 0	Read-only	0x00000131	page 4-18
			1	Processor Feature 1	Read-only	0x00000001	page 4-19
			2	Debug Feature 0	Read-only	0x00010400	page 4-20
			3	Auxiliary Feature 0	Read-only	0x00000000	page 4-21
			4	Memory Model Feature 0	Read-only	0x00210030	page 4-21
			5	Memory Model Feature 1	Read-only	0x00000000	page 4-22
			6	Memory Model Feature 2	Read-only	0x01200000	page 4-24
			7	Memory Model Feature 3	Read-only	0x00000011	page 4-25
		c2	0	Instruction Set Attributes 0	Read-only	0x01101111	page 4-26
c0	0	c2	1	Instruction Set Attributes 1	Read-only	0x13112111	page 4-27
			2	Instruction Set Attributes 2	Read-only	0x21232131	page 4-28
			3	Instruction Set Attributes 3	Read-only	0x01112131	page 4-30
			4	Instruction Set Attributes 4	Read-only	0x00010142	page 4-31
			5	Instruction Set Attributes 5	Read-only	0x00000000	page 4-32
			6-7	Reserved, *Read As Zero* (RAZ)	Read-only	0x00000000	page 4-32
		c3-c7	0-7	Reserved, RAZ	Read-only	0x00000000	-

Table 4-2 Summary of CP15 registers and operations (continued)

CRn	Op1	CRm	Op2	Register or operation	Type	Reset value	Page
		c8-c15	0-7	Undefined	-	-	-
	1	c0	0	Current Cache Size ID	Read-only	-[cd]	page 4-32
			1	Current Cache Level ID	Read-only	0x09000003[c]	page 4-34
			2-7	Undefined	-	-	-
		c1-c15	0-7				
	2	c0	0	Cache Size Selection	Read/write	Unpredictable	page 4-35
c1	0	c0	0	System Control	Read/write	-[d]	page 4-35
			1	Auxiliary Control	Read/write	-[d]	page 4-38
			2	Coprocessor Access	Read/write	0x00000000	page 4-44
			3-7	Undefined	-	-	-
		c1-c15	0-7				
c2-c4	0	c0-c15	0-7				
c5	0	c0	0	Data Fault Status	Read/write	Unpredictable	page 4-45
			1	Instruction Fault Status	Read/write	Unpredictable	page 4-46
			2-7	Undefined	-	-	-
		c1	0	Auxiliary Data Fault Status	Read/write	Unpredictable	page 4-47
c5	0	c1	1	Auxiliary Instruction Fault Status	Read/write	Unpredictable	page 4-47
			2-7	Undefined	-	-	-
		c2-c15	0-7				
c6	0	c0	0	Data Fault Address	Read/write	Unpredictable	page 4-48
			1	Undefined	-	-	-
			2	Instruction Fault Address	Read/write	Unpredictable	page 4-49
			3-7	Undefined	-	-	-
		c1	0	MPU Region Base Address	Read/write	0x00000000	page 4-50
			1	Undefined	-	-	-
			2	MPU Region Size and Enable	Read/write	0x00000000	page 4-50
			3	Undefined	-	-	-
			4	MPU Region Access Control	Read/write	0x00000000	page 4-51
			5-7	Undefined	-	-	-
		c2	0	MPU Memory Region Number	Read/write	0x00000000	page 4-53

Table 4-2 Summary of CP15 registers and operations (continued)

CRn	Op1	CRm	Op2	Register or operation	Type	Reset value	Page
			1-7	Undefined	-	-	-
		c3-c15	1-7				
c7	0	c0	0-3	Undefined	-	-	-
			4	NOP, previously Wait For Interrupt	Write-only	-	page 4-54
			5-7	Undefined	-	-	-
		c1-c4	0-7				
		c5	0	Invalidate entire instruction cache	Write-only	-	page 4-55
c7	0	c5	1	Invalidate instruction cache line by address to Point-of-Unification.	Write-only	-	page 4-55
			2-3	Undefined	-	-	-
			4	Flush prefetch buffer	Write-only	-	page 4-55
			5	Undefined	-	-	-
			6	Invalidate entire branch predictor array	Write-only	-	page 4-55
			7	Invalidate address from branch predictor array	Write-only	-	page 4-55
		c6	0	Undefined	-	-	-
			1	Invalidate data cache line by physical address	Write-only	-	page 4-55
			2	Invalidate data cache line by Set/Way	Write-only	-	page 4-55
			3-7	Undefined	-	-	-
		c7-9	0-7				
		c10	0				
			1	Clean data cache line by physical address	Write-only	-	page 4-55
			2	Clean data cache line by Set/Way	Write-only	-	page 4-55
			3	Undefined	-	-	-
			4	Data Synchronization Barrier	Write-only	-	page 4-57
			5	Data Memory Barrier	Write-only	-	page 4-57
			6-7	Undefined	-	-	-
		c11	0				

Table 4-2 Summary of CP15 registers and operations (continued)

CRn	Op1	CRm	Op2	Register or operation	Type	Reset value	Page
c7	0	c11	1	Clean data cache line by physical address to Point-of-Unification	Write-only	-	page 4-55
			2-7	Undefined	-	-	-
		c12-c13	0-7				
		c14	0				
			1	Clean and invalidate data cache line by physical address to Point-of-Unification	Write-only	-	page 4-55
		c14	2	Clean and invalidate data cache line by Set/Way	Write-only	-	page 4-55
			3-7	Undefined	-	-	-
		c15	0-7				
c8	0	c0-c15	0-7	Undefined	-	-	-
c9	0	c0	0-7	Undefined	-	-	-
		c1	0	BTCM Region	Read/write	-[d]	page 4-57
			1	ATCM Region	Read/write	-[d]	page 4-57
			2-7	Undefined	-	-	-
		c2	0	TCM selection	Read/write	0x00000000	page 4-59
			1-7	Undefined	-	-	-
		c3-c11	0-7				
		c12	0	Performance Monitor Control	Read/write	0x41141800	page 6-7
			1	Count Enable Set	Read/write	Unpredictable	page 6-8
			2	Count Enable Clear	Read/write	Unpredictable	page 6-9
			3	Overflow Flag Status	Read/write	Unpredictable	page 6-10
			4	Software Increment	Write-only	-	page 6-11
c9	0	c12	5	Performance Counter Selection	Read/write	Unpredictable	page 6-12
			6-7	Undefined	-	-	-
		c13	0	Cycle Count	Read/write	0x00000000	page 6-13
			1	Event Select	Read/write	Unpredictable	page 6-13
			2	Performance Monitor Count	Read/write	0x00000000	page 6-15
			3-7	Undefined	-	-	-

Table 4-2 Summary of CP15 registers and operations (continued)

CRn	Op1	CRm	Op2	Register or operation	Type	Reset value	Page
		c14	0	User Enable	Read/write	0x00000000	page 6-15
			1	Interrupt Enable Set	Read/write	Unpredictable	page 6-16
		c14	2	Interrupt Enable Clear	Read/write	Unpredictable	page 6-17
			3-7	Undefined	-	-	-
		c15	0-7				
c10	0	c0-c15	0-7	Undefined	-	-	-
c11	0	c0	0	Slave Port Control	Read/write	0x00000000	page 4-59
		c0	1-7	Undefined	-	-	-
		c1-c15	0-7				
c12	0	c0-c15	0-7				
c13	0	c0	0	FCSE PID	RAZ, ignore writes	0x00000000	page 4-60
			1	Context ID	Read/write	0x00000000	page 4-60
			2	User read/write Thread and Process ID	Read/write	0x00000000	page 4-61
			3	User Read-only Thread and Process ID	Read/write	0x00000000	page 4-61
			4	Privileged Only Thread and Process ID	Read/write	0x00000000	page 4-61
			5-7	Undefined	-	-	-
c13	0	c1-c15	0-7	Undefined	-	-	-
c14	0	c0-c15	0-7				
c15	0	c0	0	Secondary Auxiliary Control	Read/write	-[d]	page 4-41
			1-7	Undefined	-	-	-
		c1	0	nVAL IRQ Enable Set	Read/write	Unpredictable	page 4-62
			1	nVAL FIQ Enable Set	Read/write	Unpredictable	page 4-63
			2	nVAL Reset Enable Set	Read/write	Unpredictable	page 4-64
			3	nVAL Debug Request Enable Set	Read/write	Unpredictable	page 4-64
			4	nVAL IRQ Enable Clear	Read/write	Unpredictable	page 4-65
		c1	5	nVAL FIQ Enable Clear	Read/write	Unpredictable	page 4-66
			6	nVAL Reset Enable Clear	Read/write	Unpredictable	page 4-67
			7	nVAL Debug Request Enable Clear	Read/write	Unpredictable	page 4-68
		c2	0	Build Options 1	Read-only	-[d]	page 4-72

Table 4-2 Summary of CP15 registers and operations (continued)

CRn	Op1	CRm	Op2	Register or operation	Type	Reset value	Page
			1	Build Options 2	Read-only	-[d]	page 4-72
			2-7	Undefined	-	-	-
		c3	0	Correctable Fault Location	Read/write	Unpredictable	page 4-70
			1-7	Undefined	-	-	-
		c4	0-7				
		c5	0	Invalidate all data cache	Write-only	-	page 4-55
			1-7	Undefined	-	-	-
		c6-c13	0-7				
c15	0	c14	0	Cache Size Override	Write-only	-	page 4-69
			1-7	Undefined	-	-	-
		c15	0-7				

a. The value of bits [23:20,3:0] of the Main ID Register depend on product revision. See the register description for more information.
b. Reset value depends on number of MPU regions.
c. Reset value depends on the cache size implemented.
d. See register description for more information.

4.2.2 c0, Main ID Register

The Main ID Register returns the device ID code that contains information about the processor.

The Main ID Register is:
- a read-only register
- accessible in Privileged mode only.

Figure 4-7 shows the arrangement of bits in the register.

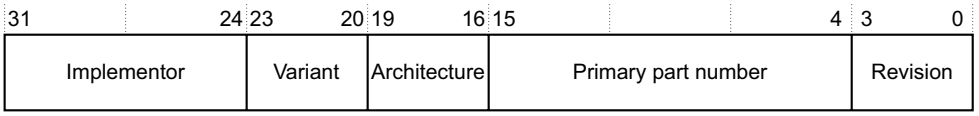


Figure 4-7 Main ID Register format

The contents of the Main ID Register depend on the specific implementation. Table 4-3 shows how the bit values correspond with the Main ID Register functions.

Table 4-3 Main ID Register bit functions

Bits	Field	Function
[31:24]	Implementer	Indicates implementer. `0x41` - ARM Limited.
[23:20]	Variant	Identifies the major revision of the processor. This is the major revision number *n* in the r*n* part of the r*n*p*n* description of the product revision status. See *Product revision information* on page 1-24 for details of the value of this field.
[19:16]	Architecture	Indicates the architecture version. `0xF` - see feature registers.
[15:4]	Primary part number	Indicates processor part number. `0xC14` - Cortex-R4.
[3:0]	Revision	Identifies the minor revision of the processor. This is the minor revision number *n* in the p*n* part of the r*n*p*n* description of the product revision status. See *Product revision information* on page 1-24 for details of the value of this field.

Note

If an `MRC` instruction is executed with CRn = c0, Opcode_1 = 0, CRm = c0, and an Opcode_2 value corresponding to an unimplemented or reserved ID register, the system control coprocessor returns the value of the main ID register.

To access the Main ID Register, read CP15 with:

```
MRC p15, 0, <Rd>, c0, c0, 0 ; Read Main ID Register
```

For more information on the processor features, see *The Processor Feature Registers* on page 4-18.

4.2.3 c0, Cache Type Register

The Cache Type Register determines the instruction and data minimum line length in bytes to enable a range of addresses to be invalidated.

The Cache Type Register is:

- a read-only register
- accessible in Privileged mode only.

The contents of the Cache Type Register depend on the specific implementation. Figure 4-8 shows the arrangement of bits in the register.

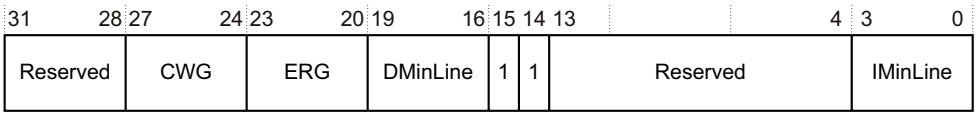


Figure 4-8 Cache Type Register format

Table 4-4 shows how the bit values correspond with the Cache Type Register functions.

Table 4-4 Cache Type Register bit functions

Bits	Field	Function
[31:28]	-	Always b1000.
[27:24]	CWG	Cache Write-back Granule `0x0` = no information provided. See maximum cache line size in *c0, Current Cache Size Identification Register* on page 4-32.
[23:20]	ERG	Exclusives Reservation Granule `0x0` = no information provided.
[19:16]	DMinLine	Indicates log2 of the number of words in the smallest cache line of the data and unified caches controlled by the processor: `0x3` = eight words in an L1 data cache line.
[15:14]	-	Always `0x3`.
[13: 4]	-	Always `0x000`.
[3: 0]	IMinLine	Indicates log2 of the number of words in the smallest cache line of the instruction caches controlled by the processor: `0x3` - eight words in an L1 instruction cache line.

To access the Cache Type Register, read CP15 with:

```
MRC p15, 0, <Rd>, c0, c0, 1 ; Returns cache details
```

4.2.4 c0, TCM Type Register

The TCM Type Register informs the processor of the number of ATCMs and BTCMs in the system.

The TCM Type Register is:

- a read-only register
- accessible in Privileged mode only.

Figure 4-9 shows the arrangement of bits in the register.

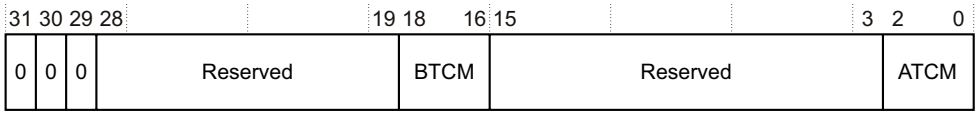


Figure 4-9 TCM Type Register format

Table 4-5 shows how the bit values correspond with the TCM Type Register functions.

Table 4-5 TCM Type Register bit functions

Bits	Field	Function
[31:29]	-	Always 0.
[28:19]	Reserved	SBZ.

Table 4-5 TCM Type Register bit functions (continued)

Bits	Field	Function
[18:16]	BTCM	Specifies the number of BTCMs implemented. This is always set to `b001` because the processor has one BTCM.
[15:3]	Reserved	SBZ.
[2:0]	ATCM	Specifies the number of ATCMs implemented. Always set to b001. The processor has one ATCM.

To access the TCM Type Register, read CP15 with:

```
MRC p15, 0, <Rd>, c0, c0, 2 ; Returns TCM type register
```

Note

- The ATCM and BTCM fields in the TCM Type Register occupy the same space as the ITCM and DTCM fields as defined by the ARM Architecture. These fields, and the corresponding TCM interfaces, can be considered equivalent to those defined in the Architecture.
- The ARM Architecture requires only the ITCM to be accessible from both instruction and data sides. In the Cortex-R4 processor, both ATCM and BTCM are accessible from both instruction and data sides.

4.2.5 c0, MPU Type Register

The MPU Type Register holds the value for the number of instruction and data memory regions implemented in the processor.

The MPU Type Register is:

- read-only register
- accessible in Privileged mode only.

Figure 4-10 shows the arrangement of bits in the register.

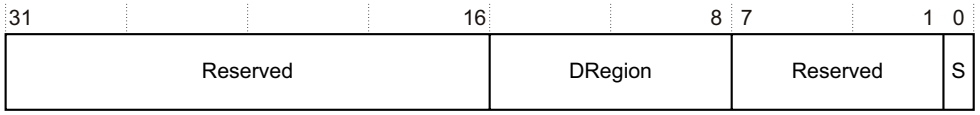


Figure 4-10 MPU Type Register format

Table 4-6 shows how the bit values correspond with the MPU Type Register functions.

Table 4-6 MPU Type Register bit functions

Bits	Field	Function
[31:16]	Reserved	SBZ.
[15:8]	DRegion	Specifies the number of unified MPU regions. Set to 0, 8 or 12 data MPU regions.
[7:1]	Reserved	SBZ.
[0]	S	Specifies the type of MPU regions, unified or separate, in the processor. Always set to 0, the processor has unified memory regions.

To access the MPU Type Register, read CP15 with:

```
MRC p15, 0, <Rd>, c0, c0, 4 ; Returns MPU details
```

4.2.6 c0, Multiprocessor ID Register

The Multiprocessor ID Register enables cores to be recognized and characterized within a multiprocessor system.

The Multiprocessor ID Register is:

- read-only register
- accessible in Privileged mode only.

Figure 4-11 shows the arrangement of bits in the register.

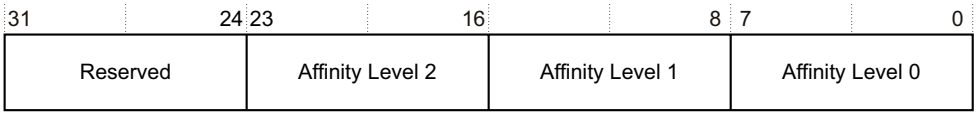


Figure 4-11 Multiprocessor ID Register format

Because this is a uniprocessor system, this register is Read-As-Zero.

To access the Multiprocessor ID Register, read CP15 with:

```
MRC p15, 0, <Rd>, c0, c0, 5 ; Returns Multiprocessor ID details
```

4.2.7 The Processor Feature Registers

There are two Processor Feature Registers, PFR0 and PFR1. This section describes:

- *c0, Processor Feature Register 0, PFR0*
- *c0, Processor Feature Register 1, PFR1* on page 4-19.

c0, Processor Feature Register 0, PFR0

The Processor Feature Register 0 provides information about the execution state support and programmer's model for the processor.

Processor Feature Register 0 is:

- a read-only register
- accessible in Privileged mode only.

Figure 4-12 shows the bit arrangement for Processor Feature Register 0.

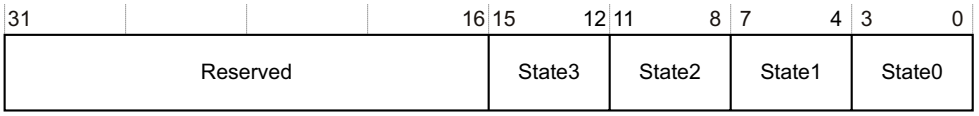


Figure 4-12 Processor Feature Register 0 format

Table 4-7 shows how the bit values correspond with the Processor Feature Register 0 functions.

Table 4-7 Processor Feature Register 0 bit functions

Bits	Field	Function
[31:16]	Reserved	SBZ.
[15:12]	State3	Indicates support for Thumb Execution Environment (ThumbEE). `0x0`, no support.
[11:8]	State2	Indicates support for acceleration of execution environments in hardware or software. `0x1`, the processor supports acceleration of execution environments in software.
[7:4]	State1	Indicates type of Thumb encoding that the processor supports. `0x3`, the processor supports Thumb encoding with all Thumb instructions.
[3:0]	State0	Indicates support for ARM instruction set. `0x1`, the processor supports ARM instructions.

To access the Processor Feature Register 0 read CP15 with:

```
MRC p15, 0, <Rd>, c0, c1, 0 ; Read Processor Feature Register 0
```

c0, Processor Feature Register 1, PFR1

The Processor Feature Register 1 provides information about the execution state support and programmer's model for the processor.

Processor Feature Register 1 is:

- a read-only register
- accessible in Privileged mode only.

Figure 4-13 shows the bit arrangement for Processor Feature Register 1.

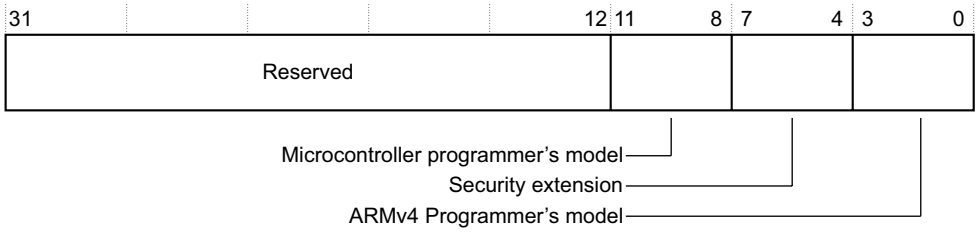


Figure 4-13 Processor Feature Register 1 format

Table 4-8 shows how the bit values correspond with the Processor Feature Register 1 functions.

Table 4-8 Processor Feature Register 1 bit functions

Bits	Field	Function
[31:12]	Reserved	SBZ.

Table 4-8 Processor Feature Register 1 bit functions (continued)

Bits	Field	Function
[11:8]	Microcontroller programmer's model	Indicates support for Microcontroller programmer's model: 0x0, no support.
[7:4]	Security extension	Indicates support for Security Extensions Architecture: 0x0, no support.
[3:0]	ARMv4 Programmer's model	Indicates support for standard ARMv4 programmer's model: 0x1, the processor supports the ARMv4 model.

To access the Processor Feature Register 1 read CP15 with:

```
MRC p15, 0, <Rd>, c0, c1, 1 ; Read Processor Feature Register 1
```

4.2.8 c0, Debug Feature Register 0

The Debug Feature Register 0 provides information about the debug system for the processor.

Debug Feature Register 0 is:

- a read-only register
- accessible in Privileged mode only.

Figure 4-14 shows the bit arrangement for Debug Feature Register 0.

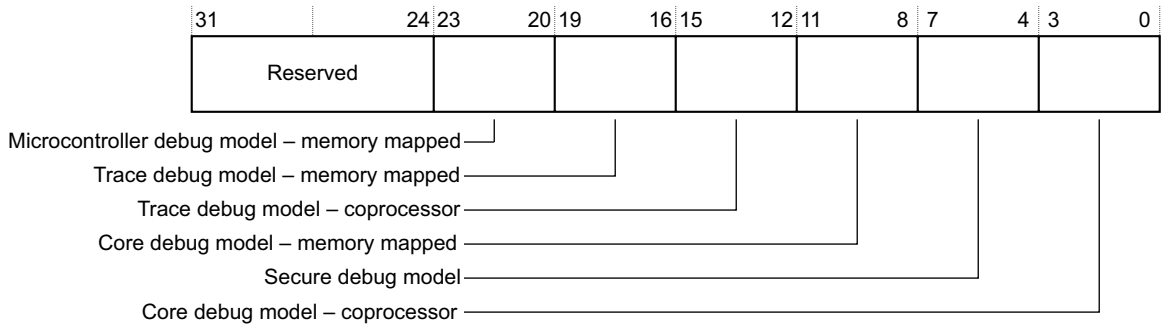


Figure 4-14 Debug Feature Register 0 format

Table 4-9 shows how the bit values correspond with the Debug Feature Register 0 functions.

Table 4-9 Debug Feature Register 0 bit functions

Bits	Field	Function
[31:24]	Reserved	SBZ.
[23:20]	Microcontroller Debug model - memory mapped	Indicates support for the microcontroller debug model - memory mapped: 0x0, no support.
[19:16]	Trace debug model - memory mapped	Indicates support for the trace debug model - memory mapped: 0x1, trace supported, memory mapped access.
[15:12]	Trace debug model - coprocessor	Indicates support for the trace debug model - coprocessor: 0x0, no support.

Table 4-9 Debug Feature Register 0 bit functions (continued)

Bits	Field	Function
[11:8]	Core debug model - memory mapped	Indicates the type of embedded processor debug model that the processor supports: `0x4`, ARMv7 based model - memory mapped.
[7:4]	Secure debug model	Indicates the type of secure debug model that the processor supports: `0x0`, no support.
[3:0]	Core debug model - coprocessor	Indicates the type of applications processor debug model that the processor supports: `0x0`, no support.

To access the Debug Feature Register 0 read CP15 with:

```
MRC p15, 0, <Rd>, c0, c1, 2 ; Read Debug Feature Register 0
```

4.2.9 c0, Auxiliary Feature Register 0

The Auxiliary Feature Register 0 provides additional information about the features of the processor.

The Auxiliary Feature Register 0 is:
- a read-only register
- accessible in Privileged mode only.

In this processor, the Auxiliary Feature Register 0 reads as `0x00000000`.

To access the Auxiliary Feature Register 0 read CP15 with:

```
MRC p15, 0, <Rd>, c0, c1, 3 ; Read Auxiliary Feature Register 0.
```

4.2.10 Memory Model Feature Registers

There are four Memory Model Feature Registers, MMFR0 to MMFR3. They are described in the following subsections:
- *c0, Memory Model Feature Register 0, MMFR0*
- *c0, Memory Model Feature Register 1, MMFR1* on page 4-22
- *c0, Memory Model Feature Register 2, MMFR2* on page 4-24
- *c0, Memory Model Feature Register 3, MMFR3* on page 4-25.

c0, Memory Model Feature Register 0, MMFR0

The Memory Model Feature Register 0 provides information about the memory model, memory management, and cache support operations of the processor.

The Memory Model Feature Register 0 is:
- a read-only register
- accessible in Privileged mode only.

Figure 4-15 on page 4-22 shows the bit arrangement for Memory Model Feature Register 0.

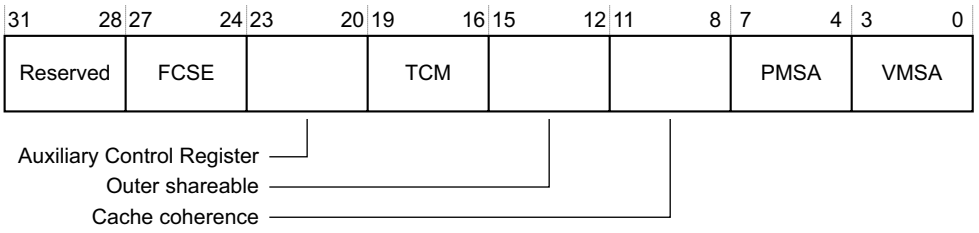


Figure 4-15 Memory Model Feature Register 0 format

Table 4-10 shows how the bit values correspond with the Memory Model Feature Register 0 functions.

Table 4-10 Memory Model Feature Register 0 bit functions

Bits	Field	Function
[31:28]	Reserved	SBZ.
[27:24]	FCSE	Indicates support for *Fast Context Switch Extension* (FCSE). `0x0`, no support.
[23:20]	Auxiliary Control Register	Indicates support for the auxiliary registers. `0x2`, the processor supports the Auxiliary Instruction and Data Fault Status Registers (AIFSR and ADFSR) and the Auxiliary Control Register.
[19:16]	TCM	Indicates support for TCM and associated DMA. `0x1`, implementation defined.
[15:12]	Outer shareable	Indicates support for the Outer shareable attribute. `0x0`, no support.
[11:8]	Cache coherence	Indicates support for cache coherency maintenance. `0x0`, no support for shared caches.
[7:4]	PMSA	Indicates support for *Physical Memory System Architecture* (PMSA). `0x3`, the processor supports PMSAv7 (subsection support).
[3:0]	VMSA	Indicates support for *Virtual Memory System Architecture* (VMSA). `0x0`, no support.

To access the Memory Model Feature Register 0 read CP15 with:

```
MRC p15, 0, <Rd>, c0, c1, 4 ; Read Memory Model Feature Register 0.
```

c0, Memory Model Feature Register 1, MMFR1

The Memory Model Feature Register 1 provides information about the memory model, memory management, and cache support of the processor.

The Memory Model Feature Register 1 is:

- a read-only register
- accessible in Privileged mode only.

Figure 4-16 on page 4-23 shows the bit arrangement for Memory Model Feature Register 1.

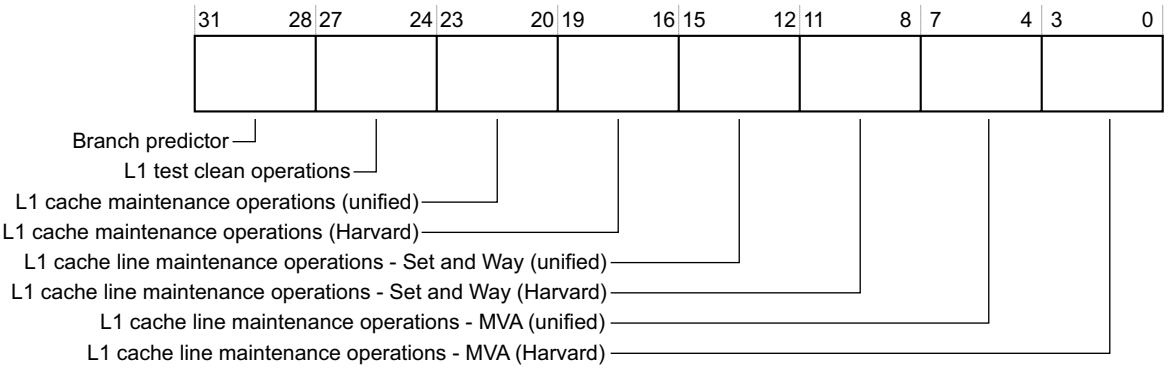


Figure 4-16 Memory Model Feature Register 1 format

Table 4-11 shows how the bit values correspond with the Memory Model Feature Register 1 functions.

Table 4-11 Memory Model Feature Register 1 bit functions

Bits	Field	Function
[31:28]	Branch predictor	Indicates Branch Predictor management requirements. `0x0`, no MMU present.
[27:24]	L1 test clean operations	Indicates support for test and clean operations on data cache, Harvard or unified architecture. `0x0`, no support.
[23:20]	L1 cache maintenance operations (unified)	Indicates support for L1 cache, entire cache maintenance operations, unified architecture. `0x0`, no support.
[19:16]	L1 cache maintenance operations (Harvard)	Indicates support for L1 cache, entire cache maintenance operations, Harvard architecture. `0x0`, no support.
[15:12]	L1 cache line maintenance operations - Set and Way (unified)	Indicates support for L1 cache line maintenance operations by Set and Way, unified architecture. `0x0`, no support.
[11:8]	L1 cache line maintenance operations - Set and Way (Harvard)	Indicates support for L1 cache line maintenance operations by Set and Way, Harvard architecture. `0x0`, no support.
[7:4]	L1 cache line maintenance operations - MVA (unified)	Indicates support for L1 cache line maintenance operations by address, unified architecture. `0x0`, no support.
[3:0]	L1 cache line maintenance operations - MVA (Harvard)	Indicates support for L1 cache line maintenance operations by address, Harvard architecture. `0x0`, no support.

To access the Memory Model Feature Register 1 read CP15 with:

```
MRC p15, 0, <Rd>, c0, c1, 5 ; Read Memory Model Feature Register 1.
```

c0, Memory Model Feature Register 2, MMFR2

The Memory Model Feature Register 2 provides information about the memory model, memory management, and cache support operations of the processor.

The Memory Model Feature Register 2 is:

- a read-only register
- accessible in Privileged mode only.

Figure 4-17 shows the bit arrangement for Memory Model Feature Register 2.

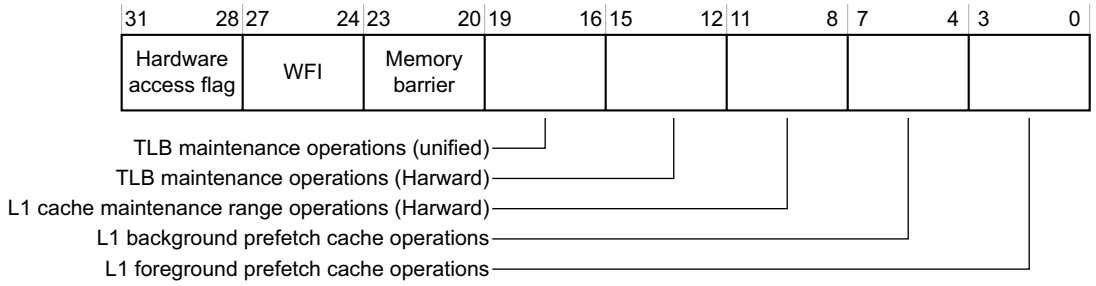


Figure 4-17 Memory Model Feature Register 2 format

Table 4-12 shows how the bit values correspond with the Memory Model Feature Register 2 functions.

Table 4-12 Memory Model Feature Register 2 bit functions

Bits	Field	Function
[31:28]	Hardware access flag	Indicates support for Hardware Access Flag. `0x0`, no support.
[27:24]	WFI	Indicates support for Wait-For-Interrupt stalling. `0x1`, the processor supports Wait-For-Interrupt.
[23:20]	Memory barrier	Indicates support for memory barrier operations. `0x2`, the processor supports: • DSB (formerly DWB) • ISB (formerly Prefetch Flush) • DMB.
[19:16]	TLB maintenance operations (unified)	Indicates support for TLB maintenance operations, unified architecture. `0x0`, no support.
[15:12]	TLB maintenance operations (Harvard)	Indicates support for TLB maintenance operations, Harvard architecture. `0x0`, no support.
[11:8]	L1 cache maintenance range operations (Harvard)	Indicates support for cache maintenance range operations, Harvard architecture. `0x0`, no support.
[7:4]	L1 background prefetch cache operations	Indicates support for background prefetch cache range operations, Harvard architecture. `0x0`, no support.
[3:0]	L1 foreground prefetch cache operations	Indicates support for foreground prefetch cache range operations, Harvard architecture. `0x0`, no support.

To access the Memory Model Feature Register 2 read CP15 with:

```
MRC p15, 0, <Rd>, c0, c1, 6 ; Read Memory Model Feature Register 2.
```

c0, Memory Model Feature Register 3, MMFR3

The Memory Model Feature Register 3 provides information about the two cache line maintenance operations for the processor.

The Memory Model Feature Register 3 is:

- a read-only register
- accessible in Privileged mode only.

Figure 4-18 shows the bit arrangement for Memory Model Feature Register 3.

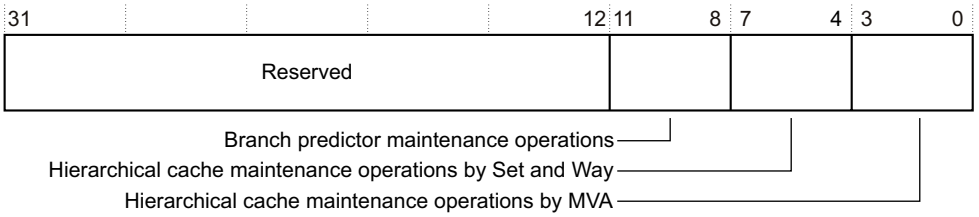


Figure 4-18 Memory Model Feature Register 3 format

Table 4-13 shows how the bit values correspond with the Memory Model Feature Register 3 functions.

Table 4-13 Memory Model Feature Register 3 bit functions

Bits	Field	Function
[31:12]	Reserved	SBZ.
[11:8]	Branch predictor maintenance operations	Indicates support for branch predictor maintenance operations in systems with hierarchical cache maintenance operations. `0x0`, no support.
[7:4]	Hierarchical cache maintenance operations by Set and Way	Indicates support for hierarchical cache maintenance operations by Set and Way. `0x1`, the processor supports invalidate cache, clean and invalidate, and clean by Set and Way.
[3:0]	Hierarchical cache maintenance operations by MVA	Indicates support for hierarchical cache maintenance operations by address. `0x1`, the processor supports: • Invalidate data cache by address • Clean data cache by address • Clean and invalidate data cache by address • Invalidate instruction cache by address • Invalidate all instruction cache entries.

To access the Memory Model Feature Register 3 read CP15 with:

```
MRC p15, 0, <Rd>, c0, c1, 7 ; Read Memory Model Feature Register 3.
```

4.2.11 Instruction Set Attributes Registers

There are eight Instruction Set Attributes Registers, ISAR0 to ISAR7, but three of these are currently unused. This section describes:

- *c0, Instruction Set Attributes Register 0, ISAR0*
- *c0, Instruction Set Attributes Register 1, ISAR1* on page 4-27
- *c0, Instruction Set Attributes Register 2, ISAR2* on page 4-28
- *c0, Instruction Set Attributes Register 3, ISAR3* on page 4-30
- *c0, Instruction Set Attributes Register 4, ISAR4* on page 4-31
- *c0, Instruction Set Attributes Registers 5-7* on page 4-32.

c0, Instruction Set Attributes Register 0, ISAR0

The Instruction Set Attributes Register 0 provides information about the instruction set that the processor supports beyond the basic set.

The Instruction Set Attributes Register 0 is:

- a read-only register
- accessible in Privileged mode only.

Figure 4-19 shows the bit arrangement for Instruction Set Attributes Register 0.

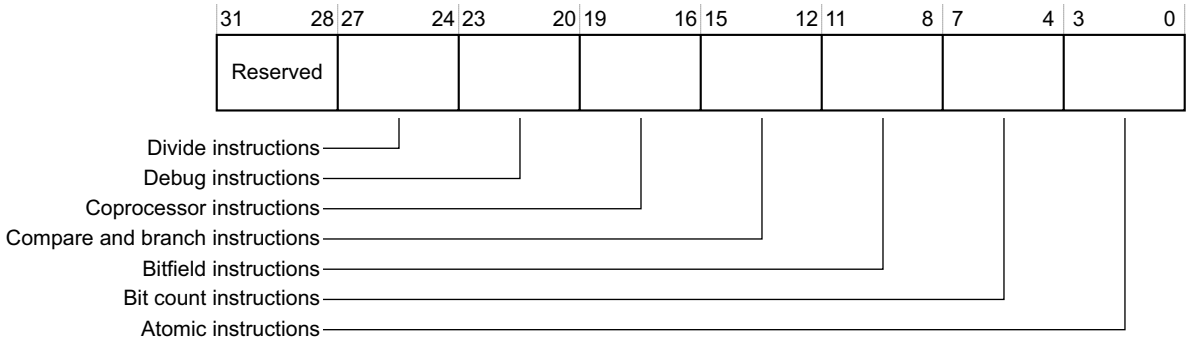


Figure 4-19 Instruction Set Attributes Register 0 format

Table 4-14 shows how the bit values correspond with the Instruction Set Attributes Register 0 functions.

Table 4-14 Instruction Set Attributes Register 0 bit functions

Bits	Field	Function
[31:28]	Reserved	SBZ
[27:24]	Divide instructions	Indicates support for divide instructions. `0x1`, the processor supports `SDIV` and `UDIV` instructions.
[23:20]	Debug instructions	Indicates support for debug instructions. `0x1`, the processor supports `BKPT`.
[19:16]	Coprocessor instructions	Indicates support for coprocessor instructions other than separately attributed feature registers, such as CP15 registers and VFP. `0x0`, no support.
[15:12]	Compare and branch instructions	Indicates support for combined compare and branch instructions. `0x1`, the processor supports combined compare and branch instructions, `CBNZ` and `CBZ`.

Table 4-14 Instruction Set Attributes Register 0 bit functions (continued)

Bits	Field	Function
[11:8]	Bitfield instructions	Indicates support for bitfield instructions. 0x1, the processor supports bitfield instructions, BFC, BFI, SBFX, and UBFX.
[7:4]	Bit counting instructions	Indicates support for bit counting instructions. 0x1, the processor supports CLZ.
[3:0]	Atomic instructions	Indicates support for atomic load and store instructions. 0x1, the processor supports SWP and SWPB.

To access the Instruction Set Attributes Register 0, read CP15 with:

```
MRC p15, 0, <Rd>, c0, c2, 0 ; Read Instruction Set Attributes Register 0
```

c0, Instruction Set Attributes Register 1, ISAR1

The Instruction Set Attributes Register 1 provides information about the instruction set that the processor supports beyond the basic set.

The Instruction Set Attributes Register 1 is:

- a read-only register
- accessible in Privileged mode only.

Figure 4-20 shows the bit arrangement for Instruction Set Attributes Register 1.

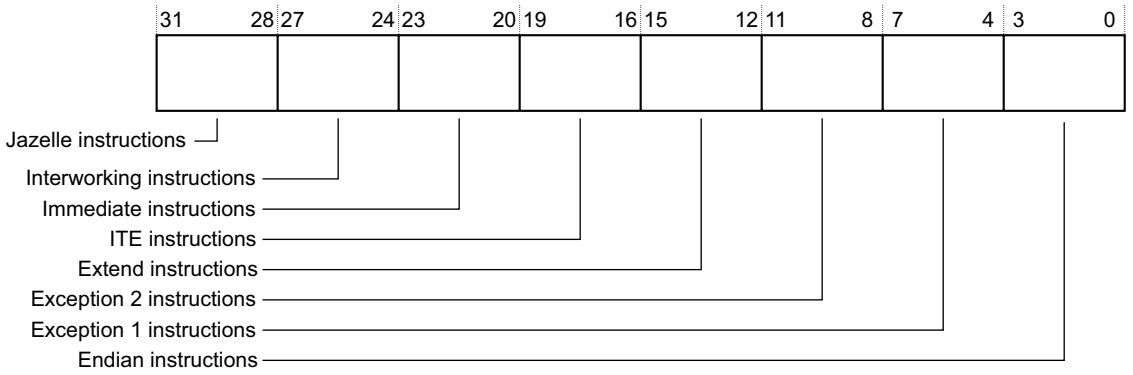


Figure 4-20 Instruction Set Attributes Register 1 format

Table 4-15 shows how the bit values correspond with the Instruction Set Attributes Register 1 functions.

Table 4-15 Instruction Set Attributes Register 1 bit functions

Bits	Field	Function
[31:28]	Jazelle instructions	Indicates support for Jazelle instructions. `0x1`, the processor supports: • `BXJ` instruction • J bit in PSRs. For more information see *Program status registers* on page 2-10 and *Acceleration of execution environments* on page 2-27.
[27:24]	Interworking instructions	Indicates support for interworking instructions. `0x3`, the processor supports: • `BX`, and T bit in PSRs • `BLX`, and PC loads have BX behavior. • Data-processing instructions in the ARM instruction set with the PC as the destination and the S bit clear have BX-like behavior.
[23:20]	Immediate instructions	Indicates support for immediate instructions. `0x1`, the processor supports: • the MOVT instruction • MOV instruction encodings with 16-bit immediates • Thumb ADD and SUB instructions with 12-bit immediates.
[19:16]	ITE instructions	Indicates support for if then instructions. `0x1`, the processor supports `IT` instructions.
[15:12]	Extend instructions	Indicates support for sign or zero extend instructions. `0x2`, the processor supports: • `SXTB`, `SXTB16`, `SXTH`, `UXTB`, `UXTB16`, and `UXTH` • `SXTAB`, `SXTAB16`, `SXTAH`, `UXTAB`, `UXTAB16`, and `UXTAH`.
[11:8]	Exception 2 instructions	Indicates support for exception 2 instructions. `0x1`, the processor supports `RFE`, `SRS`, and `CPS`.
[7:4]	Exception 1 instructions	Indicates support for exception 1 instructions. `0x1`, the processor supports `LDM` (exception return), `LDM` (user registers), and `STM` (user registers).
[3:0]	Endian instructions	Indicates support for endianness control instructions. `0x1`, the processor supports `SETEND` and E bit in PSRs.

To access the Instruction Set Attributes Register 1 read CP15 with:

```
MRC p15, 0, <Rd>, c0, c2, 1 ; Read Instruction Set Attributes Register 1
```

c0, Instruction Set Attributes Register 2, ISAR2

The Instruction Set Attributes Register 2 provides information about the instruction set that the processor supports beyond the basic set.

The Instruction Set Attributes Register 2 is:

- a read-only register
- accessible in Privileged mode only.

Figure 4-21 shows the bit arrangement for Instruction Set Attributes Register 2.

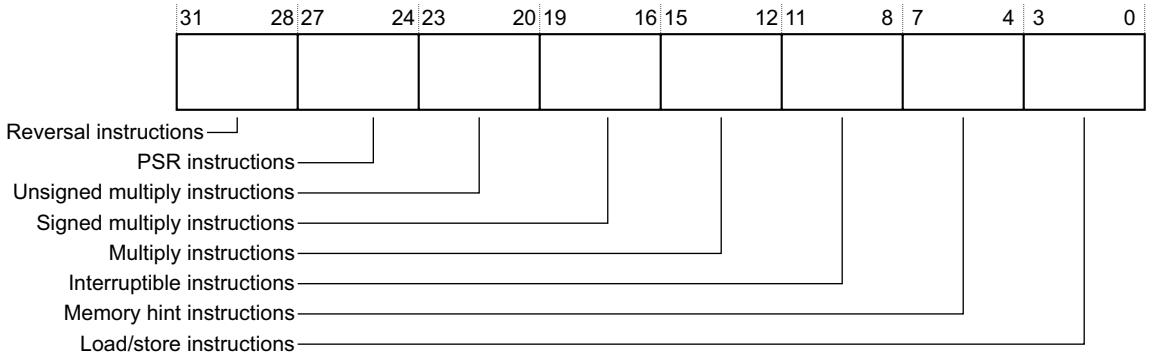


Figure 4-21 Instruction Set Attributes Register 2 format

Table 4-16 shows how the bit values correspond with the Instruction Set Attributes Register 2 functions.

Table 4-16 Instruction Set Attributes Register 2 bit functions

Bits	Field	Function
[31:28]	Reversal instructions	Indicates support for reversal instructions. `0x2`, the processor supports `REV`, `REV16`, `REVSH`, and `RBIT`.
[27:24]	PSR instructions	Indicates support for `PSR` instructions. `0x1`, the processor supports `MRS` and `MSR`, and the exception return forms of data-processing instructions.
[23:20]	Unsigned multiply instructions	Indicates support for advanced unsigned multiply instructions. `0x2`, the processor supports: • `UMULL` and `UMLAL` • `UMAAL`.
[19:16]	Signed multiply instructions	Indicates support for advanced signed multiply instructions. `0x3`, the processor supports: • `SMULL` and `SMLAL` • `SMLABB`, `SMLABT`, `SMLALBB`,`SMLALBT`, `SMLALTB`, `SMLALTT`, `SMLATB`, `SMLATT`, `SMLAWB`, `SMLAWT`, `SMULBB`, `SMULBT`, `SMULTB`, `SMULTT`, `SMULWB`, `SMULWT`, and Q flag in PSRs • `SMLAD`, `SMLADX`, `SMLALD`, `SMLALDX`, `SMLSD`, `SMLSDX`, `SMLSLD`, `SMLSLDX`, `SMMLA`, `SMMLAR`, `SMMLS`, `SMMLSR`, `SMPUL`, `SMPULR`, `SMUAD`, `SMUADX`, `SMUSD`, and `SMUSDX`.
[15:12]	Multiply instructions	Indicates support for multiply instructions. `0x2`, the processor supports `MUL`, `MLA`, and `MLS`.
[11:8]	Interruptible instructions	Indicates support for multi-access interruptible instructions. `0x1`, the processor supports restartable `LDM` and `STM`.
[7:4]	Memory hint instructions	Indicates support for memory hint instructions. `0x3`, the processor supports `PLD` and `PLI`.
[3:0]	Load/store instructions	Indicates support for additional load and store instructions. `0x1`, the processor supports `LDRD` and `STRD`.

To access the Instruction Set Attributes Register 2 read CP15 with:

```
MRC p15, 0, <Rd>, c0, c2, 2 ; Read Instruction Set Attributes Register 2
```

c0, Instruction Set Attributes Register 3, ISAR3

The Instruction Set Attributes Register 3 provides information about the instruction set that the processor supports beyond the basic set.

The Instruction Set Attributes Register 3 is:

- a read-only registers
- accessible in Privileged mode only.

Figure 4-22 shows the bit arrangement for Instruction Set Attributes Register 3.

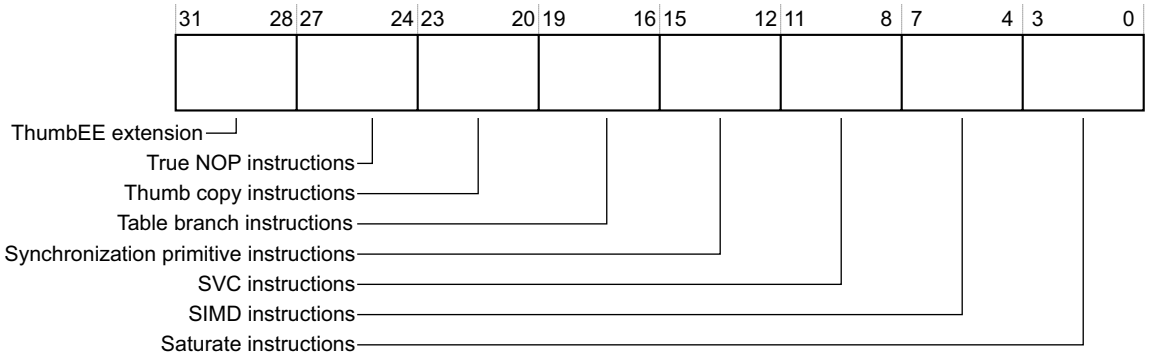


Figure 4-22 Instruction Set Attributes Register 3 format

Table 4-17 shows how the bit values correspond with the Instruction Set Attributes Register 3 functions.

Table 4-17 Instruction Set Attributes Register 3 bit functions

Bits	Field	Function
[31:28]	ThumbEE extension	Indicates support for ThumbEE Execution Environment extension. `0x0`, no support.
[27:24]	True NOP instructions	Indicates support for true `NOP` instructions. `0x1`, the processor supports `NOP16`, `NOP32` and various `NOP` compatible hints in both the ARM and Thumb instruction sets.
[23:20]	Thumb copy instructions	Indicates support for Thumb copy instructions. `0x1`, the processor supports Thumb `MOV(3)` low register ⇒ low register.
[19:16]	Table branch instructions	Indicates support for table branch instructions. `0x1`, the processor supports table branch instructions, `TBB` and `TBH`.
[15:12]	Synchronization primitive instructions	Indicates support for synchronization primitive instructions. `0x2`, the processor supports: • `LDREX` and `STREX` • `LDREXB`, `LDREXH`, `LDREXD`, `STREXB`, `STREXH`, `STREXD`, and `CLREX`.

Table 4-17 Instruction Set Attributes Register 3 bit functions (continued)

Bits	Field	Function
[11:8]	SVC instructions	Indicates support for SVC (formerly SWI) instructions. 0x1, the processor supports SVC.
[7:4]	SIMD instructions	Indicates support for *Single Instruction Multiple Data* (SIMD) instructions. 0x3, the processor supports: PKHBT, PKHTB, QADD16, QADD8, QASX, QSUB16, QSUB8, QSAX, SADD16, SADD8, SASX, SEL, SHADD16, SHADD8, SHASX, SHSUB16, SHSUB8, SHSAX, SSAT, SSAT16, SSUB16, SSUB8, SSAX, SXTAB16, SXTB16, UADD16, UADD8, UASX, UHADD16, UHADD8, UASX, UHSUB16, UHSUB8, USAX, UQADD16, UQADD8, UQASX, UQSUB16, UQSUB8, UQSAX, USAD8, USADA8, USAT, USAT16, USUB16, USUB8, USAX, UXTAB16, UXTB16, and the GE[3:0] bits in the PSRs.
[3:0]	Saturate instructions	Indicates support for saturate instructions. 0x1, the processor supports QADD, QDADD, QDSUB, QSUB and Q flag in PSRs.

To access the Instruction Set Attributes Register 3 read CP15 with:

```
MRC p15, 0, <Rd>, c0, c2, 3 ; Read Instruction Set Attributes Register 3
```

c0, Instruction Set Attributes Register 4, ISAR4

The Instruction Set Attributes Register 4 provides information about the instruction set that the processor supports beyond the basic set.

The Instruction Set Attributes Register 4 is:

- a read-only register
- accessible in Privileged mode only.

Figure 4-23 shows the bit arrangement for Instruction Set Attributes Register 4.

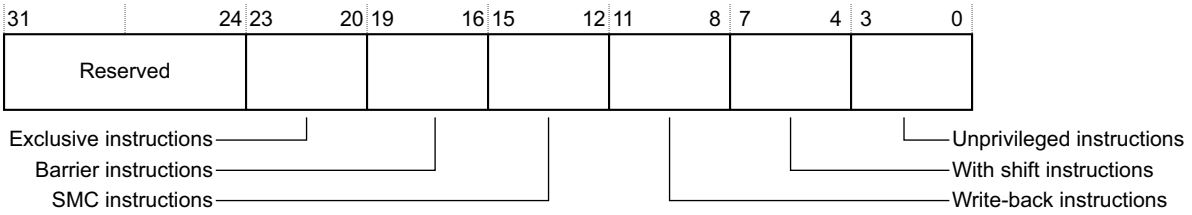


Figure 4-23 Instruction Set Attributes Register 4 format

Table 4-18 shows how the bit values correspond with the Instruction Set Attributes Register 4 functions.

Table 4-18 Instruction Set Attributes Register 4 bit functions

Bits	Field	Function
[31:24]	Reserved	SBZ.
[23:20]	Exclusive instructions	Indicates support for Exclusive instructions. 0x0, Only supports synchronization primitive instructions as indicated by bits [15:12] in the ISAR3 register. See *c0, Instruction Set Attributes Register 3, ISAR3* on page 4-30 for more information.
[19:16]	Barrier instructions	Indicates support for Barrier instructions. 0x1, the processor supports DMB, DSB, and ISB instructions.

Table 4-18 Instruction Set Attributes Register 4 bit functions (continued)

Bits	Field	Function
[15:12]	SMC instructions	Indicates support for *Secure Monitor Call* (SMC) (formerly SMI) instructions. 0x0, no support.
[11:8]	Write-back instructions	Indicates support for write-back instructions. 0x1, supports all the writeback addressing modes defined in ARMv7.
[7:4]	With shift instructions	Indicates support for with-shift instructions. 0x4, the processor supports: • the full range of constant shift options, on load/store and other instructions • register-controlled shift options.
[3:0]	Unprivileged instructions	Indicates support for Unprivileged instructions. 0x2, the processor supports LDR{SB|B|SH|H}T and STR{B|H}T.

To access the Instruction Set Attributes Register 4 read CP15 with:

```
MRC p15, 0, <Rd>, c0, c2, 4 ; Read Instruction Set Attributes Register 4
```

c0, Instruction Set Attributes Registers 5-7

The Instruction Set Attributes Registers 5-7 provide additional information about the properties of the processor.

The Instruction Set Attributes Register 5 is:
- a read-only register
- accessible in Privileged mode only.

In the processor, Instruction Set Attributes Register 5 is read as 0x00000000.

To access the Instruction Set Attributes Register 5, read CP15 with:

```
MRC p15, 0, <Rd>, c0, c2, 5 ; Read Instruction Set Attribute Register 5
```

Instruction Set Attributes Registers 6 and 7 are not implemented, and their positions in the register map are Reserved. They correspond to CP15 accesses with:

```
MRC p15, 0, <Rd>, c0, c2, 6 ; Read Instruction Set Attribute Register 6
MRC p15, 0, <Rd>, c0, c2, 7 ; Read Instruction Set Attribute Register 7
```

These registers are read-only, and are accessible in Privileged mode only.

4.2.12 c0, Current Cache Size Identification Register

The Current Cache Size Identification Register provides the current cache size information for the instruction and data caches. Architecturally, there can be up to eight levels of cache, containing instruction, data, or unified caches. This processor contains L1 instruction and data caches. The Cache Size Selection Register determines which Current Cache Size Identification Register to select, see *c0, Cache Size Selection Register* on page 4-35.

The Current Cache Size Identification Register is:
- a read-only register
- accessible in Privileged mode only.

Figure 4-24 on page 4-33 shows the bit arrangement for the Current Cache Size Identification Register.

Figure 4-24 Current Cache Size Identification Register format

Table 4-19 shows how the bit values correspond with the Current Cache Size Identification Register.

Table 4-19 Current Cache Size Identification Register bit functions

Bits	Field	Function
[31]	WT	Indicates support available for write-through: 1 = write-through support available[a]
[30]	WB	Indicates support available for write-back: 1 = write-back support available[a]
[29]	RA	Indicates support available for read allocation: 1 = read allocation support available[a]
[28]	WA	Indicates support available for write allocation: 1 = write allocation support available[a]
[27:13]	NumSets	Indicates the number of sets as (number of sets) - 1[a]
[12:3]	Associativity	Indicates the number of ways as (number of ways) - 1[a]
[2:0]	LineSize	Indicates the number of words in each cache line[a]

a. See Table 4-20 for valid bit field encodings.

The LineSize field is encoded as 2 less than log(2) of the number of words in the cache line. For example, a value of `0x0` indicates there are four words in a cache line, that is the minimum size for the cache. A value of `0x1` indicates there are eight words in a cache line.

Table 4-20 shows the individual bit field and complete register encodings for the Current Cache Size Identification Register. Use this to match the cache size and level of cache set by the *Current Cache Size Selection Register* (CSSR). See *c0, Cache Size Selection Register* on page 4-35.

Table 4-20 Bit field and register encodings for Current Cache Size Identification Register

Size	Complete register encoding	Register bit field encoding						
		WT	WB	RA	WA	NumSets	Associativity	LineSize
4KB	`0xF003E019`	1	1	1	1	`0x001F`	`0x3`	`0x1`
8KB	`0xF007E019`	1	1	1	1	`0x003F`		
16KB	`0xF00FE019`	1	1	1	1	`0x007F`		
32KB	`0xF01FE019`	1	1	1	1	`0x00FF`		
64KB	`0xF03FE019`	1	1	1	1	`0x01FF`		

To access the Current Cache Size Identification Register read CP15 with:

```
MRC p15, 1, <Rd>, c0, c0, 0 ; Read Current Cache Size Identification Register
```

4.2.13 c0, Current Cache Level ID Register

The Current Cache Level ID Register indicates the cache levels that are implemented. Architecturally, there can be a different number of cache levels on the instruction and data side. The register also captures the point-of-coherency and the point-of-unification.

The Current Cache Level ID Register is:

- a read-only register
- accessible in Privileged mode only.

Figure 4-25 shows the bit arrangement for the Current Cache Level ID Register.

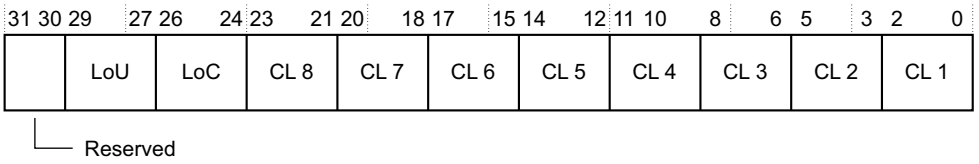


Figure 4-25 Current Cache Level ID Register format

Table 4-21 shows how the bit values correspond with the Current Cache Level ID Register.

Table 4-21 Current Cache Level ID Register bit functions

Bits	Field	Function
[31:30]	Reserved	SBZ
[29:27]	LoU	0b001 = Level of Unification
[26:24]	LoC	0b001 = Level of Coherency
[23:21]	CL 8	0b000 = no cache at *Cache Level* (CL) 8
[20:18]	CL 7	0b000 = no cache at CL 7
[17:15]	CL 6	0b000 = no cache at CL 6
[14:12]	CL 5	0b000 = no cache at CL 5
[11:9]	CL 4	0b000 = no cache at CL 4
[8:6]	CL 3	0b000 = no cache at CL 3
[5:3]	CL 2	0b000 = no cache at CL 2
[2]	CL 1	RAZ. Indicates no unified cache at CL1
[1]	CL 1	0b001 if a data cache is implemented 0b000 if no data cache is implemented
[0]	CL 1	0b001 if an instruction cache is implemented 0b000 if no instruction cache is implemented

To access the Current Cache Level ID Register, read CP15 with:

```
MRC p15, 1, <Rd>, c0, c0, 1 ; Read Current Cache Level ID Register
```

4.2.14 c0, Cache Size Selection Register

The Cache Size Selection Register holds the value that the processor uses to select the Current Cache Size Identification Register to use.

The Cache Size Selection Register is:
- a read/write register
- accessible in Privileged mode only.

Figure 4-26 shows the bit arrangement for the Cache Size Selection Register.

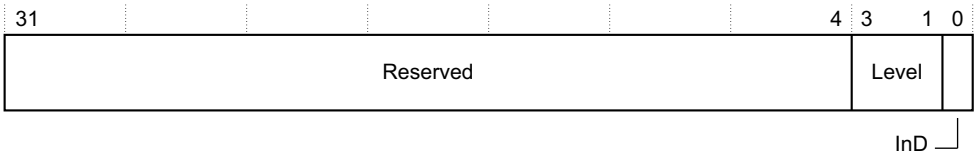


Figure 4-26 Cache Size Selection Register format

Table 4-22 shows how the bit values correspond with the Cache Size Selection Register.

Table 4-22 Cache Size Selection Register bit functions

Bits	Field	Function
[31: 4]	Reserved	SBZ.
[3:1]	Level	Identifies which cache level to select. b000 = Level 1 cache This field is read only, writes are ignored.
[0]	InD	Identifies instruction or data cache to use. 1 = instruction 0 = data.

To access the Current Cache Size Identification Registers read or write CP15 with:

```
MRC p15, 2, <Rd>, c0, c0, 0 ; Read Cache Size Selection Register
MCR p15, 2, <Rd>, c0, c0, 0 ; Write Cache Size Selection Register
```

4.2.15 c1, System Control Register

The System Control Register provides control and configuration information for:
- memory alignment, endianness, protection, and fault behavior
- MPU and cache enables and cache replacement strategy
- interrupts and the behavior of interrupt latency
- the location for exception vectors
- program flow prediction.

The System Control Register is:
- a read/write register
- accessible in Privileged mode only.

Figure 4-27 on page 4-36 shows the arrangement of bits in the register.

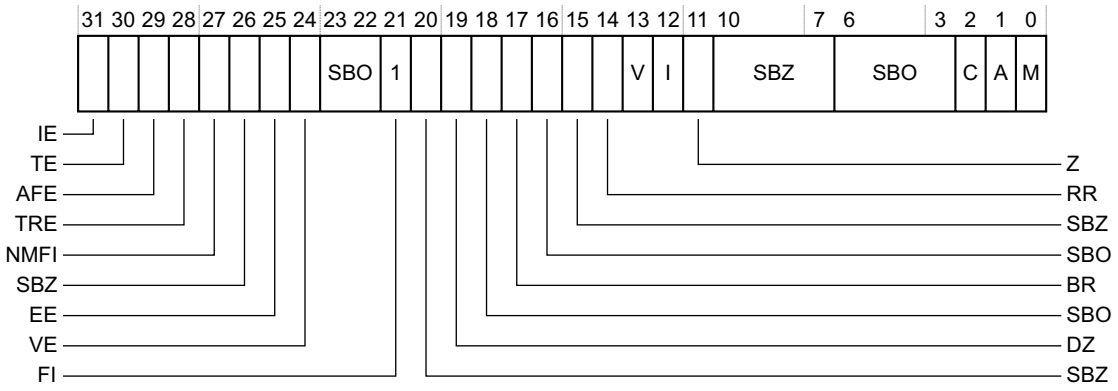


Figure 4-27 System Control Register format

Table 4-23 shows the purposes of the individual bits in the System Control Register.

Table 4-23 System Control Register bit functions

Bits	Field	Function
[31]	IE	Identifies little or big instruction endianness in use: 0 = little-endianness 1 = big-endianness. The primary input **CFGIE** defines the reset value. This bit is read-only.
[30]	TE	Thumb exception enable: 0 = enable ARM exception generation 1 = enable Thumb exception generation. The primary input **TEINIT** defines the reset value.
[29]	AFE	Access Flag Enable. On the processor this bit is SBZ.
[28]	TRE	TEX Remap Enable. On the processor this bit is SBZ.
[27]	NMFI	NMFI, non-maskable fast interrupt enable: 0 = Software can disable FIQs 1 = Software cannot disable FIQs. This bit is read-only. The configuration input **CFGNMFI** defines its value.
[26]	Reserved	SBZ.
[25]	EE	Determines how the E bit in the CPSR is set on an exception: 0 = CPSR E bit is set to 0 on an exception 1 = CPSR E bit is set to 1 on an exception. The primary input **CFGEE** defines the reset value.
[24]	VE	Configures vectored interrupt: 0 = offset for IRQ = 0x18 1 = VIC controller provides offset for IRQ. The reset value of this bit is 0.
[23:22]	Reserved	SBO.
[21]	FI	Fast Interrupts enable. On the processor Fast Interrupts are always enabled. This bit is SBO.
[20]	Reserved	SBZ.

Table 4-23 System Control Register bit functions (continued)

Bits	Field	Function
[19]	DZ	Divide by zero: 0 = do not generate an Undefined instruction exception 1 = generate an Undefined instruction exception. The reset value of this bit is 0.
[18]	Reserved	SBO.
[17]	BR	MPU background region enable.
[16]	Reserved	SBO.
[15]	Reserved	SBZ.
[14]	RR	Round-robin bit, controls replacement strategy for instruction and data caches: 0 = random replacement strategy 1 = round-robin replacement strategy. The reset value of this bit is 0. The processor always uses a random replacement strategy, regardless of the state of this bit.
[13]	V	Determines the location of exception vectors: 0 = normal exception vectors selected, address range = `0x00000000-0x0000001C` 1 = high exception vectors (HIVECS) selected, address range = `0xFFFF0000-0xFFFF001C`. The primary input **VINITHI** defines the reset value.
[12]	I	Enables L1 instruction cache: 0 = instruction caching disabled. This is the reset value. 1 = instruction caching enabled. If no instruction cache is implemented, then this bit is SBZ.
[11]	Z	Branch prediction bit. The processor supports branch prediction. This bit is SBO. The Auxiliary Control Register can control branch prediction, see *Auxiliary Control Registers* on page 4-38.
[10:7]	Reserved	SBZ.
[6:3]	Reserved	SBO.
[2]	C	Enables L1 data cache: 0 = data caching disabled. This is the reset value. 1 = data caching enabled. If no data cache is implemented, then this bit is SBZ.
[1]	A	Enables strict alignment of data to detect alignment faults in data accesses: 0 = strict alignment fault checking disabled. This is the reset value. 1 = strict alignment fault checking enabled.
[0]	M	Enables the MPU: 0 = MPU disabled. This is the reset value. 1 = MPU enabled. If no MPU is implemented, the MPU has zero regions, this bit is SBZ.

To use the System Control Register ARM recommends that you use a read-modify-write technique. To access the System Control Register, read or write CP15 with:

```
MRC p15, 0, <Rd>, c1, c0, 0 ; Read System Control Register configuration data
MCR p15, 0, <Rd>, c1, c0, 0 ; Write System Control Register configuration data
```

Attempts to read or write the System Control Register from User mode results in an Undefined exception.

4.2.16 Auxiliary Control Registers

The Auxiliary Control Registers control:

- branch prediction
- performance features
- error and parity logic.

c1, Auxiliary Control Register

The Auxiliary Control Register is:

- a read/write register
- accessible in Privileged mode only.

Figure 4-28 shows the arrangement of bits in the register.

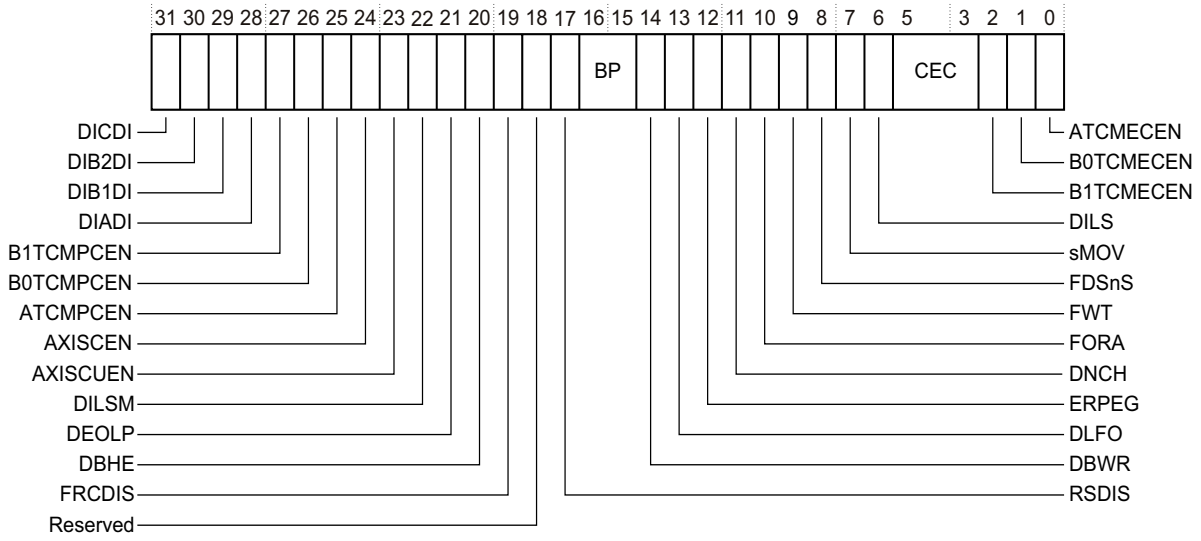


Figure 4-28 Auxiliary Control Register format

Table 4-24 shows how the bit values correspond with the Auxiliary Control Register functions.

Table 4-24 Auxiliary Control Register bit functions

Bits	Field	Function
[31]	DICDI[a]	Case C dual issue control: 0 = Enabled. This is the reset value. 1 = Disabled.
[30]	DIB2DI[a]	Case B2 dual issue control: 0 = Enabled. This is the reset value. 1 = Disabled.
[29]	DIB1DI[a]	Case B1 dual issue control: 0 = Enabled. This is the reset value. 1 = Disabled.

Table 4-24 Auxiliary Control Register bit functions (continued)

Bits	Field	Function
[28]	DIADI[a]	Case A dual issue control: 0 = Enabled. This is the reset value. 1 = Disabled.
[27]	B1TCMPCEN	B1TCM parity or ECC check enable: 0 = Disabled 1 = Enabled. The primary input **PARECCENRAM[2]**[b] defines the reset value. If the BTCM is configured with ECC, you must always set this bit to the same value as **B0TCMPCEN**.
[26]	B0TCMPCEN	B0TCM parity or ECC check enable: 0 = Disabled 1 = Enabled. The primary input **PARECCENRAM[1]**[b] defines the reset value. If the BTCM is configured with ECC, you must always set this bit to the same value as **B1TCMPCEN**.
[25]	ATCMPCEN	ATCM parity or ECC check enable: 0 = Disabled 1 = Enabled. The primary input **PARECCENRAM[0]**[b] defines the reset value.
[24]	AXISCEN	AXI slave cache RAM access enable: 0 = Disabled. This is the reset value. 1 = Enabled. **Note** When AXI slave cache access is enabled, the caches are disabled and the processor cannot run any cache maintenance operations. If the processor attempts a cache maintenance operation, an Undefined instruction exception is taken.
[23]	AXISCUEN	AXI slave cache RAM non-privileged access enable: 0 = Disabled. This is the reset value. 1 = Enabled.
[22]	DILSM	Disable *Low Interrupt Latency* (LIL) on load/store multiples: 0 = Enable LIL on load/store multiples. This is the reset value. 1 = Disable LIL on all load/store multiples.
[21]	DEOLP	Disable end of loop prediction: 0 = Enable loop prediction. This is the reset value. 1 = Disable loop prediction.
[20]	DBHE	Disable *Branch History* (BH) extension: 0 = Enable the extension. This is the reset value. 1 = Disable the extension.
[19]	FRCDIS	Fetch rate control disable: 0 = Normal fetch rate control operation. This is the reset value. 1 = Fetch rate control disabled.
[18]	Reserved	SBZ.

Table 4-24 Auxiliary Control Register bit functions (continued)

Bits	Field	Function
[17]	RSDIS	Return stack disable: 0 = Normal return stack operation. This is the reset value. 1 = Return stack disabled.
[16:15]	BP	This field controls the branch prediction policy: b00 = Normal operation. This is the reset value. b01 = Branch always taken. b10 = Branch always not taken. b11 = Reserved. Behavior is Unpredictable if this field is set to b11.
[14]	DBWR	Disable write burst in the AXI master: 0 = Normal operation. This is the reset value. 1 = Disable write burst optimization.
[13]	DLFO	Disable linefill optimization in the AXI master: 0 = Normal operation. This is the reset value. 1 = Limits the number of outstanding data linefills to two.
[12]	ERPEG[c]	Enable random parity error generation: 0 = Random parity error generation disabled. This is the reset value. 1 = Enable random parity error generation in the cache RAMs. **Note** This bit controls error generation logic during system validation. A synthesized ASIC typically does not have such models and this bit is therefore redundant for ASICs.
[11]	DNCH	Disable data forwarding for Non-cacheable accesses in the AXI master: 0 = Normal operation. This is the reset value. 1 = Disable data forwarding for Non-cacheable accesses.
[10]	FORA	Force outer read allocate (ORA) for outer write allocate (OWA) regions: 0 = No forcing of ORA. This is the reset value. 1 = ORA forced for OWA regions.
[9]	FWT	Force write-through (WT) for write-back (WB) regions: 0 = No forcing of WT. This is the reset value. 1 = WT forced for WB regions.
[8]	FDSnS	Force D-side to not-shared when MPU is off: 0 = Normal operation. This is the reset value. 1 = D-side normal Non-cacheable forced to Non-shared when MPU is off.
[7]	sMOV	sMOV of a divide does not complete out of order. No other instruction is issued until the divide is finished. 0 = Normal operation. This is the reset value. 1 = sMOV out of order disabled.
[6]	DILS	Disable low interrupt latency on all load/store instructions. 0 = Enable LIL on all load/store instructions. This is the reset value. 1 = Disable LIL on all load/store instructions.
[5:3]	CEC	Cache error control for cache parity and ECC errors. See Table 8-2 on page 8-21 and Table 8-3 on page 8-22 for details of how these bits are used. The reset value is b100.

Table 4-24 Auxiliary Control Register bit functions (continued)

Bits	Field	Function
[2]	B1TCMECEN	B1TCM external error enable: 0 = Disabled 1 = Enabled. The primary input **ERRENRAM[2]** defines the reset value.
[1]	B0TCMECEN	B0TCM external error enable: 0 = Disabled 1 = Enabled. The primary input **ERRENRAM[1]** defines the reset value.
[0]	ATCMECEN	ATCM external error enable: 0 = Disabled 1 = Enabled. The primary input **ERRENRAM[0]** defines the reset value.

a. See *Dual issue* on page 14-34
b. See *Configuration signals* on page A-4.
c. This bit is only supported if parity error generation is implemented in your design.

To access the Auxiliary Control Register, read or write CP15 with:

```
MRC p15, 0, <Rd>, c1, c0, 1 ; Read Auxiliary Control Register
MCR p15, 0, <Rd>, c1, c0, 1 ; Write Auxiliary Control Register
```

ARM recommends that any instruction that changes bits [31:28] or [7] is followed by an `ISB` instruction to ensure that the changes have taken effect before any dependent instructions are executed.

c15, Secondary Auxiliary Control Register

The Secondary Auxiliary Control Register is:

- a read/write register
- accessible in Privileged mode only.

Note

This register is implemented from the r1p*m* releases of the processor. Attempting to access this register in r0p*m* releases of the processor results in an Undefined Instruction exception.

Figure 4-29 on page 4-42 shows the arrangement of bits in the register.

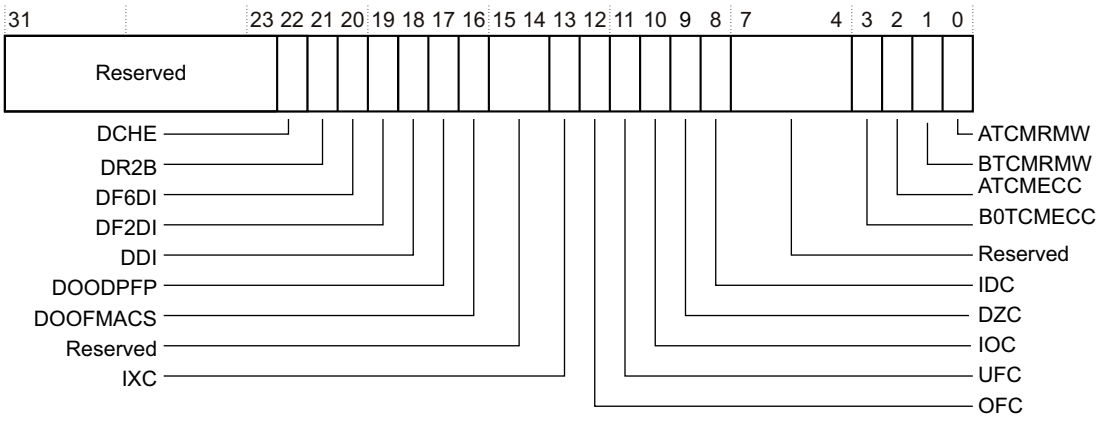


Figure 4-29 Secondary Auxiliary Control Register format

Table 4-25 shows how the bit values correspond with the Secondary Auxiliary Control Register functions.

Table 4-25 Secondary Auxiliary Control Register bit functions

Bits	Field	Function
[31:23]	Reserved	SBZ.
[22]	DCHE	Disable hard-error support in the caches.[a] 0 = Enabled. The cache logic recovers from some hard errors. You must not use this value on revisions r1p2 or earlier of the processor. 1 = Disabled. Most hard errors in the caches are fatal. This is the reset value. See *Hard errors* on page 8-5 for more information.
[21]	DR2B[b]	Enable random 2-bit error generation in cache RAMs. This bit has no effect unless ECC is configured, see *Configurable options* on page 1-13. 0 = Disabled. This is the reset value. 1 = Enabled. **Note** This bit controls error generation logic during system validation. A synthesized ASIC typically does not have such models and this bit is therefore redundant for ASICs.
[20]	DF6DI	F6 dual issue control.[c] 0 = Enabled. This is the reset value. 1 = Disabled.
[19]	DF2DI	F2_Id/F2_st/F2D dual issue control.[c] 0 = Enabled. This is the reset value. 1 = Disabled.
[18]	DDI	F1/F3/F4dual issue control.[c] 0 = Enabled. This is the reset value. 1 = Disabled.
[17]	DOODPFP	Out-of-order Double Precision Floating Point instruction control.[c] 0 = Enabled. This is the reset value. 1 = Disabled.

Table 4-25 Secondary Auxiliary Control Register bit functions (continued)

Bits	Field	Function
[16]	DOOFMACS	Out-of-order FMACS control.[c] 0 = Enabled. This is the reset value. 1 = Disabled.
[15:14]	Reserved	SBZ.
[13]	IXC	Floating-point inexact exception output mask.[c] 0 = Mask floating-point inexact exception output. The output **FPIXC** is forced to zero. This is the reset value. 1 = Propagate floating point inexact exception flag FPSCR.IXC to output **FPIXC**.
[12]	OFC	Floating-point overflow exception output mask.[c] 0 = Mask floating-point overflow exception output. The output **FPOFC** is forced to zero. This is the reset value. 1 = Propagate floating-point overflow exception flag FPSCR.OFC to output **FPOFC**.
[11]	UFC	Floating-point underflow exception output mask.[c] 0 = Mask floating-point underflow exception output. The output **FPUFC** is forced to zero. This is the reset value. 1 = Propagate floating-point underflow exception flag FPSCR.UFC to output **FPUFC**.
[10]	IOC	Floating-point invalid operation exception output mask.[c] 0 = Mask floating-point invalid operation exception output. The output **FPIOC** is forced to zero. This is the reset value. 1 = Propagate floating-point invalid operation exception flag FPSCR.IOC to output **FPIOC**.
[9]	DZC	Floating-point divide-by-zero exception output mask.[c] 0 = Mask floating-point divide-by-zero exception output. The output **FPDZC** is forced to zero. This is the reset value. 1 = Propagate floating-point divide-by-zero exception flag FPSCR.DZC to output **FPDZC**.
[8]	IDC	Floating-point input denormal exception output mask.[c] 0 = Mask floating-point input denormal exception output. The output **FPIDC** is forced to zero. This is the reset value. 1 = Propagate floating-point input denormal exception flag FPSCR.IDC to output **FPIDC**.
[7:4}	Reserved	SBZ.
[3]	BTCMECC	Correction for internal ECC logic on BTCM ports.[d] 0 = Enabled. This is the reset value. 1 = Disabled.

Table 4-25 Secondary Auxiliary Control Register bit functions (continued)

Bits	Field	Function
[2]	ATCMECC	Correction for internal ECC logic on ATCM port.[d] 0 = Enabled. This is the reset value. 1 = Disabled.
[1]	BTCMRMW	Enables 64-bit stores for the BTCMs. When enabled, the processor uses read-modify-write to ensure that all reads and writes presented on the BTCM ports are 64 bits wide.[e] 0 = Disabled 1 = Enabled. The primary input **RMWENRAM[1]** defines the reset value.
[0]	ATCMRMW	Enables 64-bit stores for the ATCM. When enabled, the processor uses read-modify-write to ensure that all reads and writes presented on the ATCM port are 64 bits wide.[e] 0 = Disabled 1 = Enabled. The primary input **RMWENRAM[0]** defines the reset value.

a. This bit is RAZ if both caches have neither ECC nor parity.
b. This bit is only supported if parity error generation is implemented in your design.
c. This bit has no effect unless the *Floating Point Unit* (FPU) has been configured, see *Configurable options* on page 1-13.
d. This bit has no effect unless TCM ECC logic has been configured for the respective TCM interface, see *Configurable options* on page 1-13.
e. This feature is not available when the TCM interface has been built with 32-bit ECC.

To access the Secondary Auxiliary Control Register, read or write CP15 with:

```
MRC p15, 0, <Rd>, c15, c0, 0 ; Read Secondary Auxiliary Control Register
MCR p15, 0, <Rd>, c15, c0, 0 ; Write Secondary Auxiliary Control Register
```

ARM recommends that any instruction that changes bits [20:16] is followed by an `ISB` instruction to ensure that the changes have taken effect before any dependent instructions are executed.

4.2.17 c1, Coprocessor Access Register

The Coprocessor Access Register sets access rights for coprocessors CP0-CP13. This register has no effect on access to CP14, the debug control coprocessor, or CP15, the system control coprocessor. This register also provides a means for software to determine if any particular coprocessor, CP0-CP13, exists in the system.

The Coprocessor Access Register is:

- a read/write register
- accessible in Privileged mode only.

Because this processor does not support coprocessors CP0 through CP9, CP12, and CP13, bits [27:24] and [19:0] in this register are read-as-zero and ignore writes.

Figure 4-30 shows the arrangement of bits in the register.

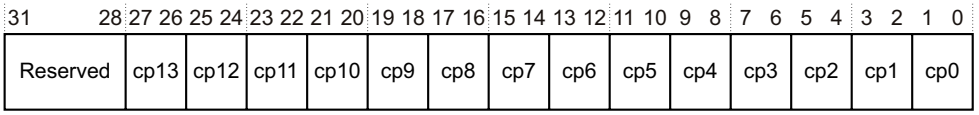


Figure 4-30 Coprocessor Access Register format

Table 4-26 shows how the bit values correspond with the Coprocessor Access Register functions.

Table 4-26 Coprocessor Access Register bit functions

Bits	Field	Function
[31:28]	Reserved	SBZ.
[27:0]	cp<n>[a]	Defines access permissions for each coprocessor. Access denied is the reset condition, and is the behavior for non-existent coprocessors. b00 = Access denied. Attempts to access generates an Undefined exception. b01 = Privileged mode access only b10 = Reserved b11 = Privileged and User mode access. Access permissions for the FPU are set by fields cp10 and cp11. For all other coprocessor fields, the value is fixed to b00.

a. n is the coprocessor number between 0 and 13.

To access the Coprocessor Access Register, read or write CP15 with:

```
MRC p15, 0, <Rd>, c1, c0, 2 ; Read Coprocessor Access Register
MCR p15, 0, <Rd>, c1, c0, 2 ; Write Coprocessor Access Register
```

4.2.18 Fault Status and Address Registers

The processor reports the status and address of faults that occur during its operation. For both data and instruction faults there are two *Fault Status Registers* (FSRs) and one *Fault Address Register* (FAR).

Fields within the Data and Instruction FSRs indicate the priority and source of a fault and the validity of the address in the corresponding FAR. Table 4-27 shows this encoding for the FSRs.

Table 4-27 Fault Status Register encodings

Priority	Sources	FSR [10,3:0]	FAR
Highest	Alignment	0b00001	Valid
	Background	0b00000	Valid
	Permission	0b01101	Valid
	Precise External Abort	0b01000	Valid
	Imprecise External Abort	0b10110	Unpredictable
	Precise Parity/ECC Error	0b11001	Valid
	Imprecise Parity/ECC Error	0b11000	Unpredictable
Lowest	Debug Event	0b00010	Unchanged

All other encodings for these FSR bits are Reserved.

c5, Data Fault Status Register

The *Data Fault Status Register* (DFSR) holds status information regarding the source of the last data abort.

The Data Fault Status Register is:

- a read/write register
- accessible in Privileged mode only.

Figure 4-31 shows the bit arrangement in the Data Fault Status Register.

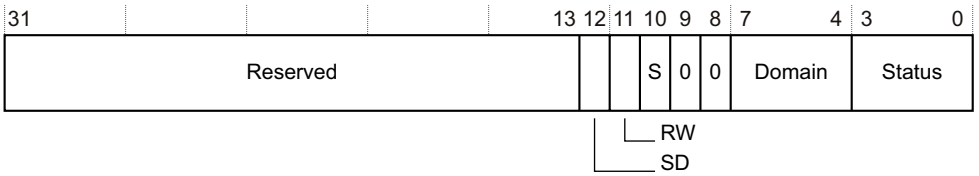


Figure 4-31 Data Fault Status Register format

Table 4-28 shows how the bit values correspond with the Data Fault Status Register functions.

Table 4-28 Data Fault Status Register bit functions

Bits	Field	Function
[31:13]	Reserved	SBZ.
[12]	SD	Distinguishes between an AXI Decode or Slave error on an external abort. This bit is only valid for external aborts. For all other aborts types of abort, this bit is set to zero: 0 = AXI Decode error (DECERR) caused the abort 1 = AXI Slave error (SLVERR, or OKAY in response to exclusive read transaction) caused the abort.
[11]	RW	Indicates whether a read or write access caused an abort: 0 = read access caused the abort 1 = write access caused the abort.
[10][a]	S	Part of the Status field.
[9:8]	-	Always read as 0. Writes ignored.
[7:4]	Domain	SBZ. This is because domains are not implemented in this processor.
[3:0][a]	Status	Indicates the type of fault generated. To determine the data fault, you must use bit [12] and bit [10] in conjunction with bits [3:0].

a. For more information on how these bits are used in reporting faults, see Table 4-27 on page 4-45.

To use the DFSR read or write CP15 with:

```
MRC p15, 0, <Rd>, c5, c0, 0  ; Read Data Fault Status Register
MCR p15, 0, <Rd>, c5, c0, 0  ; Write Data Fault Status Register
```

c5, Instruction Fault Status Register

The *Instruction Fault Status Register* (IFSR) holds status information regarding the source of the last instruction abort.

The Instruction Fault Status Register is:

- a read/write register
- accessible in Privileged mode only.

Figure 4-32 on page 4-47 shows the bit arrangement in the Instruction Fault Status Register.

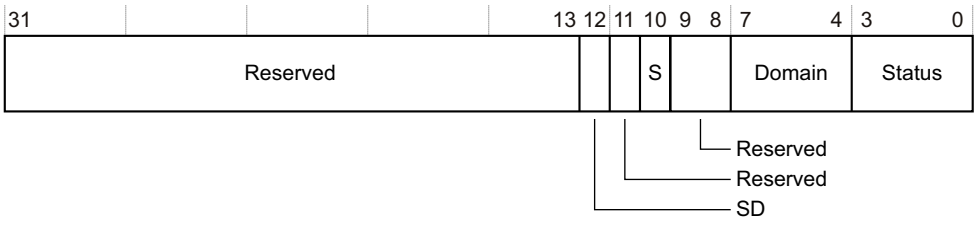


Figure 4-32 Instruction Fault Status Register format

Table 4-29 shows how the bit values correspond with the Instruction Fault Status Register functions.

Table 4-29 Instruction Fault Status Register bit functions

Bits	Field	Function
[31:13]	Reserved	SBZ.
[12]	SD	Distinguishes between an AXI Decode or Slave error on an external abort. This bit is only valid for external aborts. For all other aborts types of abort, this bit is set to zero: 0 = AXI Decode error (DECERR) caused the abort 1 = AXI Slave error (SLVERR) caused the abort.
[11]	Reserved	SBZ.
[10][a]	S	Part of the Status field.
[9:8]	Reserved	SBZ.
[7:4]	Domain	SBZ. This is because domains are not implemented in this processor.
[3:0][a]	Status	Indicates the type of fault generated. To determine the instruction fault, bit [12] and bit [10] must be used in conjunction with bits [3:0].

a. For more information on how these bits are used in reporting faults, see Table 4-27 on page 4-45.

To access the IFSR read or write CP15 with:

```
MRC p15, 0, <Rd>, c5, c0, 1  ; Read Instruction Fault Status Register
MCR p15, 0, <Rd>, c5, c0, 1  ; Write Instruction Fault Status Register
```

c5, Auxiliary Fault Status Registers

There are two auxiliary fault status registers:

- the *Auxiliary Data Fault Status Register* (ADFSR)
- the *Auxiliary Instruction Fault Status Register* (AIFSR).

These registers provide additional information about data and instruction parity, ECC, and external TCM errors.

The auxiliary fault status registers are:

- read/write registers
- accessible in Privileged mode only.

Figure 4-33 on page 4-48 shows the bit arrangement in the auxiliary fault status registers.

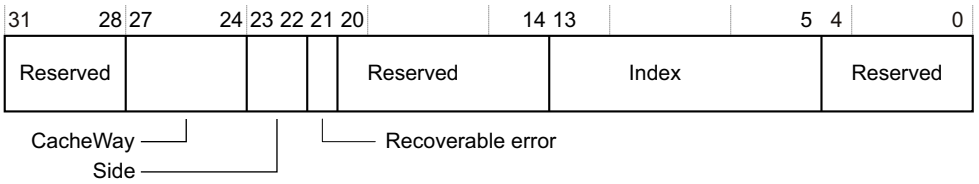


Figure 4-33 Auxiliary fault status registers format

Table 4-30 shows how the bit values correspond with the auxiliary fault status register functions.

Table 4-30 ADFSR and AIFSR bit functions

Bits	Field	Function
[31:28]	Reserved	SBZ.
[27:24]	CacheWay[a]	The value returned in this field indicates the cache way or ways in which the error occurred.
[23:22]	Side	The value returned in this field indicates the source of the error. Possible values are: b00 = Cache or AXI-master interface b01 = ATCM b10 = BTCM b11 = Reserved.
[21]	Recoverable error	The value returned in this field indicates if the error is recoverable. 0 = Unrecoverable error. 1 = Recoverable error. This includes all correctable parity/ECC errors and recoverable TCM external errors.
[20:14]	Reserved	SBZ.
[13:5]	Index[b]	This field returns the index value for the access giving the error.
[4:0]	Reserved	SBZ.

a. This field is only valid for data cache store parity/ECC errors, otherwise it is Unpredictable.
b. This field is only valid for data cache store parity/ECC errors. On the AIFSR, and for TCM accesses, this field SBZ.

To access the auxiliary fault status registers, read or write CP15 with:

```
MCR p15, 0, <Rd>, c5, c1, 0  ; Write Auxiliary Data Fault Status Register
MRC p15, 0, <Rd>, c5, c1, 0  ; Read Auxiliary Data Fault Status Register
MCR p15, 0, <Rd>, c5, c1, 1  ; Write Auxiliary Instruction Fault Status Register
MRC p15, 0, <Rd>, c5, c1, 1  ; Read Auxiliary Instruction Fault Status Register
```

The contents of an auxiliary fault status register are only valid when the corresponding Data or Instruction Fault Status Register indicates that a parity error has occurred. At other times the contents of the auxiliary fault status registers are Unpredictable.

c6, Data Fault Address Register

The *Data Fault Address Register* (DFAR) holds the address of the fault when a precise abort occurs.

The DFAR is:

- a read/write register
- accessible in Privileged mode only.

The Data Fault Address Register bits [31:0] contain the address where the precise abort occurred.

To access the DFAR read or write CP15 with:

```
MRC p15, 0, <Rd>, c6, c0, 0 ; Read Data Fault Address Register
MCR p15, 0, <Rd>, c6, c0, 0 ; Write Data Fault Address Register
```

A write to this register sets the DFAR to the value of the data written. This is useful for a debugger to restore the value of the DFAR.

The processor also updates the DFAR on debug exception entry because of watchpoints. See *Effect of debug exceptions on CP15 registers and WFAR* on page 11-42 for more information.

c6, Instruction Fault Address Register

The purpose of the *Instruction Fault Address Register* (IFAR) is to hold the address of instructions that cause a prefetch abort.

The IFAR is:

- a read/write register
- accessible in Privileged mode only.

The Instruction Fault Address Register bits [31:0] contain the Instruction Fault address.

To access the IFAR read or write CP15 with:

```
MRC p15, 0, <Rd>, c6, c0, 2 ; Read Instruction Fault Address Register
MCR p15, 0, <Rd>, c6, c0, 2 ; Write Instruction Fault Address Register
```

A write to this register sets the IFAR to the value of the data written. This is useful for a debugger to restore the value of the IFAR.

4.2.19 c6, MPU memory region programming registers

The MPU memory region programming registers program the MPU regions.

There is one register that specifies which one of the sets of region registers is to be accessed. See *c6, MPU Memory Region Number Register* on page 4-53. Each region has its own register to specify:

- region base address
- region size and enable
- region access control.

You can implement the processor with eight or 12 regions, or without an MPU entirely. If you implement the processor without an MPU, then there are no regions and no region programming registers.

Note

- When the MPU is enabled:
  - The MPU determines the access permissions for all accesses to memory, including the TCMs. Therefore, you must ensure that the memory regions in the MPU are programmed to cover the complete TCM address space with the appropriate access permissions. You must define at least one of the regions in the MPU.
  - An access to an undefined area of memory generates a background fault.
- For the TCM space the processor uses the access permissions but ignores the region attributes from MPU.

CP15, c9 sets the location of the TCM base address. For more information see *c9, BTCM Region Register* on page 4-57 and *c9, ATCM Region Register* on page 4-58.

c6, MPU Region Base Address Registers

The MPU Region Base Address Registers describe the base address of the region specified by the Memory Region Number Register. The region base address must always align to the region size.

The MPU Region Base Address Registers are:

- 32-bit read/write registers
- accessible in Privileged mode only.

Figure 4-34 shows the arrangement of bits in the registers.

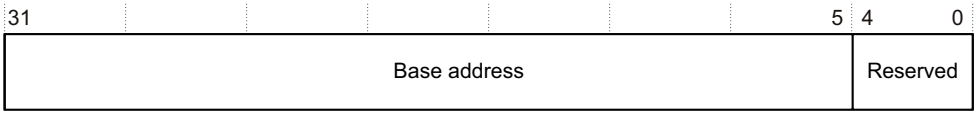


Figure 4-34 MPU Region Base Address Registers format

Table 4-31 shows how the bit values correspond with the MPU Region Base Address Register functions.

Table 4-31 MPU Region Base Address Registers bit functions

Bits	Field	Function
[31:5]	Base address	Physical base address. Defines the base address of a region.
[4:0]	Reserved	SBZ

To access an MPU Region Base Address Register, read or write CP15 with:

```
MRC p15, 0, <Rd>, c6, c1, 0 ; Read MPU Region Base Address Register
MCR p15, 0, <Rd>, c6, c1, 0 ; Write MPU Region Base Address Register
```

c6, MPU Region Size and Enable Registers

The MPU Region Size and Enable Registers:

- specify the size of the region specified by the Memory Region Number Register
- identify the address ranges that are used for a particular region
- enable or disable the region, and its sub-regions, specified by the Memory Region Number Register.

The MPU Region Size and Enable Registers are:

- 32-bit read/write registers
- accessible in Privileged mode only.

Figure 4-35 on page 4-51 shows the arrangement of bits in the registers.

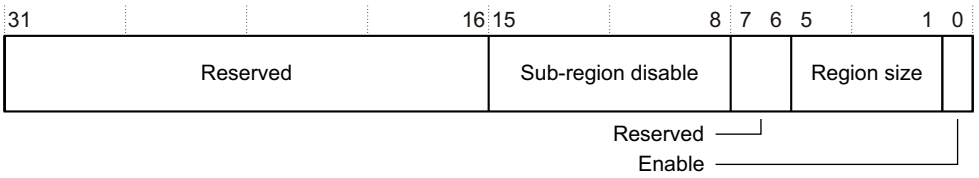


Figure 4-35 MPU Region Size and Enable Registers format

Table 4-32 shows how the bit values correspond with the MPU Region Size and Enable Registers.

Table 4-32 Region Size Register bit functions

Bits	Field	Function		
[31:16]	Reserved	SBZ.		
[15:8]	Sub-region disable	Each bit position represents a sub-region, 0-7[a]. Bit [8] corresponds to sub-region 0 ... Bit [15] corresponds to sub-region 7 The meaning of each bit is: 0 = address range is part of this region 1 = address range is not part of this region.		
	Reserved	SBZ.		
[5:1]	Region size	Defines the region size: b00000 - b00011=Unpredictable b00100 = 32 bytes b00101 = 64 bytes b00110 = 128 bytes b00111 = 256 bytes b01000 = 512 bytes b01001 = 1KB b01010 = 2KB b01011 = 4KB	b01100 = 8KB b01101 = 16KB b01110 = 32KB b01111 = 64KB b10000 = 128KB b10001 = 256KB b10010 = 512KB b10011 = 1MB b10100 = 2MB b10101 = 4MB	b10110 = 8MB b10111 = 16MB b11000 = 32MB b11001 = 64MB b11010 = 128MB b11011 = 256MB b11100 = 512MB b11101 = 1GB b11110 = 2GB b11111 = 4GB.
[0]	Enable	Enables or disables a memory region: 0 = Memory region disabled. Memory regions are disabled on reset. 1 = Memory region enabled. A memory region must be enabled before it is used.		

a. Sub-region 0 covers the least significant addresses in the region, while sub-region 7 covers the most significant addresses in the region. For more information, see *Subregions* on page 7-3.

To access an MPU Region Size and Enable Register, read or write CP15 with:

```
MRC p15, 0, <Rd>, c6, c1, 2 ; Read Data MPU Region Size and Enable Register
MCR p15, 0, <Rd>, c6, c1, 2 ; Write Data MPU Region Size and Enable Register
```

Writing a region size that is outside the range results in Unpredictable behavior.

c6, MPU Region Access Control Registers

The MPU Region Access Control Registers hold the region attributes and access permissions for the region specified by the Memory Region Number Register.

The MPU Region Access Control Registers are:

- read/write registers
- accessible in Privileged mode only.

Figure 4-36 shows the arrangement of bits in the register.

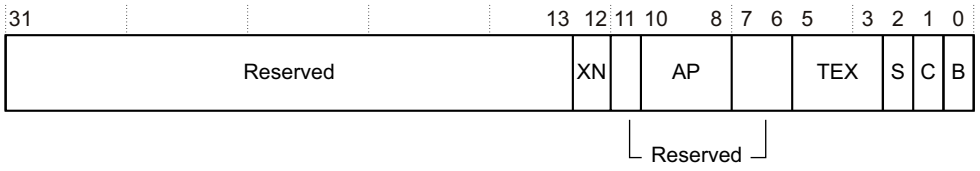


Figure 4-36 MPU Region Access Control Register format

Table 4-33 shows how the bit values correspond with the Region Access Control Register functions.

Table 4-33 MPU Region Access Control Register bit functions

Bits	Field	Function
[31:13]	Reserved	SBZ.
[12]	XN	Execute never. Determines if a region of memory is executable: 0 = all instruction fetches enabled 1 = no instruction fetches enabled.
[11]	-	Reserved.
[10:8]	AP	Access permission. Defines the data access permissions. For more information on AP bit values see, Table 4-34.
[7:6]	Reserved	SBZ.
[5:3]	TEX	Type extension. Defines the type extension attribute[a].
[2]	S	Share. Determines if the memory region is Shared or Non-shared: 0 = Non-shared. 1 = Shared. This bit only applies to Normal, not Device or Strongly Ordered memory.
[1]	C	C bit[a]:
[0]	B	B bit[a]:

a. For more information on this region attribute, see Table 7-3 on page 7-9.

Table 4-34 shows the AP bit values that determine the permissions for Privileged and User data access.

Table 4-34 Access data permission bit encoding

AP bit values	Privileged permissions	User permissions	Description
b000	No access	No access	All accesses generate a permission fault
b001	Read/write	No access	Privileged access only
b010	Read/write	Read-only	Writes in User mode generate permission faults

Table 4-34 Access data permission bit encoding (continued)

AP bit values	Privileged permissions	User permissions	Description
b011	Read/write	Read/write	Full access
b100	UNP	UNP	Reserved
b101	Read-only	No access	Privileged read-only
b110	Read-only	Read-only	Privileged/User read-only
b111	UNP	UNP	Reserved

To access the MPU Region Access Control Registers read or write CP15 with:

```
MRC p15, 0, <Rd>, c6, c1, 4 ; Read Region access control Register
MCR p15, 0, <Rd>, c6, c1, 4 ; Write Region access control Register
```

To execute instructions in User and Privileged modes:

- the region must have read access as defined by the AP bits
- the XN bit must be set to 0.

c6, MPU Memory Region Number Register

The MPU Region Registers are multiple registers with one register for each memory region implemented. The value contained in the MPU Memory Region Number Register determines which of the multiple registers is accessed.

The MPU Memory Region Number Registers are:

- read/write register
- accessible in Privileged mode only.

Figure 4-37 shows the arrangement of bits in the register.

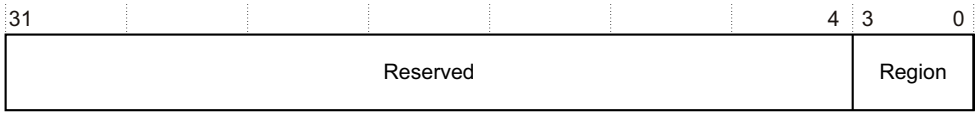


Figure 4-37 MPU Memory Region Number Register format

Table 4-35 shows how the bit values correspond with the MPU Memory Region Number Register bits.

Table 4-35 MPU Memory Region Number Register bit functions

Bits	Field	Function
[31:4]	Reserved	SBZ.
[3:0]	Region	Defines the group of registers to be accessed. Read the MPU Type Register to determine the number of supported regions, see *c0, MPU Type Register* on page 4-17.

To access the MPU Memory Region Number Register, read or write CP15 with:

```
MRC p15, 0, <Rd>, c6, c2, 0 ; Read MPU Memory Region Number Register
MCR p15, 0, <Rd>, c6, c2, 0 ; Write MPU Memory Region Number Register
```

Writing this register with a value greater than or equal to the number of regions from the MPU Type Register is Unpredictable. Associated register bank accesses are also Unpredictable.

4.2.20 Cache operations

The purpose of c7 is to manage the associated caches. The maintenance operations are formed into two management groups:

- Set and Way:
  - clean
  - invalidate
  - clean and invalidate.
- Address, usually labelled MVA for Modified Virtual Address, but on this processor all addresses are identical:
  - clean
  - invalidate
  - clean and invalidate.

In addition, the maintenance operations use these definitions:

Point of Coherency (PoC)

A point where all instruction, data, or translation-table walks are transparent to any processor in the system.

Point of Unification (PoU)

A point where instruction and data become unified and self-modifying code can function.

Figure 4-38 on page 4-55 shows the arrangement of the functions in this group that operate with the `MCR` and `MRC` instructions.

Note

The following operations, as Figure 4-38 on page 4-55 shows, are implemented as No Operation, `NOP`, on the processor:

- Wait For Interrupt, CRm= c0, Opcode_2 = 4
- Invalidate Entire Branch Predictor Array, CRm= c5, Opcode_2 = 6
- Invalidate Branch Predictor Array Line using MVA, CRm= c5, Opcode_2 = 7

The Wait For Interrupt (`WFI`) instruction provides the Wait For Interrupt function. For more information see the *ARM Architecture Reference Manual*.

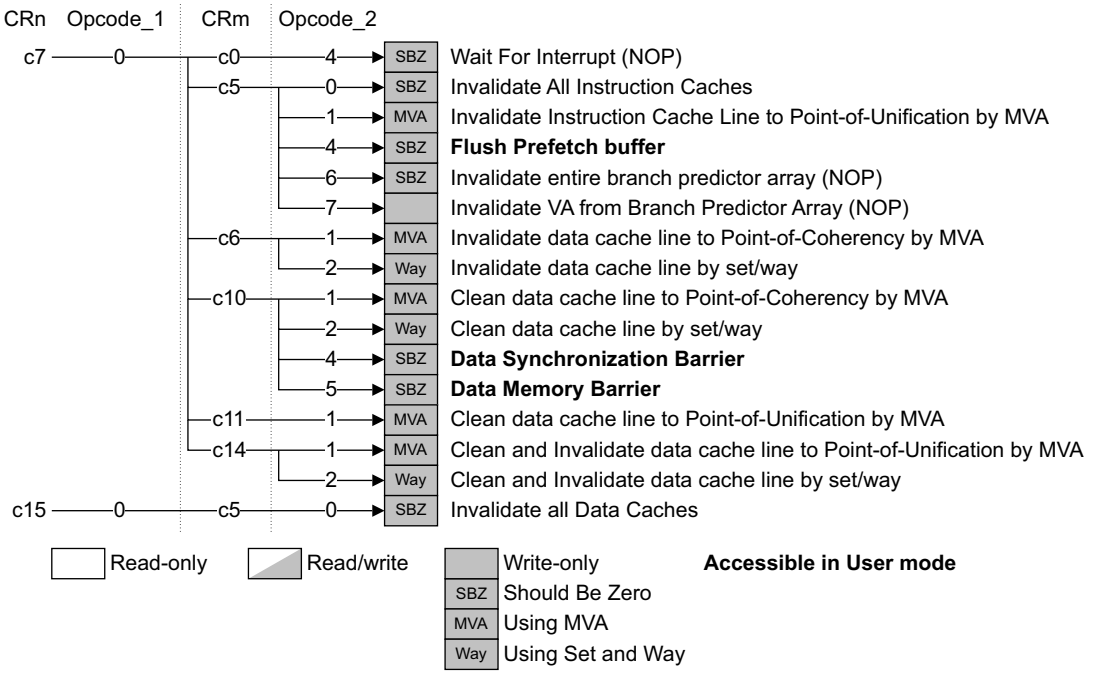


Figure 4-38 Cache operations

In addition to the register c7 cache management functions in this processor, an *Invalidate all data caches* operation is provided as a c15 operation. For convenience, that c15 operation is also described in this section.

Note

- Writing c7 with a combination of CRm and Opcode_2 not listed in Figure 4-38 results in an Undefined exception.
- In this processor, reading from c7 causes an Undefined exception.
- All accesses to c7 can only be executed in a Privileged mode of operation, except for the Flush Prefetch Buffer, Data Synchronization Barrier, and Data Memory Barrier operations. These can be performed in User mode. Attempting to execute a Privileged instruction in User mode results in an Undefined exception.
- This processor does not contain an address-based branch predictor array.

Invalidate and clean operations

The terms that describe the invalidate, clean, and prefetch operations are defined in the *ARM Architecture Reference Manual*.

You can perform invalidate and clean operations on:

- single cache lines
- entire caches.

Set and Way format

Figure 4-39 on page 4-56 shows the Set and Way format for invalidate and clean operations.

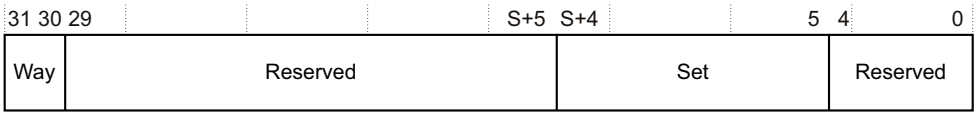


Figure 4-39 c7 format for Set and Way

Table 4-36 shows how the bit values correspond with the Cache Operation functions for Set and Way format operations.

Table 4-36 Functional bits of c7 for Set and Way

Bits	Field	Function
[31:30]	Way	Indicates the cache way to invalidate or clean.
[29:S+5]	Reserved	SBZ.
[S+4:5]	Set	Indicates the cache set to invalidate or clean. Because the cache sizes are configurable, the width of the Set field is unique to the cache size. See Table 4-37.
[4:0]]	Reserved	SBZ.

Table 4-37 shows the cache sizes and the resultant bit range for Set.

Table 4-37 Widths of the set field for L1 cache sizes

Size	Set
4KB	[9:5]
8KB	[10:5]
16KB	[11:5]
32KB	[12:5]
64KB	[13:5]

See *c0, Cache Type Register* on page 4-15 for more information on cache sizes.

Address format

Figure 4-40 shows the address format for invalidate and clean operations.

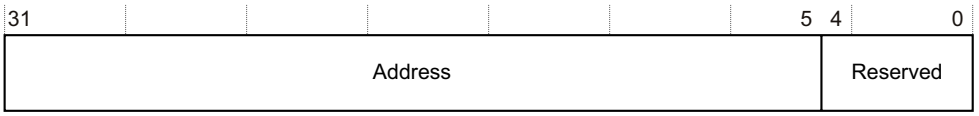


Figure 4-40 Cache operations address format

Table 4-38 shows how the bit values correspond with the address format for invalidate and clean operations.

Table 4-38 Functional bits of c7 for address format

Bits	Field	Function
[31:5]	Address	Specifies the address to invalidate or clean
[4:0]	Reserved	SBZ

Data Synchronization Barrier operation

The purpose of the Data Synchronization Barrier operation is to ensure that all outstanding explicit memory transactions complete before any following instructions begin. This ensures that data in memory is up to date before the processor executes any more instructions.

The Data Synchronization Barrier Register is:
- a write-only operation
- accessible in both User and Privileged mode.

To access the Data Synchronization Barrier operation, write CP15 with:

```
MCR p15, 0, <Rd>, c7, c10, 4 ; Data Synchronization Barrier operation
```

For more information about memory barriers, see the *ARM Architecture Reference Manual*.

Data Memory Barrier operation

The purpose of the Data Memory Barrier operation is to ensure that all outstanding explicit memory transactions complete before any following explicit memory transactions begin. This ensures that data in memory is up to date before any memory transaction that depends on it.

The Data Memory Barrier operation is:
- write-only
- accessible in User and Privileged mode.

To access the Data Memory Barrier operation write CP15 with:

```
MCR p15, 0, <Rd>, c7, c10,5  ; Data Memory Barrier Operation.
```

For more information about memory barriers, see the *ARM Architecture Reference Manual*.

4.2.21 c9, BTCM Region Register

The BTCM Region Register holds the base address and size of the BTCM. It also determines if the BTCM is enabled.

The BTCM Region Register is:
- a read/write register
- accessible in Privileged mode only.

Figure 4-41 on page 4-58 shows the arrangement of bits in the register.

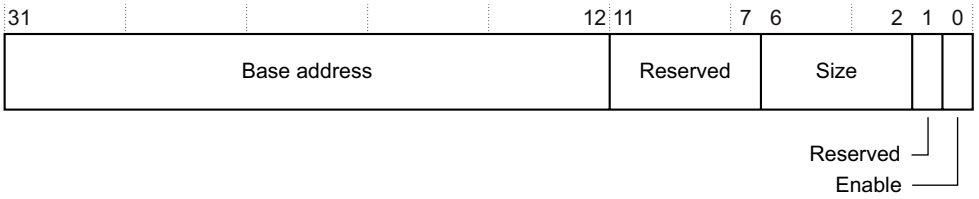


Figure 4-41 BTCM Region Registers

Table 4-39 shows how the bit values correspond with the BTCM Region Register.

Table 4-39 BTCM Region Register bit functions

Bits	Field	Function
[31:12]	Base address	Base address. Defines the base address of the BTCM. The base address must be aligned to the size of the BTCM. Any bits in the range [($\log_2$(RAMSize)-1):12] are ignored. At reset, if **LOCZRAMA** is set to: 0 =The initial base address is `0x0`. 1 =The initial base address is implementation-defined. See *Configurable options* on page 1-13.
[11:7]	Reserved	UNP on reads, SBZ on writes.
[6:2]	Size	Size. Indicates the size of the BTCM on reads. On writes this field is ignored. See *About the TCMs* on page 8-13. b00000 = 0KB b00011 = 4KB b00100 = 8KB b00101 = 16KB b00110 = 32KB b00111 = 64KB b01000 = 128KB b01001 = 256KB b01010 = 512kB b01011 = 1MB b01100 = 2MB b01101 = 4MB b01110 = 8MB
[1]	Reserved	SBZ.
[0]	Enable	Enables or disables the BTCM. 0 = Disabled 1 = Enabled. The reset value of this field is determined by the **INITRAMB** input pin.

To access the BTCM Region Register, read or write CP15 with:

```
MRC p15, 0, <Rd>, c9, c1, 0  ; Read BTCM Region Register
MCR p15, 0, <Rd>, c9, c1, 0  ; Write BTCM Region Register
```

4.2.22 c9, ATCM Region Register

The ATCM Region Register holds the base address and size of the ATCM. It also determines if the ATCM is enabled.

The ATCM Region Register is:

- a read/write register
- accessible in Privileged mode only.

Figure 4-42 on page 4-59 shows the arrangement of bits in the register.

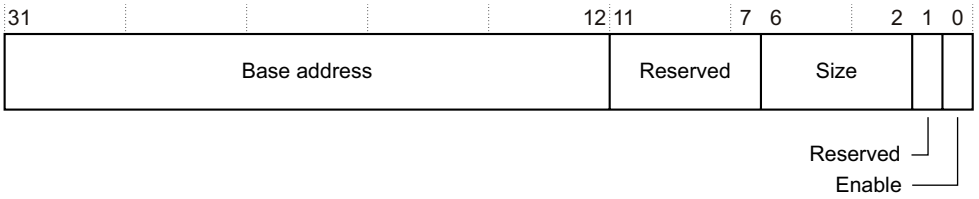


Figure 4-42 ATCM Region Registers

Table 4-40 shows how the bit values correspond with the ATCM Region Register.

Table 4-40 ATCM Region Register bit functions

Bits	Field	Function
[31:12]	Base address	Base address. Defines the base address of the ATCM. The base address must be aligned to the size of the ATCM. Any bits in the range [($\log_2$(RAMSize)-1):12] are ignored. At reset, if **LOCZRAMA** is set to: 0 = The initial base address is implementation-defined. See *Configurable options* on page 1-13 1 = The initial base address is `0x0`.
[11:7]	Reserved	UNP on reads, SBZ on writes.
[6:2]	Size	Size. Indicates the size of the ATCM on reads. On writes this field is ignored. See *About the TCMs* on page 8-13. b00000 = 0KB b00011 = 4KB b00100 = 8KB b00101 = 16KB b00110 = 32KB b00111 = 64KB b01000 = 128KB b01001 = 256KB b01010 = 512kB b01011 = 1MB b01100 = 2MB b01101 = 4MB b01110 = 8MB.
[1]	Reserved	SBZ
[0]	Enable	Enables or disables the ATCM. 0 = Disabled 1 = Enabled. The reset value of this field is determined by the **INITRAMA** input pin.

To access the ATCM Region Register, read or write CP15 with:

```
MRC p15, 0, <Rd>, c9, c1, 1  ; Read ATCM Region Register
MCR p15, 0, <Rd>, c9, c1, 1  ; Write ATCM Region Register
```

4.2.23 c9, TCM Selection Register

The TCM Selection Register determines the TCM region register that the processor writes to. The processor only supports one TCM region for each TCM interface, and the TCM Selection Register Reads-As-Zero and ignores writes. It is only accessible in Privileged mode.

4.2.24 c11, Slave Port Control Register

The Slave Port Control Register enables or disables TCM access to the AXI slave port in Privileged or User mode.

Note

Use the Auxiliary Control Register to enable access to the cache RAMs through the AXI slave port. See *Auxiliary Control Registers* on page 4-38.

The Slave Port Control Register is:

- a read/write register
- accessible in User and Privileged mode.

Figure 4-43 shows the arrangement of bits in the register.

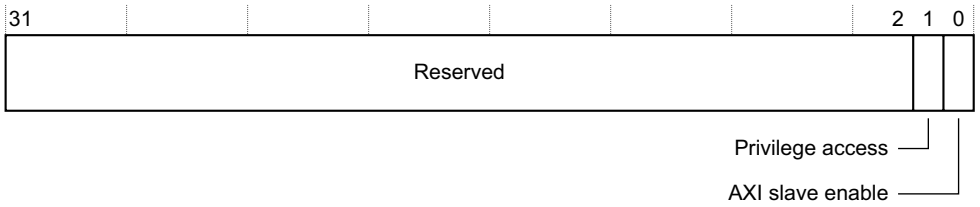


Figure 4-43 Slave Port Control Register

Table 4-41 shows how the bit values correspond with the Slave Port Control Register functions.

Table 4-41 Slave Port Control Register bit functions

Bits	Field	Function
[31:2]	Reserved	RAZ/UNP
[1]	Privilege access	Defines level of access for TCM accesses: 0 = Non-privileged and privileged access, reset value 1 = Privileged access only.
[0]	AXI slave enable	Enables or disables the AXI slave port for TCM accesses: 0 = Enables AXI slave port, reset value 1 = Disables AXI slave port.

To access the Slave Port Control Register, read or write CP15 with:

```
MRC p15, 0, <Rd>, c11, c0, 0 ; Read Slave Port Control Register
MCR p15, 0, <Rd>, c11, c0, 0 ; Write Slave Port Control Register
```

4.2.25 c13, FCSE PID Register

This processor does not support *Fast Context Switch Extension* (FCSE).

The FCSE *Process IDentifier* (PID) Register is accessible in Privileged mode only. This register reads as zero and ignores writes.

4.2.26 c13, Context ID Register

The Context ID Register holds a process *IDentification* (ID) value for the currently-running process.

The *Embedded Trace Macrocell* (ETM) and the debug logic use this register. The ETM can broadcast its value to indicate the process that is running currently. You must program each process with a unique number.

The Context ID value can also enable process dependent breakpoints and instructions.

The Context ID Register is:

- a read/write register
- accessible in Privileged mode only.

The Context ID Register, bits [31:0] contain the process ID number.

To use the Context ID Register, read or write CP15 with:

```
MRC p15, 0, <Rd>, c13, c0, 1  ; Read Context ID Register
MCR p15, 0, <Rd>, c13, c0, 1  ; Write Context ID Register
```

4.2.27 c13, Thread and Process ID Registers

The Thread and Process ID Registers provide locations to store the IDs of software threads and processes for *Operating System* (OS) management purposes.

The Thread and Process ID Registers are:

- three read/write registers:
  - User read/write Thread and Process ID Register
  - User read-only Thread and Process ID Register
  - Privileged-only Thread and Process ID Register.
- each accessible in different modes:
  - The User read/write register can be read and written in User and Privileged modes.
  - The User read-only register can only be read in User mode, but can be read and written in Privileged modes.
  - The Privileged-only register can be read and written in Privileged modes only.

To access the Thread and Process ID registers, read or write CP15 with:

```
MRC p15, 0, <Rd>, c13, c0, 2 ; Read User read/write Thread and Proc. ID Register
MCR p15, 0, <Rd>, c13, c0, 2 ; Write User read/write Thread and Proc. ID Register
MRC p15, 0, <Rd>, c13, c0, 3 ; Read User Read Only Thread and Proc. ID Register
MCR p15, 0, <Rd>, c13, c0, 3 ; Write User Read Only Thread and Proc. ID Register
MRC p15, 0, <Rd>, c13, c0, 4 ; Read Privileged Only Thread and Proc. ID Register
MCR p15, 0, <Rd>, c13, c0, 4 ; Write Privileged Only Thread and Proc. ID Register
```

Reading or writing the Thread and Process ID registers has no effect on processor state or operation. These registers provide OS support, and the OS must manage them.

You must clear the contents of all Thread and Process ID registers on process switches to prevent data leaking from one process to another. This is important to ensure the security of data. The reset value of these registers is 0.

4.2.28 Validation Registers

The processor implements a set of validation registers. This section describes:

- *c15, nVAL IRQ Enable Set Register*
- *c15, nVAL FIQ Enable Set Register* on page 4-63
- *c15, nVAL Reset Enable Set Register* on page 4-64
- *c15, nVAL Debug Request Enable Set Register* on page 4-64
- *c15, nVAL IRQ Enable Clear Register* on page 4-65
- *c15, nVAL FIQ Enable Clear Register* on page 4-66
- *c15, nVAL Reset Enable Clear Register* on page 4-67
- *c15, nVAL Debug Request Enable Clear Register* on page 4-68
- *c15, nVAL Cache Size Override Register* on page 4-69.

c15, nVAL IRQ Enable Set Register

The nVAL IRQ Enable Set Register enables any of the PMC Registers, PMC0-PMC2, and CCNT, to generate an interrupt request on overflow. If enabled, the interrupt request is signaled by **nVALIRQ** being asserted LOW.

The nVAL IRQ Enable Set Register is:

- A read/write register.
- Always accessible in Privileged mode. The USEREN Register determines access, see *c9, User Enable Register* on page 6-15.

Figure 4-44 shows the bit arrangement for the nVAL IRQ Enable Set Register.

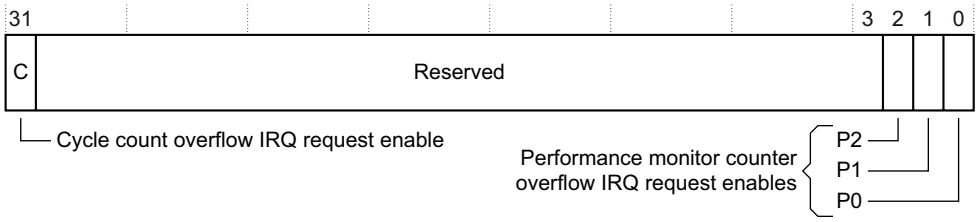


Figure 4-44 nVAL IRQ Enable Set Register format

Table 4-42 shows how the bit values correspond with the nVAL IRQ Enable Set Register.

Table 4-42 nVAL IRQ Enable Set Register bit functions

Bits	Field	Function
[31]	C	CCNT overflow IRQ request
[30: 3]	Reserved	UNP or SBZP
[2]	P2	PMC2 overflow IRQ request
[1]	P1	PMC1 overflow IRQ request
[0]	P0	PMC0 overflow IRQ request

To access the nVAL IRQ Enable Set Register, read or write CP15 with:

```
MRC p15, 0, <Rd>, c15, c1, 0 ; Read nVAL IRQ Enable Set Register
MCR p15, 0, <Rd>, c15, c1, 0 ; Write nVAL IRQ Enable Set Register
```

On reads, this register returns the current setting. On writes, interrupt requests can be enabled. If an interrupt request has been enabled it is disabled by writing to the nVAL IRQ Enable Clear Register, see *c15, nVAL IRQ Enable Clear Register* on page 4-65.

If one or more of the IRQ request fields (P2, P1, P0, and C) is enabled, and the corresponding counter overflows, then an IRQ request is indicated by **nVALIRQ** being asserted LOW. This signal might be passed to a system interrupt controller.

c15, nVAL FIQ Enable Set Register

The nVAL FIQ Enable Set Register enables any of the PMC Registers, PMC0-PMC2, and CCNT, to generate an fast interrupt request on overflow. If enabled, the interrupt request is signaled by **nVALFIQ** being asserted LOW.

The nVAL FIQ Enable Set Register is:

- A read/write register.
- Always accessible in Privileged mode. The USEREN Register determines access, see *c9, User Enable Register* on page 6-15.

Figure 4-45 shows the bit arrangement for the nVAL FIQ Enable Set Register.

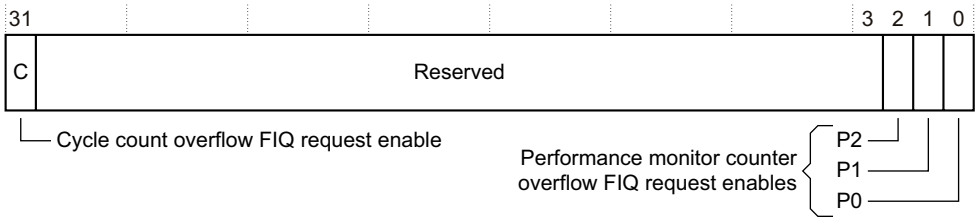


Figure 4-45 nVAL FIQ Enable Set Register format

Table 4-43 shows how the bit values correspond with the nVAL FIQ Enable Set Register.

Table 4-43 nVAL FIQ Enable Set Register bit functions

Bits	Field	Function
[31]	C	CCNT overflow FIQ request
[30:3]	Reserved	UNP or SBZP
[2]	P2	PMC2 overflow FIQ request
[1]	P1	PMC1 overflow FIQ request
[0]	P0	PMC0 overflow FIQ request

To access the FIQ Enable Set Register, read or write CP15 with:

```
MRC p15, 0, <Rd>, c15, c1, 1 ; Read FIQ Enable Set Register
MCR p15, 0, <Rd>, c15, c1, 1 ; Write FIQ Enable Set Register
```

On reads, this register returns the current setting. On writes, interrupt requests can be enabled. If an interrupt request has been enabled it is disabled by writing to the FIQ Enable Clear Register, see *c15, nVAL FIQ Enable Clear Register* on page 4-66.

If one or more of the FIQ request fields (P2, P1, P0, and C) is enabled, and the corresponding counter overflows, then an FIQ request is indicated by **nVALFIQ** being asserted LOW. This signal can be passed to a system interrupt controller.

c15, nVAL Reset Enable Set Register

The nVAL Reset Enable Set Register enables any of the PMC Registers, PMC0-PMC2, and CCNT, to generate a reset request on overflow. If enabled, the reset request is signaled by **nVALRESET** being asserted LOW.

The nVAL Reset Enable Set Register is:

- A read/write register.
- Always accessible in Privileged mode. The USEREN Register determines access, see *c9, User Enable Register* on page 6-15.

Figure 4-46 shows the bit arrangement for the nVAL Reset Enable Set Register.

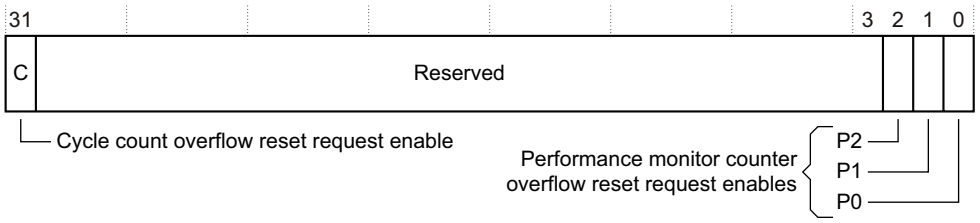


Figure 4-46 nVAL Reset Enable Set Register format

Table 4-44 shows how the bit values correspond with the nVAL Reset Enable Set Register.

Table 4-44 nVAL Reset Enable Set Register bit functions

Bits	Field	Function
[31]	C	CCNT overflow reset request
[30:3]	Reserved	UNP or SBZP
[2]	P2	PMC2 overflow reset request
[1]	P1	PMC1 overflow reset request
[0]	P0	PMC0 overflow reset request

To access the nVAL Reset Enable Set Register, read or write CP15 with:

```
MRC p15, 0, <Rd>, c15, c1, 2 ; Read nVAL Reset Enable Set Register
MCR p15, 0, <Rd>, c15, c1, 2 ; Write nVAL Reset Enable Set Register
```

On reads, this register returns the current setting. On writes, reset requests can be enabled. If a reset request has been enabled, it is disabled by writing to the nVAL Reset Enable Clear Register. See *c15, nVAL Reset Enable Clear Register* on page 4-67.

If one or more of the reset request fields (P2, P1, P0, and C) is enabled, and the corresponding counter overflows, then a reset request is indicated by **nVALRESET** being asserted LOW. This signal can be passed to a system reset controller.

c15, nVAL Debug Request Enable Set Register

The Debug Request Enable Set Register enables any of the PMC Registers, PMC0-PMC2, and CCNT, to generate a debug request on overflow. If enabled, the debug request is signaled by **VALEDBGRQ** being asserted HIGH.

The nVAL Debug Request Enable Set Register is:

- A read/write register.
- Always accessible in Privileged mode. The USEREN Register determines access, see *c9, User Enable Register* on page 6-15.

Figure 4-47 shows the bit arrangement for the nVAL Debug Request Enable Set Register.

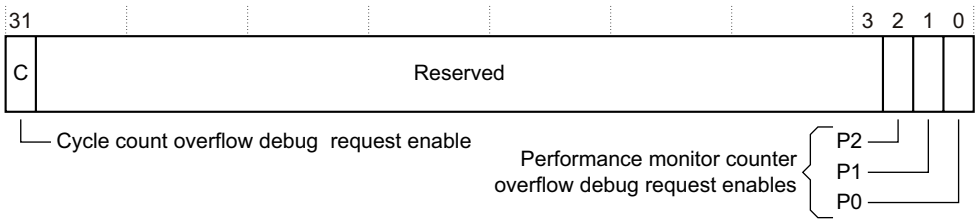


Figure 4-47 nVAL Debug Request Enable Set Register format

Table 4-45 shows how the bit values correspond with the nVAL Debug Request Enable Set Register.

Table 4-45 nVAL Debug Request Enable Set Register bit functions

Bits	Field	Function
[31]	C	CCNT overflow debug request
[30:3]	Reserved	UNP or SBZP
[2]	P2	PMC2 overflow debug request
[1]	P1	PMC1 overflow debug request
[0]	P0	PMC0 overflow debug request

To access the nVAL Debug Request Enable Set Register, read or write CP15 with:

```
MRC p15, 0, <Rd>, c15, c1, 3 ; Read nVAL Debug Request Enable Set Register
MCR p15, 0, <Rd>, c15, c1, 3 ; Write nVAL Debug Request Enable Set Register
```

On reads, this register returns the current setting. On writes, debug requests can be enabled. If a debug request has been enabled, it is disabled by writing to the nVAL Debug Request Enable Clear Register. See *c15, nVAL Debug Request Enable Clear Register* on page 4-68.

If one or more of the reset request fields (P2, P1, P0, and C) is enabled, and the corresponding counter overflows, then a debug reset request is indicated by **VALEDBGRQ** being asserted HIGH. This signal can be passed to an external debugger.

c15, nVAL IRQ Enable Clear Register

The nVAL IRQ Enable Clear Register disables overflow IRQ requests from any of the PMC Registers, PMC0-PMC2, and CCNT, for which they have been enabled.

The nVAL IRQ Enable Clear Register is:

- A read/write register.
- Always accessible in Privileged mode. The USEREN Register determines access, see *c9, User Enable Register* on page 6-15.

Figure 4-48 on page 4-66 shows the bit arrangement for the nVAL IRQ Enable Clear Register.

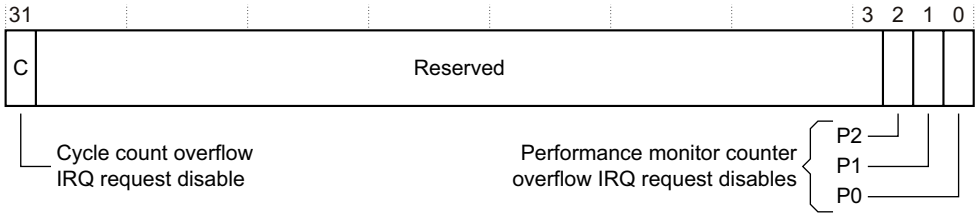


Figure 4-48 nVAL IRQ Enable Clear Register format

Table 4-46 shows how the bit values correspond with the nVAL IRQ Enable Clear Register.

Table 4-46 nVAL IRQ Enable Clear Register bit functions

Bits	Field	Function
[31]	C	CCNT overflow IRQ request
[30:3]	Reserved	UNP or SBZP
[2]	P2	PMC2 overflow IRQ request
[1]	P1	PMC1 overflow IRQ request
[0]	P0	PMC0 overflow IRQ request

To access the nVAL IRQ Enable Clear Register, read or write CP15 with:

```
MRC p15, 0, <Rd>, c15, c1, 4 ; Read  nVAL IRQ Enable Clear Register
MCR p15, 0, <Rd>, c15, c1, 4 ; Write nVAL IRQ Enable Clear Register
```

On reads, this register returns the current setting. On writes, overflow interrupt requests that are currently enabled can be disabled.

For more information of how to enable IRQ requests on counter overflows, and how the requests are signaled, see *c15, nVAL IRQ Enable Set Register* on page 4-62.

c15, nVAL FIQ Enable Clear Register

The nVAL FIQ Enable Clear Register disables overflow FIQ requests from any of the PMC Registers, PMC0-PMC2, and CCNT, that are enabled.

The nVAL FIQ Enable Clear Register is:

- A read/write register.
- Always accessible in Privileged mode. The USEREN Register determines access mode, see *c9, User Enable Register* on page 6-15.

Figure 4-49 shows the bit arrangement for the nVAL FIQ Enable Clear Register.

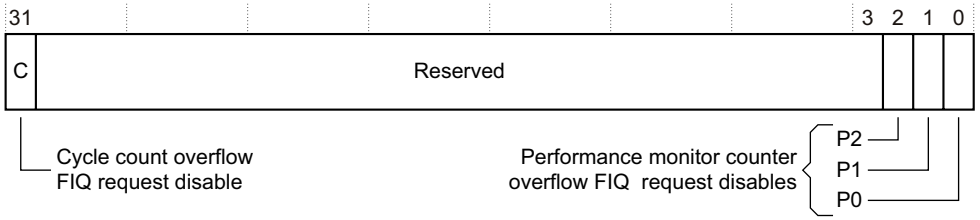


Figure 4-49 nVAL FIQ Enable Clear Register format

Table 4-47 shows how the bit values correspond with the FIQ Enable Clear Register.

Table 4-47 nVAL FIQ Enable Clear Register bit functions

Bits	Field	Function
[31]	C	CCNT overflow FIQ request
[30:3]	Reserved	UNP or SBZP
[2]	P2	PMC2 overflow FIQ request
[1]	P1	PMC1 overflow FIQ request
[0]	P0	PMC0 overflow FIQ request

To access the FIQ Enable Clear Register, read or write CP15 with:

```
MRC p15, 0, <Rd>, c15, c1, 5 ; Read  FIQ Enable Clear Register
MCR p15, 0, <Rd>, c15, c1, 5 ; Write FIQ Enable Clear Register
```

On reads, this register returns the current setting. On writes, overflow interrupt requests that are currently enabled can be disabled.

For information on how to enable FIQ requests on counter overflows, and how the requests are signaled, see *c15, nVAL FIQ Enable Set Register* on page 4-63.

c15, nVAL Reset Enable Clear Register

The nVAL Reset Enable Clear Register disables overflow reset requests from any of the PMC Registers, PMC0-PMC2, and CCNT, that are enabled.

The nVAL Reset Enable Clear Register is:

- A read/write register.
- Always accessible in Privileged mode. The USEREN Register determines access, see *c9, User Enable Register* on page 6-15.

Figure 4-50 shows the bit arrangement for the nVAL Reset Enable Clear Register.

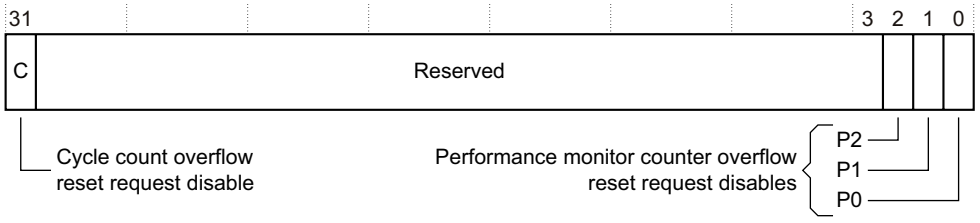


Figure 4-50 nVAL Reset Enable Clear Register format

Table 4-48 shows how the bit values correspond with the nVAL Reset Enable Clear Register.

Table 4-48 nVAL Reset Enable Clear Register bit functions

Bits	Field	Function
[31]	C	CCNT overflow reset request
[30:3]	Reserved	UNP or SBZP

Table 4-48 nVAL Reset Enable Clear Register bit functions (continued)

Bits	Field	Function
[2]	P2	PMC2 overflow reset request
[1]	P1	PMC1 overflow reset request
[0]	P0	PMC0 overflow reset request

To access the nVAL Reset Enable Clear Register, read or write CP15 with:

```
MRC p15, 0, <Rd>, c15, c1, 6 ; Read nVAL Reset Enable Clear Register
MCR p15, 0, <Rd>, c15, c1, 6 ; Write nVAL Reset Enable Clear Register
```

On reads, this register returns the current setting. On writes, overflow reset requests that are currently enabled can be disabled.

For more information of how to enable reset requests on counter overflows, and how the requests are signaled, see *c15, nVAL Reset Enable Set Register* on page 4-64.

c15, nVAL Debug Request Enable Clear Register

The nVAL Debug Request Enable Clear Register disables overflow debug requests from any of the PMC Registers, PMC0-PMC2, and CCNT, that are enabled.

The nVAL Debug Request Enable Clear Register is:

- A read/write register.
- Always accessible in Privileged mode. The USEREN Register determines access, see *c9, User Enable Register* on page 6-15.

Figure 4-51 shows the bit arrangement for the nVAL Debug Request Enable Clear Register.

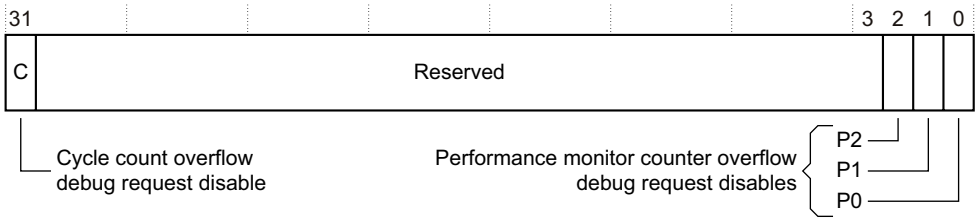


Figure 4-51 nVAL Debug Request Enable Clear Register format

Table 4-49 shows how the bit values correspond with the nVAL Debug Request Enable Clear Register.

Table 4-49 nVAL Debug Request Enable Clear Register bit functions

Bits	Field	Function
[31]	C	CCNT overflow debug request
[30:3]	Reserved	UNP or SBZP
[2]	P2	PMC2 overflow debug request
[1]	P1	PMC1 overflow debug request
[0]	P0	PMC0 overflow debug request

To access the nVAL Debug Request Enable Clear Register, read or write CP15 with:

```
MRC p15, 0, <Rd>, c15, c1, 7 ; Read nVAL Debug Request Enable Clear Register
MCR p15, 0, <Rd>, c15, c1, 7 ; Write nVAL Debug Request Enable Clear Register
```

On reads, this register returns the current setting. On writes, overflow debug requests that are currently enabled can be disabled.

For more information of how to enable debug requests on counter overflows, and how the requests are signaled, see *c15, nVAL Debug Request Enable Set Register* on page 4-64.

c15, nVAL Cache Size Override Register

The nVAL Cache Size Override Register overwrites the caches size fields in the main register. This enables you to choose a smaller instruction and data cache size than is implemented.

The nVAL Cache Size Override Register is:

- a write-only register
- only accessible in Privileged mode.

Figure 4-52 shows the bit arrangement for the nVAL Cache Size Override Register.

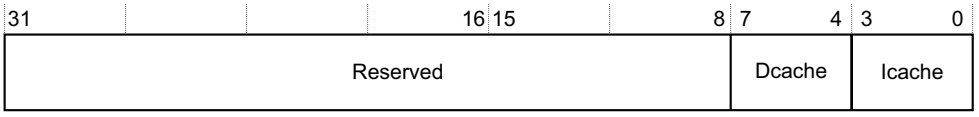


Figure 4-52 nVAL Cache Size Override Register format

Table 4-50 shows how the bit values correspond with the nVAL Cache Size Override Register.

Table 4-50 nVAL Cache Size Override Register

Bits	Field	Function
[31:8]	Reserved	SBZ.
[7:4]	Dcache	Defines the nVAL data cache size. See Table 4-51.
[3:0]	Icache	Defines the nVAL instruction cache size. See Table 4-51.

Table 4-51 shows the encodings for the nVAL instruction and data cache sizes.

Table 4-51 nVAL instruction and data cache size encodings

Encoding	Instruction and data cache size
b0000	4kB
b0001	8kB
b0011	16kB
b0111	32kB
b1111	64kB

To access the nVAL Cache Size Override Register, write CP15 with:

```
MCR p15, 0, <Rd>, c15, c14, 0 ; nVAL Cache Size Override Register
```

Note

The nVAL Cache Size Override Register can only be used to select cache sizes for which the appropriate RAM has been integrated. Larger cache sizes require deeper data and tag RAMs, and smaller cache sizes require wider tag RAMs. Therefore, it is unlikely that you can change the cache size using this register except using a simulation model of the cache RAMs.

4.2.29 Correctable Fault Location Register

The *Correctable Fault Location Register* (CFLR) indicates the location of the last correctable error that occurred during cache or TCM operations. It is not updated on speculative accesses, for example, an instruction fetch for an instruction that is not executed because of a previous branch. This register is:

- a read/write register
- accessible in Privileged mode only.

Note

This register is implemented from the r1p*m* releases of the processor. Attempting to access this register in r0p*m* releases of the processor results in an Undefined Instruction exception.

The processor updates this register regardless of whether an abort is taken or an access is retried in response to the error.

This register is updated on:

- parity or ECC errors in the instruction cache
- single-bit ECC errors in the data cache
- parity or multi-bit errors in the data cache when write-through behavior is forced
- single-bit TCM ECC errors.

The CFLR is not updated on a TCM external error or external retry request.

Every correctable error that causes a CFLR update also has an associated event. See Table 6-1 on page 6-2 for the events which are related to CFLR updates. If two correctable errors occur simultaneously, for example an AXI slave error and an LSU or PFU error, the LSU or PFU write takes priority. If multiple errors occur, the value in the CFLR reflects the location of the latest event.

The same register is updated by all correctable errors. You can read bits [25:24] to determine whether the error was from a cache or TCM access. Figure 4-53 shows the bit arrangement of the CFLR when it indicates a correctable cache error.

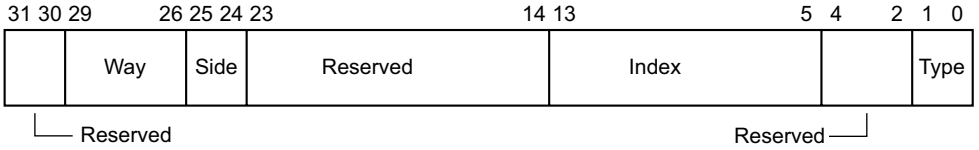


Figure 4-53 Correctable Fault Location Register - cache

Table 4-52 shows how the bit values correspond to the CFLR when it indicates a correctable cache error.

Table 4-52 Correctable Fault Location Register - cache

Bits	Field	Function
[31:30]	Reserved	RAZ
[29:26]	Way	Indicates the Way of the error.
[25:24]	Side	Indicates the source of the error. For cache errors, this value is always `0b00`.
[23:14]	Reserved	RAZ
[13:5]	Index	Indicates the index of the location where the error occurred.
[4:2]	Reserved	RAZ
[1:0]	Type	Indicates the type of access that caused the error. `0b00` = Instruction cache. `0b01` = Data cache.

Figure 4-54 shows the bit arrangement of the CFLR when it indicates a correctable TCM error.

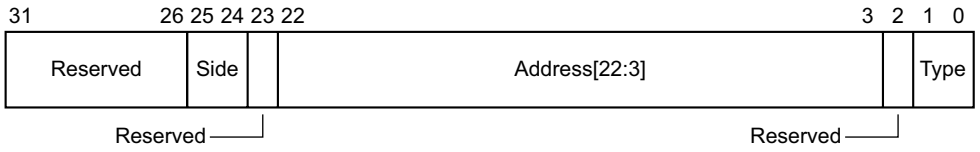


Figure 4-54 Correctable Fault Location Register - TCM

Table 4-53 shows how the bit values correspond to the CFLR when it indicates a correctable TCM error.

Table 4-53 Correctable Fault Location Register - TCM

Bits	Field	Function
[31:26]	Reserved	RAZ
[25:24]	Side	Indicates the source of the error. `0b01` = ATCM `0b10` = BTCM
[23]	Reserved	RAZ
[22:3]	Address	Indicates the address in the TCM where the error occurred.
[2]	Reserved	RAZ
[1:0]	Type	Indicates the type of access that caused the error. `0b00` = Instruction. `0b01` = Data. `0b10`, `0b11` = AXI slave.

To access the Correctable Fault Location Register, read or write CP15 with:

```
MRC p15, 0, <Rd>, c15, c3, 0 : Read CFLR
MCR p15, 0, <Rd>, c15, c3, 0 : Write CFLR
```

4.2.30 Build Options Registers

Build options registers reflect the build configuration options used to build the processor. They do not reflect any pin-configuration options. These registers are:

- read-only registers
- accessible in Privileged mode only.

Note

These registers are implemented from the r1p*m* releases of the processor. Attempting to access these registers in r0p*m* releases of the processor results in an Undefined Instruction exception.

c15, Build Options 1 Register

Figure 4-55 shows the bit arrangement for the Build Options 1 Register.

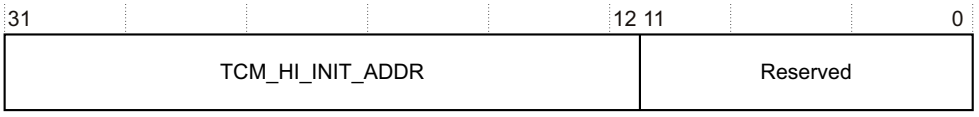


Figure 4-55 Build Options 1 Register format

Table 4-54 shows how the bit values correspond with the Build Options 1 Register.

Table 4-54 Build Options 1 Register

Bits	Field	Function
[31:12]	TCM_HI_INIT_ADDR	Default high address for the TCM.
[11:0]	Reserved	SBZ

To access the Build Options 1 Register, write CP15 with:

```
MRC p15, 0, <Rd>, c15, c2, 0 ; read Build Options 1 Register
```

c15, Build Options 2 Register

Figure 4-56 on page 4-73 shows the bit arrangement for the Build Options 2 Register.

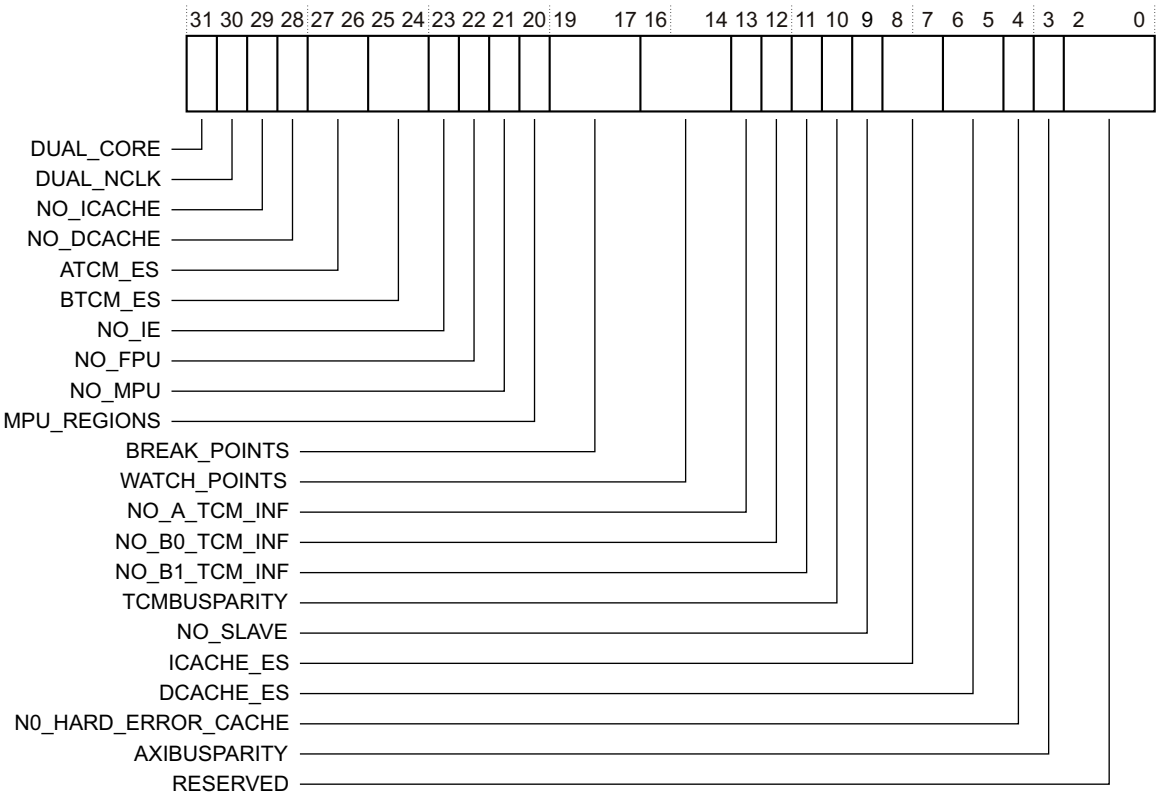


Figure 4-56 Build Options 2 Register format

Table 4-55 shows how the bit values correspond with the Build Options 2 Register.

Table 4-55 Build Options 2 Register

Bits	Field	Function
[31]	DUAL_CORE[a]	Indicates whether a second, redundant, copy of the processor logic and checking logic was instantiated: 0 = single core 1 = dual core.
[30]	DUAL_NCLK[a]	Indicates whether an inverted clock is used for the redundant core: 0 = inverted clock not used 1 = inverted clock used.
[29]	NO_ICACHE	Indicates whether the processor contains instruction cache: 0 = processor contains instruction cache 1 = processor does not contain instruction cache.
[28]	NO_DCACHE	Indicates whether the processor contains data cache: 0 = processor contains data cache 1 = processor does not contain data cache.
[27:26]	ATCM_ES	Indicates whether an error scheme is implemented on the ATCM interface: 00 = no error scheme 01 = 8-bit parity logic 10 = 32-bit error detection and correction 11 = 64-bit error detection and correction.

Table 4-55 Build Options 2 Register (continued)

Bits	Field	Function
[25:24]	BTCM_ES	Indicates whether an error scheme is implemented on the BTCM interface(s): 00 = no error scheme 01 = 8-bit parity logic 10 = 32-bit error detection and correction 11 = 64-bit error detection and correction.
[23]	NO_IE	Indicates whether the processor supports big-endian instructions: 0 = processor supports big-endian instructions 1 = processor does not support big-endian instructions.
[22]	NO_FPU	Indicates whether the processor contains a floating point unit: 0 = processor contains a floating point unit 1 = processor does not contain a floating point unit.
[21]	NO_MPU	Indicates whether the processor contains a *Memory Protection Unit* (MPU): 0 = processor contains an MPU 1 = processor does not contain an MPU.
[20]	MPU_REGIONS	Indicates the number of regions in the included MPU: 0 = 8 1 = 12. If the processor does not contain an MPU (bit [21] set to 0), this bit is set to 0.
[19:17]	BREAK_POINTS	Indicates the number of break points implemented in the processor, minus 1.
[16:14]	WATCH_POINTS	Indicates the number of watch points implemented in the processor, minus 1.
[13]	NO_A_TCM_INF	Indicates whether the processor contains an ATCM port: 0 = processor contains ATCM port 1 = processor does not contain ATCM port.
[12]	NO_B0_TCM_INF	Indicates whether the processor contains a B0TCM port: 0 = processor contains B0TCM port 1 = processor does not contain B0TCM port.
[11]	NO_B1_TCM_INF	Indicates whether the processor contains a B1TCM port: 0 = processor contains B1TCM port 1 = processor does not contain B1TCM port.
[10]	TCMBUSPARITY	Indicates whether the processor contains TCM address bus parity logic: 0 = processor does not contain TCM address bus parity logic 1 = processor contains TCM address bus parity logic.
[9]	NO_SLAVE	Indicates whether the processor contains an AXI slave port: 0 = processor contains an AXI slave port 1 = processor does not contain an AXI slave port.
[8:7]	ICACHE_ES	Indicates whether an error scheme is implemented for the instruction cache: 00 = no error scheme 01 = 8-bit parity error detection 11 = 64-bit error detection and correction. If the processor does not contain an i-cache, these bits are set to 00.

Table 4-55 Build Options 2 Register (continued)

Bits	Field	Function
[6:5]	DCACHE_ES	Indicates whether an error scheme is implemented for the data cache: 00 = no error scheme 01 = 8-bit parity error detection 10 = 32-bit error detection and correction. If the processor does not contain a d-cache, these bits are set to 00.
[4]	NO_HARD_ERROR_CACHE	Indicates whether the processor contains cache for corrected TCM errors: 0 = processor contains TCM error cache 1 = processor does not contain TCM error cache.
[3]	AXIBUSPARITY	Indicates whether the processor contains AXI bus parity logic. 0 = processor does not contain AXI bus parity logic 1 = processor contains AXI bus parity logic.
[2:0]	Reserved	Undefined.

a. The value of this bit is UNPREDICTABLE in revision r1p0 of the processor.

To access the Build Options 2 Register, write CP15 with:

```
MRC p15, 0, <Rd>, c15, c2, 1 ; read Build Options 2 Register
```

Chapter 5
Prefetch Unit

This chapter describes how the *PreFetch Unit* (PFU), in conjunction with the DPU, uses program flow prediction to locate branches in the instruction stream and the strategies used to determine if a branch is likely to be taken or not. It contains the following sections:

5.1 About the prefetch unit

The purpose of the PFU is to:

- perform speculative fetch of instructions ahead of the DPU by predicting the outcome of branch instructions
- format instruction data in a way that aids the DPU in efficient implementation.

The PFU fetches instructions from the memory system under the control of the DPU, and the internal coprocessors CP14 and CP15. In ARM state the memory system can supply up to two instructions per cycle. In Thumb state the memory system can supply up to four instructions per cycle.

The PFU buffers up to three instruction data fetches in its FIFO. There is an additional FIFO between the PFU and the DPU that can normally buffer up to eight instructions. This reduces or eliminates stall cycles after a branch instruction. This increases the performance of the processor.

Program flow prediction occurs in the PFU by:

- predicting the outcome of conditional branches using the branch predictor and, for direct branches, calculating their destination address using the offset encoded in the instruction
- predicting the destination of procedure returns using the return stack.

The DPU resolves the program flow predictions that the PFU makes.

The PFU fetches the instruction stream as dictated by:

- the Program Counter
- the branch predictor
- procedure returns signaled by the return stack
- exceptions including aborts and interrupts signaled by the DPU
- correction of mispredicted branches as indicated by the DPU.

5.2 Branch prediction

The PFU normally fetches instructions from sequential addresses. If a branch instruction is fetched, the next instruction to be fetched can only be determined with certainty after the instruction has completed execution at the end of the pipeline in the DPU. If the branch is taken, the next instruction to be executed is not sequential. The sequential instructions that the PFU has fetched while the branch instruction was executing must be flushed from the pipeline and the correct instruction fetched. This has the effect of reducing the performance of the processor.

The PFU can detect branches in the Pd-stage of the pipeline, predict whether or not the branch is taken, and determine or predict the target address for a taken branch. This enables the PFU to start fetching instructions at the destination of a taken branch before the branch has completed execution in the DPU. The branch instruction is still executed in the DPU to determine the accuracy of the prediction. If the branch was mispredicted, the pipeline must be flushed and the correct instruction fetched. In general, more branches are correctly predicted than mispredicted so fewer pipeline flushes occur and the performance of the processor is enhanced.

Two major classes of branch are addressed in the processor prediction scheme:

1. Direct branches, including `B`, `BL`, `CZB`, and `BLX` immediate, where the target address is a fixed offset, encoded in the instruction, from the program counter. If such an instruction has been fetched, and the program counter is known, predicting the destination of the branch only involves predicting whether the instruction passes or fails its condition code, that is, whether the branch is taken or not taken.
2. Indirect branches such as load and *Branch and eXchange* (`BX`), instructions which write to the PC, that can be identified as a likely return from a procedure call. Two identifiable cases are:
   - loads to the PC from an address derived from R13
   - `BX` from R0-R14.

   In these cases, if the calling operation can also be identified, the likely return address can be stored in the return stack. Typical calling operations are `BL` and `BLX` instructions.

Note

Unconditional instructions of either class of program flow are always executed, and do not affect prediction history. Unconditional return stack operations always affect the return stack.

This section describes:

- *Disabling program flow prediction*
- *Branch predictor* on page 5-4
- *Incorrect predictions and correction* on page 5-4.

5.2.1 Disabling program flow prediction

You cannot disable program flow prediction using the Z bit, bit [11], of CP15 Register c1. The Z bit is tied to 1. To disable the program flow prediction you must disable the return stack and set the branch prediction policy to not-taken. For more information see *c1, System Control Register* on page 4-35.

You can also control the return stack, the branch predictor, and the fetch rate using the Auxiliary Control Register. For more information see *Auxiliary Control Registers* on page 4-38.

5.2.2 Branch predictor

Branch prediction in the processor is dynamic and is based around a global history prediction scheme. In addition, there is extra logic to handle predictions that thrash and to predict the end of long loops.

The global history scheme is an adaptive predictor that learns the behavior of branches during execution, based on the historical pattern of behavior of the preceding branches. For each pattern of branch behavior, the history table holds a 2-bit hint value. The 2-bit hint indicates if the next branch must be predicted taken or predicted not-taken based on the behavior of previous branches. The history table contains 256 entries.

For loops beyond a certain number of iterations, the branch history is not large enough to learn the history and predict the loop exit. The PFU includes logic to count the number of iterations (up to 31) of a loop, and thereby predict the not-taken branch that exits the loop. If the number of iterations taken exceeds 31, the loop branch is never predicted as not-taken.

If multiple branch histories index into the same hint value, this can cause thrashing in the history table and reduce accuracy of the branch predictor. Logic in the branch predictor detects these cases and provides some hysteresis for the hint value.

For direct branches, the target address is calculated statically from the instruction encoding and the program counter. For indirect branches, the hint value predicts if the branch is taken or not-taken, and the return stack can sometimes be used to predict the target address. When the destination of a branch cannot be calculated statically, or popped from the return stack, PFU assumes the branch to be not-taken.

The PFU updates the history for each occurrence of a branch when the DPU indicates how the branch was resolved.

Configuring the branch predictor

You can configure the branch predictor by setting bits in the Auxiliary Control Register:

- Set bits [16:15] to b00 to enable prediction using the pattern history tables.
- Set bits [16:15] to b01 to force branches to be always predicted taken.
- Set bits [16:15] to b10 to force branches to be always predicted not-taken.
- Set bit [21] to disable prediction using the dynamic branch predictor loop cache.
- Set bit [20] to disable prediction using the dynamic branch predictor register extension cache.

For more information, see *c1, Auxiliary Control Register* on page 4-38

5.2.3 Incorrect predictions and correction

The DPU resolves branches that the dynamic branch predictor predicts at the Wr-stage of the pipeline, see Figure 1-3 on page 1-17. A misprediction causes the PFU to flush the pipeline and fetch the correct instruction stream.

5.3 Return stack

The call-return stack predicts procedural returns that are program flow changes such as loads, and branch register. The dynamic branch predictor determines if conditional procedure returns are predicted as taken or not-taken. The return stack predicts the target address for unconditional procedure returns, and conditional procedure returns that have been predicted as taken by the branch predictor.

The return stack consists of a 4-entry circular buffer. When the PFU detects a taken procedure call instruction, the PFU pushes the return address onto the return stack. The instructions that the PFU recognizes as procedure calls are:

- for ARM and Thumb instructions:
  - `BL` immediate
  - `BLX` immediate
  - `BLX Rm`.

When the return stack detects a taken return instruction, the PFU issues an instruction fetch from the location at the top of the return stack, and pops the return stack. The instructions that the PFU recognizes as procedure returns are, in both the ARM and Thumb instruction sets:

-
- `POP {..,pc}`
- `LDMIB Rn{!}, {..,pc}`
- `LDMDA Rn{!}, {..,pc}`
- `LDMDB Rn{!}, {..,pc}`
- `LDR pc, [sp], #4`
- `BX Rm`.

Return stack mispredictions can exist when:

- The prediction that a conditional return passed or failed its condition code is not correct.
- The return address is not correct. The DPU resolves indirect branches that the return stack predicts at the Ret-stage of the pipeline, see Figure 1-3 on page 1-17. A misprediction causes the PFU to flush the pipeline and fetch the correct instruction stream.

The return stack has no underflow or overflow detection. Either scenario is likely to cause a misprediction.

Note

The `MOV PC, LR` instruction is not decoded and is not predicted as a return.

Chapter 6
Events and Performance Monitor

This chapter describes the *Performance Monitoring Unit* (PMU) and event bus interface. It contains the following sections:

6.1 About the events

The processor includes logic to detect various events that can occur, for example, a cache miss. These events provide useful information about the behavior of the processor that you can use when debugging or profiling code.

The events are made visible on an output bus, **EVNTBUS**, and can be counted using registers in the *Performance Monitoring Unit* (PMU). See *Event bus interface* on page 6-19 for more information about the event bus, and *About the PMU* on page 6-6 for more information about the PMU. Table 6-1 lists the events that are generated, along with the bit position of each event on the event bus, and the numbers that the PMU uses to refer the events. Event reference numbers that are not listed are Reserved. See *Error detection events* on page 8-36 for more information on the CFLR related events.

Table 6-1 Event bus interface bit functions

EVNTBUS bit position	Description	CFLR update	Event Ref. Value
N/A	Software increment. The register is incremented only on writes to the Software Increment Register. See *c9, Software Increment Register* on page 6-11.	-	0x00
[0]	Instruction cache miss. Each instruction fetch from normal Cacheable memory that causes a refill from the level 2 memory system generates this event. Accesses that do not cause a new cache refill, but are satisfied from refilling data of a previous miss are not counted. Where instruction fetches consist of multiple instructions, these accesses count as single events. CP15 cache maintenance operations do not count as events.	-	0x01
[1]	Data cache miss. Each data read from or write to normal Cacheable memory that causes a refill from the level 2 memory system generates this event. Accesses that do not cause a new cache refill, but are satisfied from refilling data of a previous miss are not counted. Each access to a cache line to normal Cacheable memory that causes a new linefill is counted, including the multiple transactions of an LDM and STM. Write-through writes that hit in the cache do not cause a linefill and so are not counted. CP15 cache maintenance operations do not count as events.	-	0x03
[2]	Data cache access. Each access to a cache line is counted including the multiple transactions of an LDM, STM, or other operations. CP15 cache maintenance operations do not count as events.	-	0x04
[3]	Data Read architecturally executed. This event occurs for every instruction that explicitly reads data, including SWP.	-	0x06
[4]	Data Write architecturally executed. This event occurs for every instruction that explicitly writes data, including SWP.	-	0x07
[5]	Instruction architecturally executed.	-	0x08
[6]	Dual-issued pair of instructions architecturally executed.	-	0x5e
[7]	Exception taken. This event occurs on each exception taken.	-	0x09

Table 6-1 Event bus interface bit functions (continued)

EVNTBUS bit position	Description	CFLR update	Event Ref. Value
[8]	Exception return architecturally executed. This event occurs on every exception return, for example, `RFE`, `MOVS PC`, `LDM PC^`.	-	`0x0A`
[9]	Change to Context ID executed.	-	`0x0B`
[10]	Software change of PC, except by an exception, architecturally executed.	-	`0x0C`
[11]	`B` immediate, `BL` immediate or `BLX` immediate instruction architecturally executed (taken or not taken).	-	`0x0D`
[12]	Procedure return architecturally executed, other than exception returns, for example, `BX Rm; LDM PC`. `MOV PC, LR` does not generate this event, because it is not predicted as a return.	-	`0x0E`
[13]	Unaligned access architecturally executed. This event occurs for each instruction that was to an unaligned address that either triggered an alignment fault, or would have done so if the System Control Register A-bit had been set.	-	`0x0F`
[14]	Branch mispredicted or not predicted. This event occurs for every pipeline flush caused by a branch.	-	`0x10`
N/A	Cycle count.	-	`0x11`
[15]	Branches or other change in program flow that could have been predicted by the branch prediction resources of the processor.	-	`0x12`
[16]	Stall because instruction buffer cannot deliver an instruction. This can indicate an ICache miss. This event occurs every cycle where the condition is present.	-	`0x40`
[17]	Stall because of a data dependency between instructions. This event occurs every cycle where the condition is present.	-	`0x41`
[18]	Data cache write-back. This event occurs once for each line that is written back from the cache.	-	`0x42`
[19]	External memory request. Examples of this are cache refill, Non-cacheable accesses, write-through writes, cache line evictions (write-back).	-	`0x43`
[20]	Stall because of LSU being busy. This event takes place each clock cycle where the condition is met. A high incidence of this event indicates the pipeline is often waiting for transactions to complete on the external bus.	-	`0x44`
[21]	Store buffer was forced to drain completely. Examples of this are `DMB`, Strongly Ordered memory access, or similar events.	-	`0x45`
N/A	The number of cycles FIQ interrupts are disabled.	-	`0x46`
N/A	The number of cycles IRQ interrupts are disabled.	-	`0x47`
N/A	ETMEXTOUT[0].	-	`0x48`
N/A	ETMEXTOUT[1].	-	`0x49`

Table 6-1 Event bus interface bit functions (continued)

EVNTBUS bit position	Description	CFLR update	Event Ref. Value
[22]	Instruction cache tag RAM parity or ECC error (correctable).	Yes	0x4A
[23]	Instruction cache data RAM parity or ECC error (correctable).	Yes	0x4B
[24]	Data cache tag or dirty RAM parity error or correctable ECC error.	Yes	0x4C
[25]	Data cache data RAM parity error. or correctable ECC error	Yes	0x4D
[26]	TCM parity error or fatal ECC error reported from the prefetch unit.	-	0x4E
[27]	TCM parity error or fatal ECC error reported from the load/store unit.	-	0x4F
N/A	Store buffer merge.	-	0x50
N/A	LSU stall caused by full store buffer.	-	0x51
N/A	LSU stall caused by store queue full.	-	0x52
N/A	Integer divide instruction, SDIV or UDIV, executed.	-	0x53
N/A	Stall cycle caused by integer divide.	-	0x54
N/A	PLD instruction that initiates a linefill.	-	0x55
N/A	PLD instruction that did not initiate a linefill because of a resource shortage.	-	0x56
N/A	Non-cacheable access on AXI master bus.	-	0x57
[28]	Instruction cache access. This is an analog to event 0x04.	-	0x58
N/A	Store buffer operation has detected that two slots have data in same cache line but with different attributes.	-	0x59
[29]	Dual issue case A (branch).	-	0x5A
[30]	Dual issue case B1, B2, F2 (load/store), F2D.	-	0x5B
[31]	Dual issue other.	-	0x5C
[32]	Double precision floating point arithmetic or conversion instruction executed.	-	0x5D
[33]	Data cache data RAM fatal ECC error.	-	0x60
[34]	Data cache tag/dirty RAM fatal ECC error.	-	0x61
[35]	Processor livelock because of hard errors or exception at exception vector.[a]	-	0x62
[36]	Unused.	-	0x63
[37]	ATCM parity or multi-bit ECC error.	-	0x64
[38]	B0TCM parity or multi-bit ECC error.	-	0x65
[39]	B1TCM parity or multi-bit ECC error.	-	0x66
[40]	ATCM single-bit ECC error.	-	0x67
[41]	B0TCM single-bit ECC error.	-	0x68
[42]	B1TCM single-bit ECC error.	-	0x69

Table 6-1 Event bus interface bit functions (continued)

EVNTBUS bit position	Description	CFLR update	Event Ref. Value
[43]	TCM correctable ECC error reported by load/store unit.	Yes	0x6A
[44]	TCM correctable ECC error reported by prefetch unit.	Yes	0x6B
[45]	TCM parity or fatal ECC error reported by AXI slave interface.	-	0x6C
[46]	TCM correctable ECC error reported by AXI slave interface.	Yes	0x6D
N/A	Cycle count	-	0xFF

a. This event is only generated for by revisions r1p2 and later of the processor.

6.2 About the PMU

The PMU consists of three event counting registers, one cycle counting register and 12 CP15 registers, for controlling and interrogating the counters. The performance monitoring registers are always accessible in Privileged mode. You can use the *User Enable* (USEREN) Register to make all of the performance monitoring registers, except for the USEREN, *Interrupt Enable Set* (INTENS), and *Interrupt Enable Clear* (INTENC) Registers, accessible in User mode.

All three event counters are read and written through the same CP15 register. The *Performance Counter Selection* (PMNXSEL) Register determines which counter is read or written. The three Event Selection registers, one per counter, are read and written through one CP15 register in the same way.

Using the control registers, you can enable or disable each of the event counters individually, and read and reset the overflow flag for each counter. Any or all of the counters can be enabled to assert an interrupt request output, **nPMUIRQ**, on overflow.

When the processor is in Debug halt state:

- the PMU does not count events
- events are not visible on the ETM interface
- the *Cycle CouNT* (CCNT) register is halted.

For more information on Debug state see Chapter 11 *Debug*.

The PMU only counts events when non-invasive debug is enabled, that is, when either **DBGEN** or **NIDEN** inputs are asserted. The *Cycle Count* (CCNT) Register is always enabled regardless of whether non-invasive debug is enabled, unless the DP bit of the PMNC register is set. See *c9, Performance Monitor Control Register* on page 6-7.

6.3 Performance monitoring registers

The performance monitoring registers are described in:

- *c9, Performance Monitor Control Register*
- *c9, Count Enable Set Register* on page 6-8
- *c9, Count Enable Clear Register* on page 6-9
- *c9, Overflow Flag Status Register* on page 6-10
- *c9, Software Increment Register* on page 6-11
- *c9, Performance Counter Selection Register* on page 6-12
- *c9, Cycle Count Register* on page 6-13
- *c9, Event Selection Register* on page 6-13
- *c9, Performance Monitor Count Registers* on page 6-15
- *c9, User Enable Register* on page 6-15
- *c9, Interrupt Enable Set Register* on page 6-16
- *c9, Interrupt Enable Clear Register* on page 6-17.

6.3.1 c9, Performance Monitor Control Register

The *Performance MoNitor Control* (PMNC) Register controls the operation of the three count registers, and the CCNT Register.

The PMNC Register is:

- A read/write register.
- Always accessible in Privileged mode. The USEREN Register determines accessibility in User mode, see *c9, User Enable Register* on page 6-15.

Figure 6-1 shows the bit arrangement for the PMNC Register.

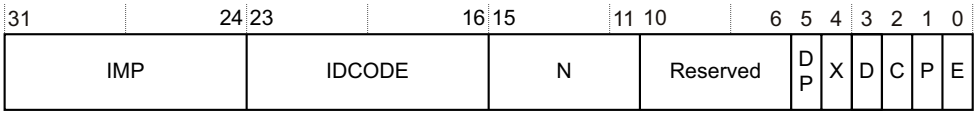


Figure 6-1 PMNC Register format

Table 6-2 shows how the bit values correspond with the PMNC Register.

Table 6-2 PMNC Register bit functions

Bits	Field	Function
[31:24]	IMP	Implementer code: 0x41 = ARM
[23:16]	IDCODE	Identification code: 0x14 = Cortex-R4
[15:11]	N	Specifies the number of counters implemented: 0x3 = three counters implemented
[10: 6]	Reserved	RAZ on reads, *Should Be Zero or Preserved* (SBZP) on writes
[5]	DP	Disable CCNT when prohibited, that is, when non-invasive debug is not enabled: 0 = Count is enabled in prohibited regions. This is the reset value. 1 = Count is disabled in prohibited regions.

Table 6-2 PMNC Register bit functions (continued)

Bits	Field	Function
[4]	X	Enable export of the events to the event bus for an external monitoring block, for example the ETM, to trace events: 0 = Export disabled. This is the reset value. 1 = Export enabled.
[3]	D	Cycle count divider: 0 = Counts every processor clock cycle. This is the reset value. 1 = Counts every 64th processor clock cycle.
[2]	C	Cycle counter reset: 0 = no action 1 = reset cycle counter, CCNT, to zero. This bit Reads-As-Zero.
[1]	P	Event counter reset: 0 = no action 1 = reset all event counters to zero. This bit Reads-As-Zero.
[0]	E	Enable: 0 = Disable all counters, including CCNT. This is the reset value. 1 = Enable all counters including CCNT.

The PMNC Register is always accessible in Privileged mode. To access the register, read or write CP15 with:

```
MRC p15, 0, <Rd>, c9, c12, 0 ; Read  PMNC Register
MCR p15, 0, <Rd>, c9, c12, 0 ; Write PMNC Register
```

6.3.2 c9, Count Enable Set Register

The *CouNT ENable Set* (CNTENS) Register enables any of the performance monitor count registers. When read, this register indicates which counters are enabled. Writing a 1 to a particular count enable bit enables that counter. Writing a 0 to a count enable bit has no effect. You must use the Count Enable Clear Register to disable the counters.

The CNTENS Register is:

- A read/write register.
- Always accessible in Privileged mode. The USEREN Register determines accessibility in User mode, see *c9, User Enable Register* on page 6-15.

The values in this register are ignored unless the E bit, bit [0], is set in the PMNC Register, see *c9, Performance Monitor Control Register* on page 6-7.

Figure 6-2 on page 6-9 shows the bit arrangement for the CNTENS Register.

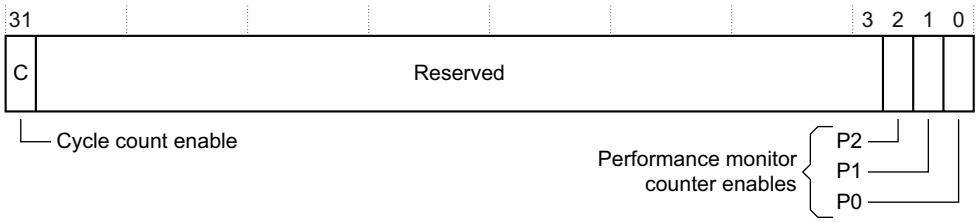


Figure 6-2 CNTENS Register format

Table 6-3 shows how the bit values correspond with the CNTENS Register.

Table 6-3 CNTENS Register bit functions

Bits	Field	Function
[31]	C	Cycle counter enable set: 0 = disable 1 = enable.
[30:3]	Reserved	UNP on reads, SBZP on writes
[2]	P2	Counter 2 enable
[1]	P1	Counter 1 enable
[0]	P0	Counter 0 enable

To access the CNTENS Register, read or write CP15 with:

```
MRC p15, 0, <Rd>, c9, c12, 1 ; Read CNTENS Register
MCR p15, 0, <Rd>, c9, c12, 1 ; Write CNTENS Register
```

The CNTENS Register retains its value when the enable bit of the PMNC is clear, even though its settings are ignored.

6.3.3 c9, Count Enable Clear Register

The *CouNT ENable Clear* (CNTENC) Register disables any of the Performance Monitor Count Registers.

When reading this register, any enable that reads as 0 indicates the corresponding counter is disabled. Any enable that reads as 1 indicates the corresponding counter is enabled.

When writing this register, any enable written with a value of 0 is ignored, that is, not updated. Any enable written with a value of 1 clears the counter enable.

The CNTENC Register is:

- A read/write register
- Always accessible in Privileged mode. The User Enable Register determines accessibility in User mode, see *c9, User Enable Register* on page 6-15.

Figure 6-3 on page 6-10 shows the bit arrangement for the CNTENC Register.

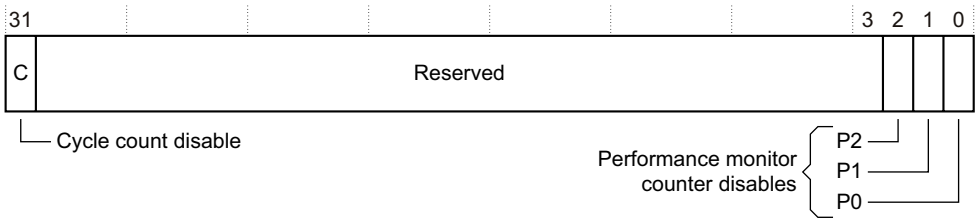


Figure 6-3 CNTENC Register format

Table 6-4 shows how the bit values correspond with the CNTENC Register.

Table 6-4 CNTENC Register bit functions

Bits	Field	Function
[31]	C	Cycle counter enable clear: 0 = disable 1 = enable.
[30:3]	Reserved	UNP on reads, SBZP on writes
[2]	P2	Counter 2 enable
[1]	P1	Counter 1 enable
[0]	P0	Counter 0 enable

To access the CNTENC Register, read or write CP15 with:

```
MRC p15, 0, <Rd>, c9, c12, 2 ; Read  CNTENC Register
MCR p15, 0, <Rd>, c9, c12, 2 ; Write CNTENC Register
```

Writing to bits in this register disables individual counters, and clears the corresponding bits in the CNTENS Register, see *c9, Count Enable Set Register* on page 6-8.

You can use the enable, EN, bit [0] of the PMNC Register to disable all performance counters including CCNT, see *c9, Performance Monitor Control Register* on page 6-7.

The CNTENC and CNTENS Registers retain their values when the enable bit of the PMNC is clear, even though their settings are ignored. The CNTENC Register can be used to clear the enabled flags for individual counters even when all counters are disabled in the PMNC Register.

6.3.4 c9, Overflow Flag Status Register

The *overflow FLAG status* (FLAG) Register indicates if performance monitor counters have overflowed.

The FLAG Register is:

- A read/write register
- Always accessible in Privileged mode. The USEREN Register determines accessibility in User mode, see *c9, User Enable Register* on page 6-15.

Figure 6-4 on page 6-11 shows the bit arrangement for the FLAG Register.

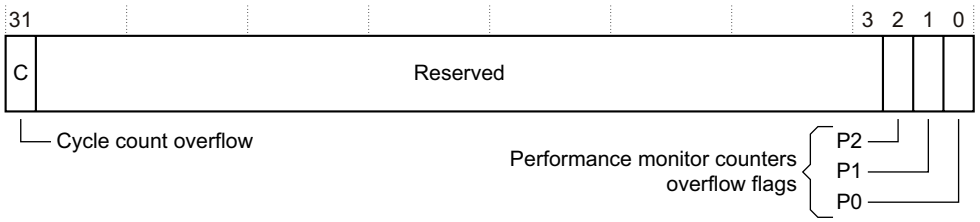


Figure 6-4 FLAG Register format

Table 6-5 shows how the bit values correspond with the FLAG Register.

Table 6-5 Overflow Flag Status Register bit functions

Bits	Field	Function
[31]	Cycle counter overflow	Cycle counter overflow flag: 0 = disable 1 = enable.
[30:3]	Reserved	UNP on reads, SBZP on writes
[2]	P2	Counter 2 overflow flag
[1]	P1	Counter 1 overflow flag
[0]	P0	Counter 0 overflow flag

To access the FLAG Register, read or write CP15 with:

```
MRC p15, 0, <Rd>, c9, c12, 3 ; Read FLAG Register
MCR p15, 0, <Rd>, c9, c12, 3 ; Write FLAG Register
```

If an overflow flag is set to 1 in the FLAG register it remains set until one of the following happens:

- writing 1 to the flag bit in the FLAG Register clears the flag
- the processor is reset.

The following operations do *not* clear the overflow flags:

- disabling the overflowed counter in the CNTENC Register
- disabling all counters in the PMNC Register
- resetting the overflowed counter using the PMNC Register.

6.3.5 c9, Software Increment Register

The *Software INCRement* (SWINCR) Register increments the count of a Performance Monitor Count Register.

The SWINCR Register is:

- A write-only register that Reads-As-Zero
- Always accessible in Privileged mode. The USEREN Register determine accessibility in User mode, see *c9, User Enable Register* on page 6-15.

Caution

You must only use the SWINCR Register to increment performance monitor count registers when the counter event is set to `0x00`, software count, in the Event Select Register, see *c9, Event Selection Register* on page 6-13.

If you attempt to use the SWINCR Register to increment a performance monitor count register when the counter event is set to a value other than `0x00` the result is Unpredictable.

Figure 6-5 shows the bit arrangement for the SWINCR Register.

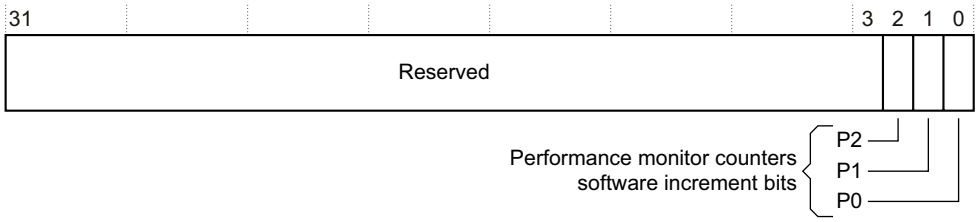


Figure 6-5 SWINCR Register format

Table 6-6 shows how the bit values correspond with the SWINCR Register.

Table 6-6 SWINCR Register bit functions

Bits	Field	Function
[31:3]	Reserved	RAZ on reads, SBZP on writes
[2]	P2	Increment Counter 2
[1]	P1	Increment Counter 1
[0]	P0	Increment Counter 0

To access the SWINCR Register, read or write CP15 with:

```
MRC p15, 0, <Rd>, c9, c12, 4 ; Read  SWINCR Register
MCR p15, 0, <Rd>, c9, c12, 4 ; Write SWINCR Register
```

6.3.6 c9, Performance Counter Selection Register

The *Performance Counter SELection* (PMNXSEL) Register selects a Performance Monitor Count Register. It determines which count register is accessed or controlled by accesses to the Event Selection Register and the Performance Monitor Count Register.

The PMNXSEL Register is:

- A read/write register
- Always accessible in Privileged mode. The USEREN Register determines accessibility in User mode, see *c9, User Enable Register* on page 6-15.

Figure 6-6 shows the bit arrangement for the PMNXSEL Register.

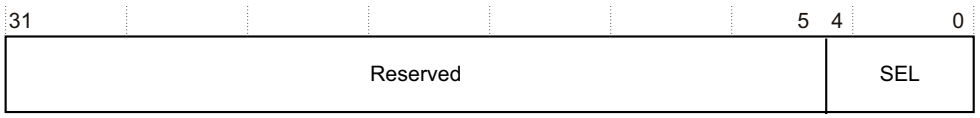


Figure 6-6 PMNXSEL Register format

Table 6-7 shows how the bit values correspond with the PMNXSEL Register functions.

Table 6-7 Performance Counter Selection Register bit functions

Bits	Field	Function
[31:5]	Reserved	RAZ on reads, SBZP on writes
[4:0]	SEL	Counter select: b00000 = selects counter 0 b00001 = selects counter 1 b00010 = selects counter 2.

Any values programmed in the PMNXSEL Register other than those specified in Table 6-7 are Unpredictable.

To access the PMNXSEL Register, read or write CP15 with:

```
MRC p15, 0, <Rd>, c9, c12, 5 ; Read  PMNXSEL Register
MCR p15, 0, <Rd>, c9, c12, 5 ; Write PMNXSEL Register
```

6.3.7 c9, Cycle Count Register

The *Cycle CouNT* (CCNT) Register counts clock cycles.

The CCNT Register is:

- A read/write register
- Always accessible in Privileged mode. The USEREN Register determines accessibility in User mode, see *c9, User Enable Register* on page 6-15.

To access the CCNT read or write CP15 with:

```
MRC p15, 0, <Rd>, c9, c13, 0 ; Read  CCNT Register
MCR p15, 0, <Rd>, c9, c13, 0 ; Write CCNT Register
```

The Cycle Count Register must be disabled before software can write to it. Any attempt by software to write to this register when enabled is Unpredictable.

6.3.8 c9, Event Selection Register

There are three Event Selection Registers in the processor, EVTSEL0 to EVTSEL2, each corresponding to one of the *Performance Monitor Count* (PMC) Registers, PMC0 to PMC2. Each register selects the events you want a PMC Register to count. The register to be accessed is determined by the value in the Performance Counter Selection Register.

The EVTSEL Register is:

- A read/write register
- Always accessible in Privileged mode. The USEREN Register determines accessibility in User mode, see *c9, User Enable Register* on page 6-15.

Figure 6-7 on page 6-14 shows the bit arrangement for the EVTSELx Register.

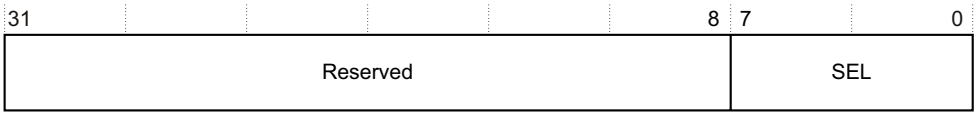


Figure 6-7 EVTSELx Register format

Table 6-8 shows how the bit values correspond with the EVTSELx Register.

Table 6-8 EVTSELx Register bit functions

Bits	Field	Function
[31:8]	Reserved	RAZ or SBZP.
[7:0]	SEL	Event number selected, see Table 6-1 on page 6-2 for values. The reset value of this field is Unpredictable.

To access the EVTSELx Register, read or write CP15 with:

```
MRC p15, 0, <Rd>, c9, c13, 1 ; Read  EVTSELx Register
MCR p15, 0, <Rd>, c9, c13, 1 ; Write EVTSELx Register
```

The absolute counts of events recorded might vary because of pipeline effects. This has negligible effect except in cases where the counters are enabled for a very short time.

In addition to the counters within the processor, most of the events that Table 6-1 on page 6-2 shows are available to the ETM unit or other external trace hardware to enable monitoring of the events. For information on how to monitor these events, see the *CoreSight ETM-R4 Technical Reference Manual*.

6.3.9 c9, Performance Monitor Count Registers

There are three PMC Registers (PMC0-PMC2) in the processor. Each PMC Register, as selected by the PMNXSEL Register, counts instances of an event selected by the EVTSEL Register. Bits [31:0] of each PMC Register contain an event count. The register to be accessed is determined by the value in the Performance Counter Selection Register.

Each PMC Register is:

- A read/write register
- Always accessible in Privileged mode. The USEREN Register determines access, see *c9, User Enable Register*.

To access the current Performance Monitor Count Registers, read or write CP15 with:

```
MRC p15, 0, <Rd>, c9, c13, 2 ; Read current PMNx Register
MCR p15, 0, <Rd>, c9, c13, 2 ; Write current PMNx Register
```

6.3.10 c9, User Enable Register

The *USER ENable* (USEREN) Register enables User mode to have access to:

- the performance monitor registers, see *Performance monitoring registers* on page 6-7
- the validation registers, see *Validation Registers* on page 4-62.

Note

The USEREN Register does not provide access to the registers that control interrupt generation.

The USEREN Register is:

- a read/write register
- writable only in Privileged mode, readable in any processor mode.

Figure 6-8 shows the bit arrangement for the USEREN Register.

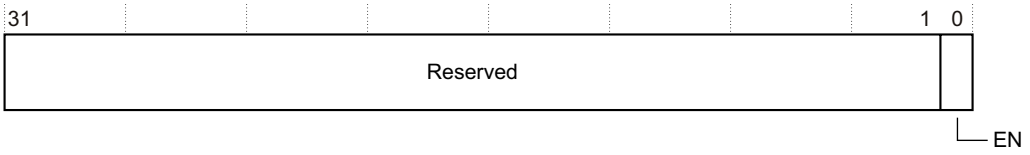


Figure 6-8 USEREN Register format

Table 6-9 shows how the bit values correspond with the Performance Monitor Count Enable Set Register.

Table 6-9 USEREN Register bit functions

Bits	Field	Function
[31:1]	Reserved	RAZ or SBZP.
[0]	EN	User mode access to performance monitor and validation registers: 0 = Disabled. This is the reset value. 1 = Enabled.

If the EN bit in the USEREN Register is not set, any attempt to access a performance monitor register or a validation register from User mode causes an Undefined instruction exception.

Note

For more information on access permissions to the performance monitor registers and validation registers, see the *ARM Architecture Reference Manual*.

To access the USEREN Register, read or write CP15 with:

```
MRC p15, 0, <Rd>, c9, c14, 0 ; Read  USEREN Register
MCR p15, 0, <Rd>, c9, c14, 0 ; Write USEREN Register
```

6.3.11 c9, Interrupt Enable Set Register

The *INTerrupt ENable Set* (INTENS) Register determines if any of the PMC Registers, PMC0-PMC2 and CCNT, generate an interrupt request on overflow.

The INTENS Register is:

- a read/write register
- accessible in Privileged mode only.

Reading this register returns the current setting. Writing to this register can enable interrupts. You can disable interrupts only by writing to the INTENC Register.

Figure 6-9 shows the bit arrangement for the INTENS Register.

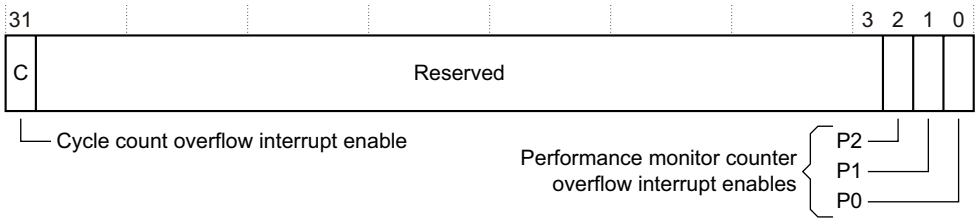


Figure 6-9 INTENS Register format

Table 6-10 shows how the bit values correspond with the INTENS Register.

Table 6-10 INTENS Register bit functions

Bits	Field	Function
[31]	C	CCNT overflow interrupt enable
[30:3]	Reserved	UNP on reads, SBZP on write
[2]	P2	PMC2 overflow interrupt enable
[1]	P1	PMC1 overflow interrupt enable
[0]	P0	PMC0 overflow interrupt enable

When reading bits [31], [2], [1], and [0] of the INTENS Register:

- 0 = interrupt disabled
- 1 = interrupt enabled.

When writing to bits [31], [2], [1], and [0] of the INTENS Register:

- 0 = no action
- 1 = interrupt enabled.

To access the Interrupt Enable Set Register, read or write CP15 with:

```
MRC p15, 0, <Rd>, c9, c14, 1 ; Read  INTENS Register
MCR p15, 0, <Rd>, c9, c14, 1 ; Write INTENS Register
```

If this unit generates an interrupt, the processor asserts the pin **nPMUIRQ**. You can route this pin to an external interrupt controller for prioritization and masking. This is the only mechanism that signals this interrupt to the processor.

Note

ARM expects that the Performance Monitor interrupt request signal, **nPMUIRQ**, connects to a system interrupt controller.

6.3.12 c9, Interrupt Enable Clear Register

The *INTerrupt ENable Clear* (INTENC) Register determines if any of the PMC Registers, PMC0-PMC2 and CCNT, generate an interrupt request on overflow.

The INTENC Register is:

- a read/write register
- accessible in Privileged mode only.

Reading this register returns the current setting. Writing to this register can disable interrupt requests. You can enable interrupt requests only by writing to the INTENS Register.

Figure 6-10 shows the bit arrangement for the INTENC Register.

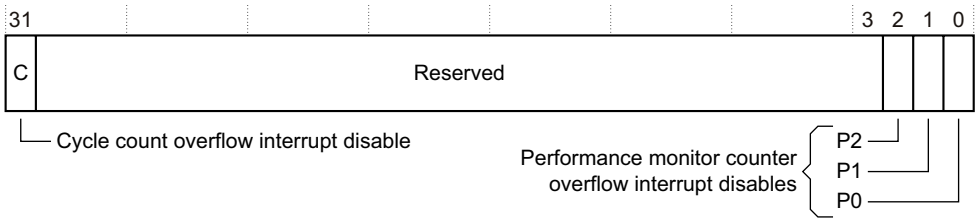


Figure 6-10 INTENC Register format

Table 6-11 shows how the bit values correspond with the INTENC Register.

Table 6-11 INTENC Register bit functions

Bits	Field	Function
[31]	C	CCNT overflow interrupt enable bit
[30:3]	Reserved	UNP on reads, SBZP on writes
[2]	P2	Interrupt on PMC2 overflow when enabled
[1]	P1	Interrupt on PMC1 overflow when enabled
[0]	P0	Interrupt on PMC0 overflow when enabled

When reading bits [31], [2], [1], and [0] of the INTENC Register:

- 0 = interrupt disabled
- 1 = interrupt enabled.

When writing to bits [31], [2], [1], and [0] of the INTENC Register:

- 0 = no action
- 1 = interrupt disabled.

To access the INTENC Register, read or write CP15 with:

```
MRC p15, 0, <Rd>, c9, c14, 2 ; Read INTENC Register
MCR p15, 0, <Rd>, c9, c14, 2 ; Write INTENC Register
```

6.4 Event bus interface

The event bus, **EVNTBUS**, is used to signal when an event has occurred. The event bus includes most, but not all, of the events that can be counted by the performance monitoring unit. Each individual event is assigned to an individual bit of this bus, and this bit is asserted for one cycle each time the event occurs.

The event bus only signals events when it is enabled. Set the X bit in the Performance Monitor Control Register to enable the event bus. See *c9, Performance Monitor Control Register* on page 6-7.

See Table 6-1 on page 6-2 to see which bit of the event bus each event is signaled on.

Note

If an event is being counted in the PMU, the count might not be incremented in exactly the same cycle that the event is signaled on the event bus.

6.4.1 Use of the event bus and counters

The event bus is designed to be connected to the ETM-R4, which enables processor events to trigger tracing for debug purposes. You can also connect it to event counting registers external to the processor, or to an interrupt generator.

Because each **EVNTBUS** pin is only asserted for one cycle for each occurrence of the event, it is possible to create composite events by ORing various **EVNTBUS** pins together. A composite event signal like this is asserted when any of the included events occur although, if multiple events occur in the same cycle, the composite event only occurs once.

The processor also has two event input pins, **ETMEXTOUT[1:0]**. This bus is normally intended for connection to the ETM, and enables the Cortex-R4 performance monitor to count events generated by the ETM. These inputs can alternatively be used for composite events generated external to the processor.

Chapter 7
Memory Protection Unit

This chapter describes the *Memory Protection Unit* (*MPU*). It contains the following sections:

7.1 About the MPU

The MPU works with the L1 memory system to control accesses to and from L1 and external memory. For a full architectural description of the MPU, see the *ARM Architecture Reference Manual*.

The MPU enables you to partition memory into regions and set individual protection attributes for each region. The MPU supports zero, eight, or twelve memory regions.

Note

If the MPU has zero regions, you cannot enable or program the MPU. Attributes are only determined from the default memory map when zero regions are implemented.

Each region is programmed with a base address and size, and the regions can be overlapped to enable efficient programming of the memory map. To support overlapping, the regions are assigned priorities, with region 0 having the lowest priority and region 11 having the highest. The MPU returns access permissions and attributes for the highest priority region where the address hits.

The MPU is programmed using CP15 registers c1 and c6, see *MPU control and configuration* on page 4-5. Memory region control read and write access is permitted only from Privileged modes.

Table 7-1 shows the default memory map.

Table 7-1 Default memory map

Address range	Instruction memory type		Data memory type		Execute Never
	Instruction cache enabled	Instruction cache disabled	Data cache enabled	Data cache disabled	
0xFFFFFFFF 0xF0000000	Normal Non-cacheable only if HIVECS is TRUE	Normal Non-cacheable only if HIVECS is TRUE	Strongly Ordered	Strongly Ordered	Instruction execution only permitted if HIVECS is TRUE
0xEFFFFFFF 0xC0000000	-	-	Strongly Ordered	Strongly Ordered	Execute Never
0xBFFFFFFF 0xA0000000	-	-	Shared Device	Shared Device	Execute Never
0x9FFFFFFF 0x80000000	-	-	Non-shared Device	Non-shared Device	Execute Never
0x7FFFFFFF 0x60000000	Normal, Cacheable, Non-shared	Normal, Non-cacheable, Non-shared	Normal, Non-cacheable, Shared	Normal, Non-cacheable, Shared	Instruction execution permitted
0x5FFFFFF 0x40000000	Normal, Cacheable, Non-shared	Normal, Non-cacheable, Non-shared	Normal, WT Cacheable, Non-shared	Normal, Non-cacheable, Shared	Instruction execution permitted
0x3FFFFFFF 0x00000000	Normal, Cacheable, Non-shared	Normal, Non-cacheable, Non-shared	Normal, WBWA Cacheable , Non-shared	Normal, Non-cacheable, Shared	Instruction execution permitted

This section describes:
- *Memory regions*
- *Overlapping regions* on page 7-4
- *Background regions* on page 7-6
- *TCM regions* on page 7-6.

7.1.1 Memory regions

Before the MPU is enabled, you must program at least one valid protection region. If you do not do this, the processor will enter a state that only reset can recover.

When the MPU is disabled, no access permission checks are performed, and memory attributes are assigned according to the default memory map. See Table 7-1 on page 7-2.

For more information on how to enable or disable the MPU, see *MPU interaction with memory system* on page 7-11.

Depending on the implementation, the MPU has a maximum of eight or 12 regions. Using CP15 register c6 you can specify the following for each region:
- region base address
- region size
- subregion enables
- region attributes
- region access permissions
- region enable.

Region base address

The base address defines the start of the memory region. You must align this to a region-sized boundary. For example, if a region size of 8KB is programmed for a given region, the base address must be a multiple of 8KB.

Note

If the region is not aligned correctly, this results in Unpredictable behavior.

Region size

The region size is specified as a 5-bit value, encoding a range of values from 32 bytes, a cache-line length, to 4GB. Table 4-32 on page 4-51 shows the encoding.

Subregions

Each region can be split into eight equal sized non-overlapping subregions. An access to a memory address in a disabled subregion does not use the attributes and permissions defined for that region. Instead, it uses the attributes and permissions of a lower priority region or generates a background fault if no other regions overlap at that address. This enables increased protection and memory attribute granularity.

All region sizes between 256 bytes and 4GB support eight subregions. Region sizes below 256 bytes do not support subregions, and the subregion disable field is SBZ/UNP for regions of less than 256 bytes in size.

Region attributes

Each region has a number of attributes associated with it. These control how a memory access is performed when the processor accesses an address that falls within a given region. The attributes are:

- Memory Type, one of:
  - Strongly Ordered
  - Device
  - Normal
- Shared or Non-shared
- Non-cacheable
- Write-through Cacheable
- Write-back Cacheable
- Read allocation
- Write allocation.

See *Memory types* on page 7-7 for more information about memory types, and *Region attributes* on page 7-9 for a description of how to assign types and attributes to a region.

Region access permissions

Each region can be given no access, read-only access, or read/write access permissions for Privileged or all modes. In addition, each region can be marked as *eXecute Never* (XN) to prevent instructions being fetched from that region.

For example, if a User mode application attempts to access a *Privileged mode access only* region a permission fault occurs.

The ARM architecture uses constants known as *inline literals* to perform address calculations. The assembler and compiler automatically generate these constants and they are stored inline with the instruction code. To ensure correct operation, only a memory region that has permission for data read access can execute instructions. For more information, see the *ARM Architecture Reference Manual*. For information about how to program access permissions, see Table 4-34 on page 4-52.

Instructions cannot be executed from regions with Device or Strongly-Ordered memory type attributes. The processor treats such regions as if they have XN permissions.

7.1.2 Overlapping regions

You can program the MPU with two or more overlapping regions. For overlapping regions, a fixed priority scheme determines attributes and permissions for memory access to the overlapping region. Attributes and permissions for region 11 take highest priority, those for region 0 take lowest priority. For example:

Region 2 Is 4KB in size, starting from address `0x3000`. Privileged mode has full access, and User mode has read-only access.

Region 1 Is 16KB in size, starting from address `0x0000`. Both Privileged and User modes have full access.

When the processor performs a data write to address `0x3010` while in User mode, the address falls into both region 1 and region 2, as Figure 7-1 on page 7-5 shows. Because these regions have different permissions, the permissions associated with region 2 are applied. Because User mode is read access only for this region, a permission fault occurs, causing a data abort.

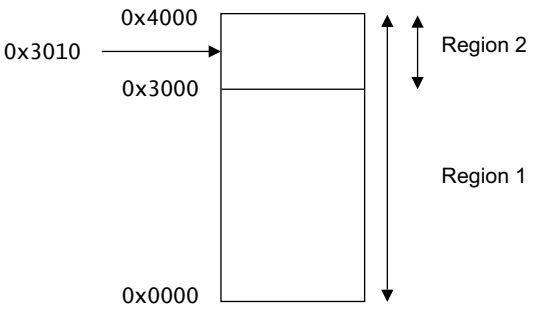


Figure 7-1 Overlapping memory regions

Example of using regions that overlap

You can use overlapping regions for stack protection. For example:

- allocate to region 1 the appropriate size for all stacks
- allocate to region 2 the minimum region size, 32 bytes, and position it at the end of the stack for the current process
- set the region 2 access permissions to No Access.

If the current process overflows the stack it uses, a write access to region 2 by the processor causes the MPU to raise a permission fault.

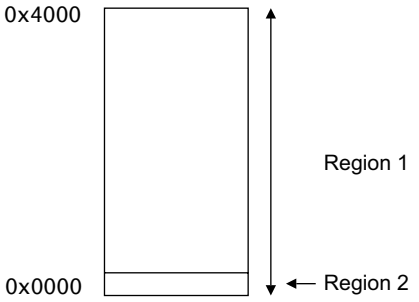


Figure 7-2 Overlay for stack protection

Example of using subregions

You can use subregions for stack protection. For example:

- Allocate to region 1 the appropriate size for all stacks.
- Set the least-significant subregion disable bit. That is, set the subregion disable field, bits [15:8], of the CP15 MPU Region Size Register to `0x01`.

If the current process overflows the stack it uses, a write access by the processor to the disabled subregion causes the MPU to raise a background fault.

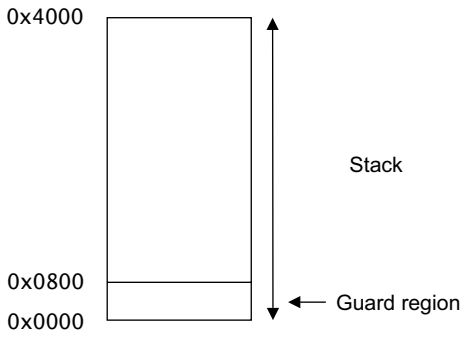


Figure 7-3 Overlapping subregion of memory

7.1.3 Background regions

Overlapping regions increase the flexibility of how the regions can be mapped onto physical memory devices in the system. You can also use the overlapping properties to specify a background region. For example, you might have a number of physical memory areas sparsely distributed across the 4GB address space. If a programming error occurs, the processor might issue an address that does not fall into any defined region.

If the address that the processor issues falls outside any of the defined regions, the MPU is hard-wired to abort the access. That is, all accesses for an address that is not mapped to a region in the MPU generate a background fault. You can override this behavior by programming region 0 as a 4GB background region. In this way, if the address does not fall into any of the other 11 regions, the attributes and access permissions you specified for region 0 control the access.

In Privileged modes, you can also override this behavior by setting the BR bit, bit [17], of the System Control Register. This causes Privileged accesses that fall outside any of the defined regions to use the default memory map.

7.1.4 TCM regions

Any memory address that you configure to be accessed using a TCM interface is given Normal, Non-shared type attributes, regardless of the attributes of any MPU region that the address also belongs to. Access permissions for an address in a TCM region are preserved from the MPU region that the address also belongs to. For more information, see *About the TCMs* on page 8-13.

7.2 Memory types

The ARM Architecture defines a set of memory types with characteristics that are suited to particular devices. There are three mutually exclusive memory type attributes:

- Strongly Ordered
- Device
- Normal.

MPU memory regions can each be assigned a memory type attribute. Table 7-2 shows a summary of the memory types.

Table 7-2 Memory attributes summary

Memory type attribute	Shared or Non-shared	Other attributes	Description
Strongly Ordered	-	-	All memory accesses to Strongly Ordered memory occur in program order. All Strongly Ordered accesses are assumed to be shared.
Device	Shared	-	For memory-mapped peripherals that several processors share.
	Non-shared	-	For memory-mapped peripherals that only a single processor uses.
Normal	Shared	Non-cacheable Write-through Cacheable Write-back Cacheable	For normal memory that is shared between several processors.
	Non-shared	Non-cacheable Write-through Cacheable Write-back Cacheable	For normal memory that only a single processor uses.

Note

The processor's L1 cache does not cache shared normal regions.

For more information on memory attributes and types, memory barriers, and ordering requirements for memory accesses, see the *ARM Architecture Reference Manual* and *Application Note 204, Understanding processor memory types and access ordering*.

7.2.1 Using memory types

The processor's memory system contains a store buffer which helps to improve the throughput of accesses to Normal type memory. See *Store buffer* on page 8-18 for more information. Because of the ordering rules which they must follow, accesses to other types of memory typically have a lower throughput or higher latency than accesses to Normal memory. In particular:

- reads from Device memory must first drain the store buffer of all writes to Device memory
- all accesses to Strongly Ordered memory must first drain the store buffer completely.

Similarly, when it is accessing Strongly Ordered or Device type memory, the processor's response to interrupts must be modified, and the interrupt response latency is longer. See *Low interrupt latency* on page 2-19 for more information.

To ensure optimum performance, you must understand the architectural semantics of the different memory types. Use Device memory type for appropriate memory regions, typically peripherals, and only use Strongly Ordered memory type for memory regions where it is essential.

7.3 Region attributes

Each region has a number of attributes associated with it. These control how a memory access is performed when the processor accesses an address that falls within a given region. The attributes are:

- Memory type, see *Memory types* on page 7-7, one of:
  - Strongly Ordered
  - Device
  - Normal
- Shared or Non-shared
- Non-cacheable
- Write-through cacheable
- Write-back cacheable
- Read allocation
- Write allocation.

The Region Access Control Registers use five bits to encode the memory region type. These are the TEX)[2:0], C and B bits. Table 7-3 shows the mapping of these bits to memory region attributes.

Note

In earlier versions of the architecture, the TEX, C, and B bits were known as the Type Extension, Cacheable and Bufferable bits. These names no longer adequately describe the function of the B, C, and TEX bits.

All memory attributes which are Cacheable, write-back or write-through, are also implicitly read-allocate. Table 7-3 shows which attributes are write-allocate.

In addition, the Region Access Control Registers contain the shared bit, S. This bit only applies to Normal memory, and determines whether the memory region is Shared (1) or Non-shared (0).

Table 7-3 TEX[2:0], C, and B encodings

TEX[2:0]	C	B	Description	Memory Type	Shareable?
000	0	0	Strongly-ordered.	Strongly-ordered	Shareable
000	0	1	Shareable Device.	Device	Shareable
000	1	0	Outer and Inner write-through, no write-allocate.	Normal	S bit[a]
000	1	1	Outer and Inner write-back, no write-allocate.	Normal	S bit[a]
001	0	0	Outer and Inner Non-cacheable.	Normal	S bit[a]
001	0	1	Reserved.	-	-
001	1	0			
001	1	1	Outer and Inner write-back, write-allocate.	Normal	S bit[a]
010	0	0	Non-shareable Device.	Device	Non-shareable
010	0	1	Reserved.	-	-

Table 7-3 TEX[2:0], C, and B encodings (continued)

TEX[2:0]	C	B	Description		Memory Type	Shareable?
010	1	X	Reserved.		-	-
011	X	X	Reserved.		-	-
1BB	A	A	Cacheable memory:	AA[b] = Inner policy BB[b] = Outer policy	Normal	S bit[a]

a. Region is Shareable if S == 1, and Non-shareable if S == 0.
b. Table 7-4 shows the encoding for these bits.

7.3.1 Cacheable memory policies

When TEX[2] == 1, the memory region is Cacheable memory, and the rest of the encoding defines the Inner and Outer cache policies:

TEX[1:0] defines the Outer cache policy

C,B defines the Inner cache policy

The same encoding is used for the Outer and Inner cache policies. Table 7-4 shows the encoding.

Table 7-4 Inner and Outer cache policy encoding

Memory attribute encoding	Cache policy
00	Non-cacheable
01	Write-back, write-allocate
10	Write-through, no write-allocate
11	Write-back, no write-allocate

When the processor performs a memory access through its AXI bus master interface:

- the Inner attributes are indicated on the **A*USERM** signals. For the encodings, see Table 9-3 on page 9-5
- the Outer attributes are indicated on the and **A*CACHEM** signals. For the encodings, see Table 9-2 on page 9-5.

For more information on region attributes, see the *ARM Architecture Reference Manual*.

7.4 MPU interaction with memory system

This section describes how to enable and disable the MPU. After you enable or disable the MPU, the pipeline must be flushed using `ISB` and `DSB` instructions to ensure that all subsequent instruction fetches see the effect of turning on or off the MPU.

Before you enable or disable the MPU you must:

1. Program all relevant CP15 registers. This includes setting up at least one memory region that covers the currently executing code, and that the attributes and permissions of that region are the same as the attributes and permissions of the region in the default memory map that covers the code, and that the region is executable in Privileged mode.
2. Clean and invalidate the data caches.
3. Disable caches.
4. Invalidate the instruction cache.

The following code is an example of enabling the MPU:

```
MRC p15, 0, R1, c1, c0, 0    ; read CP15 register 1
ORR R1, R1, #0x1
DSB
MCR p15, 0, R1, c1, c0, 0    ; enable MPU
ISB
Fetch from programmed memory map
Fetch from programmed memory map
Fetch from programmed memory map
Fetch from programmed memory map
```

The following code is an example of disabling the MPU:

```
MRC p15, 0, R1, c1, c0, 0    ; read CP15 register 1
BIC R1, R1, #0x1
DSB
MCR p15, 0, R1, c1, c0, 0    ; disable MPU
ISB
Fetch from default memory map
Fetch from default memory map
Fetch from default memory map
Fetch from default memory map
```

Table 7-1 on page 7-2 shows the default memory map.

7.5 MPU faults

The MPU can generate three types of fault:

- *Background fault*
- *Permission fault*
- *Alignment fault*.

When a fault occurs, the memory access or instruction fetch is precisely aborted, and a prefetch abort or data abort exception is taken as appropriate. No memory accesses are performed on the AXI bus master interface. For more information about fault handling, see *Fault handling* on page 8-7.

7.5.1 Background fault

A background fault is generated when the MPU is enabled and a memory access is made to an address that is not within an enabled subregion of an MPU region. A background fault does not occur if the background region is enabled and the access is Privileged. See *Background regions* on page 7-6.

7.5.2 Permission fault

A permission fault is generated when a memory access does not meet the requirements of the permissions defined for the memory region that it accesses. See *Region access permissions* on page 7-4.

7.5.3 Alignment fault

An alignment fault is generated if a data access is performed to an address that is not aligned for the size of the access, and strict alignment is required for the access. A number of instructions that access memory, for example, `LDM` and `STC`, require strict alignment. See the *ARM Architecture Reference Manual* for details. In addition, strict alignment can be required for all data accesses by setting the A-bit in the System Control Register. See *c1, System Control Register* on page 4-35.

7.6 MPU software-accessible registers

Figure 4-2 on page 4-5 shows the CP15 registers that control the MPU.

When the MPU is not present, the *c6, MPU memory region programming registers* on page 4-49 read as zero and ignore writes in Privileged mode. No Undefined instruction exceptions are taken.

Chapter 8
Level One Memory System

This chapter describes the processor Level one (L1) memory system. It contains the following sections:

8.1 About the L1 memory system

The processor L1 memory system can be configured during implementation and integration. It can consist of:

- separate instruction and data caches
- multiple *Tightly-Coupled Memory* (TCM) areas
- a *Memory Protection Unit* (MPU).

The instruction-side and data-side can each optionally have their own L1 caches. The cache architecture is Harvard, that is, only instructions can be fetched from the i-cache, and only data can be fetched from the d-cache. In parallel with each of the caches are two areas of dedicated RAM accessible to both the instruction and data sides. These are regions of TCM. You can implement one TCM using the ATCM interface and up to two TCMs using the BTCM interface. Figure 8-1 on page 8-3 shows this.

Each TCM and cache can be configured at implementation time to have an error detection and correction scheme to protect the data stored in the memory from errors. Each TCM interface also has support for logic external to the processor to tell the processor that an error has occurred.

The MPU handles accesses to both the instruction and data sides. The MPU is responsible for protection checking, address access permissions, and memory attributes. Some of these functions can be passed to the L2 memory system through the AXI master. See Chapter 7 *Memory Protection Unit* for more information about the MPU.

The L1 memory system includes a monitor for exclusive accesses. Exclusive load and store instructions can be used, for example, `LDREX`, `STREX`, with the appropriate memory monitoring to provide inter-process or inter-processor synchronization and semaphores. See the *ARM Architecture Reference Manual* for more details. The monitor can handle some exclusive monitoring internally to the processor.

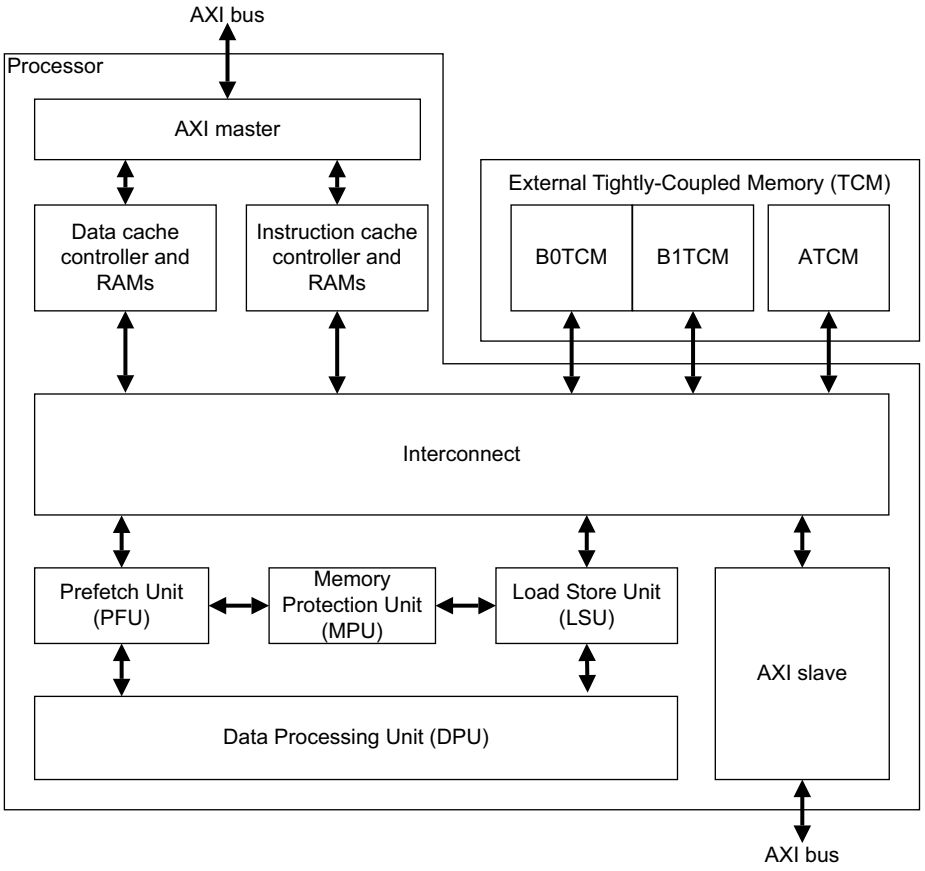


Figure 8-1 L1 memory system block diagram

8.2 About the error detection and correction schemes

In silicon devices, stray radiation and other effects can cause the data stored in a RAM to be corrupted. The TCMs and caches on Cortex-R4 can be configured to detect and correct errors that can occur in the RAMs. Extra, redundant data is computed by the processor and stored in the RAMs alongside the real data. When the processor reads data from the RAMs, it checks that the redundant data is consistent with the real data and can either signal an error, or attempt to correct the error.

A number of different error schemes are available, and are described in:

- *Parity*
- *64-bit ECC* on page 8-5
- *32-bit ECC* on page 8-5.

Each has different properties in terms of the number of errors that can be detected, and corrected, and the amount of extra RAM required to store the redundant data. Because different logic is required for each scheme, the scheme must be chosen in the build-configuration, although you can enable or disable, or change the behavior of the error schemes using software-configuration. This section describes the generic properties of each of the schemes. See Appendix B *ECC Schemes* for more information about the advantages and disadvantages of each scheme to the implementer. The details of operation of the error schemes for the caches are described in *Cache error detection and correction* on page 8-20, and for the TCMs in *TCM internal error detection and correction* on page 8-14.

The error schemes are each described in terms of their operation on a doubleword (64 bits) of data, because this is the amount of data that the processor L1 memory system can transfer each cycle. The tag and dirty RAMs associated with the caches are different sizes, but the principles are the same. An error is considered to be a single bit of data that has been inverted relative to its correct value.

Figure 8-2 shows the error schemes. The shaded areas represent bits with errors.

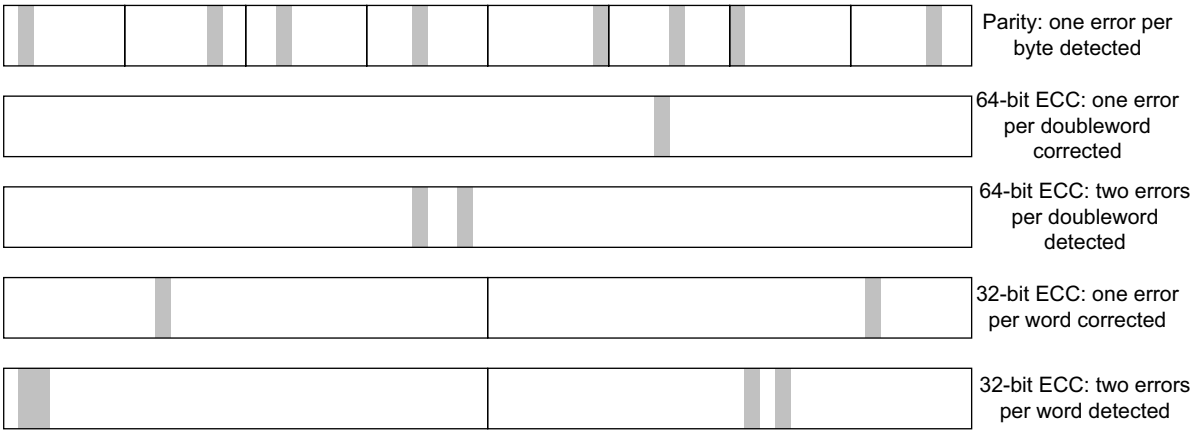


Figure 8-2 Error detection and correction schemes

8.2.1 Parity

For each byte, a parity bit is computed and stored with that byte. This requires eight bits of parity, or redundant data per doubleword. With a parity scheme, a single error in a byte or its parity bit can be detected, but not corrected. This means that, provided they are all in different bytes, eight errors can be detected per doubleword. However, if there are two errors in any individual byte, this cannot be detected. Odd or even parity can be used, and this can be pin-configured during integration.

8.2.2 Error checking and correction

The processor supports *Error Checking and Correction* (ECC) schemes for either 64-bits or 32-bits of data, and these have similar properties, although though the size of the data chunk that the ECC scheme applies to is different. For each data chunk, either 32-bits or 64-bits, aligned, a number of redundant code bits are computed and stored with the data. This enables the processor to detect up to two errors in the data chunk or its code bits, and correct any single error in the data chunk or its associated code bits. This is sometimes referred to as a *Single-Error-Correction, Double-Error-Detection* (SEC-DED) ECC scheme.

If there are more than two errors in a data chunk and its associated code bits, they might or might not be detected. The error scheme might interpret such a condition as a single-error and make an unsuccessful attempt at a correction.

64-bit ECC

Eight code bits are computed for each 64 bits of data. The scheme can correct any single error occurring in any doubleword, and detect any two errors occurring in any doubleword.

32-bit ECC

Seven code bits are computed for each 32 bits of data, so 14 bits of redundant data are required for each doubleword. The scheme can correct two errors per doubleword, if they are in different words. Four errors can be detected per doubleword, if there are two in each word.

8.2.3 Read-Modify-Write

The smallest unit of data that the processor can write is a byte. However, both the ECC schemes are computed on data chucks that are larger than this. To write any data to a RAM protected with ECC requires the error code for that data to be recomputed and rewritten. If the entire data chunk is not written, for example, a halfword, 16-bits, is written to address `0x4` of a RAM with a 32-bit error scheme, the error code must be computed partly from the data being written, and partly from data already stored in the RAM. In this example, the halfword in the RAM at address `0x6`.

To compute the error code for such a write, the processor must first read data from the RAM, then merge the data to be written with it, to compute the error code, then write the data to the RAM, along with the new error code. This process is referred to as read-modify-write.

8.2.4 Hard errors

The errors described in this chapter are all assumed to be soft errors, that is, one or more bits of the data stored in a RAM chunk are inverted. A new value can still be written to the RAM and read back correctly, unless another soft error occurs in the meantime.

If the error in the memory is a hard error, that is, a physical failure of the RAM circuit so that a bit can never be read or written reliably, the processor might not be able to correct and recover from the error. The processor contains features that enable it to recover from some hard errors. If you are implementing the processor and require these features, contact ARM to discuss the features and your requirements.

8.2.5 Error correction

When a correctable error is detected in data that has been read from a RAM, the processor has various ways of generating the correct data, which follow two schemes:

Correct inline

The error code bits are used to correct the data read from the RAM, and this data is used. This is the simplest way of correcting the data.

Correct-and-retry

The error code bits are used to correct the data, and this data is then written back to the RAM. The processor then repeats the read access by re-executing the instruction that caused the read, and reads the corrected data from the RAM if no more errors have occurred. This takes more clock cycles (at least nine) in the event of an error, but has the side-effect of correcting the data in the RAM so that the errors in the data cannot become worse.

Note

Because RAM errors generally occur infrequently, the extra cycles required to perform correct-and-retry do not have a significant impact on average performance.

The correction method that the processor uses depends on the individual error. The processor uses correct inline error correction when it detects a correctable error on a TCM read made by the AXI-slave interface. The processor uses correct-and-retry correction when it detects a correctable ECC error on a TCM read made by the instruction-side or data-side.

8.3 Fault handling

Faults can occur on instruction fetches for the following reasons:
- MPU background fault
- MPU permission fault
- External AXI slave error (SLVERR)
- External AXI decode error (DECERR)
- Cache parity or ECC error
- TCM parity or ECC error
- TCM external error
- TCM external retry request
- Breakpoints, and vector capture events.

Faults can occur on data accesses for the following reasons:
- MPU background fault
- MPU permission fault
- MPU alignment fault
- External AXI slave error (SLVERR)
- External AXI decode error (DECERR)
- Cache parity or ECC error
- TCM parity or ECC error
- TCM external error
- TCM external retry request
- Watchpoints.

Fault handling is described in:
- *Faults*
- *Fault status information* on page 8-9
- *Correctable Fault Location Register* on page 8-10
- *Usage models* on page 8-10.

8.3.1 Faults

The classes of fault that can occur are:
- *MPU faults*
- *External faults* on page 8-8
- *Cache and TCM parity and ECC errors* on page 8-8
- *TCM external faults* on page 8-8
- *Debug events* on page 8-9.

MPU faults

The MPU can generate an abort for various reasons. See *MPU faults* on page 7-12 for more details. MPU faults are always precise, and take priority over other types of abort. If an MPU fault occurs on an access that is not in the TCM, and is Non-cacheable, or has generated a cache-miss, the AXI transactions for that access is not performed.

External faults

A memory access performed through the AXI master interface can generate two different types of error response, a slave error (SLVERR) or decode error (DECERR). These are known as external errors, because they are generated by the AXI system outside the processor. Precise aborts are generated for instruction fetches, data loads, and data stores to strongly-ordered-type memory. Stores to normal-type or device-type memory generate imprecise aborts.

Note

An AXI slave that cannot handle exclusive transactions returns OKAY in response to an exclusive read. This is also treated as an external error, and the processor behaves as if the response was SLVERR.

Cache and TCM parity and ECC errors

If the processor has been configured with the appropriate build options, it can detect data errors occurring in the cache and TCM RAMs using parity or ECC logic. For more information on cache errors, see *Handling cache parity errors* on page 8-21 and *Handling cache ECC errors* on page 8-22. For more information on TCM errors, see *Handling TCM parity errors* on page 8-15 and *Handling TCM ECC errors* on page 8-15. Depending on the software configuration of the processor, these errors are either ignored, generate an abort, are automatically corrected without generating an abort, or are corrected and generate an abort. If the processor is in debug-halt-state, an error that is otherwise automatically corrected generates an abort.

Parity and ECC errors can only occur on reads, although these reads might be a side-effect of store instructions. Aborts generated by loads are always precise. Aborts generated by store instructions to the TCM are also always precise, while those to the cache are always imprecise. These errors can also occur on some cache-maintenance operations, see *Errors on cache maintenance operations* on page 8-23, and generate imprecise aborts.

Many of the parity and ECC errors are also signaled by the generation of events. See Chapter 6 *Events and Performance Monitor*. Some of these events are generated when the error is detected, regardless of whether or not an abort is taken. Aborts are only taken when a memory access with an error is committed. Others are signaled when and only when the abort is taken.

Any parity or ECC error that can be corrected by the processor is considered to be a *correctable fault*, regardless of whether or not the processor is configured to correct the fault.

TCM external faults

The TCM port includes signals that can be used to signal an error on a TCM transaction. See the *Cortex-R4 and Cortex-R4F Integration Manual* for more information about the TCM port. If enabled, this causes the processor to take the appropriate type of abort for instruction and data accesses, or to generate a SLVERR response to an AXI-slave transaction. Write transactions always generate imprecise aborts, while read transactions always generate precise aborts.

An error signaled on a read transaction can also signal a retry request, which requests that the processor retry the same operation rather than take an exception.

A retry request from the TCM port is considered to be a *recoverable error*. All correctable ECC faults are also considered to be recoverable.

Debug events

The debug logic in the processor can be configured to generate breakpoints or vector capture events on instruction fetches, and watchpoints on data accesses. If the processor is software-configured for monitor-mode debugging, an abort is taken when one of these events occurs, or when a BKPT instruction is executed. For more details, see Chapter 11 *Debug*.

Precise and imprecise aborts

See *Aborts* on page 2-22 for more information about the differences between precise and imprecise aborts.

8.3.2 Fault status information

When an abort occurs, information about the cause of the fault is recorded in a number of registers, depending on the type of abort:

- *Abort exceptions*
- *Precise abort exceptions* on page 8-10
- *Imprecise abort exceptions* on page 8-10.

Abort exceptions

The following registers are updated when any abort exception is taken:

Link Register

The r14_abt register is updated to provide information about the address of the instruction that the exception was taken on, in a similar way to other types of exception. See *Exceptions* on page 2-16 for more details. This information can be used to resume program execution after the abort has been handled.

Note

When a prefetch abort has occurred, ARM recommends that you do not use the link register value for determining the aborting address, because 32-bit Thumb instructions do not have to be word aligned and can cause an abort on either halfword. This applies even if all of the code in the system does not use the extra 32-bit Thumb instructions introduced in ARMv6T2, because the earlier BL and BLX instructions are both 32 bits long. Use the Fault Address Register instead, as described in this section.

Saved Program Status Register

The SPSR_abt register is updated to record the state and mode of the processor when the exception was taken, in a similar way to other types of exception. See *Exceptions* on page 2-16 for more details.

Fault Status Register

There are two fault status registers, one for prefetch aborts (IFSR) and one for data aborts (DFSR). These record the type of abort that occurred, and whether it occurred on a read or a write. In particular, this enables the abort handler to distinguish between precise aborts, imprecise aborts, and debug events. For details of the format of this register and the encodings used, see *Fault Status and Address Registers* on page 4-45.

Precise abort exceptions

The following registers are updated when a precise abort exception is taken:

Fault Address Register

There are two fault address registers, one for prefetch aborts (IFAR) and one for data aborts (DFAR). These indicate the address of the memory access that caused the fault. See *Fault Status and Address Registers* on page 4-45.

Auxiliary Fault Status Register

There are two auxiliary fault status registers, one for prefetch aborts (AIFSR) and one for data aborts (ADFSR). These record additional information about the nature and location of the fault, including whether it was a recoverable error or not, whether it occurred in the cache or AXI-master interface, ATCM or BTCM and, if appropriate, which cache way the error occurred in. The cache index is not recorded on a precise abort, because this information can be derived from the fault address. See *Fault Status and Address Registers* on page 4-45.

Imprecise abort exceptions

The following register is updated when an imprecise abort exception is taken:

Auxiliary Data Fault Status Register

The ADFSR is updated to indicate whether or not the fault was recoverable, whether it occurred in the cache, ATCM or BTCM and, if appropriate, which cache set and way the error occurred in. Because the DFAR is not updated on imprecise aborts, imprecise aborts cannot normally be located, except when the error occurred in the cache.

The effect of debug events on these registers is described in *Debug exception* on page 11-41.

8.3.3 Correctable Fault Location Register

When a correctable fault generates an abort exception, information about the location of that fault is recorded in the various fault status registers. However, if the fault is automatically corrected by the processor, depending on the configuration, an exception might not be generated, and the fault status registers might not be not updated. In all cases, information about the location of the fault is recorded in the *Correctable Fault Location Register* (CFLR).

All correctable faults are recorded in the same register, regardless of whether it was an instruction-fetch, a data-access, or a DMA (AXI-slave) access that generated the fault, and whether the fault occurred in the ATCM, BTCM or cache. The CFLR contains information to identify what sort of access generated the fault, and which device it occurred in. See *Correctable Fault Location Register* on page 4-70 for more details of the format of this register. Each time the CFLR is updated, the information already in the CFLR is discarded and therefore the CFLR can only contain information about the most recent correctable fault.

8.3.4 Usage models

This section describes some ways in which errors can be handled in a system. Exactly how you program the processor to handle errors depends on the configuration of your processor and system, and what you are trying to achieve.

If an abort exception is taken, the abort handler reads the information in the link register, SPSR, and fault status registers to determine the type of abort. Some types of abort are fatal to the system, and others can be fixed, and program execution resumed. For example, an MPU background fault might indicate a stack overflow, and be rectified by allocating more stack and

reprogramming the MPU to reflect this. Alternatively, an imprecise external abort might indicate that a software error meant that a store instruction occurred to an unmapped memory address. Such an abort is fatal to the system or process because no information is recorded about the address the error occurred on, or the instruction which caused the error.

Table 8-1 shows which types of abort are typically fatal because either the location of the error is not recorded or the error is unrecoverable. Some aborts that are marked as not fatal might turn out to be fatal in some systems when the cause of the error has been determined. For example, an MPU background fault might indicate a stack overflow, which can be rectified, or it might indicate that, because of a bug, the software has accessed a nonexistent memory location, which can be fatal. These cases can be distinguished by determining the location where the error occurred. If an error is unrecoverable, that is, it is not a correctable parity or ECC error, and it is not a TCM external retry request, it is normally fatal regardless of whether or not the location of the error is recorded. When an abort is taken on an external TCM, parity, or ECC error, the appropriate Auxiliary Fault Status Register records whether the error was recoverable. See *Fault Status and Address Registers* on page 4-45.

Table 8-1 Types of aborts

Type	Conditions	Source	Precise	Fatal
MPU fault	Access not permitted by MPU[a]	MPU	Yes	No
Precise External	Load using L2 memory interface	AXI	Yes	No
Imprecise External	Store to Normal or Device memory using L2 memory interface	AXI	No	Yes
Precise Parity/ECC Cache	Load from cache[b]	Cache	Yes	Maybe[c]
Precise Parity/ECC TCM	Load/store from/to TCM[d]	TCM	Yes	Maybe[c]
Precise TCM external error	Load/store from/to TCM[e]	TCM	Yes	Yes
Imprecise Parity/ECC Cache	Store to cache or cache maintenance operation[b]	Cache	No	Maybe[c]
Imprecise TCM external error	Store to TCM[e]	TCM	No	Yes

a. See *MPU faults* on page 7-12 for more information about the types of MPU fault.
b. See *Cache error detection and correction* on page 8-20 for more information about parity/ECC errors from the cache.
c. These types of error can be correctable or uncorrectable. Uncorrectable errors are typically fatal. Correctable errors are automatically corrected by the hardware and might not cause the abort handler to be called. See *Cache error detection and correction* on page 8-20 and *TCM internal error detection and correction* on page 8-14.
d. See *TCM internal error detection and correction* on page 8-14 for more information about parity/ECC errors from the TCM.
e. Aborts generated by external TCM errors are always unrecoverable, and therefore fatal, see *External TCM errors* on page 8-16 for more information about external errors from the TCM.

Correctable errors

In a system in which the processor is configured to automatically correct ECC errors without taking an abort exception, you can still configure it to respond to such errors. Connect the event output or outputs that indicate a correctable error to an interrupt controller. When such an event occurs, the interrupt input to the processor is set, and the processor will take an interrupt exception. When your interrupt handler has identified the source of the interrupt as a correctable error, it can read the CFLR to determine where the ECC error occurred. You can examine this information to identify trends in such errors. By masking the interrupt when necessary, your software can ensure that when critical code is executing, the processor corrects the error automatically, but delays examining information about the error until after the critical code has completed.

When the processor is in debug halt-state, any correctable error is corrected as appropriate, but the memory access is not repeated to fetch the correct data, therefore the instruction generating the error does not complete successfully. Instead, the sticky precise abort flag in the DSCR is set. See *CP14 c1, Debug Status and Control Register* on page 11-14.

8.4 About the TCMs

The processor has two TCM interfaces to support the connection of local memories. The ATCM interface has one TCM port. The BTCM interface can support one or two TCM ports. Each TCM port is a physical connection on the processor that is suitable for connection to SRAM with minimal glue logic. These ports are optimized for low latency memory.

The TCM ports are designed to be connected to RAM, or RAM-like memory, that is, Normal-type memory. The processor can issue speculative read accesses on these interfaces, and interrupt store instructions that have issued some but not all of their write accesses. Therefore, both read and write accesses through the TCM interfaces can be repeated. This means that the TCM ports are generally not suitable for read- or write-sensitive devices such as FIFOs. ROM can be connected to the TCM ports, but normally only if ECC is not used. See *Hard errors* on page 8-5. If the access is speculative, the processor ignores any error or retry signaled on the TCM port.

The TCM ports also have wait and error signals to support slow memories and external error detection and correction. For more information, see *External TCM errors* on page 8-16.

The PFU can read data using the TCM interfaces. The LSU and AXI slave can each read and write data using the TCM interfaces.

Each TCM interface has a dedicated base address that you can place anywhere in the physical address map, and must not be backed by memory implemented externally. The ATCM and BTCM interfaces must have separate base addresses and must not overlap.

This section describes:

- *TCM attributes and permissions*
- *ATCM and BTCM configuration* on page 8-14
- *TCM internal error detection and correction* on page 8-14
- *TCM arbitration* on page 8-15
- *TCM initialization* on page 8-16
- *TCM port protocol* on page 8-16
- *External TCM errors* on page 8-16
- *AXI slave interfaces for TCMs* on page 8-17.

8.4.1 TCM attributes and permissions

Accesses to the TCMs from the LSU and PFU are checked against the MPU for access permission. Memory access attributes and permissions are not exported on this interface. Reads that generate an MPU fault are broadcast on the TCM interface but the abort is taken before the data is used, ensuring protection is maintained.

TCMs always behave as Non-cacheable Non-shared Normal memory, irrespective of the memory type attributes defined in the MPU for a memory region containing addresses held in the TCM. Access permissions for TCM accesses are the same as the permission attributes that the MPU assigns to the same address. See Chapter 7 *Memory Protection Unit* for more information about memory attributes, types, and permissions.

Note

Any address in an MPU region with device or strongly-ordered memory type attributes is implicitly given *execute-never* (XN) permissions. If such an address is also in a TCM region, XN permissions are applied to TCM accesses to that address. None of the other device or strongly-ordered behaviors apply to an address in a TCM region.

8.4.2 ATCM and BTCM configuration

The TCM interfaces are configured during implementation and integration.

You can configure the ATCM interface to be removed, and not included in the processor design. If implemented, the ATCM can have only a single port.

You can configure the BTCM interface to:

- be removed, and not included in the processor design
- have a single BTCM port
- have two banked BTCM ports, interleaved on either:
  - Bit [3] of the address
  - The most significant bit of the BTCM interface address. This depends on the size of the BTCM.

During implementation, you can configure the ATCM and/or the BTCM to use an error-protection scheme to protect the data stored in the TCM, see *TCM internal error detection and correction*.

The size of each TCM interface is configured during integration. See the *Cortex-R4 and Cortex-R4F Integration Manual* for more information. The permissible TCM sizes are:

- 0KB
- 4KB
- 8KB
- 16KB
- 32KB
- 64KB
- 128KB
- 256KB
- 512KB
- 1MB
- 2MB
- 4MB
- 8MB.

If the BTCM interface has two ports, the size of the RAM attached to each port is half the total size for the BTCM interface.

The size of the TCM interfaces is visible to software in the TCM Region Registers, see *c9, BTCM Region Register* on page 4-57 and *c9, ATCM Region Register* on page 4-58. All TCM interface build configuration options can be read from the Build Options Registers, see *c15, Build Options 1 Register* on page 4-72 and *c15, Build Options 2 Register* on page 4-72.

8.4.3 TCM internal error detection and correction

Each TCM interface can be configured with either parity, 32-bit ECC, or 64-bit ECC error schemes. Both the BTCM ports must have the same error scheme. The following sections describe these error schemes:

- *Handling TCM parity errors* on page 8-15
- *Handling TCM ECC errors* on page 8-15.

Handling TCM parity errors

If a TCM interface has been built with parity error checking, you can enable this by setting the appropriate bits in the Auxiliary Control Register. See *c1, Auxiliary Control Register* on page 4-38. If the BTCM interface has been built with two ports, parity checking can be enabled for each port individually. You can pin-configure the processor to set the enable bits and therefore enable parity checking on reset, by tying off the **PARECCENRAM** input as required.

Parity bits for the data are generated on all TCM writes, regardless of whether or not the parity bits are being checked on reads. When a parity error is detected on a TCM read, a precise abort is generated. The type of the abort is shown in the appropriate *Fault Status Register* (FSR) as being a precise parity error. The processor cannot correct parity errors in the TCM.

When you use the parity error detection scheme, the **PARLVRAM** input to the processor selects between odd and even parity.

Handling TCM ECC errors

If a TCM interface has been built with either 32-bit or 64-bit ECC error checking, you can enable this by setting the appropriate bits in the Auxiliary Control Register. See *c1, Auxiliary Control Register* on page 4-38. On the BTCM interface, ECC checking can only be enabled for both ports or neither port. You can pin-configure the processor to set the enable bits and therefore enable ECC checking on reset, by tying off the **PARECCENRAM** input as required.

When a fatal error, that is, a 2-bit ECC error, is detected on a TCM read, an error is generated. Instruction and data reads generate the appropriate type of precise abort, and the AXI-slave interface returns a SLVERR response to the AXI system.

When a correctable error, that is, a 1-bit ECC error, is detected on a TCM read made by the AXI-slave interface, the processor corrects the data inline before returning to the system.

When a correctable ECC error is detected on a TCM read made by the instruction-side or data-side, the processor normally generates the correct data and writes it back to the TCM. In the meantime, the processor retries the read to fetch the correct instruction or data. By setting the appropriate bits in the Secondary Auxiliary Control Register, you can disable this behavior. See *c15, Secondary Auxiliary Control Register* on page 4-41. Instead of correcting the error in the TCM, the processor generates the appropriate type of precise abort.

All ECC code generation and ECC checking must be performed on a complete data chunk, either 32-bits or 64-bits depending on the configuration. If a read access smaller than the data chunk is required, the whole chunk is read. If a write smaller than the data chunk is required, the processor must perform read-modify-write to generate the correct data and ECC code, but it only does this when ECC error checking is enabled. The data read as part of the read-modify-write sequence is checked for ECC errors, and the errors are handled in the same way as for any other TCM read. The ECC code is generated and written to the TCM for every write, regardless of whether error checking is enabled or not, but the code is only correct if the write was of a complete data chunk or if the processor performed read-modify-write to generate the complete data chunk. All data and instruction aborts generated by the ECC logic are indicated in the appropriate FSR as being a precise parity error.

8.4.4 TCM arbitration

Each TCM port receives requests from the LSU, PFU, and AXI slave. In most cases, the LSU has the highest priority, followed by the PFU, with the AXI slave having lowest priority.

When a higher-priority device is accessing a TCM port, an access from a lower-priority device must stall.

When either the LSU or the AXI slave interface is performing a read-modify-write operation on a TCM port, various internal data hazards exist for either the AXI-slave interface or the LSU. In these cases, additional stall cycles are generated, beyond those normally required for arbitration. For optimum performance of the processor when configured with ECC, ensure that all write bursts to the TCM from the AXI slave interface write an entire data chunk, that is, 32-bits or 64-bits, naturally aligned, depending on the error scheme.

8.4.5 TCM initialization

You can enable the processor to boot from the ATCM or the BTCM. The **INITRAMA** and **INITRAMB** pins, when tied HIGH, enable the ATCM and the BTCM respectively on leaving reset. The **LOCZRAMA** pin forces one of the TCMs to have its base address at `0x0`. If **LOCZRAMA** is tied HIGH, the initial base address of the ATCM is `0x0`, otherwise the initial base address of the BTCM is `0x0`. In both cases, the initial base address of the other TCM is implementation-defined, see *Configurable options* on page 1-13.

The ATCM Region Register and BTCM Region Register respectively determine the base address for the ATCM and BTCM. For information on how to read the TCM region registers, see *c9, BTCM Region Register* on page 4-57 or *c9, ATCM Region Register* on page 4-58 as appropriate. For information about pre-loading data into the TCMs, see *TCM* on page 3-3.

8.4.6 TCM port protocol

Each TCM port operates independently to read and write data to and from the memory attached to it. Information about which memory location is to be accessed is passed on the TCM port along with write data and associated error code or parity bits, if appropriate. In addition, the TCM port provides information about whether the access results from an instruction fetch from the PFU, a data access from the LSU, or a DMA transfer from the AXI slave interface. Each TCM port also has an associated parity bit, computed from the address and control signals for that port.

Read data and associated error code or parity bits are read back from the TCM port. In addition, the TCM memory controller can indicate that the processor must wait one or more cycles before reading the response, or signal that an error has occurred and must be either aborted or retried. For more information about TCM errors, see *External TCM errors*.

For more information about TCM port protocol, the signals and timing, see the *Cortex-R4 and Cortex-R4F Integration Manual*.

8.4.7 External TCM errors

Each TCM port has a number of features that support the integration of a TCM RAM with an error checking scheme implemented in the RAM controller logic outside of the processor, that is, by the integrator.

Errors can be signaled to each TCM port if the external error checking scheme detects one and, if enabled, the processor generates an instruction or data abort or an AXI error response as appropriate. On a TCM read from either the instruction-side or data-side, the TCM controller can indicate that the read must be retried instead of generating an abort.

You can enable external errors for each TCM port individually by setting the appropriate bits in the Auxiliary Control Register. See *c1, Auxiliary Control Register* on page 4-38. If external errors are not enabled for a TCM port, the processor ignores any error signaled on that port. You can pin-configure the processor to set the enable bits, and therefore enable external error checking on reset, by tying off the **ERRENRAM** input as required.

In addition, an external error detection scheme might require that data is read and written in particular sized chunks. The load/store-64 feature, when enabled for a particular TCM interface, causes all loads and stores to the TCM ports to be of 64-bits of data. This feature is also known as *Read-Modify-Write* (RMW), because it causes the processor to generate read-modify-write sequences for any store of less than 64-bits. You can enable RMW behavior for each TCM interface individually by setting the appropriate bits in the Secondary Auxiliary Control Register. See *c1, Auxiliary Control Register* on page 4-38. You can pin-configure the processor to set the enable bits and therefore RMW behavior on reset, by tying off the **RMWENRAM** input as required.

Note

The load/store-64 feature is not available on any TCM interface that has been configured with 32-bit ECC.

The error inputs on each TCM port can also be used to signal other types of error, for example, when an address accessed is out of range for the RAM attached to the TCM port. Errors signaled on writes from the data-side generate an imprecise abort. All other aborts generated by external errors are precise. The type of abort is shown in the appropriate FSR as either precise or imprecise parity error.

8.4.8 AXI slave interfaces for TCMs

The processor has a 64-bit AXI slave interface that provides access to the TCM interfaces from the AXI bus. This interface is included by default, but can be excluded during configuration of the processor.

You can use the slave port for access to the TCM memories. This also enables you to construct a system with a consistent view of memory. That is, the TCMs can be available at the same address to the processor and to the system bus.

The AXI slave port accesses have lower priority than the LSU or PFU accesses.

The MPU does not check accesses from the AXI slave. You can configure the processor to enable privileged or nonprivileged access to the TCM interfaces from the AXI slave port.

The AXI slave interface does not support locked and exclusive accesses. This means that AXI masters, other than the processor, cannot safely use semaphores in the TCMs. Although the Cortex-R4 processor can use semaphores in the TCMs for inter-process synchronization, you must not use the AXI-slave interface to write to TCM semaphores. The processor has no logic to preserve its own exclusivity against such writes.

For more information on the AXI slave interface, see *AXI slave interface* on page 9-20.

8.5 About the caches

The L1 memory system can be configured to include instruction and data caches of varying sizes. You can configure whether the cache controller is included and, if it is, configure the size of each cache independently. The cached instructions or data are fetched from external memory using the L2 memory interface. The cache controllers use RAMs that are integrated into the Cortex-R4 macrocell during implementation.

Any access that is not for a TCM is handled by the appropriate cache controller. If the access is to Cacheable memory, and the cache is enabled, a lookup is performed in the cache and, if found in the cache, that is, a cache hit, the data is fetched from or written into the cache. When the cache is not enabled and for Non-cacheable memory, the accesses are performed using the L2 memory interface.

Both caches allocate a memory location to a cache line on a cache miss because of a read, that is, all Cacheable locations are *Read-Allocate* (RA). In addition, the data cache can allocate on a write access if the memory location is marked as *Write-Allocate* (WA). When a cache line is allocated, the appropriate memory is fetched into a linefill buffer by the L2 memory interface before being written to the cache. See *Linefill buffers and the AXI master interface* on page 9-4. The linefill buffers always fetch the requested data first, and then the rest of the cache line. This enables the data read to be used by the pipeline without waiting for the linefill to complete and is known as *critical word first* and *non-blocking* behavior. If an error is reported to the L2 memory interface for a linefill, the linefill does not update the cache RAMs, but an abort is only generated if the error was reported on the critical word.

If all the cache lines in a set are valid, to allocate a different address to the cache, the cache controller must evict a line from the cache.

Writes accesses that hit in the cache are written into the cache RAMs. If the memory location is marked as *Write-Through* (WT), the write is also performed on the L2 memory interface, so that the data stored in the RAM remains coherent with the external memory system. If the memory is *Write-Back* (WB), the cache line is marked as dirty, and the write is only performed on the L2 memory interface when the line is evicted. When a dirty cache line is evicted, the data is passed to the Eviction Buffer in the L2 memory interface to be written to the external memory system. See *Eviction buffer* on page 9-5 for more information.

The cache controllers also manage the cache maintenance operations described in *Cache maintenance operations* on page 8-19.

Each cache can also be configured with either parity or ECC error checking schemes. If an error checking scheme is implemented and enabled, then the tags associated with each line, and data read from the cache are checked whenever a lookup is performed in the cache. See *Cache error detection and correction* on page 8-20 for more information.

For more information on the general rules about memory attributes and behavior, see the *ARM Architecture Reference Manual*.

8.5.1 Store buffer

The cache controller includes a store buffer to hold data before it is written to the cache RAMs or passed to the AXI master interface. The store buffer has four entries. Each entry can contain up to 64 bits of data and a 32-bit address. All write requests from the data-side that are not to a TCM interface are stored in the store buffer.

Store buffer merging

The store buffer has merging capabilities. If a previous write access has updated an entry, other write accesses on the same line can merge into this entry. Merging is only possible for stores to Normal memory.

Merging is possible between several entries that can be linked together if the data inside the different entries belong to the same cache line.

No merging occurs for writes to Strongly Ordered or Device memory. The processor automatically drains the store buffer before performing Strongly Ordered accesses or Device reads.

Store buffer behavior

The store buffer redirects write requests to the following blocks:

- Cache controller for Cacheable write hits:

  The store buffer sends a cache lookup to check that the cache hits in the specified line, and if so, the store buffer merges its data into the cache when the entry is drained.

- AXI master interface:
  - For Non-cacheable stores or write-through Cacheable stores, a write access is performed on the AXI master interface.
  - For write-back, write-allocate stores that miss in the data cache, a linefill is started using either of the two linefill buffers. When the linefill data is returned from the L2 memory system, the data in the store buffer is merged into the linefill buffer.

Store buffer draining

A store buffer entry is drained if:

- All bytes in the entry have been written. This might result from merging.
- The entry can be merged into a linefill buffer.
- The entry contains a store to Device or Strongly Ordered memory.

The store buffer is completely drained when:

- an explicit drain request is done for:
  - system control coprocessor cache maintenance operations
  - a `DMB` or `DSB` instruction
  - a load or store to Strongly Ordered memory
  - an exclusive load or store to Shared memory
  - a `SWP` or `SWPB` to Non-cacheable memory.
- the store buffer is full or likely to become full.

The store buffer is drained of all stores to Device memory before a load is performed from Device memory.

8.5.2 Cache maintenance operations

All cache maintenance operations are done through the system control coprocessor, CP15. The system control coprocessor operations supported for the data cache are:

- Invalidate all
- Invalidate by address (MVA)

- Invalidate by Set/Way combination
- Clean by address (MVA)
- Clean by Set/Way combination
- Clean and Invalidate by address (MVA)
- Clean and Invalidate by Set/Way combination
- *Data Memory Barrier* (DMB) and *Data Synchronization Barrier* (DSB) operations.

The system control coprocessor operations supported for the instruction cache are:
- Invalidate all
- Invalidate by address.

For more information on cache operations, see *Cache operations* on page 4-54.

8.5.3 Cache error detection and correction

This section describes how the processor detects, handles, reports, and corrects cache memory errors. Memory errors have *Fault Status Register* (FSR) values to distinguish them from other abort causes.

This section describes:
- *Error build options*
- *Address decoder faults* on page 8-21
- *Handling cache parity errors* on page 8-21
- *Handling cache ECC errors* on page 8-22
- *Errors on instruction cache read* on page 8-23
- *Errors on data cache read* on page 8-23
- *Errors on data cache write* on page 8-23
- *Errors on evictions* on page 8-23
- *Errors on cache maintenance operations* on page 8-23.

Error build options

The caches can detect and correct errors depending on the build options used in the implementation. The build options for the instruction cache can be different to the data cache.

If the parity build option is enabled, the cache is protected by parity bits. For both the instruction and data cache, the data RAMs include one parity bit per byte of data. The tag RAM contains one parity bit to cover the tag and valid bit.

If the ECC build option is enabled:

- The instruction cache is protected by a 64-bit ECC scheme. The data RAMs include eight bits of ECC code for every 64 bits of data. The tag RAMs include seven bits of ECC code to cover the tag and valid bit.
- The data cache is protected by a 32-bit ECC scheme. The data RAMs include seven bits of ECC code for every 32 bits of data. The tag RAMs include seven bits of ECC code to cover the tag and valid bit. The dirty RAM includes four bits of ECC to cover the dirty bit and the two outer attributes bits.

Address decoder faults

The error detection schemes described in this section provide protection against errors that occur in the data stored in the cache RAMs. Each RAM normally includes a decoder which enables access to that data and, if an error occurs in this logic, it is not normally detected by these error detection schemes. The processor includes features that enable it to detect some address decoder faults. If you are implementing the processor and require these features, contact ARM to discuss the features and your requirements.

Handling cache parity errors

Table 8-2 shows the behavior of the processor on a cache parity error, depending on bits [5:3] of the Auxiliary Control Register, see *Auxiliary Control Registers* on page 4-38.

Table 8-2 Cache parity error behavior

Value	Behavior
b000	Abort on all parity errors, force write through, enable hardware recovery
b001	
b010	
b011	Reserved
b100	Disable parity checking
b101	Force write-through, enable hardware recovery, do not generate aborts on parity errors
b110	
b111	Reserved

See *Disabling or enabling error checking* on page 8-32 for information on how to safely change these bits.

Hardware recovery

When parity checking is enabled, hardware recovery is always enabled. Memory marked as write-back write-allocate behaves as write-though. This ensures that cache lines can never be dirty, therefore the error can always be recovered from by invalidating the cache line that contains the parity error. The processor automatically performs this invalidation when an error is detected. The correct data can then be re-read from the L2 memory system.

Parity aborts

If aborts on parity errors are enabled, software is notified of the error by a data abort or prefetch abort. The error is still automatically corrected by the hardware even if an abort is generated.

If abort generation is not enabled, the hardware recovery is invisible to software. If required, software can use events and the Correctable Fault Location Register to monitor the errors that are detected and corrected. See *Error detection events* on page 8-36 and *Correctable Fault Location Register* on page 4-70.

Handling cache ECC errors

Table 8-3 shows the behavior of the processor on a cache ECC error, depending on bits [5:3] of the Auxiliary Control Register, see *Auxiliary Control Registers* on page 4-38.

Table 8-3 Cache ECC error behavior

Value	Behavior
b000	Abort on all ECC errors, enable hardware recovery
b001	
b010	Abort on all ECC errors, force write-through, enable hardware recovery
b011	Reserved
b100	Disable ECC checking
b101	Enable hardware recovery, do not generate aborts on ECC errors
b110	Force write-through, enable hardware recovery, do not generate aborts on ECC errors
b111	Reserved

See *Disabling or enabling error checking* on page 8-32 for information on how to safely change these bits.

When ECC checking is enabled, hardware recovery is always enabled. When an ECC error is detected, the processor tries to evict the cache line containing the error. If the line is clean, it is invalidated, and the correct data is reloaded from the L2 memory system. If the line is dirty, the eviction writes the dirty data out to the L2 memory system, and in the process it corrects any 1-bit errors. The corrected data is then reloaded from the L2 memory system.

If a 2-bit error is detected in a dirty line, the error is not correctable. If the 2-bit error is in the tag or dirty RAM, no data is written to the L2 memory system. If the 2-bit error is in the data RAM, the cache line is written to the L2 memory system, but the AXI master port **WSTRBM** signal is LOW for the data that contains the error. If an uncorrectable error is detected, an abort is always generated because data might have been lost. It is expected that such a situation can be fatal to the software process running.

If one of the force write-though settings is enabled, memory marked as write-back write-allocate behaves as write-though. This ensures that cache lines can never be dirty, therefore the error can always be recovered from by invalidating the cache line that contains the ECC error.

All detectable errors in the instruction cache can always be recovered from because the instruction cache can never contain dirty data.

ECC aborts

If aborts on ECC errors are enabled, software is notified of the error by a data abort or prefetch abort. The error is still automatically corrected by the hardware even if an abort is generated.

If abort generation is not enabled, the hardware recovery is invisible to software. If required, software can use events and the Correctable Fault Location Register to monitor the errors that are detected and corrected. See *Error detection events* on page 8-36 and *Correctable Fault Location Register* on page 4-70.

Errors on instruction cache read

All parity or ECC errors detected on instruction cache reads are correctable. If aborts are enabled, a precise prefetch abort exception occurs. The instruction FAR gives the address that caused the error to be detected. The instruction FSR indicates a parity error on a read. The auxiliary FSR indicates that the error was in the cache and which cache Way the error was in.

Errors on data cache read

If parity or ECC aborts are enabled, or an uncorrectable ECC error is detected, a precise data abort exception occurs. The data FAR gives the address that caused the error to be detected. The data FSR indicates a precise read parity error. The auxiliary FSR indicates that the error was in the cache and which cache Way the error was in.

Errors on data cache write

If parity or ECC aborts are enabled, or an uncorrectable ECC error is detected, an imprecise data abort exception occurs. Because the abort is imprecise, the data FAR is Unpredictable. The data FSR indicates an imprecise write parity error. The auxiliary FSR indicates that the error was in the cache and which cache Way and Index the error was in.

In write-through cache regions the store that caused the error is written to external memory using the L2 memory interface so data is not lost and the error is not fatal.

Errors on evictions

If the cache controller has determined a cache miss has occurred, it might have to do an eviction before a linefill can take place. This can occur on reads, and on writes if write-allocation is enabled for the region. Certain cache maintenance operations also generate evictions. If it is a data-cache line which is dirty, an ECC error might be detected on the line being evicted:

- if the error is correctable, it is corrected inline before the data is written to the external memory using the L2 memory interface
- if there is an uncorrectable error in the tag or dirty RAM, the write is not done and an imprecise abort occurs
- if there is an uncorrectable error in the data RAM, the AXI master port **WSTRBM** signal is deasserted for the word(s) with an error, and an imprecise abort occurs.

An imprecise abort can also occur on a correctable error depending on the Auxiliary Control Register bits [5:3], see *Auxiliary Control Registers* on page 4-38. Any detected error is signaled with the appropriate event.

Note

When parity checking is enabled, force write-though is always enabled. Therefore the cache lines can never be dirty, and so evictions are not required. Force write-through can also be enabled with ECC checking.

Errors on cache maintenance operations

The following sections describe errors on cache maintenance operations:

- *Invalidate all instruction cache* on page 8-24
- *Invalidate all data cache* on page 8-24
- *Invalidate instruction cache by address* on page 8-24
- *Invalidate data cache by address* on page 8-24

- *Invalidate data cache by set/way*
- *Clean data cache by address*
- *Clean data cache by set/way* on page 8-25
- *Clean and invalidate data cache by address* on page 8-25
- *Clean and invalidate data cache by set/way* on page 8-25.

Invalidate all instruction cache

This operation ignores all errors in the cache and sets all instruction cache entries to invalid regardless of error events. This operation cannot generate an imprecise abort, and no error events are signaled.

Invalidate all data cache

This operation ignores all errors in the cache and sets all data cache entries to invalid regardless of errors. This operation cannot generate an imprecise abort and no error events are signaled.

Invalidate instruction cache by address

This operation requires a cache lookup. Any errors found in the set that was looked up are fixed by invalidating that line and, if the address in question is found in the set, it is invalidated.

This operation cannot generate an imprecise abort. Any detected error is signaled with the appropriate event.

Invalidate data cache by address

This operation requires a cache lookup. Any correctable errors found in the set that was looked up are fixed and, if the address in question is found in the set, it is invalidated.

Any uncorrectable errors cause an imprecise abort. An imprecise abort can also be raised on a correctable error if aborts on RAM errors are enabled in the Auxiliary Control Register.

Any detected error is signaled with the appropriate event.

Invalidate data cache by set/way

This operation does not require a cache lookup. It refers to a particular cache line.

The entry at the given set/way is marked as invalid regardless of any errors. This operation cannot generate an imprecise abort. Any detected error is signaled with the appropriate event.

Clean data cache by address

This operation requires a cache lookup. Any correctable errors found in the set that was looked up are fixed and, if the address in question is found in the set, the instruction carries on with the clean operation. When the tag lookup is done, the dirty RAM is checked.

Note

When force write-through is enabled, the dirty bit is ignored.

If the tag or dirty RAM has an uncorrectable error, the data is not written to memory.

If the line is dirty, the data is written back to external memory. If the data has an uncorrectable error, the words with the error have their **WSTRBM** AXI signal deasserted. If there is a correctable error, the line has the error corrected inline before it is written back to memory.

Any uncorrectable errors cause an imprecise abort. An imprecise abort can also be raised on a correctable error if aborts on RAM errors are enabled in the Auxiliary Control Register.

Any detected error is signaled with the appropriate event.

Clean data cache by set/way

This operation does not require a cache lookup. It refers to a particular cache line.

The tag and dirty RAMs for the cache line are checked.

Note

When force write-through is enabled, the dirty bit is ignored.

If the tag or dirty RAM has an uncorrectable error, the data is not written to memory.

If the line is dirty, the data is written back to external memory. If the data has an uncorrectable error, the words with the error have their **WSTRBM** AXI signal deasserted. If there is a correctable error, the line has the error corrected inline before it is written back to memory.

Any uncorrectable errors found cause an imprecise abort. An imprecise abort can also be raised on a correctable error if aborts on RAM errors are enabled in the Auxiliary Control Register.

Any detected error is signaled with the appropriate event.

Clean and invalidate data cache by address

This operation requires a cache lookup. Any correctable errors found in the set that was looked up are fixed and, if the address in question is found in the set, the instruction carries on with the clean and invalidate operation. When the tag lookup is done, the dirty RAM is checked.

Note

When force write-through is enabled, the dirty bit is ignored.

If the tag or dirty RAM has an uncorrectable error, the data is not written to memory.

If the line is dirty, the data is written back to external memory. If the data has an uncorrectable error, the words with the error have their **WSTRBM** AXI signal deasserted. If there is a correctable error, the line has the error corrected inline before it is written back to memory.

Any uncorrectable errors found cause an imprecise abort. An imprecise abort can also be raised on a correctable error if aborts on RAM errors are enabled in the Auxiliary Control Register.

Any detected error is signaled with the appropriate event.

Clean and invalidate data cache by set/way

This operation does not require a cache lookup. It refers to a particular cache line.

The tag and dirty RAMs for the cache line are checked.

Note

When force write-through is enabled, the dirty bit is ignored.

If the tag or dirty RAM has an uncorrectable error, the data is not written to memory.

If the line is dirty, the data is written back to external memory. If the data has an uncorrectable error, the words with the error have their **WSTRBM** AXI signal deasserted. If there is a correctable error, the line has the error corrected inline before it is written back to memory.

Any uncorrectable errors found cause an imprecise abort. An imprecise abort can also be raised on a correctable error if aborts on RAM errors are enabled in the Auxiliary Control Register.

Any detected error is signaled with the appropriate event.

8.5.4 Cache RAM organization

This section describes RAM organization in the following sections:

- *Tag RAM*
- *Dirty RAM* on page 8-27
- *Data RAM* on page 8-27.

Tag RAM

The tag RAMs consist of four ways of up to 512 lines. The width of the RAM depends on the build options selected, and the size of the cache. The following tables show the tag RAM bits:

- Table 8-4 shows the tag RAM bits when parity is implemented
- Table 8-5 shows the tag RAM bits when ECC is implemented
- Table 8-6 shows the tag RAM bits when neither parity nor ECC is implemented.

Table 8-4 Tag RAM bit descriptions, with parity

Bit in the tag cache line	Description
Bit [23]	Parity bit
Bit [22]	Valid bit
Bits [21:0]	Tag value

Table 8-5 Tag RAM bit descriptions, with ECC

Bit in the tag cache line	Description
Bits [29:23]	ECC code bits
Bit [22]	Valid bit
Bits [21:0]	Tag value

Table 8-6 Tag RAM bit descriptions, no parity or ECC

Bit in the tag cache line	Description
Bit [22]	Valid bit
Bits [21:0]	Tag value

A cache line is marked as valid by bit [22] of the tag RAM. Each valid bit is associated with a whole cache line, so evictions always occur on the entire line.

Table 8-7 shows the tag RAM cache sizes and associated RAM organization, assuming no parity or ECC. For parity, the width of the tag RAMs must be increased by one bit. For ECC, the width of the tag RAMs must be increased by seven bits.

Table 8-7 Cache sizes and tag RAM organization

Cache size	Tag RAM organization
4KB	4 banks 23 bits 32 lines
8KB	4 banks 22 bits 64 lines
16KB	4 banks 21 bits 128 lines
32KB	4 banks 20 bits 256 lines
64KB	4 banks 19 bits 512 lines

Dirty RAM

For the data cache only, the dirty RAM stores the following information:

- two bits for line outer attributes for evictions
- one line dirty bit
- four ECC code bits if the ECC build option is enabled.

The dirty RAM array consists of one bank of up to 512 12-bit lines, 4 ways x 3 bits. If ECC is enabled, the dirty RAM is 28 bits wide. Each line of dirty RAM contains all the information of the four ways for a given index.

Each time a dirty bit is written, the outer bits of the line and, if implemented, the ECC code bits, are also written. The dirty RAM is bit-enabled. Table 8-8 shows the organization of a dirty RAM line.

Table 8-8 Organization of a dirty RAM line

Bit in the dirty cache line	Description
Bits [6:3]	ECC bits, if implemented
Bits [2:1]	Outer attributes that are re-encoded on **AWCACHE** when an eviction is sent to the AXI bus: 01 = WB, WA 10 = WT 11 = WB, no WA 00 = Non-cacheable.
Bit [0]	Dirty bit

Data RAM

Data RAM is organized as eight banks of 32-bit wide lines, or in the instruction cache as four banks of 64-bit wide lines. This RAM organization means that it is possible to:

- Perform a cache look-up with one RAM access, all banks selected together. This is done for nonsequential read operations. Figure 8-3 on page 8-28 shows this.
- Select the appropriate bank RAM for sequential read operations. Figure 8-4 on page 8-28 shows this.

- Write a line to the eviction buffer in one cycle, a 256-bit read access.
- Fill a line in one cycle from the linefill buffer, a 256-bit write access.

Figure 8-3 shows a cache look-up being performed on all banks with one RAM access.

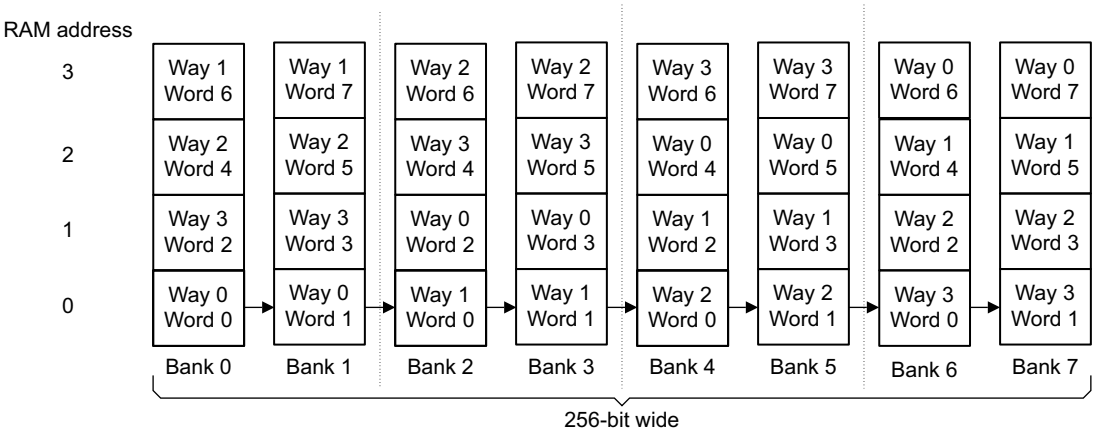


Figure 8-3 Nonsequential read operation performed with one RAM access.

Figure 8-4 shows the appropriate bank RAM being selected for a sequential read operation.

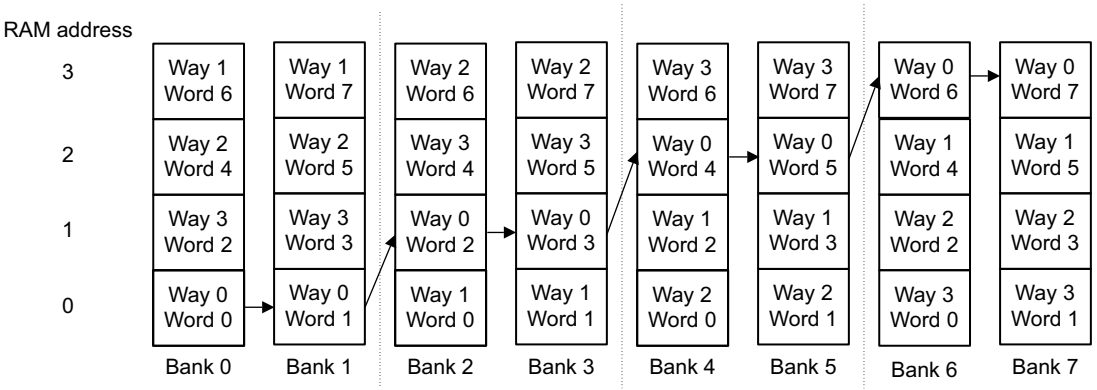


Figure 8-4 Sequential read operation performed with one RAM access

The data RAM organization is optimized for 64-bit read operations, because with the same address, two words on the same way can be selected.

Data RAM sizes depend on the build option selected, and are described in:

- *Data RAM sizes without parity or ECC implemented* on page 8-29
- *Data RAM sizes with parity implemented* on page 8-29
- *Data RAM sizes with ECC implemented* on page 8-30.

Data RAM sizes without parity or ECC implemented

Table 8-9 shows the organization for instruction and data caches when neither parity nor ECC is implemented.

Table 8-9 Instruction cache data RAM sizes, no parity or ECC

Cache size	Data RAMs
4KB, 4 1KB ways	4 banks 64 bits 128 lines or 8 banks 32 bits 128 lines
8KB, 4 2KB ways	4 banks 64 bits 256 lines or 8 banks 32 bits 256 lines
16KB, 4 4KB ways	4 banks 64 bits 512 lines or 8 banks 32 bits 512 lines
32KB, 4 8KB ways	4 banks 64 bits 1024 lines or 8 banks 32 bits 1024 lines
64KB, 4 16KB ways	4 banks 64 bits 2048 lines or 8 banks 32 bits 2048 lines

Table 8-10 Data cache data RAM sizes, no parity or ECC

Cache size	Data RAMs
4KB, 4 1KB ways	8 banks 32 bits 128 lines
8KB, 4 2KB ways	8 banks 32 bits 256 lines
16KB, 4 4KB ways	8 banks 32 bits 512 lines
32KB, 4 8KB ways	8 banks 32 bits 1024 lines
64KB, 4 16KB ways	8 banks 32 bits 2048 lines

Data RAM sizes with parity implemented

Table 8-11 shows the organization for instruction and data caches when parity is implemented. For parity error detection, one bit is added per byte, so four bits are added for each RAM bank.

Table 8-11 Instruction cache data RAM sizes, with parity

Cache size	Data RAMs
4KB, 4 1KB ways	4 banks 72 bits 128 lines or 8 banks 36 bits 128 lines
8KB, 4 2KB ways	4 banks 72 bits 256 lines or 8 banks 36 bits 256 lines
16KB, 4 4KB ways	4 banks 72 bits 512 lines or 8 banks 36 bits 512 lines
32KB, 4 8KB ways	4 banks 72 bits 1024 lines or 8 banks 36 bits 1024 lines
64KB, 4 16KB ways	4 banks 72 bits 2048 lines or 8 banks 36 bits 2048 lines

Table 8-12 Data cache data RAM sizes, with parity

Cache size	Data RAMs
4KB, 4 1KB ways	8 banks 36 bits 128 lines
8KB, 4 2KB ways	8 banks 36 bits 256 lines
16KB, 4 4KB ways	8 banks 36 bits 512 lines
32KB, 4 8KB ways	8 banks 36 bits 1024 lines
64KB, 4 16KB ways	8 banks 36 bits 2048 lines

Table 8-13 shows the organization of the data cache RAM bits when parity is implemented.

Table 8-13 Data cache RAM bits, with parity

RAM bits	Description
Bit [35]	Parity bit for byte[31:24]
Bit [34]	Parity bit for byte[23:16]
Bit [33]	Parity bit for byte[15:8]
Bit [32]	Parity bit for byte[7:0]
Bits [31:0]	Data[31:0]

Parity bits are grouped together in bits[35:32] so that data and parity bits are easily differentiated. With this design the parity bit is selected alongside the related data byte, so that when data is updated, the parity bit is also updated.

Data RAM sizes with ECC implemented

Table 8-14 shows the organization for the instruction cache when ECC is implemented. For ECC error detection, eight bits are added per 64 bits, so four bits are added for each RAM bank.

Table 8-14 Instruction cache data RAM sizes with ECC

Cache size	Data RAMs
4KB, 4 1KB ways	4 banks 72 bits 128 lines or 8 banks 36 bits 128 lines
8KB, 4 2KB ways	4 banks 72 bits 256 lines or 8 banks 36 bits 256 lines
16KB, 4 4KB ways	4 banks 72 bits 512 lines or 8 banks 36 bits 512 lines
32KB, 4 8KB ways	4 banks 72 bits 1024 lines or 8 banks 36 bits 1024 lines
64KB, 4 16KB ways	4 banks 72 bits 2048 lines or 8 banks 36 bits 2048 lines

Table 8-15 shows the organization for the data cache when ECC is implemented. For ECC error detection, seven bits are added per 32 bits, so seven bits are added for each RAM bank.

Table 8-15 Data cache data RAM sizes with ECC

Cache size	Data RAMs
4KB, 4 1KB ways	8 banks 39 bits 128 lines
8KB, 4 2KB ways	8 banks 39 bits 256 lines
16KB, 4 4KB ways	8 banks 39 bits 512 lines
32KB, 4 8KB ways	8 banks 39 bits 1024 lines
64KB, 4 16KB ways	8 banks 39 bits 2048 lines

Table 8-16 shows the organization of the data cache RAM bits when ECC is implemented.

Table 8-16 Data cache RAM bits, with ECC

RAM bits	Description
Bits [39:32]	ECC code bits for data [31:0]
Bits [31:0]	Data [31:0]

8.5.5 Cache interaction with memory system

This section describes how to enable or disable the cache RAMs, and to enable or disable error checking. After you enable or disable the instruction cache, you must issue an `ISB` instruction to flush the pipeline. This ensures that all subsequent instruction fetches see the effect of enabling or disabling the instruction cache.

After reset, you must invalidate each cache before enabling it.

When disabling the data cache, you must clean the entire cache to ensure that any dirty data is flushed to L2 memory.

Before enabling the data cache, you must invalidate the entire data cache if L2 memory might have changed since the cache was disabled.

Before enabling the instruction cache, you must invalidate the entire instruction cache if L2 memory might have changed since the cache was disabled.

See *Enabling or disabling AXI slave accesses* on page 9-23 and *Accessing RAMs using the AXI slave interface* on page 9-24 for information about how to access the cache RAMs using the AXI slave interface.

Disabling or enabling all of the caches

The following code is an example of enabling caches:

```
MRC p15, 0, R1, c1, c0, 0  ; Read System Control Register configuration data
ORR R1, R1, #0x1 <<12      ; instruction cache enable
ORR R1, R1, #0x1 <<2       ; data cache enable
DSB
MCR p15, 0, r0, c15, c5, 0 ; Invalidate entire data cache
MCR p15, 0, r0, c7, c5, 0  ; Invalidate entire instruction cache
MCR p15, 0, R1, c1, c0, 0  ; enabled cache RAMs
ISB
```

The following code is an example of disabling the caches:

```
MRC p15, 0, R1, c1, c0, 0  ; Read System Control Register configuration data
BIC R1, R1, #0x1 <<12      ; instruction cache disable
BIC R1, R1, #0x1 <<2       ; data cache disable
DSB
MCR p15, 0, R1, c1, c0, 0  ; disabled cache RAMs
ISB
; Clean entire data cache. This routine will depend on the data cache size. It can be
omitted if it is known that the data cache has no dirty data
```

Disabling or enabling instruction cache

The following code is an example of enabling the instruction cache:

```
MRC p15, 0, R1, c1, c0, 0  ; Read System Control Register configuration data
ORR R1, R1, #0x1 <<12      ; instruction cache enable
MCR p15, 0, r0, c7, c5, 0  ; Invalidate entire instruction cache
MCR p15, 0, R1, c1, c0, 0  ; enabled instruction cache
ISB
```

The following code is an example of disabling the instruction cache:

```
MRC p15, 0, R1, c1, c0, 0   ; Read System Control Register configuration data
BIC R1, R1, #0x1 <<12       ; instruction cache enable
MCR p15, 0, R1, c1, c0, 0   ; disabled instruction cache
ISB
```

Disabling or enabling data cache

The following code is an example of enabling the data cache:

```
MRC p15, 0, R1, c1, c0, 0  ; Read System Control Register configuration data
ORR R1, R1, #0x1 <<2
DSB
MCR p15, 0, r0, c15, c5, 0 ; Invalidate entire data cache
MCR p15, 0, R1, c1, c0, 0  ; enabled data cache
```

The following code is an example of disabling the cache RAMs:

```
MRC p15, 0, R1, c1, c0, 0  ; Read System Control Register configuration data
BIC R1, R1, #0x1 <<2
DSB
MCR p15, 0, R1, c1, c0, 0  ; disabled data cache
; Clean entire data cache. This routine will depend on the data cache size. It can be
omitted if it is known that the data cache has no dirty data.
```

Disabling or enabling error checking

Software must take care when changing the error checking bits in the Auxiliary Control Register. If the bits are changed when the caches contain data, the parity or ECC bits in the caches might not be correct for the new setting, resulting in unexpected errors and data loss. Therefore the bits in the Auxiliary Control Register must only be changed when both caches are turned off and the entire cache must be invalidated after the change.

The following code is the recommended sequence to perform the change:

```
MRC p15, 0, r0, c1, c0, 0  ; Read System Control Register
BIC r0, r0, #0x1 << 2      ; Disable data cache bit
BIC r0, r0, #0x1 << 12     ; Disable instruction cache bit
DSB
MCR p15, 0, r0, c1, c0, 0  ; Write System Control Register
ISB ; Ensures following instructions are not executed from cache
```

```
; Clean entire data cache. This routine will depend on the data cache size. It can be
omitted if it is known that the data cache has no dirty data (e.g. if the cache has not
been enabled yet).
MRC p15, 0, r1, c1, c0, 1  ; Read Auxiliary Control Register
; Change bits 5:3 as needed
MCR p15, 0, r1, c1, c0, 1  ; Write Auxiliary Control Register
MCR p15, 0, r0, c15, c5, 0 ; Invalidate entire data cache
MCR p15, 0, r0, c7, c5, 0  ; Invalidate entire instruction cache
MRC p15, 0, r0, c1, c0, 0  ; Read System Control Register
ORR r0, r0, #0x1 << 2      ; Enable data cache bit
ORR r0, r0, #0x1 << 12     ; Enable instruction cache bit
DSB
MCR p15, 0, r0, c1, c0, 0  ; Write System Control Register
ISB
```

8.6 Internal exclusive monitor

The processor L1 memory system has an internal exclusive monitor. This is a two state, open and exclusive, state machine that manages load/store exclusive (LDREXB, LDREXH, LDREX, LDREXD, STREXB, STREXH, STREX and STREXD) accesses and clear exclusive (CLREX) instructions. You can use these instructions, operating in the L1 memory system, to construct semaphores and ensure synchronization between different processes. By adding an external exclusive monitor, you can also use these instructions in the L2 memory system to construct semaphores and ensure synchronization between different processors. See the *ARM Architecture Reference Manual* for more information about how these instructions work.

When a load-exclusive access is performed, the internal exclusive monitor moves to the exclusive state. It moves back to the open state when a store exclusive access or clear exclusive instruction is performed. The internal exclusive monitor holds exclusivity state for the Cortex-R4 processor only. It does not record the address of the memory that a load-exclusive access was performed to. Any store exclusive access performed when the state is open fails. If the state is exclusive, the access passes if it is to non-shared memory but, if it is to shared memory, the access must be performed as an exclusive using the L2 memory interface. Whether the shared store-exclusive access passes or fails depends on the state of an external exclusive monitor which can track accesses made by other processors in the system.

8.7 Memory types and L1 memory system behavior

The behavior of the L1 memory system depends on the type attribute of the memory that is being accessed:

- Only Normal, Non-shared memory can be cached in the RAMs.
- The store buffer can merge any stores to Normal memory. See *Store buffer* on page 8-18 for more information.
- Only Normal memory is considered restartable, that is, a multi-word transfer can be abandoned part way through because of an interrupt, to be restarted after the interrupt has been handled. See *Interrupts* on page 2-18 for more information about interrupt behavior.
- Only the internal exclusive monitor is used for exclusive accesses to Non-shared memory. Exclusive accesses to shared memory are checked using the internal monitor and also, if necessary, any external monitor, using the L2 memory interface.
- Accesses resulting from `SWP` and `SWPB` instructions to Cacheable memory are not marked as locked when performed using the L2 memory interface.

Table 8-17 summarizes the processor memory types and associated behavior.

Table 8-17 Memory types and associated behavior

Memory type		Cacheable	Merging	Restartable	Internal exclusives	Locked swaps
Normal	Shared	No	Yes	Yes	Partially	Yes
	Non-shared	Yes	Yes	Yes	Yes	No
Device	Shared	No	No	No	Partially	Yes
	Non-shared	No	No	No	Yes	Yes
Strongly Ordered	Shared	No	No	No	Partially	Yes

8.8 Error detection events

The processor generates a number of events related to the internal error detection and correction schemes in the TCMs and caches. For more information, see Table 6-1 on page 6-2. This section describes:

- *TCM error events*
- *Instruction-cache error events*
- *Data-cache error events*
- *Events and the CFLR*.

8.8.1 TCM error events

TCM parity and ECC error events are only signaled for TCM reads, although this includes the read-modify-write sequence performed for some stores. Most errors detected by the internal parity or ECC logic are signaled twice:

- once on a TCM-centric event
- once on a processor-centric event.

The TCM-centric events consist of two events per TCM port, one for fatal, that is, 2-bit ECC or parity errors and one for correctable, that is, 1-bit ECC errors. These events are generated three clock cycles after the data read cycle. Consequently, these events are sometimes signaled on speculative TCM reads, such as instructions which are prefetched but never executed because of a branch earlier in the instruction sequence.

Note

When an external error is signaled on a TCM access, the TCM-centric events are still generated as appropriate, based on the data returned, as if no external error had been signaled.

The processor-centric TCM events are only signaled for errors in data that would have otherwise been used by the processor. Errors on speculative reads never generate these errors. They consist of fatal and correctable events for:

- the prefetch unit, to signal errors on instruction fetches
- the load/store unit, to signal errors on data accesses
- the AXI slave interface, to signal errors on DMA accesses.

8.8.2 Instruction-cache error events

All parity and ECC errors are correctable in the i-cache. Therefore there are only two events, to indicate when an error is detected in a read from the tag RAM, or from the data RAM. These events are only signaled for non-speculative instruction fetches and certain cache maintenance operations. See *Cache error detection and correction* on page 8-20.

8.8.3 Data-cache error events

The d-cache can generate fatal and correctable errors, and therefore has four events, one for each type of error in the data RAM and in the tag or dirty RAMs. These events are only signaled for non-speculative data accesses, cache line evictions, and certain cache maintenance operations. See *Cache error detection and correction* on page 8-20.

8.8.4 Events and the CFLR

The *Correctable Fault Location Register* (CFLR) records the location of the last correctable error detected on a non-speculative access. See *Correctable Fault Location Register* on page 4-70 for more information. Every correctable error that is recorded in the CFLR also

generates an event. See Table 6-1 on page 6-2 to see which events are CFLR-related. For correctable cache errors, the CLFR does not record whether the error occurred in the data RAM or tag/dirty RAM. This distinction is only made by the events.

Chapter 9
Level Two Interface

This chapter describes the features of the Level two (L2) interface not covered in the *AMBA AXI Protocol Specification*. It contains the following sections:

9.1 About the L2 interface

This section describes the processor L2 interface. The L2 interface consists of AXI master and AXI slave interfaces.

The processor is designed for use in larger chip designs using the *Advanced Microcontroller Bus Architecture* (AMBA) AXI protocol. The processor uses the L2 interfaces as its interface to memory and peripheral devices.

External AXI masters and the processor can use the AXI slave interface to access the processor RAMs. You can use the AXI slave interface for DMA access into and out of the TCMs or to perform software test of the TCMs and cache RAMs.

9.2 AXI master interface

The processor has a single AXI master interface, with one port which is used for:

- I-cache linefills
- D-cache linefills and evictions
- *Non-cacheable* (NC) Normal-type memory instruction fetches
- NC Normal-type memory data accesses
- Device and Strongly-ordered type data accesses, normally to peripherals.

The port is 64 bits wide, and conforms to the AXI standard as described in the *AMBA AXI Protocol Specification*. Within the AXI standard, the master port uses the **AWUSERM** and **ARUSERM** signals to indicate inner memory attributes.

The master interface can run at the same frequency as the processor or at a lower synchronous frequency. See *AXI interface clocking* on page 3-9 for more information.

In addition, the AXI master interface produces or checks parity bits for each AXI channel. These additional signals are not part of the AXI specification. See the *Cortex-R4 and Cortex-R4F Integration Manual* for more information.

Note

References in this section to an *AXI slave* refer to the AXI slave in the external system which is connected to the Cortex-R4 AXI master port. This is not necessarily the Cortex-R4 AXI slave port.

The following sections describe the attributes of the AXI master interface, and provide information about the types of burst generated:

- *Identifiers for AXI bus accesses* on page 9-4
- *Write response* on page 9-4
- *Linefill buffers and the AXI master interface* on page 9-4
- *Eviction buffer* on page 9-5
- *Memory attributes* on page 9-5.

Table 9-1 shows the AXI master interface attributes.

Table 9-1 AXI master interface attributes

Attribute	Value	Comments
Write issuing capability	4	Made up of four outstanding writes that can be evictions, single writes, or write bursts.[a]
Read issuing capability	7	Made up of five linefills on the data side, one NC read on the data side, and one read on the instruction side, that can be NC or linefill.
Combined issuing capability	11[a]	-
Write ID capability	2	-
Write interleave capability	1	The AXI master interface presents all write data in order.
Read ID capability	7	Made up of five linefills on the data side, one NC read on the data side, and one linefill or NC read on the instruction side.

a. When there are three outstanding write transactions, only data is issued for the fourth. Only three outstanding write addresses are issued.

9.2.1 Identifiers for AXI bus accesses

Accesses on the AXI bus use ID values as follows:

Outstanding write/read access on different IDs

This means, for example, that a *Non-cacheable* (NC) read and linefills can be outstanding on the AXI bus simultaneously as long as the IDs are different.

At the same time, there can be:

- up to seven outstanding reads, each with one of seven different ID values, that consists of:
  - a data side read NC access, RID0
  - an instruction side read NC access or an instruction side read Cacheable access, RID1
  - five outstanding data side linefills on the AXI bus, RID3 - RID7.
- up to two IDs on outstanding writes, that consist of:
  - single or burst NC writes or *write-through* (WT) writes, WID0
  - evictions, WID1.

Outstanding write accesses with the same ID

When the address and data of the first write are both put on AXI bus, another write request with same ID can be sent when the address or data channel is released. For example, the new address can be sent with the same ID, before the target accepts the data of the first write.

Note

- The AXI master does not generate two outstanding read accesses with the same ID.
- The AXI master does not interleave write data from two different bursts, even if the bursts have different IDs.

9.2.2 Write response

The AXI master requires that the slave does not return a write response until it has received both the write data and the write address.

9.2.3 Linefill buffers and the AXI master interface

On the data side there are two *LineFill Buffers* (LFBs), LFB0 and LFB1. Each request from the data cache controller or from the *STore Buffer* (STB) can be allocated to either LFB0 or LFB1.

On the instruction side, there is one LFB. This is the *Instruction LFB* (ILFB), that treats instruction linefill requests or Non-cacheable instruction reads in the same way.

The linefill buffers:

- get returned data from the AXI bus for linefill requests
- get returned data from the AXI bus for any Non-cacheable `LDR` or `LDMs`
- get data from the STB to write as a burst on the AXI bus (LFB0 and LFB1 only).

Single writes do not use LFBs.

The LFBs are 256 bits wide so that an entire cache line can be written to the cache RAMs in one cycle. While the LFB is being filled from L2 memory, its bytes can be merged with write data from the STB.

9.2.4 Eviction buffer

As soon as a linefill is requested, the selected evicted cache line is loaded into the *EViction Buffer* (EVB). The EVB forwards this information to the AXI bus when possible.

The EVB has a structure of 256 bits for data and 32 bits for the address. See *Cache line write-back (eviction)* on page 9-13 for details of the AXI transaction generated.

The EVB is removed if cache RAMs are not implemented for the processor.

9.2.5 Memory attributes

The Cortex-R4 AXI master interface uses the **ARCACHEM**, **AWCACHEM**, **ARUSERM**, and **AWUSERM** signals to indicate the memory attributes of the transfer, as returned by the MPU. Table 9-2 Shows the encodings used for the signals **ARCACHEM** and **AWCACHEM** of the master interface. These are generated from the memory type and outer region attributes.

Table 9-2 ARCACHEM and AWCACHEM encodings

Encoding[a]	Meaning
b0000	Strongly Ordered
b0001	Device
b0011	Non-cacheable
b0110	Cacheable, write-through, allocate on reads only
b0111	Cacheable, write-back, allocate on reads only
b1111	Cacheable write-back, allocate on reads and writes

a. All encodings not shown in the table are reserved.

Table 9-3 shows the encodings the master interface uses for the **ARUSERM** and **AWUSERM** signals. These are generated from the memory type and inner region attributes.

Table 9-3 ARUSERM and AWUSERM encodings

Encoding[a]	Meaning
b00001	Strongly Ordered
b00010	Device, Non-shared
b00011	Device, shared
b00110	Non-cacheable, Non-shared
b00111	Non-cacheable, shared
b01100	Cacheable, write-through, read-allocate only, Non-shared
b01101	Cacheable, write-through, read-allocate only, shared
b11110	Cacheable, write-back, read- and write-allocate, Non-shared
b11111	Cacheable, write-back, read- and write-allocate, shared

a. All encodings not shown in the table are reserved.

Memory system implications for AXI accesses

The attributes of the memory being accessed can affect an AXI access. The L1 memory system can cache any Normal memory address that is marked as either:

- Cacheable, write-back, read- and write-allocate, non-shared
- Cacheable, write-through, read-allocate only, non-shared.

However, Device and Strongly Ordered memory is always Non-cacheable. Also, any unaligned access to Device or Strongly Ordered memory generates an alignment fault and therefore does not cause any AXI transfer. This means that the access examples given in this chapter never show unaligned accesses to Device or Strongly Ordered memory.

9.3 AXI master interface transfers

The processor conforms to the AXI specification, but it does not generate all the AXI transaction types that the specification permits. This section describes the types of AXI transaction that the Cortex-R4 AXI master does not generate. If you are designing an AXI slave to work only with the Cortex-R4 processor, and there are no other AXI masters in your system, you can take advantage of these restrictions and the interface attributes described above to simplify the slave.

This section also contains tables that show some of the types of AXI burst that the processor generates. However, because a particular type of transaction is not shown here does not mean that the processor does not generate such a transaction.

Note

An AXI slave device connected to the Cortex-R4 AXI master port must be capable of handling every kind of transaction permitted by the AXI specification, except where there is an explicit statement in this chapter that such a transaction is not generated. You must not infer any additional restrictions from the example tables given. Restrictions described here are applicable to the r1p0, r1p1, and r1p2 revisions of the processor, and might not be true for future revisions.

Load and store instructions to Non-cacheable memory might not result in an AXI transfer because the data might either be retrieved from, or merged into the internal store data buffers. The exceptions to this are loads or stores to Strongly Ordered or Device memory. These always result in AXI transfers. See *Strongly Ordered and Device transactions* on page 9-8.

Restrictions on AXI transfers on page 9-8 describes restrictions on the type of transfers that the Cortex-R4 AXI master interface generates. The AXI master port never deasserts the buffered write response and read data channel ready signals, **BREADYM** and **RREADYM**. You must not make any other assumptions about the AXI handshaking signals, except that they conform to the *AMBA AXI Protocol Specification*.

The following sections give examples of transfers generated by the AXI master interface:

- *Strongly Ordered and Device transactions* on page 9-8
- *Linefills* on page 9-13
- *Cache line write-back (eviction)* on page 9-13
- *Non-cacheable reads* on page 9-13
- *Non-cacheable or write-through writes* on page 9-15
- *AXI transaction splitting* on page 9-16
- *Normal write merging* on page 9-17.

9.3.1 Restrictions on AXI transfers

The Cortex-R4 AXI master interface applies the following restrictions to the AXI transactions it generates:

- A burst never transfers more than 32 bytes.
- The burst length is never more than 8 transfers.
- No transaction ever crosses a 32-byte boundary in memory. See *AXI transaction splitting* on page 9-16.
- FIXED bursts are never used.
- The write address channel always issues INCR type bursts, and never WRAP or FIXED.
- WRAP type read bursts, see *Linefills* on page 9-13:
  - are used only for linefills (reads) of Cacheable Normal non-shared memory
  - always have a size of 64 bits, and a length of 4 transfers
  - always have a start address that is 64-bit aligned.
- If the transfer size is 8 bits or 16 bits then the burst length is always 1 transfer.
- The transfer size is never greater than 64 bits, because it is a 64-bit AXI bus.
- Instruction fetches, identified by **ARPROT[2]**, are always a 64 bit transfer size, and never locked or exclusive.
- Transactions to Device and Strongly Ordered memory are always to addresses that are aligned for the transfer size. See *Strongly Ordered and Device transactions*.
- Exclusive and Locked accesses are always to addresses that are aligned for the transfer size.
- Write data is never interleaved.
- In addition to the above, there are various limitations to the ID values that the AXI master interface uses. See *Identifiers for AXI bus accesses* on page 9-4.

9.3.2 Strongly Ordered and Device transactions

A load or store instruction to or from Strongly Ordered or Device memory always generates AXI transactions of the same size as implied by the instruction. All accesses using `LDM`, `STM`, `LDRD`, or `STRD` instructions to Strongly Ordered or Device memory occur as 32-bit transfers.

LDRB

Table 9-4 shows the values of **ARADDRM**, **ARBURSTM**, **ARSIZEM**, and **ARLENM** for a Non-cacheable `LDRB` from bytes 0-7 in Strongly Ordered or Device memory.

Table 9-4 Non-cacheable LDRB

Address[2:0]	ARADDRM	ARBURSTM	ARSIZEM	ARLENM
`0x0` (byte 0)	`0x00`	Incr	8-bit	1 data transfer
`0x1` (byte 1)	`0x01`	Incr	8-bit	1 data transfer
`0x2` (byte 2)	`0x02`	Incr	8-bit	1 data transfer
`0x3` (byte 3)	`0x03`	Incr	8-bit	1 data transfer

Table 9-4 Non-cacheable LDRB (continued)

Address[2:0]	ARADDRM	ARBURSTM	ARSIZEM	ARLENM
0x4 (byte 4)	0x04	Incr	8-bit	1 data transfer
0x5 (byte 5)	0x05	Incr	8-bit	1 data transfer
0x6 (byte 6)	0x06	Incr	8-bit	1 data transfer
0x7 (byte 7)	0x07	Incr	8-bit	1 data transfer

LDRH

Table 9-5 shows the values of **ARADDRM**, **ARBURSTM**, **ARSIZEM**, and **ARLENM** for a Non-cacheable LDRH from halfwords 0-3 in Strongly Ordered or Device memory.

Table 9-5 LDRH from Strongly Ordered or Device memory

Address[3:0]	ARADDRM	ARBURSTM	ARSIZEM	ARLENM
0x0 (halfword 0)	0x00	Incr	16-bit	1 data transfer
0x2 (halfword 1)	0x02	Incr	16-bit	1 data transfer
0x4 (halfword 2)	0x04	Incr	16-bit	1 data transfer
0x6 (halfword 3)	0x06	Incr	16-bit	1 data transfer

Note

A load of a halfword from Strongly Ordered or Device memory addresses 0x1, 0x3, 0x5, or 0x7 generates an alignment fault.

LDR or LDM that transfers one register

Table 9-6 shows the values of **ARADDRM**, **ARBURSTM**, **ARSIZEM**, and **ARLENM** for a Non-cacheable LDR or an LDM that transfers one register, (an LDM1) in Strongly Ordered or Device memory.

Table 9-6 LDR or LDM1 from Strongly Ordered or Device memory

Address[2:0]	ARADDRM	ARBURSTM	ARSIZEM	ARLENM
0x0 (word 0)	0x00	Incr	32-bit	1 data transfer
0x4 (word 1)	0x04	Incr	32-bit	1 data transfer

Note

A load of a word from Strongly Ordered or Device memory addresses 0x1, 0x2, 0x3, 0x5, 0x6, or 0x7 generates an alignment fault.

LDM that transfers five registers

Table 9-7 shows the values of **ARADDRM**, **ARBURSTM**, **ARSIZEM**, and **ARLENM** for a Non-cacheable `LDM` that transfers five registers (an `LDM5`) in Strongly Ordered or Device memory.

Table 9-7 LDM5, Strongly Ordered or Device memory

Address[4:0]	ARADDRM	ARBURSTM	ARSIZEM	ARLENM
`0x00` (word 0)	`0x00`	Incr	32-bit	5 data transfers
`0x04` (word 1)	`0x04`	Incr	32-bit	5 data transfers
`0x08` (word 2)	`0x08`	Incr	32-bit	5 data transfers
`0x0C` (word 3)	`0x0C`	Incr	32-bit	5 data transfers

Note

A load-multiple from address `0x1`, `0x2`, `0x3`, `0x5`, `0x6`, `0x7`, `0x9`, `0xA`, `0xB`, `0xD`, `0xE`, or `0xF` generates an alignment fault.

STRB

Table 9-8 shows the values of **AWADDRM**, **AWBURSTM**, **AWSIZEM**, and **AWLENM** for an `STRB` to Strongly Ordered or Device memory over the AXI master port.

Table 9-8 STRB to Strongly Ordered or Device memory

Address[4:0]	AWADDRM	AWBURSTM	AWSIZEM	AWLENM	WSTRBM
`0x00` (byte 0)	`0x00`	Incr	8-bit	1 data transfer	b00000001
`0x01` (byte 1)	`0x01`	Incr	8-bit	1 data transfer	b00000010
`0x02` (byte 2)	`0x02`	Incr	8-bit	1 data transfer	b00000100
`0x03` (byte 3)	`0x03`	Incr	8-bit	1 data transfer	b00001000
`0x04` (byte 4)	`0x04`	Incr	8-bit	1 data transfer	b00010000
`0x05` (byte 5)	`0x05`	Incr	8-bit	1 data transfer	b00100000
`0x06` (byte 6)	`0x06`	Incr	8-bit	1 data transfer	b01000000
`0x07` (byte 7)	`0x07`	Incr	8-bit	1 data transfer	b10000000

STRH

Table 9-9 shows the values of **AWADDRM**, **AWBURSTM**, **AWSIZEM**, and **AWLENM** for an `STRH` over the AXI master port to Strongly Ordered or Device memory.

Table 9-9 STRH to Strongly Ordered or Device memory

Address[2:0]	AWADDRM	AWBURSTM	AWSIZEM	AWLENM	WSTRBM
`0x0` (halfword 0)	`0x00`	Incr	16-bit	1 data transfer	b00000011
`0x2` (halfword 1)	`0x02`	Incr	16-bit	1 data transfer	b00001100
`0x4` (halfword 2)	`0x04`	Incr	16-bit	1 data transfer	b00110000
`0x6` (halfword 3)	`0x06`	Incr	16-bit	1 data transfer	b11000000

Note

A store of a halfword to Strongly Ordered or Device memory addresses `0x1`, `0x3`, `0x5`, or `0x7` generates an alignment fault.

STR or STM of one register

Table 9-10 shows the values of **AWADDRM**, **AWBURSTM**, **AWSIZEM**, and **AWLENM** for an `STR` or an `STM` that transfers one register (an `STM1`) over the AXI master port to Strongly Ordered or Device memory.

Table 9-10 STR or STM1 to Strongly Ordered or Device memory

Address[2:0]	AWADDRM	AWBURSTM	AWSIZEM	AWLENM	WSTRBM
`0x0` (word0)	`0x00`	Incr	32-bit	1 data transfer	b00001111
`0x4` (word 1)	`0x04`	Incr	32-bit	1 data transfer	b11110000

Note

A store of a word to Strongly Ordered or Device memory addresses `0x1`, `0x2`, `0x3`, `0x5`, `0x6`, or `0x7` generates an alignment fault.

STM of seven registers

Table 9-11 shows the values of **AWADDRM**, **AWBURSTM**, **AWSIZEM**, and **AWLENM** for an `STM` that writes seven registers (an `STM7`) over the AXI master port to Strongly Ordered or Device memory.

Table 9-11 STM7 to Strongly Ordered or Device memory to word 0 or 1

Address[4:0]	AWADDRM	AWBURSTM	AWSIZEM	AWLENM	First WSTRBM
`0x00` (word 0)	`0x00`	Incr	32-bit	7 data transfers	b00001111
`0x04` (word 1)	`0x04`	Incr	32-bit	7 data transfers	b11110000

Note

A store-multiple to address `0x1`, `0x2`, `0x3`, `0x5`, `0x6`, or `0x7` generates an alignment fault.

9.3.3 Linefills

Loads and instruction fetches from Normal, Cacheable memory that do not hit in the cache generate a cache linefill when the appropriate cache is enabled. Table 9-12 shows the values of **ARADDRM**, **ARBURSTM**, **ARSIZEM**, and **ARLENM** for cache linefills.

Table 9-12 Linefill behavior on the AXI interface

Address[4:0][a]	ARADDRM	ARBURSTM	ARSIZEM	ARLENM
0x00-0x07	0x00	Wrap	64-bit	4 data transfers
0x08-0x0F	0x08	Wrap	64-bit	4 data transfers
0x10-0x17	0x10	Wrap	64-bit	4 data transfers
0x18-0x1F	0x18	Wrap	64-bit	4 data transfers

a. These are the bottom five bits of the address of the access that cause the linefill, that is, the address of the critical word.

9.3.4 Cache line write-back (eviction)

When a valid and dirty cache line is evicted from the d-cache, a write-back of the data must occur. Table 9-13 shows the values of **AWADDRM**, **AWBURSTM**, **AWSIZEM**, and **AWLENM** for cache line write-backs, over the AXI master interface.

Table 9-13 Cache line write-back

AWADDRM[4:0]	AWBURSTM	AWSIZEM	AWLENM
0x00	Incr	64-bit	4 data transfers

9.3.5 Non-cacheable reads

Load instructions accessing Non-cacheable Normal memory generate AXI bursts that are not necessarily the same size or length as the instruction implies. In addition, if the data to be read is contained in the store buffer, the instruction might not generate an AXI read transaction at all.

The tables in this section give examples of the types of AXI transaction that might result from various load instructions, accessing various addresses in Non-cacheable Normal memory. They are provided as examples only, and are not an exhaustive description of the AXI transactions. Depending on the state of the processor, and the timing of the accesses, the actual bursts generated might have a different size and length to the examples shown, even for the same instruction.

Table 9-14 shows possible values of **ARADDRM**, **ARBURSTM**, **ARSIZEM**, and **ARLENM** for an `LDRH` from bytes 0-7 in Non-cacheable Normal memory.

Table 9-14 LDRH from Non-cacheable Normal memory

Address[2:0]	ARADDRM	ARBURSTM	ARSIZEM	ARLENM
0x0 (byte 0)	0x00	Incr	16-bit	1 data transfer
0x1 (byte 1)	0x00	Incr	32-bit	1 data transfer
0x2 (byte 2)	0x00	Incr	64-bit	1 data transfer
0x3 (byte 3)	0x03	Incr	32-bit	2 data transfers

Table 9-14 LDRH from Non-cacheable Normal memory (continued)

Address[2:0]	ARADDRM	ARBURSTM	ARSIZEM	ARLENM
0x4 (byte 4)	0x04	Incr	16-bit	1 data transfer
0x5 (byte 5)	0x04	Incr	32-bit	1 data transfer
0x6 (byte 6)	0x06	Incr	16-bit	1 data transfer
0x7 (byte 7)	0x07	Incr	32-bit	2 data transfers

Table 9-15 shows possible values of **ARADDRM**, **ARBURSTM**, **ARSIZEM**, and **ARLENM** for a Non-cacheable LDR or an LDM that transfers one register, an LDM1.

Table 9-15 LDR or LDM1 from Non-cacheable Normal memory

Address[2:0]	ARADDRM	ARBURSTM	ARSIZEM	ARLENM
0x0 (byte 0) (word 0)	0x00	Incr	32-bit	1 data transfer
0x1 (byte 1)	0x01	Incr	64-bit	1 data transfer
0x2 (byte 2)	0x00	Incr	64-bit	1 data transfer
0x3 (byte 3)	0x00	Incr	64-bit	2 data transfers
0x4 (byte 4) (word 1)	0x04	Incr	32-bit	1 data transfer
0x5 (byte 5)	0x05	Incr	32-bit	2 data transfers
0x6 (byte 6)	0x06	Incr	16-bit	1 data transfer
	0x08	Incr	16-bit	1 data transfer
0x7 (byte 7)	0x04	Incr	32-bit	2 data transfers

Table 9-16 show possible values of **ARADDRM**, **ARBURSTM**, **ARSIZEM**, and **ARLENM** for a Non-cacheable LDM that transfers five registers (an LDM5).

Table 9-16 LDM5, Non-cacheable Normal memory or cache disabled

Address[4:0]	ARADDRM	ARBURSTM	ARSIZEM	ARLENM
0x00 (word 0)	0x00	Incr	64-bit	3 data transfers
0x04 (word 1)	0x04	Incr	64-bit	3 data transfers
0x08 (word 2)	0x08	Incr	64-bit	3 data transfers
0x0C (word 3)	0x0C	Incr	64-bit	3 data transfers
0x10 (word 4)	0x10	Incr	64-bit	2 data transfers
	0x00	Incr	32-bit	1 data transfer
0x14 (word 5)	0x14	Incr	64-bit	2 data transfers
	0x00	Incr	64-bit	1 data transfer

Table 9-16 LDM5, Non-cacheable Normal memory or cache disabled (continued)

Address[4:0]	ARADDRM	ARBURSTM	ARSIZEM	ARLENM
0x18 (word 6)	0x18	Incr	64-bit	1 data transfer
	0x00	Incr	64-bit	2 data transfers
0x1C (word 7)	0x1C	Incr	32-bit	1 data transfer
	0x00	Incr	64-bit	2 data transfers

9.3.6 Non-cacheable or write-through writes

Store instructions to Non-cacheable or write-through Normal memory generate AXI bursts that are not necessarily the same size or length as the instruction implies. The AXI master port asserts byte-lane-strobes, **WSTRBM[7:0]**, to ensure that only the bytes that were written by the instruction are updated.

The tables in this section give examples of the types of AXI transaction that might result from various store instructions, accessing various addresses in Non-cacheable Normal memory. They are provided as examples only, and are not an exhaustive description of the AXI transactions. Depending on the state of the processor, and the timing of the accesses, the actual bursts generated might have a different size and length to the examples shown, even for the same instruction.

In addition, write operations to Normal memory can be merged to create more complex AXI transactions. See *Normal write merging* on page 9-17 for examples.

Table 9-17 shows possible values of **AWADDRM**, **AWBURSTM**, **AWSIZEM**, and **AWLENM** for an STRH to Normal memory.

Table 9-17 STRH to Cacheable write-through or Non-cacheable Normal memory

Address[2:0]	AWADDRM	AWBURSTM	AWSIZEM	AWLENM	WSTRBM
0x0 (byte 0)	0x00	Incr	32-bit	1 data transfer	b00000011
0x1 (byte 1)	0x00	Incr	32-bit	1 data transfer	b00000110
0x2 (byte 2)	0x02	Incr	64-bit	1 data transfer	b00001100
0x3 (byte 3)	0x03	Incr	32-bit	2 data transfers	b00001000 b00010000
0x4 (byte 4)	0x04	Incr	16-bit	1 data transfer	b00110000
0x5 (byte 5)	0x05	Incr	32-bit	1 data transfer	b01100000
0x6 (byte 6)	0x06	Incr	16-bit	1 data transfer	b11000000
0x7 (byte 7)	0x07	Incr	8-bit	1 data transfer	b10000000
	0x08	Incr	8-bit	1 data transfer	b00000001

Table 9-18 shows possible values of **AWADDRM**, **AWBURSTM**, **AWSIZEM**, and **AWLENM** for an `STR` or an `STM` that transfers one register, an `STM1`, to Normal memory through the AXI master port.

Table 9-18 STR or STM1 to Cacheable write-through or Non-cacheable Normal memory

Address[2:0]	AWADDRM	AWBURSTM	AWSIZEM	AWLENM	WSTRBM
`0x0` (byte 0) (word 0)	`0x00`	Incr	32-bit	1 data transfer	b00001111
`0x1` (byte 1)	`0x01`	Incr	64-bit	1 data transfer	b00011110
`0x2` (byte 2)	`0x00`	Incr	64-bit	1 data transfer	b00111100
`0x3` (byte 3)	`0x03`	Incr	64-bit	2 data transfers	b01111000 b00000000
`0x4` (byte 4) (word 1)	`0x04`	Incr	32-bit	1 data transfer	b11110000
`0x5` (byte 5)	`0x05`	Incr	32-bit	2 data transfers	b11100000 b00000001
`0x6` (byte 6)	`0x06` `0x08`	Incr Incr	16-bit 16-bit	1 data transfer 1 data transfer	b11000000 b00000011
`0x7` (byte 7)	`0x04`	Incr	32-bit	2 data transfers	b10000000 b00000111

9.3.7 AXI transaction splitting

The processor splits AXI bursts when it accesses addresses across a cache line boundary, that is, a 32-byte boundary. An instruction which accesses memory across one or two 32-byte boundaries generates two or three AXI bursts respectively. The following examples show this behavior. They are provided as examples only, and are not an exhaustive description of the AXI transactions. Depending on the state of the processor, and the timing of the accesses, the actual bursts generated might have a different size and length to the examples shown, even for the same instruction.

For example, `LDMIA R10, {R0-R5}` loads six words from memory. The number of AXI transactions generated by this instruction depends on the base address, R10:

- If all six words are in the same cache line, there is a single AXI transaction. For example, for `LDMIA R10, {R0-R5}` with `R10 = 0x1008`, the interface might generate a burst of three, 64-bit read transfers, as shown in Table 9-19.

Table 9-19 AXI transaction splitting, all six words in same cache line

ARADDRM	ARBURSTM	ARSIZEM	ARLENM
`0x1008`	Incr	64-bit	3 data transfers

- If the data comes from two cache lines, then there are two AXI transactions. For example, for `LDMIA R10, {R0-R5}` with `R10 = 0x1010`, the interface might generate one burst of two 64-bit reads, and one burst of a single 64-bit read, as shown in Table 9-20.

Table 9-20 AXI transaction splitting, data in two cache lines

ARADDRM	ARBURSTM	ARSIZEM	ARLENM
`0x1010`	Incr	64-bit	2 data transfers
`0x1020`	Incr	64-bit	1 data transfer

Table 9-21 shows possible values of **ARADDRM**, **ARBURSTM**, **ARSIZEM**, and **ARLENM** for an `LDR` or `LDM1` to Non-cacheable Normal memory that crosses a cache line boundary.

Table 9-21 Non-cacheable LDR or LDM1 crossing a cache line boundary

Address[4:0]	ARADDRM	ARBURSTM	ARSIZEM	ARLENM
`0x1D` (byte 29)	`0x1C`	Incr	32-bit	1 data transfer
	`0x00`	Incr	32-bit	1 data transfer
`0x1E` (byte 30)	`0x1E`	Incr	16-bit	1 data transfer
	`0x00`	Incr	64-bit	1 data transfer
`0x1F` (byte 31)	`0x1F`	Incr	8-bit	1 data transfer
	`0x00`	Incr	32-bit	1 data transfer

Table 9-22 shows possible values of **ARADDRM**, **ARBURSTM**, **ARSIZEM**, and **ARLENM** for an `STRH` to Non-cacheable Normal memory that crosses a cache line boundary.

Table 9-22 Cacheable write-through or Non-cacheable STRH crossing a cache line boundary

Address[4:0]	AWADDRM	AWBURSTM	AWSIZEM	AWLENM	WSTRBM
`0x1F` (byte 31)	`0x1F`	Incr	8-bit	1 data transfer	b10000000
	`0x00`	Incr	16-bit	1 data transfer	b00000001

9.3.8 Normal write merging

A store instruction to Non-cacheable, or write-through Normal memory might not result in an AXI transfer because of the merging of store data in the internal buffers.

The STB can detect when it contains more than one write request to the same cache line for write-through Cacheable or Non-cacheable Normal memory. This means it can combine the data from more than one instruction into a single write burst to improve the efficiency of the AXI port. If the AXI master receives several write requests that do not form a single contiguous burst it can choose to output a single burst, with the **WSTRBW** signal low for the bytes that do not have any data.

For write accesses to Normal memory, the STB can perform writes out of order, if there are no address dependencies. It can do this to best use its ability to merge accesses.

The instruction sequence in Example 9-1 on page 9-18 shows the merging of writes.

Example 9-1 Write merging

```
MOV r0, #0x4000
STRH  r1, [r0, #0x18]; Store a halfword at 0x4018
STR   r2, [r0, #0xC] ; Store a word at 0x400C
STMIA r0, {r4-r7}    ; Store four words at 0x4000
STRB  r3, [r0, #0x1D]; Store a byte at 0x401D
```

If the memory at address `0x4000` is marked as Strongly Ordered or Device type memory, the AXI transactions shown in Table 9-23 are generated.

Table 9-23 AXI transactions for Strongly Ordered or Device type memory

AWADDRM	AWBURSTM	AWSIZEM	AWLENM	WSTRBM
`0x4018`	Incr	16-bit	1 data transfer	0b00000011
`0x400C`	Incr	32-bit	1 data transfer	0b11110000
`0x4000`	Incr	32-bit	4 data transfers	0b00001111 0b11110000 0b00001111 0b11110000
`0x401D`	Incr	8-bit	1 data transfer	0b00100000

In the example above, each store instruction produces an AXI burst of the same size as the data written by the instruction.

Table 9-24 shows a possible resulting transaction if the same memory is marked as Non-cacheable Normal, or Cacheable write-through.

Table 9-24 AXI transactions for Non-cacheable Normal or Cacheable write-through memory

AWADDRM	AWBURSTM	AWSIZEM	AWLENM	WSTRBM
`0x4000`	Incr	64-bit	4 data transfers	0b11111111 0b11111111 0b00000000 0b00100011

In this example:

- The store buffer has merged the `STRB` and `STRH` writes into one buffer entry, and therefore a single AXI transfer, the fourth in the burst.
- The writes, which occupy three buffer entries, have been merged into a single AXI burst of four transfers.
- The write generated by the `STR` instruction has not occurred, because it was overwritten by the `STM` instruction.
- The write transfers have occurred out of order with respect to the original program order.

The transactions shown in Table 9-24 on page 9-18 show this behavior. They are provided as examples only, and are not an exhaustive description of the AXI transactions. Depending on the state of the processor, and the timing of the accesses, the actual bursts generated might have a different size and length to the examples shown, even for the same instruction.

If the same memory is marked as write-back Cacheable, and the addresses are allocated into a cache line, no AXI write transactions occur until the cache line is evicted and performs a write-back transaction. See *Cache line write-back (eviction)* on page 9-13.

9.4 AXI slave interface

The processor has a single AXI slave interface, with one port. The port is 64 bits wide and conforms to the AXI standard as described in the *AMBA AXI Protocol Specification*. Within the AXI standard, the slave port uses the **AWUSERS** and **ARUSERS** each as four separate chip select input signals to enable access to:

- BTCM
- ATCM
- instruction cache RAMs
- data cache RAMs.

The external AXI system must generate the chip select signals. The slave interface routes the access to the required RAM.

In addition, the AXI slave interface produces or checks parity bits for each AXI channel. These additional signals are not part of the AXI specification. See the *Cortex-R4 and Cortex-R4F Integration Manual* for more information.

The slave interface can run at the same frequency as the processor or at a lower, synchronous frequency. See *AXI interface clocking* on page 3-9 for more information. If asynchronous clocking is required an external asynchronous AXI register slice is required.

The AXI slave provides access to the TCMs and competes for access to the TCMs with the LSU and PFU. Both the LSU and PFU normally have a higher priority than the AXI slave.

If two BTCM ports are used, you can configure these to interleave in the address map, so any AXI slave access that is denied access to the BTCM on the first cycle of the access gains access on the second cycle when the LSU is using the other port, and can continue in lock-step with the LSU, assuming both are accessing sequential data. Accesses to the ATCM are more likely to encounter a conflict because there is only one port on the interface.

Memory BIST ports are routed through the AXI slave interface logic, to access the RAMs. Memory BIST access is assumed only to occur when no other accesses are taking place, and takes highest priority.

9.4.1 AXI slave interface for cache RAMs

You can use the AXI slave for software testing of the cache RAMs in functional mode. When the AXI slave is enabled to access the RAMs, the processor considers the caches as cache-off, so that the instruction and data requests cannot interact with AXI slave requests. AXI slave requests access the cache RAMs. Instruction and data requests are considered as Non-cacheable and do not perform any lookup in the caches.

The AXI slave interface accesses each cache RAM individually.

On the instruction cache side the AXI slave can access:

- data cache RAMs, data and parity or ECC code bits
- tag RAMs, tag and parity or ECC code bits.

On the data cache side, the AXI slave can access:

- data cache RAMs, data and parity or ECC code bits
- tag RAMs, tag and parity or ECC code bits
- dirty RAM, dirty bit and attributes, and ECC code bits.

A simple decode of two address bits and four way address bits determines which of the data, tag, or dirty RAMs is accessed within the caches. The AXI access is given a SLVERR error response when access to nonexistent cache RAM is indicated.

9.4.2 TCM parity and ECC support

The TCMs can support parity or ECC, as described in *TCM internal error detection and correction* on page 8-14. If a write transaction is issued to the AXI slave, the slave interface calculates the required parity or ECC bits to store to the TCM. ECC schemes require the AXI slave to perform a read-modify-write sequence if the write data width is smaller than the ECC chunk size.

If a read transaction is issued to the AXI slave, the slave interface reads the parity or ECC bits and, if error checking is enabled for the appropriate TCM, checks the data for errors. If the interface detects a correctable error, it corrects it inline and returns the correct data on the AXI bus. It does not update the data in the TCM to correct it. If the interface detects an uncorrectable error, it generates a SLVERR error response to the AXI transaction.

9.4.3 External TCM errors

If an error response is given to a TCM access from the AXI slave interface, and external errors are enabled for the appropriate TCM port, the AXI slave returns a SLVERR response to the AXI transaction.

The AXI slave ignores late-error and retry responses from the TCM.

9.4.4 Cache parity and ECC support

When the caches support parity or ECC, the AXI slave interface can read and write the parity or ECC code bits directly. No errors are detected automatically, and on writes the AXI slave does not automatically generate the correct parity or ECC code values.

Note

The AXI slave interface provides read/write access to the cache RAMs for functional test. It is not suitable for preloading the caches.

9.4.5 AXI slave control

By default, both privileged and non-privileged accesses can be made to the Cortex-R4 TCM RAMs through the AXI slave port. To disable non-privileged accesses, you can set bit [1] in the Slave Port Control Register. You can disable all slave accesses by setting bit [0] of the register. See *c11, Slave Port Control Register* on page 4-59.

Access to the cache RAMs can only be made when bit [24] of the Auxiliary Control Register is set. By default, only privileged accesses can be made to the cache RAMs, but you can enable non-privileged accesses by setting bit [23] of the Auxiliary Control Register. When cache RAM access is enabled, both caches are treated as if they were not enabled. See *Auxiliary Control Registers* on page 4-38.

The AXI access is given a SLVERR error response when access is not permitted.

9.4.6 AXI slave characteristics

This section describes the capabilities of the AXI slave interface, and the attributes of its AXI port. You must not make any other assumptions about the behavior of the AXI slave port except that it conforms to the *AMBA AXI Protocol Specification*.

- The AXI slave interface supports merging of data. When handling an AXI burst of data less than 64-bits wide, the AXI slave interface attempts to perform the minimum number of TCM accesses required to read or write the data. When an ECC error scheme is in use, this sometimes reduces the number of read-modify-write sequences that the AXI slave must perform.
- The AXI slave interface does not support:
  - Security Extensions, all accesses are secure, so **AxPROT**[1] is not used
  - data and instruction transaction signaling, so **AxPROT**[2] is not used
  - memory type and cacheability, so **AxCACHE** is not used
  - atomic accesses. The AXI slave accepts locked transactions but makes no use of the locking information, that is, **AxLOCK**.
- The AXI slave interface has no exclusive access monitor. If there are any exclusive accesses, the AXI slave interface responds with an OKAY response.
- The width of the ID signals for the AXI slave port is 8 bits.

  You must avoid building the processor into an AXI system that requires more than 8 bits of ID. The number of bits of ID required by a system can often be reduced by compressing the encoding to remove unused values. The AXI master port does not use all possible values. See *Identifiers for AXI bus accesses* on page 9-4 for details.

Table 9-25 shows the AXI slave port attributes.

Table 9-25 AXI slave interface attributes

Attribute	Value	Comments
Combined acceptance capability	7	-
Write interleave depth	1	All write data must be presented to the AXI slave interface in order
Read data reorder depth	1	The AXI slave interface returns all read data in order, even if the bursts have different IDs

9.5 Enabling or disabling AXI slave accesses

This section describes how to enable or disable AXI slave accesses to the cache RAMs. When caches are accessible by the AXI slave interface, the caches are considered to be cache-off from the processor. After turning the interface on or off, an ISB instruction must flush the pipeline so that all subsequent instruction fetches return valid data.

The following code is an example of enabling AXI slave accesses to the cache RAMs:

```
MRC p15, 0, R1, c1, c0, 1  ; Read Auxiliary Control Register
ORR R1, R1, #0x1 <<24
DSB
MCR p15, 0, R1, c1, c0, 1  ; enabled AXI slave accesses to the cache RAMs
ISB
; Clean entire data cache. This routine will depend on the data cache size. It can be
omitted if it is known that the data cache has no dirty data
Fetch from uncached memory
Fetch from uncached memory
Fetch from uncached memory
Fetch from uncached memory
```

The following code is an example of disabling AXI slave accesses to the cache RAMs. No cache invalidation is performed because it is assumed that, after accessing the cache RAMs, the AXI slave interface restored the previously valid data to them.

```
MRC p15, 0, R1, c1, c0, 1    ; Read Auxiliary Control Register
BIC R1, R1, #0x1 <<24
DSB
MCR p15, 0, R1, c1, c0, 1    ; disabled AXI slave accesses to the cache RAMs
ISB
Fetch from cached memory
Fetch from cached memory
Fetch from cached memory
Fetch from cached memory
```

9.6 Accessing RAMs using the AXI slave interface

This section describes how to access the TCM and cache RAMs using the AXI slave interface.

Table 9-26 shows the bits of the **ARUSERS** or **AWUSERS** inputs to use to access RAM or a group of RAMs. Each bit is a one-hot 4-bit input, with each bit corresponding to a particular RAM or group of RAMs.

Table 9-26 RAM region decode

AxUSERS bit	One-hot RAM select
[3]	Data cache RAMs
[2]	Instruction cache RAMs
[1]	B0TCM and B1TCM
[0]	ATCM

For the caches and the BTCMs, more decoding is performed depending on the address of the request, **ARADDRS** for reads and **AWADDRS** for writes. For more information see:

- *TCM RAM access* on page 9-25
- *Cache RAM access* on page 9-26.

Note

Because **AWUSERS** and **AWADDRS** work in the same way as **ARUSERS** and **ARADDRS**, the following sections only describe **ARUSERS** and **ARADDRS**.

9.6.1 TCM RAM access

Table 9-27 shows the decode of the **ARUSERS[3:0]** signal, and the state of the address signals for accessing the TCM RAMs. The table also shows the **SLBTCMSB** configuration input signal that determines the address bit that is used, either:

- **ARADDRS[3]**
- **ARADDRS[MSB]**, see Table 9-28.

Table 9-27 TCM chip-select decode

BTCM ports	ARUSERS[3:0]	ARADDRS[3]	ARADDRS[MSB]	SLBTCMSB	RAM selected
Don't care	0001	-	-	-	ATCM
1	0010	-	-	-	B0TCM
2	0010	0	-	0	B0TCM
2	0010	1	-	0	B1TCM
2	0010	-	0	1	B0TCM
2	0010	-	1	1	B1TCM

In Table 9-27 **ARADDRS[MSB]** means the most significant address bit for the TCM RAM, and Table 9-28 shows the MSB bit for the different TCM RAM sizes.

Table 9-28 MSB bit for the different TCM RAM sizes

TCM size	ARADDRS[MSB]
4KB	[11]
8KB	[12]
16KB	[13]
32KB	[14]
64KB	[15]
128KB	[16]
256KB	[17]
512KB	[18]
1MB	[19]
2MB	[20]
4MB	[21]
8MB	[22]

ARADDRS[22:3] indicates the address of the doubleword within the TCM that you want to access. If you are accessing a TCM that is smaller than the maximum 8MB, then it is possible to address a doubleword that is outside of the physical size of the TCM.

An access to the TCM RAMs is given a SLVERR error response if:

- It is outside the physical size of the targeted TCM RAM, that is, bits of **ARADDRS[22:MSB+1]** are non-zero.

- There is no TCM present. The mapping of bus addresses to **ARUSERS** and **ARADDRS** is determined when the processor is integrated. You must understand this mapping to use of the AXI-slave interface within your system.

9.6.2 Cache RAM access

This section contains the following:

- *Memory map when accessing the cache RAMs*
- *Data RAM access* on page 9-27
- *Tag RAM access* on page 9-29
- *Dirty RAM access* on page 9-31.
- *Other examples of accessing cache RAMs* on page 9-32

Memory map when accessing the cache RAMs

The memory maps for the data and instruction caches have the same format. Because the instruction cache does not have a dirty RAM, accesses to it generate the SLVERR error response.

Table 9-29, Table 9-30, and Table 9-31 on page 9-27 show the chip-select decodes for selecting the cache RAMs in the processor.

Table 9-29 Cache RAM chip-select decode

Inputs		RAM selected
ARUSERS[3:0]	**ARADDRS[22:19]**	
0100	0000	Instruction cache data RAM
0100	0001	Instruction cache tag RAM
0100	0010	Not used, generates an error
0100	0011	Not used, generates an error
0100	**ARADDRS[22:21]** != 00	Not used, generates an error
1000	0000	Data cache data RAM
1000	0001	Data cache tag RAM
1000	0010	Data cache dirty RAM
1000	0011	Not used, generates an error
1000	**ARADDRS[22:21]** != 00	Not used, generates an error

Table 9-30 Cache tag/valid RAM bank/address decode

Inputs	RAM bank selected	Cache way
ARADDRS[18:15]		
0001	Bank 0	0

Table 9-30 Cache tag/valid RAM bank/address decode (continued)

Inputs ARADDRS[18:15]	RAM bank selected	Cache way
0010	Bank 1	1
0100	Bank 2	2
1000	Bank 3	3

Table 9-31 Cache data RAM bank/address decode

Inputs ARADDRS[18:15]	ARADDRS[3]	RAM bank selected
0001	0	Bank 0
0001	1	Bank 1
0010	0	Bank 2
0010	1	Bank 3
0100	0	Bank 4
0100	1	Bank 5
1000	0	Bank 6
1000	1	Bank 7

Note

You can only access the cache RAMs using 32-bit or 64-bit AXI transfers. Using an 8-bit or a 16-bit transfer size generates a SLVERR error response.

Data RAM access

The following tables shows the data formats for cache data RAM accesses:

- Table 9-32 shows the format when neither parity nor ECC is implemented
- Table 9-33 on page 9-28 shows the format when parity is implemented
- Table 9-34 on page 9-28 shows the instruction cache format when ECC is implemented
- Table 9-35 on page 9-28 shows the data cache format when ECC is implemented.

Table 9-32 Data format, instruction cache and data cache, no parity and no ECC

Data bit	Description
[63:48]	Not used, read-as-zero
[47:32]	Data value, [31:16] or [63:48]
[31:16]	Not used, read-as-zero
[15:0]	Data value, [15:0] or [47:32]

Table 9-33 Data format, instruction cache and data cache, with parity

Data bit	Description
[63:50]	Not used, read-as-zero
[49]	Parity bit for data value [31:24] or [63:56]
[48]	Parity bit for data value [23:16] or [55:48]
[47:32]	Data value, [31:16] or [63:48]
[31:18]	Not used, read-as-zero
[17]	Parity bit for data value [15:8] or [47:40]
[16]	Parity bit for data value [7:0] or [39:32]
[15:0]	Data value, [15:0] or [47:32]

Table 9-34 Data format, instruction cache, with ECC

Data bit	Description
[63:52]	Not used, read-as-zero
[51:48]	Upper or lower half of the ECC 64 code[a]
[47:32]	Data value, [31:16] or [63:48]
[31:20]	Not used, read-as-zero
[19:16]	Upper or lower half of the ECC 64 code[b]
[15:0]	Data value, [15:0] or [47:32]

a. If accessing bits [31:16] of the data, bits [51:48] hold the lower half of the ECC code. If accessing bits [63:48] of the data, bits [51:48] hold the upper half of the ECC code.
b. If accessing bits [15:0] of the data, bits [19:16] hold the lower half of the ECC code. If accessing bits [47:32] of the data, bits [19:16] hold the upper half of the ECC code.

Table 9-35 Data format, data cache, with ECC

Data bit	Description
[63:55]	Not used, read-as-zero
[54:48]	ECC 32 code[a]
[47:32]	Data value, [31:16] or [63:48]
[31:23]	Not used, read-as-zero
[22:16]	ECC 32 code
[15:0]	Data value [15:0] or [47:32]

a. For a 64 bit access, the ECC bits are duplicated in bits [22:16] and bits [54:48], and the two copies are identical. For a 32 bit access, the ECC bits refer to the whole 32 bit data value, even though only 16 bits of data are accessed.

Tag RAM access

The following tables show the data formats for tag RAM accesses:

- Table 9-36 shows the format for read accesses when neither parity nor ECC is implemented
- Table 9-37 shows the format for read accesses when parity is implemented
- Table 9-38 shows the format for read accesses when ECC is implemented
- Table 9-39 on page 9-30 shows the format for write accesses when neither parity nor ECC is implemented
- Table 9-40 on page 9-30 shows the format for write accesses when parity is implemented
- Table 9-41 on page 9-30 shows the format for write accesses when ECC is implemented.

Table 9-36 Tag register format for reads, no parity or ECC

Data bit	Description
[63:55]	Not used, read-as-zero
[54]	Valid, way 2/3
[53:32]	Tag value, way 2/3
[31:23]	Not used, read-as-zero
[22]	Valid, way 0/1
[21:0]	Tag value, way 0/1

Table 9-37 Tag register format for reads, with parity

Data bit	Description
[63:56]	Not used, read-as-zero
[55]	Parity, way 2/3
[54]	Valid, way 2/3
[53:32]	Tag value, way 2/3
[31:24]	Not used, read-as-zero
[23]	Parity, way 0/1
[22]	Valid, way 0/1
[21:0]	Tag value, way 0/1

Table 9-38 Tag register format for reads, with ECC

Data bit	Description
[63:62]	Not used, read-as-zero
[61:55]	ECC, way 2/3
[54]	Valid, way 2/3
[53:32]	Tag value, way 2/3

Table 9-38 Tag register format for reads, with ECC (continued)

Data bit	Description
[31:30]	Not used, read-as-zero
[29:23]	ECC, way 0/1
[22]	Valid, way 0/1
[21:0]	Tag value, way 0/1

Table 9-39 Tag register format for writes, no parity or ECC

Data bit	Description
[63:23]	Not used, read-as-zero
[22]	Valid, all ways
[21:0]	Tag value, all ways

Table 9-40 Tag register format for writes, with parity

Data bit	Description
[63:24]	Not used, read-as-zero
[23]	Parity. all ways
[22]	Valid, all ways
[21:0]	Tag value, all ways

Table 9-41 Tag register format for writes, with ECC

Data bit	Description
[63:30]	Not used, read-as-zero
[29:23]	ECC, all ways
[22]	Valid, all ways
[21:0]	Tag value, all ways

Note

For tag RAM writes, only bits [23:0] of the data bus are used. If two tag RAMs are written at the same time, they are both written with the same data. To write only one tag RAM using the AXI Slave, select only one RAM with bits [18:15] of the address bus.

Dirty RAM access

The following tables show the data format for accessing the dirty RAM:

- Table 9-42 shows the format when parity is implemented, or no error scheme is implemented
- Table 9-43 shows the format when ECC is implemented.

Table 9-42 Dirty register format, with parity or with no error scheme

Data bit	Description
[63:27]	Not used, read-as-zero
[26:25]	Outer attributes, way 3
[24]	Dirty value, way 3
[23:19]	Not used, read-as-zero
[18:17]	Outer attributes, way 2
[16]	Dirty value, way 2
[15:11]	Not used, read-as-zero
[10:9]	Outer attributes, way 1
[8]	Dirty value, way 1
[7:3]	Not used, read-as-zero
[2:1]	Outer attributes, way 0
[0]	Dirty value, way 0

Note

When parity checking is enabled, all Cacheable accesses are forced to write-through. Therefore the dirty RAM is not used and does not require parity protection.

Table 9-43 Dirty register format, with ECC

Data bit	Description
[63:31]	Not used, read-as-zero
[30:27]	ECC, way 3
[26:25]	Outer attributes, way 3
[24]	Dirty value, way 3
[23]	Not used, read-as-zero
[22:19]	ECC, way 2
[18:17]	Outer attributes, way 2
[16]	Dirty value, way 2
[15]	Not used, read-as-zero

Table 9-43 Dirty register format, with ECC (continued)

Data bit	Description
[14:11]	ECC, way 1
[10:9]	Outer attributes, way 1
[8]	Dirty value, way 1
[7]	Not used, read-as-zero
[6:3]	ECC, way 0
[2:1]	Outer attributes, way 0
[0]	Dirty value, way 0

Other examples of accessing cache RAMs

Normally **ARADDRS[18:15]** is a one-hot field, and only accesses one RAM at a time.

However, if you want to access two tag RAMs, such as banks 0 and 2 or banks 1 and 3 at the same time, use:

- **ARADDRS[18:15]** = 4'b0101 to access banks 0 and 2
- **ARADDRS[18:15]** = 4'b1010 to access banks 1 and 3.

This enables data to be read from two tag RAMs simultaneously, and the same data to be written to two tag RAMs simultaneously. To write different data to each tag RAM, you must ensure only one tag RAM is accessed at a time.

You can access any combination of dirty RAM banks simultaneously. For example, to access all dirty RAM banks use:

ARADDRS[18:15] = 4'b1111.

If you break these rules, for example if you access tag RAM banks 0 and 1, no SLVERR response is generated, and any attempt to read or write banks in other combinations or multiple banks of other RAMs is Unpredictable.

Note

If you attempt to read or write cache RAMs outside the physical cache size implemented, the MSBs for that read or write access are ignored. For example, accessing `0x10000000` or `0x00000000` addresses in the cache RAM accesses the same physical location `0x0`. This means that such accesses are aliased and no errors are generated.

Chapter 10
Power Control

This chapter describes the processor power control functions. It contains the following sections:

10.1 About power control

The features of the processor that improve energy efficiency include:

- branch and return prediction, reducing the number of incorrect instruction fetch and decode operations
- the caches use sequential access information to reduce the number of accesses to the tag RAMs and to unwanted data RAMs.

In the processor, extensive use is also made of gated clocks and gates to disable inputs to unused functional blocks. Only the logic actively in use to perform a calculation consumes any dynamic power.

10.2 Power management

The processor supports four levels of power management. This section describes:

- *Run mode*
- *Standby mode*
- *Dormant mode*
- *Shutdown mode*
- *Communication to the Power Management Controller* on page 10-4.

10.2.1 Run mode

Run mode is the normal mode of operation where all of the functionality of the processor is available.

10.2.2 Standby mode

Standby mode disables most of the clocks of the device, while keeping the design powered up. This reduces the power drawn to the static leakage current, plus a tiny clock power overhead required to enable the device to wake up from the Standby mode.

The transition from Standby mode to Run mode is caused by:

- the arrival of an interrupt, whether masked or unmasked
- a debug request, whether debug is enabled or disabled
- a reset.

The debug request can be generated by an externally generated debug request, using the **EDBGRQ** pin on the processor, or from a Debug Halt instruction issued to the processor through the debug *Advanced Peripheral Bus* (APB).

Entry into Standby mode is performed by executing the *Wait For Interrupt* (`WFI`) instruction. To ensure that the entry into the Standby mode does not affect the memory system, the `WFI` automatically performs a Data Synchronization Barrier operation. This ensures that all explicit memory accesses occur in program order before the `WFI` has completed.

Systems using the VIC interface must ensure that the VIC is not masking any interrupts that are required for restarting the processor when in this mode of operation.

When the processor clocks are stopped the **STANDBYWFI** signal is asserted to indicate that the processor is in Standby mode.

When the processor is in Standby mode and the AXI slave interface receives a transaction, the processor clocks are temporarily restarted and **STANDBYWFI** is deasserted to enable it to service the transaction, but it does not return to Run mode.

10.2.3 Dormant mode

Dormant mode ensures that only the processor logic, but not the processor TCM and cache RAMs, is powered down. In dormant mode, the processor state, apart from the cache and TCM state, is stored to memory before entry into this mode, and restored after exit. For more information on how to implement and use dormant mode in your design, contact ARM.

10.2.4 Shutdown mode

Shutdown mode has the entire device powered down, and you must externally save all state, including cache and TCM state. The processor is returned to Run mode by asserting and deasserting **nRESET**. When you perform state saving, you must ensure that interrupts are

disabled and finish with a Data Synchronization Barrier operation. When all the state of the processor is saved the processor executes a `WFI` instruction. The **STANDBYWFI** signal is asserted to indicate that the processor can enter Shutdown mode.

10.2.5 Communication to the Power Management Controller

You can use a *Power Management Controller* (PMC) to control the powering up and powering down of the processor. The communication mechanism between the processor and the PMC is a memory-mapped controller that is accessed by the processor performing Strongly-Ordered accesses to it.

The **STANDBYWFI** signal from the processor informs the PMC of the powerdown mode to adopt.

The **STANDBYWFI** signal can also signal that the processor is ready to have its power state changed. **STANDBYWFI** is asserted in response to a `WFI` operation.

Chapter 11
Debug

This chapter describes the processor debug unit. These features assist the development of application software, operating systems, and hardware. This chapter contains the following sections:

11.1 Debug systems

The Cortex-R4 processor is one component of a debug system. Figure 11-1 shows a typical system.

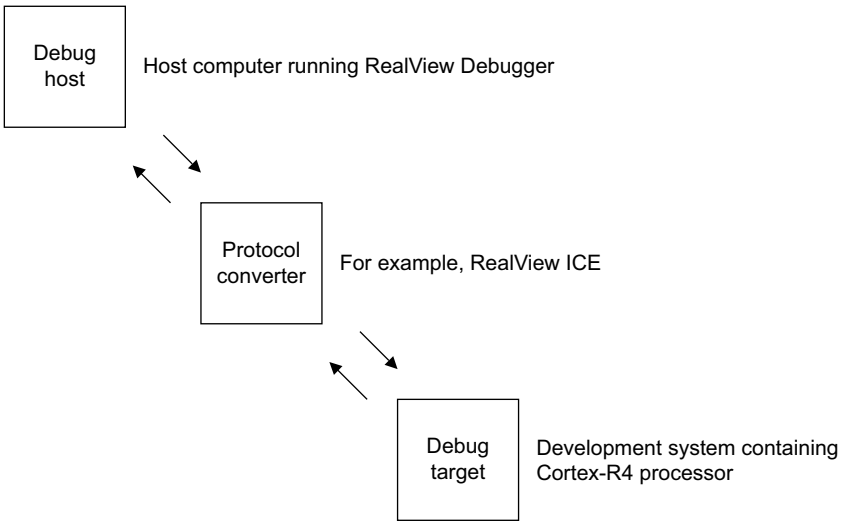


Figure 11-1 Typical debug system

This typical system has three parts, described in the following sections:

- *Debug host*
- *Protocol converter*
- *Debug target*.

11.1.1 Debug host

The debug host is a computer, for example a personal computer, running a software debugger such as RealView™ Debugger. The debug host enables you to issue high-level commands such as setting breakpoint at a certain location, or examining the contents of a memory address.

11.1.2 Protocol converter

The debug host connects to the processor development system using an interface such as Ethernet. The messages broadcast over this connection must be converted to the interface signals of the debug target. A protocol converter performs this function, for example, RealView ICE.

11.1.3 Debug target

The debug target is the lowest level of the system. An example of a debug target is a development system with a Cortex-R4 test chip or a silicon part with a Cortex-R4 macrocell.

The debug target must implement some system support for the protocol converter to access the processor debug unit using the *Advanced Peripheral Bus* (APB) slave port.

The debug unit enables you to:

- stall program execution
- examine the internal state of the processor and the state of the memory system
- resume program execution.

11.2 About the debug unit

The processor debug unit assists in debugging software running on the processor. You can use the processor debug unit, in combination with a software debugger program, to debug:

- application software
- operating systems
- ARM processor-based hardware systems.

The debug unit enables you to:

- stop program execution
- examine and alter processor state
- examine and alter memory and peripheral state
- restart the processor.

You can debug software running on the processor in the following ways:

- Halting debug-mode debugging
- Monitor debug-mode debugging
- Trace debugging, see *ETM interface* on page 1-11.

The processor debug unit conforms to the ARMv7 debug architecture. For more information see the *ARM Architecture Reference Manual*.

11.2.1 Halting debug-mode debugging

When the processor debug unit is in Halting debug-mode, the processor halts when a debug event, such as a breakpoint, occurs. When the processor is halted, an external debugger can examine and modify the processor state using the APB slave port. This debug mode is invasive to program execution.

11.2.2 Monitor debug-mode debugging

When the processor debug unit is in Monitor debug-mode, the processor takes a debug exception instead of halting. A special piece of software, a monitor target, can then take control to examine or alter the processor state. Monitor debug-mode is essential in real-time systems where the processor cannot be halted to collect information. Examples of these systems are engine controllers and servo mechanisms in hard drive controllers that cannot stop the code without physically damaging the components.

When debugging in Monitor debug-mode, the processor stops execution of the current program and starts execution of a monitor target. The state of the processor is preserved in the same manner as all ARM exceptions. The monitor target communicates with the debugger to access processor and coprocessor state, and to access memory contents and peripherals. Monitor debug-mode requires a debug monitor program to interface between the debug hardware and the software debugger.

11.2.3 Programming the debug unit

The processor debug unit is programmed using the APB slave interface. See Table 11-3 on page 11-6 for a complete list of memory-mapped debug registers accessible using the APB slave interface. Some features of the debug unit that you can access using the memory-mapped registers are:

- instruction address comparators for triggering breakpoints, see *Breakpoint Value Registers* on page 11-23 and *Breakpoint Control Registers* on page 11-23

- data address comparators for triggering watchpoints, see *Watchpoint Value Registers* on page 11-26 and *Watchpoint Control Registers* on page 11-26
- a bidirectional *Debug Communication Channel* (DCC), see *Debug communications channel* on page 11-55
- all other state information associated with the debug unit.

11.3 Debug register interface

You can access the processor debug register map using the APB slave port. This is the only way to get full access to the processor debug capability. ARM recommends that if your system requires the processor to access its own debug registers, you choose a system interconnect structure that enables the processor to access the APB slave port by executing load and stores to an appropriate area of physical memory.

This section describes:

- *Coprocessor registers*
- *CP14 access permissions*
- *Coprocessor registers summary*
- *Memory-mapped registers* on page 11-6
- *Memory addresses for breakpoints and watchpoints* on page 11-7
- *Power domains* on page 11-8
- *Effects of resets on debug registers* on page 11-8
- *APB port access permissions* on page 11-8.

11.3.1 Coprocessor registers

Although most of the processor debug registers are accessible through the memory-mapped interface, there are several registers that you can access through a coprocessor interface. This is important for boot-strap access to the register file. It enables software running on the processor to identify the debug architecture version that the device implements.

11.3.2 CP14 access permissions

By default, you can access all CP14 debug registers from a nonprivileged mode. However, you can program the processor to disable user-mode access to all coprocessor registers using bit [12] of the DSCR, see *CP14 c1, Debug Status and Control Register* on page 11-14 for more information. CP14 debug registers accesses are always permitted when the processor is in debug state regardless of the processor mode.

Table 11-1 shows access to the CP14 debug registers.

Table 11-1 Access to CP14 debug registers

Debug state	Processor mode	DSCR[12]	CP14 debug access
Yes	X	X	Permitted
No	User	b0	Permitted
No	User	b1	Not permitted[a]
No	Privileged	X	Permitted

a. Instructions attempting to access CP14 registers cause the processor to take an Undefined exception.

11.3.3 Coprocessor registers summary

Table 11-2 on page 11-6 shows a set of valid CP14 instructions for accessing the debug registers. All CP14 instructions not listed are Undefined.

Note

The CP14 debug instructions are defined as having Opcode_1 set to 0.

Table 11-2 CP14 debug registers summary

Instruction	Mnemonic	Description
`MRC p14, 0, <Rd>, c0, c0, 0`	DIDR	Debug Identification Register. See *CP14 c0, Debug ID Register* on page 11-10.
`MRC p14, 0, <Rd>, c1, c0, 0`	DRAR	Debug ROM Address Register. See *CP14 c0, Debug ROM Address Register* on page 11-12.
`MRC p14, 0, <Rd>, c2, c0, 0`	DSAR	Debug Self Address Register. See *CP14 c0, Debug Self Address Offset Register* on page 11-12.
`MRC p14, 0, <Rd>, c0, c5, 0` `STC p14, c5, <addressing mode>`	DTRRX	Host to Target Data Transfer Register. See *Data Transfer Register* on page 11-18.
`MCR p14, 0, <Rd>, c0, c5, 0` `LDC p14, c5, <addressing mode>`	DTRTX	Target to Host Data Transfer Register. See *Data Transfer Register* on page 11-18.
`MRC p14, 0, <Rd>, c0, c1, 0` `MRC p14, 0, PC, c0, c1, 0`	DSCR	Debug Status and Control Register. See *CP14 c1, Debug Status and Control Register* on page 11-14.

11.3.4 Memory-mapped registers

Table 11-3 shows the complete list of memory-mapped registers accessible at the APB slave interface.

Note

You must ensure that the base address of this 4KB register map is aligned to a 4KB boundary in physical memory.

Table 11-3 Debug memory-mapped registers

Offset (hex)	Register number	Access	Mnemonic	Description
`0x000`	c0	R	DIDR	*CP14 c0, Debug ID Register* on page 11-10
`0x004-0x014`	c1-c5	R	-	RAZ
`0x18`	c6	RW	WFAR	*Watchpoint Fault Address Register* on page 11-19
`0x01C`	c7	RW	VCR	*Vector Catch Register* on page 11-19
`0x020`	c8	R	-	RAZ
`0x024`	c9	RW	ECR	Not implemented in this processor. Reads as zero.
`0x028`	c10	RW	DSCCR	*Debug State Cache Control Register* on page 11-21.
`0x02C`	c11	R	-	RAZ
`0x030-0x07C`	c12-c31	R	-	RAZ

Table 11-3 Debug memory-mapped registers (continued)

Offset (hex)	Register number	Access	Mnemonic	Description
0x080	c32	RW	DTRRX	*Data Transfer Register* on page 11-18
0x084	c33	W	ITR	*Instruction Transfer Register* on page 11-21
0x088	c34	RW	DSCR	*CP14 c1, Debug Status and Control Register* on page 11-14
0x08C	c35	RW	DTRTX	*Data Transfer Register* on page 11-18
0x090	c36	W	DRCR	*Debug Run Control Register* on page 11-22
0x094-0x0FC	c37-c63	R	-	RAZ
0x100-0x11C	c64-c71	RW	BVR	*Breakpoint Value Registers* on page 11-23
0x120-0x13C	c72-c79	R	-	RAZ
0x140-0x15C	c80-c87	RW	BCR	*Breakpoint Control Registers* on page 11-23
0x160-0x17C	c88-c95	R	-	RAZ
0x180-0x19C	c96-c103	RW	WVR	*Watchpoint Value Registers* on page 11-26
0x1A0-0x1BC	c104-c111	R	-	RAZ
0x1C0-0x1DC	c112-c119	RW	WCR	*Watchpoint Control Registers* on page 11-26
0x1E0-0x1FC	c120-c127	R	-	RAZ
0x200-0x2FC	c128-c191	R	-	RAZ
0x300	c192	R	OSLAR	Not implemented in this processor. Reads as zero.
0x304	c193	R	OSLSR	*Operating System Lock Status Register* on page 11-28
0x308	c194	R	OSSRR	Not implemented in this processor. Reads as zero.
0x30C	c195	R	-	RAZ
0x310	c196	RW	PRCR	*Device Power-down and Reset Control Register* on page 11-30
0x314	c197	R	PRSR	*Device Power-down and Reset Status Register* on page 11-30
0x318-0x7FC	c198-c511	R	-	RAZ
0x800-0x8FC	c512-575	R	-	RAZ
0x900-0xCFC	c576-c831	R	-	RAZ
0xD00-0xDFC	c832-c895	R	-	*Processor ID Registers* on page 11-32
0xE00-0xE7C	c896-c927	R	-	RAZ
0xE80-0xEFC	c928-c959	-	-	Chapter 13 *Integration Test Registers*
0xF00-0xFFC	c960-c1023	-	-	*Management registers* on page 11-32

11.3.5 Memory addresses for breakpoints and watchpoints

The *Vector Catch Register* (VCR) sets breakpoints on exception vectors as instruction addresses.

The *Watchpoint Fault Address Register* (WFAR) reads an address and a processor state dependent offset, +8 for ARM and +4 for Thumb.

11.3.6 Power domains

The processor has a single power domain. Therefore, it does not support the Event Catch Register, the OS Lock, or the OS Save and Restore functionality.

11.3.7 Effects of resets on debug registers

The processor has two reset signals which affect the debug registers in the following ways:

nSYSPORESET

You must assert this signal when powering up to set the non-debug processor logic to a known state.

PRESETDBGn

You can assert this signal to set all of the debug logic to a known state, without affecting the state of the remainder of the processor logic.

11.3.8 APB port access permissions

The restrictions for accessing the APB slave port are described as follows:

Privilege of memory access

You must configure the system to disable accesses to the memory-mapped registers based on the privilege of the memory access.

Power down

The processor only supports a single power domain, therefore you must configure the system to return an error response to all accesses made to the APB interface while the processor is powered-down.

Privilege of memory access permission

When non-privileged software attempts to access the APB slave port, the system must ignore the access or generate an error response to the access. You must implement this restriction at the system level because the APB protocol does not have a privileged or user control signal. You can choose to have the system either ignore the access or generate an error response.

You can place additional restrictions on memory transactions that are permitted to access the APB port. However, ARM does not recommend this.

Locks permission

You can lock the APB slave port so that access to some debug registers is restricted. ARM Architecture v7 defines two locks:

Software lock

The external debugger can set this lock to prevent software from modifying the debug registers settings. A debug monitor can also set this lock prior to returning control to the application to reduce the chance of erratic code changing the debug settings. When this lock is set, writes to all debug registers are ignored, except those generated by the external debugger, which override the lock. For more information, see *Lock Access Register* on page 11-34.

OS Lock The processor does not support OS Lock.

Note

- These locks are set to their reset values only on reset of the debug logic, provided by **PRESETDBGn**.
- You must set the **PADDRDBG31** input signal to 1 for accesses originated from the external debugger for the Software Lock override feature to work.

Table 11-4 External debug interface access permissions

		Registers			
PADDRDBG31	**Lock**	**DRCR, PRCR, PRSR**	**Other Debug registers**	**LAR**	**Other registers**
X	X[a]	NPOSS[b]	NPOSS[b]	NPOSS[b]	NPOSS[b]
1	X[a]	OK[c]	OK[c]	OK[c]	OK[c]
0	1[d]	WI[e]	WI[e]	OK[c]	WI[e]
0	0	OK[c]	OK[c]	OK[c]	OK[c]

a. X indicates that the outcome does not depend on this condition.
b. Not possible. Accessing debug registers while the processor is powered down is not possible.
c. OK indicates that the access succeeds.
d. LSR[1] bit is set.
e. WI indicates that writes are ignored.

11.4 Debug register descriptions

Table 11-5 shows definitions of terms used in the register descriptions.

Table 11-5 Terms used in register descriptions

Term	Description
R	Read-only. Written values are ignored.
W	Write-only. This bit cannot be read. Reads return an Unpredictable value.
RW	Read or write.
RAZ	Read-As-Zero. Always zero when read.
RAO	Read-As-One. Always one when read.
SBZP	*Should-Be-Zero* (SBZ) or *Preserved* (P). Must be written as 0 or preserved by writing the same value previously read from the same fields on the same processor. These bits are usually reserved for future expansion.
UNP	A read from this bit returns an Unpredictable value.

11.4.1 Accessing debug registers

To access the CP14 debug registers you set Opcode_1 and Opcode_2 to zero. The CRn and CRm fields of the coprocessor instructions encode the CP14 debug register number, where the register number is `{<Opcode2>, <CRm>}`. In addition, the CRn field can specify additional registers.

Table 11-6 shows the CP14 debug register map.

Table 11-6 CP14 debug register map

CRn	Op1	CRm	Op2	CP14 debug register name	Abbreviation	Reference
c0	0	c0	0	Debug ID Register	DIDR	*CP14 c0, Debug ID Register*
c1	0	c0	0	Debug ROM Address Register	DRAR	*CP14 c0, Debug ROM Address Register* on page 11-12
c2	0	c0	0	Debug Self Address Offset Register	DSAR	*CP14 c0, Debug Self Address Offset Register* on page 11-12
c3-c15	0	c0	0	Reserved	-	-
c0	0	c1	0	Debug Status and Control Register	DSCR	*CP14 c1, Debug Status and Control Register* on page 11-14
c1-c15	0	c1	0	Reserved	-	-
c0-c15	0	c2-c4	0	Reserved	-	-
c0	0	c5	0	Data Transfer Register	DTR	*Data Transfer Register* on page 11-18

11.4.2 CP14 c0, Debug ID Register

The DIDR is a read-only register that identifies the debug architecture version and specifies the number of debug resources that the processor implements.

The Debug ID Register is:

- in CP14 c0
- a 32 bit read-only register
- accessible in User and Privileged modes.

Figure 11-2 shows the bit arrangement of the DIDR.

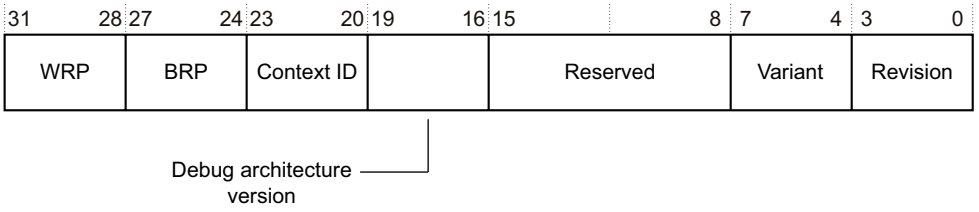


Figure 11-2 Debug ID Register format

Table 11-7 shows how the bit values correspond with the Debug ID Register functions.

Table 11-7 Debug ID Register functions

Bits	Field	Function
[31:28]	WRP	Number of Watchpoint Register Pairs: b0000 = 1 WRP b0001 = 2 WRPs ... b0111 = 8 WRPs.
[27: 24]	BRP	Number of Breakpoint Register Pairs: b0001 = 2 BRPs b0010 = 3 BRPs ... b0111 = 8 BRPs.
[23:20]	Context	Number of Breakpoint Register Pairs with context ID comparison capability: b0000 = 1 BRP has context ID comparison capability
[19:16]	Debug architecture version	Debug architecture version: b0100 denotes ARMv7 Debug.
[15:8]	Reserved	RAZ.
[7: 4]	Variant	Implementation-defined variant number. See *Product revision information* on page 1-24 for details of the value of this field.
[3: 0]	Revision	Implementation-defined revision number. See *Product revision information* on page 1-24 for details of the value of this field.

The values of the following fields of the Debug ID Register agree with the values in CP15 c0, Main ID Register:

- DIDR[3:0] is the same as CP15 c0 bits [3:0]
- DIDR[7:4] is the same as CP15 c0 bits [23:20].

See *c0, Main ID Register* on page 4-14 for more information of CP15 c0, Main ID Register.

The reason for duplicating these fields here is that the Debug ID Register is also accessible through the APB slave port. This enables an external debugger to determine the variant and revision numbers without stopping the processor.

To use the Debug ID Register, read CP14 c0 with:

```
MRC p14, 0, <Rd>, c0, c0, 0 ; Read Debug ID Register
```

11.4.3 CP14 c0, Debug ROM Address Register

The Debug ROM Address Register is a read-only register that returns a 32-bit Debug ROM Address Register value. This is the address that indicates where in memory a debug monitor can locate the debug bus ROM specified by the CoreSight™ multiprocessor trace and debug architecture. This ROM holds information about all the components in the debug bus. You can configure the address read in this register during integration using the **DBGROMADDR[31:12]** and **DBGROMADDRV** inputs. **DBGROMADDRV** must be tied off to 1 if **DBGROMADDR[31:12]** is tied off to a valid value.

The Debug ROM Address Register is:

- in CP14 c0, sub-register c1
- a 32 bit read-only register
- accessible in User and Privileged modes.

Figure 11-3 shows the bit arrangement of the Debug ROM address register.

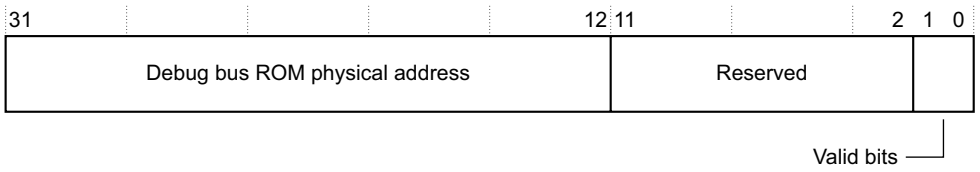


Figure 11-3 Debug ROM Address Register format

Table 11-8 shows how the bit values correspond with the Debug ROM Address Register functions.

Table 11-8 Debug ROM Address Register functions

Bits	Field	Function
[31:12]	Debug bus ROM address.	Indicates bits [31:12] of the debug bus ROM address.
[11: 2]	Reserved	SBZ.
[1:0]	Valid bits	Indicates that the ROM address is valid. Reads b11 if **DBGROMADDRV** is set to 1, otherwise reads b00. **DBGROMADDRV** must be set to 1 if **DBGROMADDR[31:12]** is set to a valid value.

To use the Debug ROM Address Register, read CP14 c0 with:

```
MRC p14, 0, <Rd>, c1, c0, 0 ; Read Debug ROM Address Register
```

11.4.4 CP14 c0, Debug Self Address Offset Register

The Debug Self Address Offset Register is a read-only register that returns a 32-bit offset value from the Debug ROM Address Register to the address of the processor debug registers. You can configure the address read in this register during integration using the **DBGSELFADDR[31:12]** and **DBGSELFADDRV** inputs. **DBGSELFADDRV** must be tied off to 1 if **DBGSELFADDR[31:12]** is tied off to a valid value.

The Debug Self Address Offset Register is:

- in CP14 c0, sub-register c2
- a 32 bit read-only register
- accessible in User and Privileged modes.

Figure 11-4 shows the bit arrangement of the Debug Self Address Offset Register.

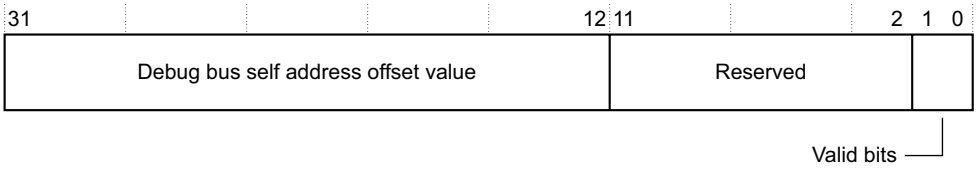


Figure 11-4 Debug Self Address Offset Register format

Table 11-9 shows how the bit values correspond with the Debug Self Address Offset Register functions.

Table 11-9 Debug Self Address Offset Register functions

Bits	Field	Function
[31:12]	Debug bus self address offset value	Indicates bits [31:12] of the two's complement offset from the debug ROM physical address to the physical address where the debug registers are mapped.
[11: 2]	Reserved	UNP on reads, SBZP on writes.
[1:0]	Valid bits	Reads b11 if **DBGSELFADDRV** is set to 1, otherwise reads b00. **DBGSELFADDRV** must be set to 1 if **DBGSELFADDR[31:12]** is set to a valid value.

To use the Debug Self Address Offset Register, read CP14 c0 with:

```
MRC p14, 0, <Rd>, c2, c0, 0           ; Read Debug Self Address Offset Register
```

11.4.5 CP14 c1, Debug Status and Control Register

The DSCR contains status and control information about the debug unit. Figure 11-5 shows the bit arrangement of the DSCR.

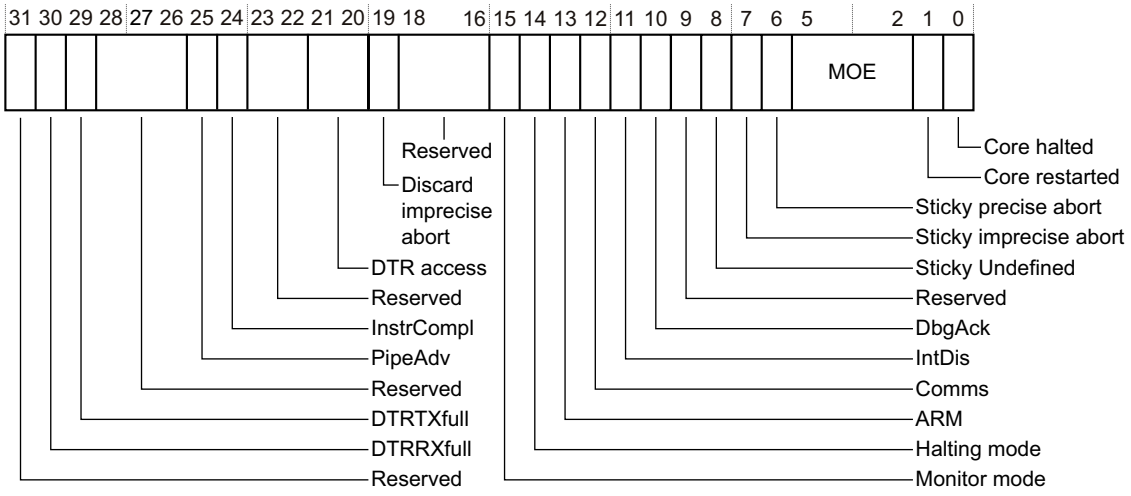


Figure 11-5 Debug Status and Control Register format

Table 11-10 shows how the bit values correspond with Debug Status and Control Register functions.

Table 11-10 Debug Status and Control Register functions

Bits	Field	Function
[31]	Reserved	RAZ on reads, SBZP on writes.
[30]	DTRRXfull	The DTRRXfull flag: 0 = Read-DTR, DTRRX, empty, reset value 1 = Read-DTR, DTRRX, full. When set, this flag indicates to the processor that there is data available to read at the DTRRX. It is automatically set on writes to the DTRRX by the debugger, and is cleared when the processor reads the CP14 DTR. If the flag is not set, the DTRRX returns an Unpredictable value.
[29]	DTRTXfull	The DTRTXfull flag: 0 = Write-DTR, DTRTX, empty, reset value 1 = Write-DTR, DTRTX, full. When clear, this flag indicates to the processor that the DTRTX is ready to receive data. It is automatically cleared on reads of the DTRTX by the debugger, and is set when the processor writes to the CP14 DTR. If this bit is set and the processor attempts to write to the DTRTX, the register contents are overwritten and the DTRRXfull flag remains set.
[28:26]	Reserved	RAZ on reads, SBZP on writes.
[25]	PipeAdv	Sticky pipeline advance read-only bit. This bit enables the debugger to detect whether the processor is idle. In some situations, this might mean that the system bus port is deadlocked. This bit is set to 1 when the processor pipeline retires one instruction. It is cleared by a write to DRCR[3]. 0 = no instruction has completed execution since the last time this bit was cleared 1 = an instruction has completed execution since the last time this bit was cleared.

Table 11-10 Debug Status and Control Register functions (continued)

Bits	Field	Function
[24]	InstrCompl	Instruction complete read-only bit. This flag determines whether the processor has completed execution of an instruction issued through the APB port. 0 = processor is currently executing an instruction fetched from the ITR Register 1 = processor is not currently executing an instruction fetched from the ITR Register. When the APB port reads the DSCR and this bit is clear, then a subsequent write to the ITR Register is ignored unless DSCR[21:20] is not equal to 0. If DSCR[21:20] is not equal to 0, the ITR write stalls until the processor completes execution of the current instruction. If the processor is not in debug state, then the value read for this flag is Unpredictable. The flag is set to 1 on entry to debug state.
[23:22]	Reserved	RAZ on reads, SBZP on writes.
[21:20]	DTR access	DTR access mode. You can use this field to optimize DTR traffic between a debugger and the processor. b00 = Non-blocking mode, the default b01 = Stall mode b10 = Fast mode b11 = Reserved. **Note** • This field only affects the behavior of DSCR, DTR, and ITR accesses through the APB port, and not through CP14 debug instructions. • Non-blocking mode is the default setting. Improper use of the other modes might result in the debug access bus becoming deadlocked. See *DTR access mode* on page 11-17 for more information.
[19]	Discard imprecise abort	The Discard imprecise abort bit is set when the processor is in debug state and is cleared on exit from debug state. While this bit is set, the processor does not take imprecise Data Aborts. However, the sticky imprecise Data Abort bit is set to 1. 0 = do not discard imprecise Data Aborts 1 = discard imprecise Data Aborts.
[18-16]	Reserved	RAZ on reads, SBZP on writes.
[15]	Monitor mode	The Monitor debug-mode enable bit: 0 = Monitor debug-mode disabled, this is the reset value 1 = Monitor debug-mode enabled. If Halting debug-mode is enabled through bit [14], then the processor is in Halting debug-mode regardless of the value of bit [15]. If the external interface input **DBGEN** is LOW, this bit reads as 0. The programmed value is masked until **DBGEN** is HIGH, and at that time the read value reverts to the programmed value.
[14]	Halting mode	The Halting debug-mode enable bit: 0 = Halting debug-mode disabled, this is the reset value 1 = Halting debug-mode enabled. If the external interface input **DBGEN** is LOW, this bit reads as 0. The programmed value is masked until **DBGEN** is HIGH, and at that time the read value reverts to the programmed value.

Table 11-10 Debug Status and Control Register functions (continued)

Bits	Field	Function
[13]	ARM	Execute ARM instruction enable bit: 0 = disabled, this is the reset value 1 = enabled. If this bit is set and an ITR write succeeds, the processor fetches an instruction from the ITR for execution. If this bit is set to 1 when the processor is not in debug state, the behavior of the processor is Unpredictable.
[12]	Comms	CP14 debug user access disable control bit: 0 = CP14 debug user access enable, this is the reset value 1 = CP14 debug user access disable. If this bit is set and a User mode process attempts to access any CP14 debug registers, an Undefined instruction exception is taken.
[11]	IntDis	Interrupts disable bit: 0 = interrupts enabled, this is the reset value 1 = interrupts disabled. If this bit is set, the **IRQ** and **FIQ** input signals are inhibited. The external debugger can optionally use this bit to execute pieces of code in normal state as part of the debugging process to avoid having an interrupt taking control of the program flow. For example, the debugger might use this bit to execute an OS service routine to bring a page from disk into memory. It might be undesirable to service any interrupt during the routine execution.
[10]	DbgAck	DbgAck bit. If this bit is set to 1, the **DBGACK** output signal is forced HIGH, regardless of the processor state. The external debugger can optionally use this bit to execute pieces of code in normal state as part of the debugging process for the system to behave as if the processor is in debug state. Some systems rely on **DBGACK** to determine whether data accesses are application or debugger generated. This bit is 0 on reset.
[9]	Reserved	RAZ on reads, SBZP on writes.
[8]	Sticky Undefined	Sticky Undefined bit: 0 = no Undefined exception occurred in debug state since the last time this bit was cleared 1 = an Undefined exception occurred while in debug state since the last time this bit was cleared. This flag detects Undefined exceptions generated by instructions issued to the processor through the ITR. This bit is set to 1 when an Undefined instruction exception occurs while the processor is in debug state and is cleared by writing a 1 to DRCR[2].
[7]	Sticky imprecise abort	Sticky imprecise Data Abort bit: 0 = no imprecise Data Aborts occurred since the last time this bit was cleared 1 = an imprecise Data Abort occurred since the last time this bit was cleared. This flag detects imprecise Data Aborts triggered by instructions issued to the processor through the ITR. This bit is set to 1 when an imprecise Data Abort occurs while the processor is in debug state and is cleared by writing a 1 to DRCR[2].
[6]	Sticky precise abort	Sticky precise Data Abort bit: 0 = no precise Data Abort occurred since the last time this bit was cleared 1 = a precise Data Abort occurred since the last time this bit was cleared. This flag detects precise Data Aborts generated by instructions issued to the processor through the ITR. This bit is set to 1 when a precise Data Abort occurs while the processor is in debug state and is cleared by writing to the DRCR[2].

Table 11-10 Debug Status and Control Register functions (continued)

Bits	Field	Function
[5:2]	MOE	Method of entry bits: b0000 = a **DRCR[0]** halting debug event occurred b0001 = a breakpoint occurred b0100 = an **EDBGRQ** halting debug event occurred b0011 = a BKPT instruction occurred b1010 = a precise watchpoint occurred others = reserved. These bits are set to indicate any of: • the cause of a debug exception • the cause for entering debug state. A Prefetch Abort or Data Abort handler must check the value of the CP15 Fault Status Register to determine whether a debug exception occurred and then use these bits to determine the specific debug event.
[1][a]	Core restarted	Core restarted bit: 0 = the processor is exiting debug state 1 = the processor has exited debug state. This is the reset value. The debugger can poll this bit to determine when the processor responds to a request to leave debug state.
[0][a]	Core halted	Core halted bit: 0 = the processor is in normal state. This is the reset value. 1 = the processor is in debug state. The debugger can poll this bit to determine when the processor has entered debug state.

a. These bits always reflect the status of the processor, therefore they only have a reset value if the particular reset event affects the processor. For example, a **PRESETDBGn** event leaves these bits unchanged and a processor reset event such as **nSYSPORESET** sets DSCR[18] to a 0 and DSCR[1:0] to 10.

To use the Debug Status and Control Register, read or write CP14 c1 with:

```
MRC p14, 0, <Rd>, c0, c1, 0 ; Read Debug Status and Control Register
MCR p14, 0, <Rd>, c0, c1, 0 ; Write Debug Status and Control Register
```

DTR access mode

You can use the DTR access mode field to optimize data transfer between a debugger and the processor.

The DTR access mode can be one of the following:

- Nonblocking. This is the default mode.
- Stall.
- Fast.

In Non-blocking mode, reads from DTRTX and writes to DTRRX and ITR are ignored if the appropriate latched ready flag is not in the ready state. These latched flags are updated on DSCR reads. The following applies:

- writes to DTRRX are ignored if DTRRXfull_l is set to b1
- reads from DTRTX are ignored, and return an Unpredictable value, if DTRTXfull_l is set to b0

- writes to ITR are ignored if InstrCompl_l is set to b0
- following a successful write to DTRRX, DTRRXfull and DTRRXfull_l are set to b1
- following a successful read from DTRTX, DTRTXfull and DTRTXfull_l are cleared to b0
- following a successful write to ITR, InstrCompl and InstrCompl_l are cleared to b0.

Debuggers accessing these registers must first read DSCR. This has the side-effect of copying DTRRXfull and DTRTXfull to DTRRXfull_l and DTRTXfull_l. The debugger must then:

- write to the DTRRX if the DTRRXfull flag was b0 (DTRRXfull_l is b0)
- read from the DTRTX if the DTRTXfull flag was b1 (DTRTXfull_l is b1)
- write to the ITR if the InstrCompl_l flag was b1.

However, debuggers can issue both actions together and later determine from the read DSCR value whether the operations were successful.

In Stall mode, the APB accesses to DTRRX, DTRTX, and ITR stall under the following conditions:

- writes to DTRRX are stalled until DTRRXfull is cleared
- writes to ITR are stalled until InstrCompl is set
- reads from DTRTX are stalled until DTRTXfull is set.

Fast mode is similar to Stall mode except that in Fast mode, the processor fetches an instruction from the ITR when a DTRRX write or DTRTX read succeeds. In Stall mode and Nonblocking mode, the processor fetches an instruction from the ITR when an ITR write succeeds.

11.4.6 Data Transfer Register

The DTR consists of two separate physical registers:

- the DTRRX (Read Data Transfer Register)
- the DTRTX (Write Data Transfer Register).

The register accessed is dependent on the instruction used:

- writes, `MCR` and `LDC` instructions, access the DTRTX
- reads, `MRC` and `STC` instructions, access the DTRRX.

Note

Read and write are used with respect to the processor.

For information on the use of these registers with the DTRTXfull flag and DTRRXfull flag, see *Debug communications channel* on page 11-55. The Data Transfer Register, bits [31:0] contain the data to be transferred.

Table 11-11 shows how the bit values correspond with the DTRRX and DTRTX functions.

Table 11-11 Data Transfer Register functions

Bits	Field	Function
[31:0]	Data	Reads the Data Transfer Register. This is read-only for the CP14 interface. **Note** Reads of the DTRRX through the coprocessor interface cause the DTRTXfull flag to be cleared. However, reads of the DTRRX through the APB port do not affect this flag.
[31:0]	Data	Writes the Data Transfer Register. This is write-only for the CP14 interface. **Note** Writes to the DTRTX through the coprocessor interface cause the DTRRXfull flag to be set. However, writes to the DTRTX through the APB port do not affect this flag.

11.4.7 Watchpoint Fault Address Register

The *Watchpoint Fault Address Register* (WFAR) is a read/write register that holds the address of the instruction that triggers the watchpoint.

Figure 11-6 shows the bit arrangement of the Watchpoint Fault Address Register.

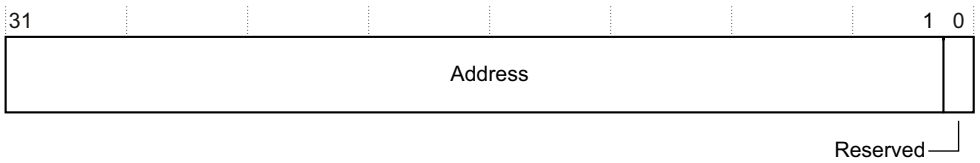


Figure 11-6 Watchpoint Fault Address Register format

Table 11-12 shows how the bit values correspond with the WFAR functions.

Table 11-12 Watchpoint Fault Address Register functions

Bits	Field	Function
[31:1]	Address	This is the address of the watchpointed instruction. When a watchpoint occurs in ARM state, the WFAR contains the address of the instruction causing it plus an offset of `0x8`. When a watchpoint occurs in Thumb state, the offset is plus `0x4`.
[0]	Reserved	RAZ.

11.4.8 Vector Catch Register

The processor supports efficient exception vector catching. The read/write Vector Catch Register controls this, as Figure 11-7 on page 11-20 shows.

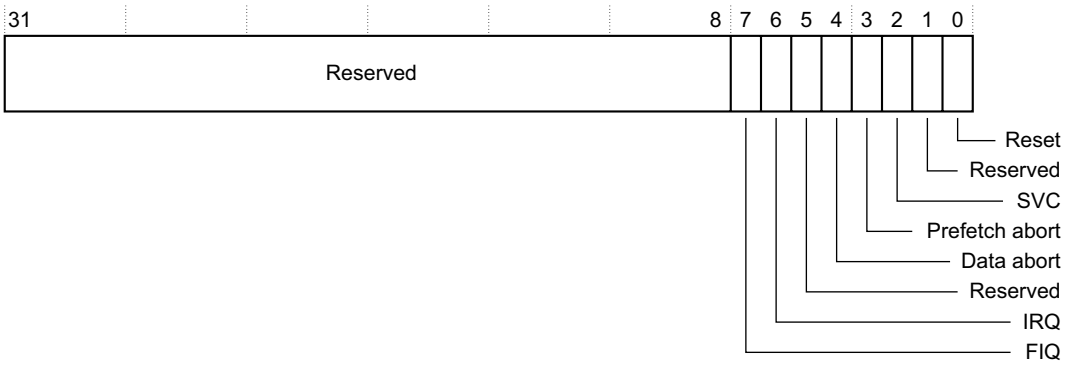


Figure 11-7 Vector Catch Register format

If one of the bits in this register is set and the instruction at the corresponding vector is committed for execution, the processor either enters debug state or takes a debug exception.

Note

- Under this model, any prefetch from an exception vector can trigger a vector catch, not only the ones because of exception entries. An explicit branch to an exception vector might generate a vector catch debug event.
- If any of the bits are set when the processor is in Monitor debug-mode, then the processor ignores the setting and does not generate a vector catch debug event. This prevents the processor entering an unrecoverable state. The debugger must program these bits to zero when Monitor debug-mode is selected and enabled to ensure forward-compatibility.

Table 11-13 shows how the bit values correspond with the Vector Catch Register functions.

Table 11-13 Vector Catch Register functions

Bits	Field	Reset value	Normal address	High vectors address	Function	Access
[31:8]	Reserved	0	-	-	Do not modify on writes. On reads, the value returns zero.	RAZ or SBZP
[7]	FIQ	0	0x0000001C	0xFFFF001C	Vector catch enable.	RW
[6]	IRQ	-	0x00000018[a]	0xFFFF0018[a]	Vector catch enable.	-
[5]	Reserved	0	-	-	Do not modify on writes. On reads, the value returns zero.	RAZ or SBZP
[4]	Data Abort	0	0x00000010	0xFFFF0010	Vector catch enable.	RW
[3]	Prefetch Abort	0	0x0000000C	0xFFFF000C	Vector catch enable.	RW
[2]	SVC	0	0x00000008	0xFFFF0008	Vector catch enable.	RW
[1]	Reserved	0	0x00000004	0xFFFF0004	Vector catch enable, Undefined instruction.	RW
[0]	Reset	0	0x00000000	0xFFFF0000	Vector catch enable.	RW

a. If the VIC interface is enabled, the address is the last IRQ handler address supplied by the VIC, whether or not high vectors are in use.

11.4.9 Debug State Cache Control Register

The DSCCR controls the L1 cache behavior when the processor is in debug state.

Figure 11-8 shows the bit arrangement of the DSCCR.

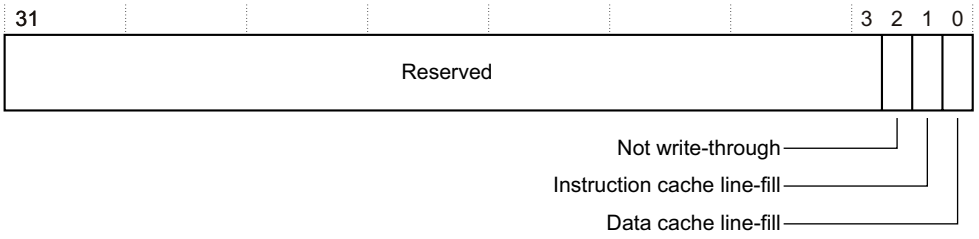


Figure 11-8 Debug State Cache Control Register format

For information on the usage model of the DSCCR register, see *Cache debug* on page 11-50.

Table 11-14 shows how the bit values correspond with the Debug State Cache Control Register functions.

Table 11-14 Debug State Cache Control Register functions

Bits	Field	Reset value	Description
[31:3]	Reserved	0	Reserved. Do not modify on writes. On reads, the value returns zero.
[2]	nWT	0	Not write-through: 1 = normal operation of regions marked as write-back in debug state 0 = force write-through behavior for regions marked as write-back in debug state, this is the reset value.
[1]	nIL	0	Instruction cache line-fill: 1 = normal operation of L1 instruction cache in debug state 0 = L1 instruction cache line-fills disabled in debug state, this is the reset value.
[0]	nDL	0	Data cache line-fill: 1 = normal operation of L1 data cache in debug state 0 = L1 data cache line-fills disabled in debug state, this is the reset value.

11.4.10 Instruction Transfer Register

The ITR enables the external debugger to feed instructions into the processor for execution while in debug state. The ITR is a write-only register. Reads from the ITR return an Unpredictable value.

The Instruction Transfer Register, bits [31:0] contain the ARM instruction for the processor to execute while in debug state. The reset value of this register is Unpredictable.

Note

Writes to the ITR when the processor is not in debug state or the DSCR[13] execute instruction enable bit is cleared are Unpredictable. When an instruction is issued to the processor, the debug unit prevents the next instruction from being issued until the DSCR[25] instruction complete bit is set.

11.4.11 Debug Run Control Register

The DRCR requests the processor to enter or leave debug state. It also clears the sticky exception bits present in the DSCR.

Figure 11-9 shows the bit arrangement of the DRCR.

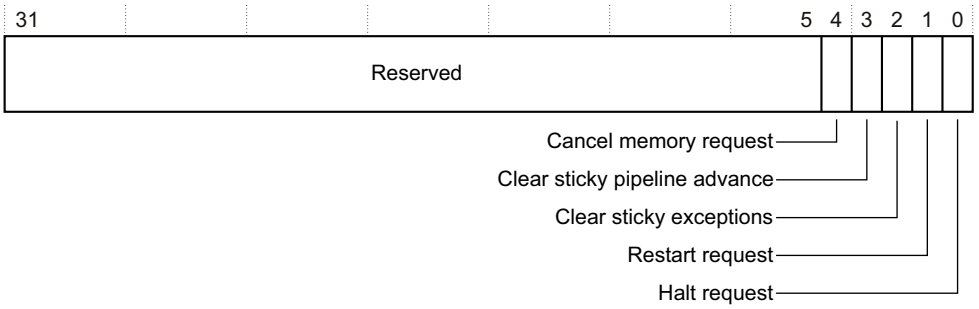


Figure 11-9 Debug Run Control Register format

Table 11-15 shows how the bit values correspond with the Debug Run Control Register functions.

Table 11-15 Debug Run Control Register functions

Bits	Field	Function
[31:5]	Reserved	RAZ.
[4]	Cancel memory requests	If 1 is written to this bit, the processor abandons any pending memory transactions until it can enter debug state. Debug state entry is the acknowledge event that clears this request. Abandoned transactions have the following behavior: • abandoned stores might write an Unpredictable value to the target address • abandoned loads return an Unpredictable value to the register bank. An abandoned transaction does not cause any exception. Additional instruction fetches or data accesses after the processor entered debug state have an Unpredictable behavior. This bit enables the debugger to progress on a deadlock so the processor can enter debug state. For a debug state entry to occur, a halting debug event must be requested before this bit is set. If you write a 1 to this bit when **DBGEN** is LOW, the write has no effect.[a]
[3]	Clear sticky pipeline advance	Writing a 1 to this bit clears DSCR[25].
[2]	Clear sticky exceptions	Writing a 1 to this bit clears DSCR[8:6].
[1]	Restart request	Writing a 1 to this bit requests that the processor leaves debug state. This request is held until the processor exits debug state. When the debugger makes this request, it polls DSCR[1] until it reads 1. This bit always reads as zero. Writes are ignored when the processor is not in debug state.
[0]	Halt request	Writing a 1 to this bit triggers a halting debug event, that is, a request that the processor enters debug state. This request is held until the debug state entry occurs. When the debugger makes this request, it polls DSCR[0] until it reads 1. This bit always reads as zero. Writes are ignored when the processor is already in debug state.

a. Entry into debug state is not expected to be recoverable.

11.4.12 Breakpoint Value Registers

Each BVR is associated with a *Breakpoint Control Register* (BCR). BCRy is the corresponding control register for BVRy.

A pair of breakpoint registers, BVRy/BCRy, is called a *Breakpoint Register Pair* (BRP). BVR0-7 are paired with BCR0-7 to make BRP0-7.

The breakpoint value contained in this register corresponds to either an instruction address or a context ID. Breakpoints can be set on:

- an instruction address
- a context ID value
- an instruction address and context ID pair.

For an instruction address and context ID pair, two BRPs must be linked. A debug event is generated when both the instruction address and the context ID pair match at the same time.

Table 11-16 shows how the bit values correspond with the Breakpoint Value Registers functions.

Table 11-16 Breakpoint Value Registers functions

Bits	Reset value	Description
[31:0]	`0x0`	Breakpoint value

Note

- Only BRPn supports context ID comparison, where n+1 is the number of breakpoint register pairs implemented in the processor.
- Bits [1:0] of Registers BVR0 to BVR(n-1) are Do Not Modify on writes and Read-As-Zero because these registers do not support context ID comparisons.
- The contents of the CP15 Context ID Register give the context ID value for a BVR to match. For information on the Context ID Register, see Chapter 4 *System Control Coprocessor*.

11.4.13 Breakpoint Control Registers

The BCR is a read/write register that contains the necessary control bits for setting:

- breakpoints
- linked breakpoints.

Figure 11-10 shows the bit arrangement of the BCRs.

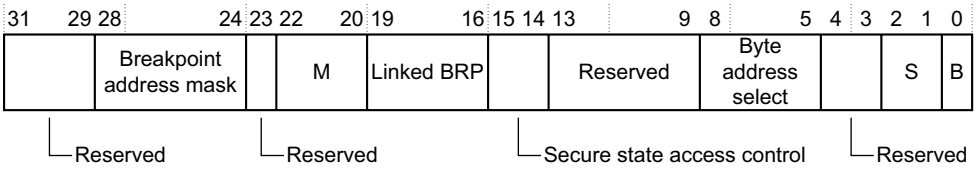


Figure 11-10 Breakpoint Control Registers format

Table 11-17 shows how the bit values correspond with the Breakpoint Control Registers functions.

Table 11-17 Breakpoint Control Registers functions

Bits	Field	Function
[31:29]	Reserved	Do not modify on writes. On reads, the value returns zero.
[28:24]	Breakpoint address mask	This field sets a breakpoint on a range of addresses by masking lower order address bits out of the breakpoint comparison.[a] b00000 = no mask b00001 = Reserved b00010 = Reserved b00011 = `0x00000007` mask for instruction address b00100 = `0x0000000F` mask for instruction address b00101 = `0x0000001F` mask for instruction address ... b11111 = `0x7FFFFFFF` mask for instruction address.
[23]	Reserved	-
[22:20]	M	Meaning of BVR: b000 = instruction address match b001 = linked instruction address match b010 = unlinked context ID b011 = linked context ID b100 = instruction address mismatch b101 = linked instruction address mismatch b11x = Reserved. For more information, see Table 11-18 on page 11-25
[19:16]	Linked BRP number	The binary number encoded here indicates another BRP to link this one with. **Note** • if a BRP is linked with itself, it is Unpredictable whether a breakpoint debug event is generated • if this BRP is linked to another BRP that is not configured for linked context ID matching, it is Unpredictable whether a breakpoint debug event is generated.
[15:14]	Secure state access control	RAZ or SBZP.
[13:9]	Reserved	Do not modify on writes. On reads, the value returns zero.

Table 11-17 Breakpoint Control Registers functions (continued)

Bits	Field	Function
[8:5]	Byte address select	For breakpoints programmed to match an instruction address, the debugger must write a word-aligned address to the BVR. You can then use this field to program the breakpoint so it hits only if certain byte addresses are accessed.[b] If the BRP is programmed for instruction address match: b0000 = the breakpoint never hits bxxx1 = the breakpoint hits if the byte at address (BVR & 0xFFFFFFFC) +0 is accessed bxx1x = the breakpoint hits if the byte at address (BVR & 0xFFFFFFFC) +1 is accessed bx1xx = the breakpoint hits if the byte at address (BVR & 0xFFFFFFFC) +2 is accessed b1xxx = the breakpoint hits if the byte at address (BVR & 0xFFFFFFFC) +3 is accessed b1111 = the breakpoint hits if any of the four bytes starting at address (BVR & 0xFFFFFFFC) +0 is accessed. If the BRP is programmed for instruction address mismatch, the breakpoint hits where the corresponding instruction address breakpoint does not hit, that is, the range of addresses covered by an instruction address mismatch breakpoint is the negative image of the corresponding instruction address breakpoint. If the BRP is programmed for context ID comparison, this field must be set to b1111. Otherwise, breakpoint and watchpoint debug events might not be generated as expected.
[4:3]	Reserved	-
[2:1]	S	Supervisor access control. The breakpoint can be conditioned on the mode of the processor: b00 = User, System, or Supervisor b01 = Privileged b10 = User b11 = any.
[0]	B	Breakpoint enable: 0 = Breakpoint disabled. This is the reset value. 1 = Breakpoint enabled.

a. If BCR[28:24] is not set to b00000, then BCR[8:5] must be set to b1111. Otherwise the behavior is Unpredictable. In addition, if BCR[28:24] is not set to b00000, then the corresponding BVR bits that are not being included in the comparison Should Be Zero. Otherwise the behavior is Unpredictable. If this BRP is programmed for context ID comparison, this field must be set to b00000. Otherwise the behavior is Unpredictable. There is no encoding for a full 32-bit mask but the same effect of a *break anywhere* breakpoint can be achieved by setting BCR[22] to 1 and BCR[8:5] to b0000.

b. Writing a value to BCR[8:5] so that BCR[8] is not equal to BCR[7] or BCR[6] is not equal to BCR[5] has Unpredictable results.

Table 11-18 Meaning of BVR bits [22:20]

BVR[22:20]	Meaning
b000	The corresponding BVR[31:2] is compared against the instruction address bus and the state of the processor against this BCR. It generates a breakpoint debug event on a joint instruction address and state match.
b001	The corresponding BVR[31:2] is compared against the instruction address bus and the state of the processor against this BCR. This BRP is linked with the one indicated by BCR[19:16] linked BRP field. They generate a breakpoint debug event on a joint instruction address, context ID, and state match.
b010	The corresponding BVR[31:0] is compared against CP15 Context ID Register, c13 and the state of the processor against this BCR. This BRP is not linked with any other one. It generates a breakpoint debug event on a joint context ID and state match. For this BRP, BCR[8:5] must be set to b1111. Otherwise it is Unpredictable whether a breakpoint debug event is generated.

Table 11-18 Meaning of BVR bits [22:20] (continued)

BVR[22:20]	Meaning
b011	The corresponding BVR[31:0] is compared against CP15 Context ID Register, c13. This BRP links another BRP (of the BCR[21:20]=b01 type), or WRP (with WCR[20]=b1). They generate a breakpoint or watchpoint debug event on a joint instruction address or data address and context ID match. For this BRP, BCR[8:5] must be set to b1111, BCR[15:14] must be set to b00, and BCR[2:1] must be set to b11. Otherwise it is Unpredictable whether a breakpoint debug event is generated.
b100	The corresponding BVR[31:2] and BCR[8:5] are compared against the instruction address bus and the state of the processor against this BCR. It generates a breakpoint debug event on a joint instruction address mismatch and state match.
b101	The corresponding BVR[31:2] and BCR[8:5] are compared against the instruction address bus and the state of the processor against this BCR. This BRP is linked with the one indicated by BCR[19:16] linked BRP field. It generates a breakpoint debug event on a joint instruction address mismatch, state and context ID match.
b11x	Reserved. The behavior is Unpredictable.

11.4.14 Watchpoint Value Registers

Each WVR is associated with a *Watchpoint Control Register* (WCR). WCRy is the corresponding register for WVRy.

A pair of watchpoint registers, WVRy and WCRy, is called a *Watchpoint Register Pair* (WRP). WVR0-7 are paired with WCR0-7 to make WRP0-7.

The watchpoint value contained in the WVR always corresponds to a data address and can be set either on:

- a data address
- a data address and context ID pair.

For a data address and context ID pair, a WRP and a BRP with context ID comparison capability must be linked. A debug event is generated when both the data address and the context ID pair match simultaneously. Table 11-19 shows the bit field definitions for the Watchpoint Value Registers.

Table 11-19 Watchpoint Value Registers functions

Bits	Description
[31:2]	Watchpoint address.
[1:0]	Reserved. Do not modify on writes. On reads, the value returns zero.

11.4.15 Watchpoint Control Registers

The WCRs contain the necessary control bits for setting:

- watchpoints
- linked watchpoints.

Figure 11-11 on page 11-27 shows the bit arrangement of the Watchpoint Control Registers.

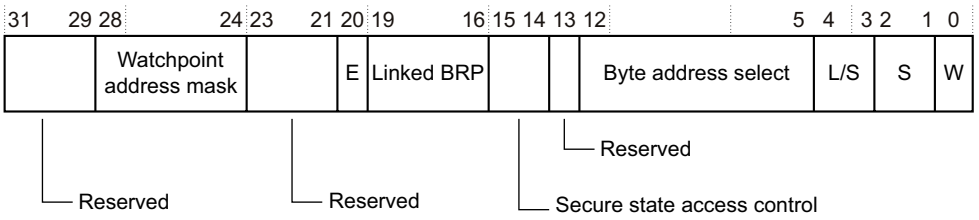


Figure 11-11 Watchpoint Control Registers format

Table 11-20 shows how the bit values correspond with the Watchpoint Control Registers functions.

Table 11-20 Watchpoint Control Registers functions

Bits	Field	Function
[31:29]	Reserved	Do not modify on writes. On reads, the value returns zero.
[28:24]	Watchpoint address mask	This field watches a range of addresses by masking lower order address bits out of the watchpoint comparison. b00000 = no mask b00001 = Reserved b00010 = Reserved b00011 = `0x00000007` mask for data address b00100 = `0x0000000F` mask for data address b00101 = `0x0000001F` mask for data address ... b11111 = `0x7FFFFFFF` mask for data address. **Note** • If WCR[28:24] is not set to b00000, then WCR[12:5] must be set to b11111111. Otherwise the behavior is Unpredictable. • If WCR[28:24] is not set to b00000, then the corresponding WVR bits that are not being included in the comparison Should Be Zero. Otherwise the behavior is Unpredictable. • To watch for a write to any byte in an 8-byte aligned object of size 8 bytes, ARM recommends that a debugger sets WCR[28:24] to b00111, and WCR[12:5] to b11111111. This is compatible with both ARMv7 debug compliant implementations that have an 8-bit WCR[12:5] and with those that have a 4-bit WCR[8:5] byte address select field.
[23:21]	Reserved	Do not modify on writes. On reads, the value returns zero.
[20]	E	Enable linking bit: 0 = linking disabled 1 = linking enabled. When this bit is set, this watchpoint is linked with the context ID holding BRP selected by the linked BRP field.
[19:16]	Linked BRP	Linked BRP number. The binary number encoded here indicates a context ID holding BRP to link this WRP with. If this WRP is linked to a BRP that is not configured for linked context ID matching, it is Unpredictable whether a watchpoint debug event is generated.
[15:14]	Secure state access control	RAZ or SBZP.
[13]	Reserved	Appear as zero when read. Do not modify on writes.

Table 11-20 Watchpoint Control Registers functions (continued)

Bits	Field	Function
[12:5]	Byte address select	The WVR is programmed with word-aligned address. You can use this field to program the watchpoint so it only hits if certain byte addresses are accessed: **b00000000** The watchpoint never hits. **bxxxxxxx1** The watchpoint hits if the byte at address (WVR[31:0] & 0xFFFFFFFC) +0 is accessed. **bxxxxxx1x** The watchpoint hits if the byte at address (WVR[31:0] & 0xFFFFFFFC) +1 is accessed. **bxxxxx1xx** The watchpoint hits if the byte at address (WVR[31:0] & 0xFFFFFFFC) +2 is accessed. **bxxxx1xxx** The watchpoint hits if the byte at address (WVR[31:0] & 0xFFFFFFFC) +3 is accessed. **bxxx1xxxx** The watchpoint hits if the byte at address (WVR[31:0] & 0xFFFFFFF8) +4 is accessed. **bxx1xxxxx** The watchpoint hits if the byte at address (WVR[31:0] & 0xFFFFFFF8) +5 is accessed. **bx1xxxxxx** The watchpoint hits if the byte at address (WVR[31:0] & 0xFFFFFFF8) +6 is accessed. **b1xxxxxxx** The watchpoint hits if the byte at address (WVR[31:0] & 0xFFFFFFF8) +7 is accessed.
[4:3]	L/S	Load/store access. The watchpoint can be conditioned to the type of access: b00 = Reserved b01 = load, load exclusive, or swap b10 = store, store exclusive or swap b11 = either. A SWP or SWPB triggers on load, store, or either. A load exclusive instruction triggers on load or either. A store exclusive instruction triggers on store or either, whether it succeeds or not.
[2:1]	S	Privileged access control. The watchpoint can be conditioned to the privilege of the access: b00 = reserved b01 = Privileged, match if the processor does a privileged access to memory b10 = User, match only on non-privileged accesses b11 = either, match all accesses. **Note** For all cases, the match refers to the privilege of the access, not the mode of the processor.
[0]	W	Watchpoint enable: 0 = Watchpoint disabled. This is the reset value. 1 = Watchpoint enabled.

11.4.16 Operating System Lock Status Register

The *Operating System Lock Status Register* (OSLSR) contains status information about the locked debug registers.

Figure 11-12 on page 11-29 shows the bit arrangement of the OSLSR.

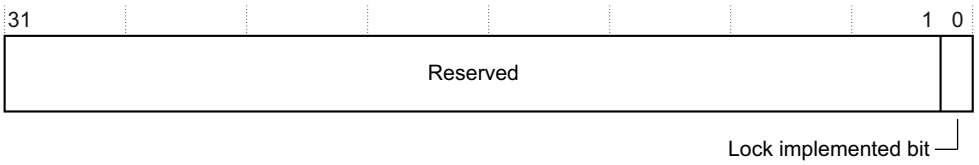


Figure 11-12 OS Lock Status Register format

Table 11-21 shows how the bit values correspond with the OS Lock Status Register functions.

Table 11-21 OS Lock Status Register functions

Bits	Field	Function
[31:1]	Reserved	RAZ.
[0]	Lock implemented bit	Indicates that the OS lock functionality is not implemented. This bit always reads 0.

11.4.17 Authentication Status Register

The Authentication Status Register is a read-only register that reads the current values of the configuration inputs that determine the debug permission level.

Figure 11-13 shows the bit arrangement of the Authentication Status Register.

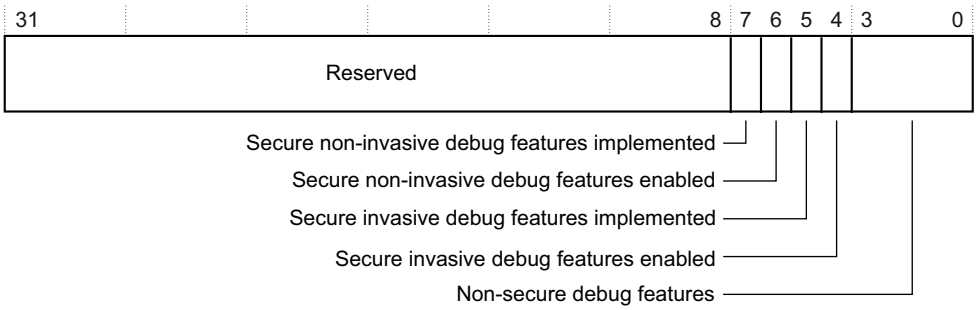


Figure 11-13 Authentication Status Register format

Table 11-22 shows how the bit values correspond with the Authentication Status Register functions.

Table 11-22 Authentication Status Register bit functions

Bits	Field	Value	Function
[31:8]	Reserved	-	RAZ
[7]	Secure non-invasive debug features implemented	`0b1`	Implemented
[6]	Secure non-invasive debug features enabled	**DBGEN** || **NIDEN**	Non-invasive debug enable field
[5]	Secure invasive debug features implemented	`0b1`	Implemented
[4]	Secure invasive debug features enabled	**DBGEN**	Invasive debug enable field
[3:0]	Non-secure debug features[a]	`0x0`	Not implemented

a. Cortex-R4 does not implement the Security Extensions, so all the debug features are considered secure.

11.4.18 Device Power-down and Reset Control Register

The PRCR is a read/write register that controls reset and power-down related functionality.

Figure 11-14 shows the bit arrangement of the PRCR.

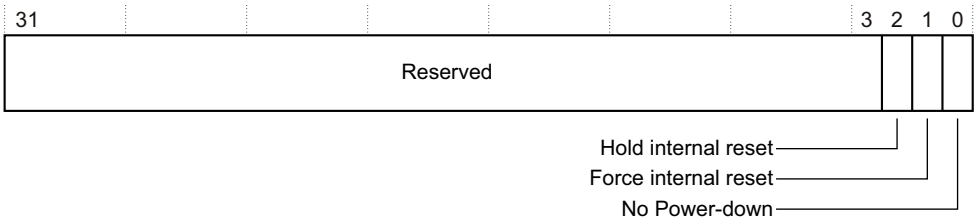


Figure 11-14 PRCR format

Table 11-23 shows how the bit values correspond with the Device Power down and Reset Control Register functions.

Table 11-23 PRCR functions

Bits	Field	Function
[31:3]	Reserved	Do not modify on writes. On reads, the value returns zero.
[2]	Hold internal reset	Hold internal reset bit. This bit can be used to prevent the processor from running again before the debugger detects a power-down event and restores the state of the debug registers in the processor. This bit does not have any effect on initial system power-up as **nSYSPORESET** clears it. 0 = Do not hold internal reset on power-up or warm reset. This is the reset value. 1 = Hold the processor non-debug logic in reset on warm reset until this flag is cleared.
[1]	Force internal reset	When a 1 is written to this bit, the processor asserts the **DBGRSTREQ** output for four cycles. You can connect this output to an external reset controller which, in turn, resets the processor.
[0]	No power-down	When set to 1, the **DBGNOPWRDWN** output signal is HIGH. This output connects to the system power controller and is interpreted as a request to operate in emulate mode. In this mode, the processor is not actually powered down when requested by software or hardware handshakes. This mode is useful when debugging applications on top of working operating systems. 0 = **DBGNOPWRDWN** is LOW. This is the reset value 1 = **DBGNOPWRDWN** is HIGH.

11.4.19 Device Power-down and Reset Status Register

The PRSR is a read-only register that provides information about the reset and power-down state of the processor.

Figure 11-15 on page 11-31 shows the bit arrangement of the PRSR.

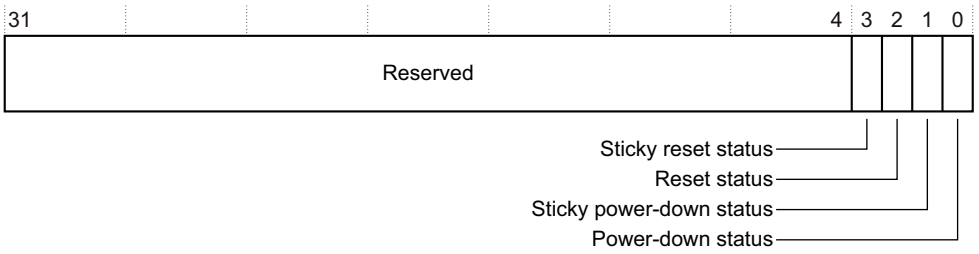


Figure 11-15 PRSR format

Table 11-24 shows how the bit values correspond with the PRSR functions.

Table 11-24 PRSR functions

Bits	Field	Function
[31:4]	Reserved	Do not modify on writes. On reads, the value returns zero.
[3]	Sticky reset status	Sticky reset status bit. This bit is cleared on read. 0 = the processor has not been reset since the last time this register was read. This is the reset value. 1 = the processor has been reset since the last time this register was read. This sticky bit is set to 1 when **nSYSPORESET** is asserted.
[2]	Reset status	Reset status bit: 0 = the processor is not currently held in reset 1 = the processor is currently held in reset. This bit reads 1 when **nSYSPORESET** is asserted.
[1]	Sticky power-down status	Reserved. Always zero.
[0]	Power-down status	Reserved. Always one.

11.5 Management registers

The Management Registers define the standardized set of registers that all CoreSight components implement. This section describes these registers.

Table 11-25 shows the contents of the Management Registers for the processor debug unit.

Table 11-25 Management Registers

Offset (hex)	Register number	Access	Mnemonic	Description
0xD00-0xDFC	832-895	R	-	Processor Identifier Registers. See *Processor ID Registers*.
0xF00	960	RW	ITCTRL	Integration Mode Control Registers. See *Integration Mode Control Register (ITCTRL)* on page 13-9.
0xFA0	1000		CLAIMSET	Claim Tag Set Register. See *Claim Tag Set Register* on page 11-33.
0xFA4	1001		CLAIMCLR	Claim Tag Clear Register. See *Claim Tag Clear Register* on page 11-34.
0xFB0	1004	W	LOCKACCESS	Lock Access Register. See *Lock Access Register* on page 11-34.
0xFB4	1005	R	LOCKSTATUS	Lock Status Register. See *Lock Status Register* on page 11-34.
0xFB8	1006	R	AUTHSTATUS	Authentication Status Register. See *Authentication Status Register* on page 11-29.
0xFB8-0xFC4	1006-1009	R	-	Reserved.
0xFC8	1010	R	DEVID	Device Identifier. Reserved.
0xFCC	1011	R	DEVTYPE	Device Type Register. See *Device Type Register* on page 11-35.
0xFD0-0xFFC	1012-1023	R	-	Identification Registers. See *Debug Identification Registers* on page 11-35.

11.5.1 Processor ID Registers

The Processor ID Registers are read-only registers that return the same values as the corresponding CP15 Main ID Register and Feature ID Registers. See Chapter 4 *System Control Coprocessor* for details about the information contained in these registers.

Table 11-26 shows the offset value, register number, mnemonic, and description that are associated with each Process ID Register.

Table 11-26 Processor Identifier Registers

Offset (hex)	Register number	Mnemonic	Function
0xD00	832	MIDR	Main ID Register
0xD04	833	CTR	Cache Type Register
0xD08	834	TCMTR	TCM Type Register
0xD0C	835	-	Alias of MIDR

Table 11-26 Processor Identifier Registers (continued)

Offset (hex)	Register number	Mnemonic	Function
0xD10	836	MPUIR	MPU Type Register
0xD14	837	MPIDR	Multiprocessor Affinity Register
0xD18-0xD1C	838-839	-	Alias of MIDR
0xD20	840	ID_PFR0	Processor Feature Register 0
0xD24	841	ID_PFR1	Processor Feature Register 1
0xD28	842	ID_DFR0	Debug Feature Register 0
0xD2C	843	ID_AFR0	Auxiliary Feature Register 0
0xD30	844	ID_MMFR0	Processor Feature Register 0
0xD34	845	ID_MMFR1	Processor Feature Register 1
0xD38	846	ID_MMFR2	Processor Feature Register 2
0xD3C	847	ID_MMFR3	Processor Feature Register 3
0xD40	848	ID_ISAR0	ISA Feature Register 0
0xD44	849	ID_ISAR1	ISA Feature Register 1
0xD48	850	ID_ISAR2	ISA Feature Register 2
0xD4C	851	ID_ISAR3	ISA Feature Register 3
0xD50	852	ID_ISAR4	ISA Feature Register 4
0xD54	853	ID_ISAR5	ISA Feature Register 5

11.5.2 Claim Registers

The Claim Tag Set Register and the Claim Tag Clear Register enable an external debugger to claim debug resources.

Claim Tag Set Register

Figure 11-16 shows the bit arrangement of the Claim Tag Set Register.

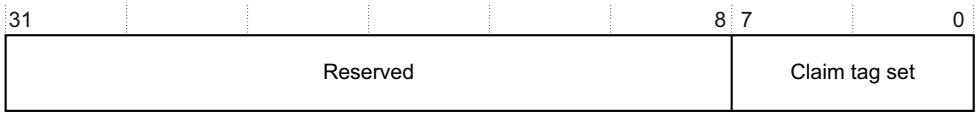


Figure 11-16 Claim Tag Set Register format

Table 11-27 shows how the bit values correspond with the Claim Tag Set Register functions.

Table 11-27 Claim Tag Set Register functions

Bits	Field	Function
[31:8]	Reserved	RAZ or SBZP.
[7:0]	Claim tag set	RAO. Sets claim tags on writes.

Writing b1 to a specific claim tag set bit sets that claim tag. Writing b0 to a specific claim tag bit has no effect. This register always reads `0xFF`, indicating eight claim tags are implemented.

Claim Tag Clear Register

Figure 11-16 on page 11-33 shows the bit arrangement of the Claim Tag Set Register.

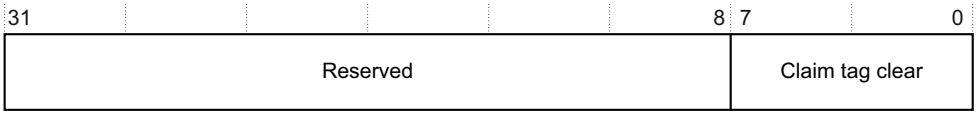


Figure 11-17 Claim Tag Clear Register format

Table 11-28 shows how the bit values correspond with the Claim Tag Clear Register functions.

Table 11-28 Functional bits of the Claim Tag Clear Register

Bit	Field	Description
[31:8]	Reserved	RAZ or SBZP.
[7:0]	Claim tag clear	R/W. Reset value is `0x00`.

Writing b1 to a specific claim tag clear bit clears that claim tag. Writing b0 has no effect. Reading this register returns the current claim tag value.

11.5.3 Lock Access Register

The Lock Access Register is a write-only register that controls writes to the debug registers. The purpose of the Lock Access Register is to reduce the risk of accidental corruption to the contents of the debug registers. It does not prevent all accidental or malicious damage. Because the state of the Lock Access Register is in the debug power domain, it is not lost when the processor powers down.

The Lock Access Register, bits [31:0] contain a key which controls the lock status. To unlock the debug registers, write a `0xC5ACCE55` key to this register. To lock the debug registers, write any other value. Accesses to locked debug registers are ignored. The lock is set on reset.

11.5.4 Lock Status Register

The Lock Status Register is a read-only register that returns the current lock status of the debug registers.

Figure 11-18 shows the bit arrangement of the Lock Status Register.

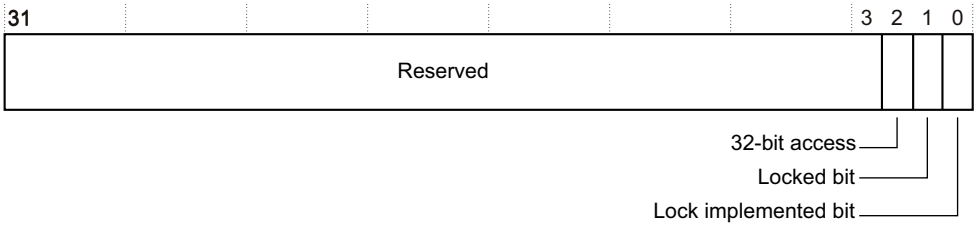


Figure 11-18 Lock Status Register format

Table 11-29 shows how the bit values correspond with the Lock Status Register functions.

Table 11-29 Lock Status Register functions

Bits	Field	Function
[31:3]	Reserved	Do not modify on writes. On reads, the value returns zero.
[2]	32-bit access	Indicates that a 32-bit access is required to write the key to the Lock Access Register. This bit always reads 0.
[1]	Locked bit	Locked bit: 0 = Writes are permitted. 1 = Writes are ignored. This is the reset value.
[0]	Lock implemented bit	Indicates that the OS lock functionality is implemented. This bit always reads 1.

11.5.5 Device Type Register

The Device Type Register is a read-only register that indicates the type of debug component.

Figure 11-19 shows the bit arrangement of the Device Type Register.

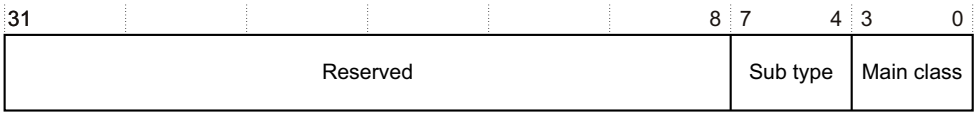


Figure 11-19 Device Type Register format

Table 11-30 shows how the bit values correspond with the Device Type Register functions.

Table 11-30 Device Type Register functions

Bits	Field	Function
[31:8]	Reserved	Do not modify on writes. On reads, the value returns zero.
[7:4]	Subtype	`0x1`, indicates that the sub-type of the device is *processor core*.
[3:0]	Main class	`0x5`, indicates that the main class of the device is *debug logic*.

11.5.6 Debug Identification Registers

The Debug Identification Registers are read-only registers that consist of the Peripheral Identification Registers and the Component Identification Registers. The Peripheral Identification Registers provide standard information that all CoreSight components require. Only bits [7:0] of each register are used. The remaining bits Read-As-Zero.

The Component Identification Registers identify the processor as a CoreSight component. Only bits [7:0] of each register are used, the remaining bits Read-As-Zero. The values in these registers are fixed.

Table 11-31 shows the offset value, register number, and description that are associated with each Peripheral Identification Register.

Table 11-31 Peripheral Identification Registers

Offset (hex)	Register number	Function
0xFD0	1012	Peripheral Identification Register 4
0xFD4	1013	Reserved
0xFD8	1014	Reserved
0xFDC	1015	Reserved
0xFE0	1016	Peripheral Identification Register 0
0xFE4	1017	Peripheral Identification Register 1
0xFE8	1018	Peripheral Identification Register 2
0xFEC	1019	Peripheral Identification Register 3

Table 11-32 shows fields that are in the Peripheral Identification Registers.

Table 11-32 Fields in the Peripheral Identification Registers

Field	Size	Description
4KB Count	4 bits	Indicates the Log_2 of the number of 4KB blocks occupied by the debug device. The processor debug registers occupy a single 4KB block, therefore this field is always 0x0.
JEP106 Identity Code	4+7 bits	Identifies the designer of the processor. This field consists of a 4-bit continuation code and a 7-bit identity code. Because the processor is designed by ARM, the continuation code is 0x4 and the identity code is 0x3B. For more information see JEP106M, Standard Manufacture's Identification Code.
Part number	12 bits	Indicates the part number of the processor. The part number for the processor is 0xC14.
Revision	4 bits	Indicates the major and minor revision of the product. The major revision contains functionality changes and the minor revision contains bug fixes for the product. The revision number starts at 0x0 and increments by 1 at both major and minor revisions. See *Product revision information* on page 1-24 for details of the value of this field.
RevAnd	4 bits	Indicates the manufacturer revision number. This number starts at 0x0 and increments by the integrated circuit manufacturer on metal fixes. For the Cortex-R4 processor, the initial value is 0x0 but this value can be changed by the manufacturer.
Customer modified	4 bits	Indicates an endorsed modification to the device. On this processor the value is always 0x0.

Table 11-33 shows how the bit values correspond with the Peripheral ID Register 0 functions.

Table 11-33 Peripheral ID Register 0 functions

Bits	Value	Description
[31:8]	-	Reserved
[7:0]	0x14	Indicates bits [7:0] of the Part number for the processor

Table 11-34 shows how the bit values correspond with the Peripheral ID Register 1 functions.

Table 11-34 Peripheral ID Register 1 functions

Bits	Value	Description
[31:8]	-	Reserved
[7:4]	0xB	Indicates bits [3:0] of the JEDEC JEP106 Identity Code
[3:0]	0xC	Indicates bits [11:8] of the Part number for the processor

Table 11-35 shows how the bit values correspond with the Peripheral ID Register 2 functions.

Table 11-35 Peripheral ID Register 2 functions

Bits	Value	Description
[31:8]	-	Reserved.
[7:4]	-	Indicates the revision number for the Cortex-R4 processor. See *Product revision information* on page 1-24 for more information.
[3]	0x1	This field is always set to 1. It indicates that the processor uses a JEP 106 identity code.
[2:0]	0x3	Indicates bits [6:4] of the JEDEC JEP106 Identity Code.

Table 11-36 shows how the bit values correspond with the Peripheral ID Register 3 functions.

Table 11-36 Peripheral ID Register 3 functions

Bits	Value	Description
[31:8]	-	Reserved.
[7:4]	0x0	Indicates the manufacturer revision number. This value changes based on the metal fixes made by the manufacturer.
[3:0]	0x0	Customer modified. See Table 11-32 on page 11-36.

Table 11-37 shows how the bit values correspond with the Peripheral ID Register 4 functions.

Table 11-37 Peripheral ID Register 4 functions

Bits	Value	Description
[31:8]	-	Reserved.
[7:4]	0x0	Indicates the number of blocks the debug component occupies. This field is always set to 0.
[3:0]	0x4	Indicates the JEDEC JEP106 continuation code. For the processor, this value is 4.

Table 11-38 shows the offset value, register number, and value that are associated with each Component Identification Register.

Table 11-38 Component Identification Registers

Offset (hex)	Register number	Value	Description
0xFF0	1020	0x0D	Component Identification Register 0
0xFF4	1021	0x90	Component Identification Register 1
0xFF8	1022	0x05	Component Identification Register 2
0xFFC	1023	0xB1	Component Identification Register 3

11.6 Debug events

A processor responds to a debug event in one of the following ways:

- ignores the debug event
- takes a debug exception
- enters debug state.

This section describes:

- *Software debug event*
- *Halting debug event* on page 11-40.
- *Behavior of the processor on debug events* on page 11-40
- *Debug event priority* on page 11-40
- *Watchpoint debug events* on page 11-40.

11.6.1 Software debug event

A software debug event is any of the following:

- A watchpoint debug event. This occurs when:
  - The data address for a load or store matches the watchpoint value.
  - All the conditions of the WCR match.
  - The watchpoint is enabled.
  - The linked context ID-holding BRP, if any, is enabled and its value matches the context ID in CP15 c13. See Chapter 4 *System Control Coprocessor*.
  - The instruction that initiated the memory access is committed for execution.

  Watchpoint debug events are only generated if the instruction passes its condition code.
- A breakpoint debug event. This occurs when:
  - An instruction was fetched and the instruction address or the CP15 Context ID register c13 matched the breakpoint value.
  - At the same time the instruction was fetched, all the conditions of the BCR for unlinked context ID breakpoint generation matched the I-side control signals.
  - The breakpoint is enabled.
  - The instruction is committed for execution. These debug events are generated whether the instruction passes or fails its condition code.
- A BKPT debug event. This occurs when a `BKPT` instruction is committed for execution. `BKPT` is an unconditional instruction.
- A vector catch debug event. This occurs when:
  - An instruction was prefetched and the address matched a vector location address. This includes any kind of prefetch, not only the ones because of exception entry.
  - At the same time the instruction was fetched, the corresponding bit of the VCR was set, that is, the vector catch is enabled.
  - The instruction is committed for execution. These debug events are generated whether the instruction passes or fails its condition code.

11.6.2 Halting debug event

The debugger or the system can cause the processor to enter into debug state by triggering any of the following halting debug events:

- assertion of the **EDBGRQ** signal, an External Debug Request
- write to the DRCR[0] Halt Request control bit.

If **EDBGRQ** is asserted while **DBGEN** is HIGH but invasive debug is not permitted, the devices asserting this signal must hold it until the processor enters debug state, that is, until **DBGACK** is asserted. Otherwise, the behavior of the processor is Unpredictable. For DRCR[0] halting debug events, the processor records them internally until it is in a state and mode so that they can be taken.

11.6.3 Behavior of the processor on debug events

This section describes how the processor behaves on debug events while not in debug state. See *Debug state* on page 11-44 for information on how the processor behaves while in debug state. When the processor is in Monitor debug-mode, Prefetch Abort and Data Abort vector catch debug events are ignored. All other software debug events generate a debug exception such as Data Abort for watchpoints, and Prefetch Abort for anything else.

When debug is disabled, the `BKPT` instruction generates a debug exception, Prefetch Abort. All other software debug events are ignored.

When **DBGEN** is LOW, debug is disabled regardless of the value of DSCR[15:14].

Table 11-39 shows the behavior of the processor on debug events.

Table 11-39 Processor behavior on debug events

DBGEN	DSCR[15:14]	Debug mode	Action on software debug event	Action on halting debug event
0	bxx	Debug disabled	Ignore or Prefetch Abort (for `BKPT`)	Ignore
1	b00	None	Ignore or Prefetch Abort (for `BKPT`)	Debug state entry
1	bx1	Halting	Debug state entry	Debug state entry
1	b10	Monitor	Debug exception	Debug state entry

11.6.4 Debug event priority

Breakpoint, instruction address or CID match, vector catch, and halting debug events have the same priority. If more than one of these events occurs on the same instruction, it is Unpredictable which event is taken.

Breakpoint, instruction address or CID match, vector catch cancel the instruction that they occur on, therefore a watchpoint cannot be taken on such an instruction.

11.6.5 Watchpoint debug events

A precise watchpoint exception has similar behavior to a precise data abort exception:

- the processor sets R14_abt to the address of the instruction to return to plus `0x08`.
- the processor does not complete the watchpointed instruction.

If the watchpointed access is subject to a precise data abort, then the precise abort takes priority over the watchpoint because it is a higher priority exception.

11.7 Debug exception

The processor takes a debug exception when a software debug event occurs while in Monitor debug-mode. Prefetch Abort and Data Abort Vector catch debug events are ignored. The debug software must carefully program certain debug events to prevent the processor from entering an unrecoverable state. If the processor takes a debug exception because of a breakpoint, BKPT, or vector catch debug event, the processor performs the following actions:

- sets the DSCR[5:2] method-of-entry bits to indicate that a breakpoint occurred
- sets the CP15 IFSR and IFAR registers as described in *Effect of debug exceptions on CP15 registers and WFAR* on page 11-42
- performs the same sequence of actions as in a Prefetch Abort exception by:
  - updating the SPSR_abt with the saved CPSR
  - changing the CPSR to abort mode and the state indicated by the TE bit with normal interrupts and imprecise aborts disabled
  - setting R14_abt as for a regular Prefetch Abort exception, that is, this register holds the address of the cancelled instruction plus `0x04`
  - setting the PC to the appropriate Prefetch Abort vector.

Note

The Prefetch Abort handler is responsible for checking the IFSR to determine if a debug exception or other kind of Prefetch Abort exception caused the exception entry. If the cause is a debug exception, the Prefetch Abort handler must branch to the debug monitor. The R14_abt register holds the address of the instruction to restart.

If the processor takes a debug exception because of a watchpoint debug event, the processor performs the following actions:

- sets the DSCR[5:2] method-of-entry bits to indicate that a precise watchpoint occurred
- sets the CP15 DFSR, DFAR, and WFAR registers as described in *Effect of debug exceptions on CP15 registers and WFAR* on page 11-42
- performs the same sequence of actions as in a Data Abort exception by:
  - updating the SPSR_abt with the saved CPSR
  - changing the CPSR to the state indicated by the TE bit with normal interrupts and imprecise aborts disabled
  - setting R14_abt as a regular Data Abort exception, that is, this register gets the address of the cancelled instruction plus `0x08`
  - setting the PC to the appropriate Data Abort vector.

Note

The Data Abort handler must check the DFSR to determine if the exception entry was caused by a Debug exception or other kind of Data Abort exception. If the cause is a Debug exception, the Data Abort handler must branch to the debug monitor. The R14_abt register holds the address of the instruction to restart.

Table 11-40 shows the values in the link register after exceptions.

Table 11-40 Values in link register after exceptions

Cause of fault	ARM	Thumb	Return address (RA[a]) meaning
Breakpoint	RA+4	RA+4	Breakpointed instruction address
Watchpoint	RA+8	RA+8	Watchpointed instruction address
`BKPT` instruction	RA+4	RA+4	`BKPT` instruction address
Vector catch	RA+4	RA+4	Vector address
Prefetch Abort	RA+4	RA+4	Address of the instruction where the execution can resume
Data Abort	RA+8	RA+8	Address of the instruction where the execution can resume

a. This is the address of the instruction that the processor can execute first on debug exception return. The address of the access that hit the watchpoint is in the WFAR.

The following sections describe:
- *Effect of debug exceptions on CP15 registers and WFAR*
- *Avoiding unrecoverable states* on page 11-43.

11.7.1 Effect of debug exceptions on CP15 registers and WFAR

The four CP15 registers that record abort information are:
1. *Data Fault Address Register* (DFAR)
2. *Instruction Fault Address Register* (IFAR)
3. *Instruction Fault Status Register* (IFSR)
4. *Data Fault Status Register* (DFSR).

For more information on these registers, see Chapter 4 *System Control Coprocessor*.

If the processor takes a debug exception because of a watchpoint debug event, the processor performs the following actions on these registers:

- it does not change the IFSR or IFAR
- it updates the DFSR with the debug event encoding
- it writes an Unpredictable value to the DFAR
- it updates the WFAR with the address of the instruction that accessed the watchpointed address, plus a processor state dependent offset:
  - + 8 for ARM state
  - + 4 for Thumb state.

If the processor takes a debug exception because of a breakpoint, `BKPT`, or vector catch debug event, the processor performs the following actions on these registers:
- it updates the IFSR with the debug event encoding
- it writes an Unpredictable value to the IFAR
- it does not change the DFSR, DFAR, or WFAR.

11.7.2 Avoiding unrecoverable states

The processor ignores vector catch debug events on the Prefetch or Data Abort vectors while in Monitor debug-mode because these events would otherwise put the processor in an unrecoverable state.

The debuggers must avoid other similar cases by following these rules, that apply only if the processor is in Monitor debug-mode:

- if BCR[22:20] is set to b010, and unlinked context ID breakpoint is selected, then the debugger must program BCR[2:1] for the same breakpoint as stated in this section
- if BCR[22:20] is set to b100 or b101, and instruction address mismatch breakpoint is selected, then the debugger must program BCR[2:1] for the same breakpoint as stated in this section.

The debugger must write BCR[2:1] for the same breakpoint as either b00 or b10, that selects either match in only USR, SYS, or SVC modes or match in only USR mode, respectively. The debugger must not program either b01, that is, match in any Privileged mode, or b11, that is, match in any mode.

You must only request the debugger to write b00 to BCR[2:1] if you know that the abort handler does not switch to one of the USR, SYS, or SVC mode before saving the context that might be corrupted by a later debug event. You must also be careful about requesting the debugger to set a breakpoint or BKPT debug event inside a Prefetch Abort or Data Abort handler, or a watchpoint debug event on a data address that any of these handlers might access.

In general, you must only set breakpoint or BKPT debug events inside an abort handler after it saves the abort context. You can avoid breakpoint debug events in abort handlers by setting BCR[2:1] as previously described.

If the code being debugged is not running in a Privileged mode, you can prevent watchpoint debug events in abort handlers by setting WCR[2:1] to b10 for match only non-privileged accesses.

Failure to follow these guidelines can lead to debug events occurring before the handler is able to save the context of the abort. This causes the corresponding registers to be overwritten, and results in Unpredictable software behavior.

11.8 Debug state

The debug state enables an external agent, usually a debugger, to control the processor following a debug event. While in debug state, the processor behaves as follows:

- The DSCR[0] core halted bit is set.
- The **DBGACK** signal is asserted, see *DBGACK* on page 11-51.
- The DSCR[5:2] method of entry bits are set appropriately.
- The processor is halted. The pipeline is flushed and no instructions are fetched.
- The processor does not change the execution mode. The CPSR is not altered.
- Exceptions are treated as described in *Exceptions in debug state* on page 11-47.
- Interrupts are ignored.
- New debug events are ignored.

The following sections describe:

- *Entering debug state*
- *Behavior of the PC and CPSR in debug state* on page 11-45
- *Executing instructions in debug state* on page 11-46
- *Writing to the CPSR in debug state* on page 11-46
- *Privilege* on page 11-46
- *Accessing registers and memory* on page 11-46
- *Coprocessor instructions* on page 11-47
- *Effect of debug state on non-invasive debug* on page 11-47
- *Effects of debug events on processor registers* on page 11-47
- *Exceptions in debug state* on page 11-47
- *Leaving debug state* on page 11-48.

11.8.1 Entering debug state

When a debug event occurs while the processor is in Halting debug-mode, it switches to a special state called *debug state* so the debugger can take control. You can configure Halting debug-mode by setting DSCR[14].

If a halting debug event occurs, the processor enters debug state even when Halting debug-mode is not configured. While the processor is in debug state, the PC does not increment on instruction execution. If the PC is read at any point after the processor has entered debug state, but before an explicit PC write, it returns a value as described in Table 11-41, depending on the previous state and the type of debug event.

Table 11-41 shows the read PC value after debug state entry for different debug events.

Table 11-41 Read PC value after debug state entry

Debug event	ARM	Thumb	Return address (RA[a]) meaning
Breakpoint	RA+8	RA+4	Breakpointed instruction address.
Watchpoint	RA+8	RA+4	Address of the instruction where the execution resumes. This is several instructions after the one that hit the watchpoint.
`BKPT` instruction	RA+8	RA+4	`BKPT` instruction address.

Table 11-41 Read PC value after debug state entry (continued)

Debug event	ARM	Thumb	Return address (RA[a]) meaning
Vector catch	RA+8	RA+4	Vector address.
External debug request signal activation	RA+8	RA+4	Address of the instruction where the execution resumes.
Debug state entry request command	RA+8	RA+4	Address of the instruction where the execution resumes.
OS unlock event	RA+8	RA+4	Address of the instruction where the execution resumes.
CTI debug request signal	RA+8	RA+4	Address of the instruction where the execution resumes.

a. This is the address of the instruction that the processor can execute first on debug exception return. The address of the instruction that hit the watchpoint is in the WFAR.

11.8.2 Behavior of the PC and CPSR in debug state

The behavior of the PC and CPSR registers while the processor is in debug state is as follows:

- The PC is frozen on entry to debug state. That is, it does not increment on the execution of ARM instructions. However, the processor still updates the PC as a response to instructions that explicitly modify the PC.
- If the PC is read after the processor has entered debug state, it returns a value as described in Table 11-41 on page 11-44, depending on the previous state and the type of debug event.
- If the debugger executes a sequence for writing a certain value to the PC and subsequently it forces the processor to restart without any additional write to the PC or CPSR, the execution starts at the address corresponding to the written value.
- If the debugger forces the processor to restart without having performed a write to the PC, the restart address is Unpredictable.
- If the debugger writes to the CPSR, subsequent reads from the PC return an Unpredictable value, and if it forces the processor to restart without having performed a write to the PC, the restart address is Unpredictable. However, CPSR reads after a CPSR write return the written value.
- If the debugger writes to the PC, subsequent reads from the PC return an Unpredictable value.
- If the debugger forces the processor to execute an instruction that writes to the PC and this instruction fails its condition codes, the PC is written with an Unpredictable value. That is, if the debugger forces the processor to restart, the restart address is Unpredictable. Also, if the debugger reads the PC, the read value is Unpredictable.
- While the processor is in debug state, the CPSR does not change unless written to by an instruction. In particular, the CPSR IT execution state bits do not change on instruction execution. The CPSR IT execution state bits do not have any effects on instruction execution.
- If the processor executes a data processing instruction with Rd==R15 and S==0, then alu-out[0] must equal the current value of the CPSR T bit, otherwise the processor behavior is Unpredictable.

11.8.3 Executing instructions in debug state

In debug state, the processor executes instructions issued through the *Instruction Transfer Register* (ITR). Before the debugger can force the processor to execute any instruction, it must enable this feature through DSCR[13].

While the processor is in debug state, it always decodes instructions from the ITR as per the ARM instruction set, regardless of the value of the T and J bits of the CPSR.

The following restrictions apply to instructions executed through the ITR while in debug state:

- with the exception of branch instructions and instructions that modify the CPSR, the processor executes any ARM instruction in the same manner as if it was not in debug state
- the branch instructions `B`, `BL`, `BLX(1)`, and `BLX(2)` are Unpredictable
- certain instructions that normally update the CPSR are Unpredictable
- instructions that load a value into the PC from memory are Unpredictable.

11.8.4 Writing to the CPSR in debug state

The only instruction that can update the CPSR while in debug state is the `MSR` instruction. All other ARMv7 instructions that write to the CPSR are Unpredictable, that is, the `BX`, `BXJ`, `SETEND`, `CPS`, `RFE`, `LDM(3)`, and data processing instructions with Rd==R15 and S==1.

The behavior of the CPSR forms of the `MSR` and `MRS` instructions in debug state is different to their behavior in normal state:

- When not in debug state, an `MSR` instruction that modifies the execution state bits in the CPSR is Unpredictable. However, in debug state an MSR instruction can update the execution state bits in the CPSR. An *Instruction Synchronization Barrier* (ISB) sequence must follow a direct modification of the execution state bits in the CPSR by an `MSR` instruction.
- When not in debug state, an `MRS` instruction reads the CPSR execution state bits as zeros. However, in debug state an `MRS` instruction returns the actual values of the execution state.

The debugger must execute an `ISB` sequence after it writes to the CPSR execution state bits using an `MSR` instruction. If the debugger reads the CPSR using an `MRS` instruction after a write to any of these bits, but before an `ISB` sequence, the value that `MRS` returns is Unpredictable. Similarly, if the debugger forces the processor to leave debug state after an `MSR` writes to the execution state bits, but before any `ISB` sequence, the behavior of the processor is Unpredictable.

11.8.5 Privilege

When the processor is in debug state, ARM instructions issued through the ITR are subject to different rules about whether they can perform privileged actions. The general rule is that all instructions and operations are permitted in debug state.

11.8.6 Accessing registers and memory

The processor always accesses register banks and memory as indicated by the CPSR mode bits, in both normal and debug state. For example, if the CPSR mode bits indicate the processor is in User mode, ARM register reads and returns the User mode banked registers, and memory accesses are presented to the MPU as not privileged.

11.8.7 Coprocessor instructions

CP14 and CP15 instructions can always be executed in debug state regardless of processor mode.

11.8.8 Effect of debug state on non-invasive debug

The processor non-invasive debug features are the ETM and *Performance Monitoring Unit* (PMU). All of these non-invasive debug features are disabled when the processor is in debug state. For more information, see Chapter 4 *System Control Coprocessor* and *ETM interface* on page 1-11.

When the processor is in debug state:

- the ETM ignores all instructions and data transfers
- PMU events are not counted
- events are not visible to the ETM
- the PMU *Cycle Count Register* (CCNT) is stopped.

11.8.9 Effects of debug events on processor registers

On entry to debug state, the processor does not update any general-purpose or program status register. This includes the SPSR_abt and R14_abt registers. In addition, the processor does not update any coprocessor registers, including the CP15 IFSR, DFSR, DFAR, or IFAR registers, except for CP14 DSCR[5:2] method-of-entry bits. These bits indicate the type of debug event that caused the entry into debug state.

Note

On entry to debug state, the processor updates the WFAR register with the address of the instruction accessing the watchpointed address plus:

- + 8 in ARM state
- + 4 in Thumb state.

11.8.10 Exceptions in debug state

While in debug state, exceptions are handled as follows:

Reset This exception is taken as in a normal processor state. This means the processor leaves debug state because of the system reset.

Prefetch Abort

This exception cannot occur because the processor does not fetch any instructions while in debug state.

Debug The processor ignores debug events, including BKPT instructions.

SVC The processor ignores SVC exceptions.

Undefined

When an Undefined exception occurs in debug state, the behavior of the processor is as follows:

- PC, CPSR, SPSR_und, and R14_und are unchanged
- the processor remains in debug state
- DSCR[8], sticky Undefined bit, is set.

Precise Data abort

When a precise Data Abort occurs in debug state, the behavior of the processor is as follows:

- PC, CPSR, SPSR_abt, and R14_abt are unchanged
- the processor remains in debug state
- DSCR[6], sticky precise data abort bit, is set
- DFSR and DFAR are set to the same values as if the abort had occurred in normal state.

Imprecise Data Abort

When an imprecise Data Abort occurs in debug state, the behavior of the processor is as follows, regardless of the setting of the CPSR A bit:

- PC, CPSR, SPSR_abt, and R14_abt are unchanged
- the processor remains in debug state
- DSCR[7], sticky imprecise data abort bit, is set
- the imprecise Data Abort does not cause the processor to perform an exception entry sequence so DFSR remains unchanged
- the processor does not act on this imprecise Data Abort on exit from the debug state, that is, the imprecise abort is discarded.

Imprecise Data Aborts on entry and exit from debug state

On entering debug state, the processor executes a *Data Synchronization Barrier* (DSB) sequence to ensure that any outstanding imprecise Data Aborts are detected, before starting debug operations.

If the DSB operation detects an imprecise Data Abort, the processor records this event and its type as if the CPSR A bit was set. The purpose of latching this event is to ensure that it can be taken on exit from the debug state.

Before forcing the processor to leave debug state, the debugger must execute a DSB sequence to ensure that all debugger-generated imprecise Data Aborts are detected, and therefore discarded, while still in debug state. After exiting debug state, the processor acts on any previously recorded imprecise Data Aborts if permitted by the CPSR A bit.

11.8.11 Leaving debug state

The debugger can force the processor to leave debug state:

- by setting the restart request bit, DRCR[1], to 1
- through the *Cross Trigger Interface* (CTI) external restart request mechanism.

When one of those restart requests occurs, the processor:

1. Clears the DSCR[1] core restarted flag.
2. Leaves debug state.
3. Clears the DSCR[0] core halted flag.
4. Drives the **DBGACK** signal LOW, unless the DSCR[11] DbgAck bit is set to 1.
5. Starts executing instructions from the address last written to the PC in the processor mode and state indicated by the current value of the CPSR. The CPSR IT execution state bit is restarted with the current value applying to the first instruction on restart.

6. Sets the DSCR[1] core restarted flag to 1.

11.9 Cache debug

This section describes cache debug. It consists of:

- *Cache pollution in debug state*
- *Cache coherency in debug state*
- *Cache usage profiling*.

11.9.1 Cache pollution in debug state

If bit [0] of the *Debug State Cache Control Register* (DSCCR) is set to 0 while the processor is in debug state, then the L1 data cache does not perform any line fill.

Note

No special feature is required to prevent L1 instruction cache pollution because instruction side fetches cannot occur while in debug state.

11.9.2 Cache coherency in debug state

The debugger can update memory while in debug state:

- to replace an instruction with a `BKPT`, or to restore the original instruction
- to download code for the processor to execute on leaving debug state.

The debugger can maintain cache coherency in both these situations with the following features:

- If bit [2] of the DSCCR is set to 0 while the processor is in debug state, then the processor treats any memory access that hits in L1 data cache as write-through, regardless of the memory region attributes. This guarantees that the L1 instruction cache can see the changes to the code region without the debugger executing a time-consuming and device-specific sequence of cache clean operations.
- After the code is written to memory, the debugger can execute either a CP15 instruction cache invalidate all operation, or a CP15 instruction cache invalidate line operation.

Note

The processor can normally execute CP15 instruction cache invalidate all operation or CP15 instruction cache invalidate line operation only in Privileged mode. However, in debug state the processor can execute these instructions even when invasive debug is not permitted in Privileged mode. This exception to the rule enables the debugger to maintain coherency.

11.9.3 Cache usage profiling

You can obtain cache usage profiling information using the *Performance Monitoring Unit* (PMU). The processor can count cache accesses and misses over a period of time. See Chapter 6 *Events and Performance Monitor*.

11.10 External debug interface

The system can access memory-mapped debug registers through the processor APB slave port. This section describes the APB interface and the miscellaneous debug input and output signals:

- *APB signals*
- *Miscellaneous debug signals*
- *Authentication signals* on page 11-52.

11.10.1 APB signals

The APB slave port is compliant with the AMBA *Advanced Peripheral Bus* specification v3 and can be connected to the *Debug Access Port* (DAP). This APB slave interface supports 32-bits wide data, stalls, slave-generated aborts, and ten address bits [11:2] mapping 4KB of memory. An extra **PADDRDBG31** signal indicates to the processor the source of access.

Table A-12 on page A-17 shows the external debug interface signals.

11.10.2 Miscellaneous debug signals

This section describes the miscellaneous debug signals.

EDBGRQ

This signal generates a halting debug event, that is, it requests the processor to enter debug state. When this occurs, the DSCR[5:2] method-of-debug entry bits are set to b0100. When **EDBGRQ** is asserted, it must be held until **DBGACK** is asserted. Failure to do so leads to Unpredictable behavior of the processor.

DBGACK

The processor asserts **DBGACK** to indicate that the system has entered debug state. It serves as a handshake for the **EDBGRQ** signal. The **DBGACK** signal is also driven HIGH when the debugger sets the DSCR[10] DbgAck bit to 1.

DBGNOPWRDWN

The processor asserts **DBGNOPWRDWN** when bit [0] of the Device Power down and Reset Control Register is 1. The processor power controller must work in Emulate mode when this signal is HIGH.

DBGROMADDR

The **DBGROMADDR** signal specifies bits [31:12] of the debug ROM physical address. This is a configuration input and must be tied off or only change while the processor is in reset. In a system with multiple debug ROMs, this address must be tied off to point to the top-level ROM address.

DBGROMADDRV is the valid signal for **DBGROMADDR**. If the address cannot be determined, **DBGROMADDR** must be tied off to zero and **DBGROMADDRV** must be tied LOW. The value of these signals can be read from the *Debug ROM Address Register* (DRAR).

DBGSELFADDR

The **DBGSELFADDR** signal specifies bits [31:12] of the offset from the debug ROM physical address to the physical address where the processor APB port is mapped to the base of the 4KB debug register map. This is a configuration input and must be tied off or only change while the processor is in reset.

DBGSELFADDRV is the valid signal for **DBGSELFADDR**. If the offset cannot be determined, **DBGSELFADDR** must be tied off to zero and **DBGSELFADDRV** must be tied LOW. The value of these signals can be read from the *Debug Self Address Register* (DSAR).

DBGRESTART

The **DBGRESTART** signal is used to bring the processor out of debug halt state. The processor acknowledges **DBGRESTART** by asserting **DBGRESTARTED**, and then starts fetching instructions when **DBGRESTART** is deasserted.

DBGRESTARTED

The processor asserts **DBGRESTARTED** in response to a **DBGRESTART** request, when it is ready to exit debug halt state and return to normal run state.

DBGTRIGGER

The processor asserts **DBGTRIGGER** to indicate that the system has accepted a debug request and attempts to enter debug state. It is not a handshake for the **EDBGRQ** signal. If **DBGACK** does not go HIGH following **DBGTRIGGER**, the memory system has stopped responding and the processor has not entered debug state.

Table A-13 on page A-17 shows the debug miscellaneous signals.

11.10.3 Authentication signals

Table 11-42 shows a list of the valid authentication signals and the associated debug permissions. Authentication signals are used to configure the processor so its activity can only be debugged or traced in a certain subset of processor modes.

Table 11-42 Authentication signal restrictions

DBGEN[a]	NIDEN	Non-invasive debug permitted in User and Privileged modes
0	0	No
X	1	Yes
1	0	Yes

a. When **DBGEN** is LOW, the processor behaves as if DSCR[15:14] equals b00 with the exception that halting debug events are ignored when this signal is LOW.

Changing the authentication signals

The **NIDEN**, and **DBGEN** input signals are either tied off to some fixed value or controlled by some external device.

If software running on the processor has control over an external device that drives the authentication signals, it must make the change using a safe sequence:

1. Execute an implementation-specific sequence of instructions to change the signal value. For example, this might be a single `STR` instruction that writes certain value to a control register in a system peripheral.
2. If step1 involves any memory operation, issue a *Data Synchronization Barrier* (`DSB`) instruction.
3. Poll the DSCR or Authentication Status Register to check whether the processor has already detected the changed value of these signals. This is required because the system might not issue the signal change to the processor until several cycles after the `DSB` completes.
4. Issue an *Instruction Synchronization Barrier* (`ISB`) instruction.

The software cannot perform debug or analysis operations that depend on the new value of the authentication signals until this procedure is complete. The same rules apply when the debugger has control of the processor through the ITR while in debug state.

The values of the **DBGEN** and **NIDEN** signals can be determined by polling DSCR[17:16], DSCR[15:14], or the Authentication Status Register.

11.11 Using the debug functionality

This section provides some examples of using the processor debug functionality, both from the point of view of a software engineer writing code to run on an ARM processor and of a developer creating debug tools for the processor. In the former case, examples are given in ARM assembly language. In the latter case, the examples are in C pseudo-language, intended to convey the algorithms to be used. These examples are not intended as source code for a debugger.

The debugger examples use a pair of pseudo-functions such as the following:

```
uint32 ReadDebugRegister(int reg_num)
{
    // read the value of the debug register reg_num at address reg_num << 2
}

WriteDebugRegister(int reg_num, uint32 val)
{
    // write the value val to the debug register reg_num at address reg_num >> 2
}
```

A basic function for using the debug state is executing an instruction through the ITR. Example 11-1 shows the sequence for executing an ARM instruction through the ITR.

Example 11-1 Executing an ARM instruction through the ITR

```
ExecuteARMInstruction(uint32 instr)
{
    // Step 1. Poll DSCR until InstrCompl is set.
    repeat
    {
        dscr := ReadDebugRegister(34);
    }
    until (dscr & (1<<24));
    // Step 2. Write the opcode to the ITR.
    WriteDebugRegister(33, instr);
    // Step 3. Poll DSCR until InstrCompl is set.
    repeat
    {
        dscr := ReadDebugRegister(34);
    }
    until (dscr & (1<<24);
}
```

This section describes:

- *Debug communications channel* on page 11-55
- *Programming breakpoints and watchpoints* on page 11-57
- *Single-stepping* on page 11-60
- *Debug state entry* on page 11-61
- *Debug state exit* on page 11-62
- *Accessing registers and memory in debug state* on page 11-63
- *Emulating power down* on page 11-71.

11.11.1 Debug communications channel

There are two ways that an external debugger can send data to or receive data from the processor:

- The debug communications channel, when the processor is not in debug state. It is defined as the set of resources used for communicating between the external debugger and software running on the processor.
- The mechanism for forcing the processor to execute ARM instructions, when the processor is in debug state. For more information, see *Executing instructions in debug state* on page 11-46.

Rules for accessing the DCC

At the processor side, the debug communications channel resources are:

- CP14 Debug Register c5 (DTR)
- CP14 Debug Register c1 (DSCR).

The ARMv7 debug architecture is implemented on the processor so that:

- If a read of the CP14 DSCR returns 1 for the DTRTXfull flag:
  - a following read of the CP14 DTR returns valid data and DTRTXfull is cleared. No prefetch flush is required between these two CP14 instructions.
  - a following write to the CP14 DTR is Unpredictable.
- If a read of the CP14 DSCR returns 0 for the DTRTXfull flag:
  - a following read of the CP14 DTR returns an Unpredictable value.
  - a following write to the CP14 DTR writes the intended 32-bit word, and sets DTRRXfull to 1. No prefetch flush is required between these two CP14 instructions.

When Nonblocking mode is selected for DTR accesses, the following conditions are true for memory-mapped DSCR, memory-mapped DTRRX, and DTRTX registers:

- If a read of the memory-mapped DSCR returns 0 for the DTRTXfull flag:
  - a following read of the memory-mapped DTRTX is ignored. For example, the content of DTRRXfull is unchanged and the read returns an Unpredictable value.
  - a following write of the memory-mapped DTRRX passes valid data to the processor and sets DTRTXfull to 1.
- If a read of the memory-mapped DSCR returns 1 for the DTRTXfull flag:
  - a following read of the memory-mapped DTRTX returns valid data and clears DTRRXfull.
  - a following write of the memory-mapped DTRRX is ignored, that is, both DTRTXfull and DTRRX contents are unchanged.

The ARMv7 debug architecture does not support other uses of the DCC resources. In particular, the processor does not support the following:

- CP14 DSCR[30:29] flags to access the memory-mapped DTRRX and DTRTX registers
- polling memory-mapped DSCR[30:29] flags to access CP14 DTR.

Software access to the DCC

Software running on the processor that sends data to the debugger through the target-to-host channel can use the sequence of instructions that Example 11-2 shows.

Example 11-2 Target to host data transfer (target end)

```
            ; r0 -> word to send to the debugger
WriteDCC    MRC         p14, 0, PC, c0, c1, 0
            BEQ         WriteDCC
            MCR         p14, 0, Rd, c0, c5, 0
            BX          lr
```

Example 11-3 shows the sequence of instructions for sending data to the debugger through the host-to-target channel.

Example 11-3 Host to target data transfer (target end)

```
            ; r0 -> word sent by the debugger
ReadDCC     MRC         p14, 0, PC, c0, c1, 0
            BCC         ReadDCC
            MRC         p14, 0, Rd, c0, c5, 0
            BX          lr
```

Debugger access to the DCC

When not in debug state, a debugger can access the DCC through the external interface. The following examples show the pseudo-code operations for these accesses.

Example 11-4 shows the code for target-to-host data transfer.

Example 11-4 Target to host data transfer (host end)

```
uint32        ReadDCC()
{
        // Step 1. Poll DSCR until DTRTXfull is set to 1.
        repeat
        {
            dscr := ReadDebugRegister(34);
        }
        until (dscr & (1<<29));
        // Step 2. Read the value from DTRTX.
        dtr_val := ReadDebugRegister(35);

        return dtr_val;
}
```

Example 11-5 shows the code for host-to-target data transfer.

Example 11-5 Host to target data transfer (host end)

```
WriteDCC(uint32 dtr_val)
```

```
{
        // Step 1. Poll DSCR until DTRRXfull is clear.
        repeat
        {
            dscr := ReadDebugRegister(34);
        }
        until (!(dscr & (1<<30)));
        // Step 2. Write the value to DTRRX.
        WriteDebugRegister(32, dtr_val);
}
```

While the processor is running, if the DCC is used as a data channel, it might be appropriate to poll the DCC regularly.

Example 11-6 shows the code for polling the DCC.

Example 11-6 Polling the DCC (host end)

```
PollDCC
{
    dscr := ReadDebugRegister(34);
    if (dscr & (1<<29))
    {
        // DTRTX (target -> host transfer register) full
        dtr := ReadDebugRegister(35)
        ProcessTargetToHostWord(dtr);
    }
    if (!(dscr & (1<<30)))
    {
        // DTRRX (host -> target transfer register) empty
        dtr := GetNextHostToTargetWord()
        WriteDebugRegister(32, dtr);
    }
}
```

11.11.2 Programming breakpoints and watchpoints

This section describes the following operations:

- *Programming simple breakpoints and the byte address select*
- *Setting a simple aligned watchpoint* on page 11-58
- *Setting a simple unaligned watchpoint* on page 11-59.

Programming simple breakpoints and the byte address select

When programming a simple breakpoint, you must set the byte address select bits in the control register appropriately. For a breakpoint in ARM state, this is simple. For Thumb state, you must calculate the value based on the address.

For a simple breakpoint, you can program the settings for the other control bits as Table 11-43 shows:

Table 11-43 Values to write to BCR for a simple breakpoint

Bits	Value to write	Description
[31:29]	0b000	Reserved
[28:24]	0b00000	Breakpoint address mask
[23]	0b0	Reserved
[22:20]	0b000	Meaning of BVR
[19:16]	0b0000	Linked BRP number
[15:9]	0b00	Reserved
[8:5]	Derived from address	Byte address select
[4:3]	0b00	Reserved
[2:1]	0b11	Supervisor access control
[0]	0b1	Breakpoint enable

Example 11-7 shows the sequence of instructions for setting a simple breakpoint.

Example 11-7 Setting a simple breakpoint

```
SetSimpleBreakpoint(int break_num, uint32 address, iset_t isa)
{
    // Step 1. Disable the breakpoint being set.
    WriteDebugRegister(80 + break_num, 0x0);
    // Step 2. Write address to the BVR, leaving the bottom 2 bits zero.
    WriteDebugRegister(64 + break_num, address & 0xFFFFFFC);
    // Step 3. Determine the byte address select value to use.
    case (isa) of
    {
    // Note: The processor does not support Jazelle or ThumbEE states,
    // but the ARMv7 Debug architecture does
    when JAZELLE:
        byte_address_select := (1 << (address & 3));
    when THUMB:
        byte_address_select := (3 << (address & 2));
    when ARM:
        byte_address_select := 15;
    }
    // Step 4. Write the mask and control register to enable the breakpoint.
breakpoint
    WriteDebugRegister(80 + break_num, 7 | (byte_address_select << 5));
}
```

Setting a simple aligned watchpoint

The simplest and most common type of watchpoint watches for a write to a given address in memory. In practice, a data object spans a range of addresses but is aligned to a boundary corresponding to its size, so you must set the byte address select bits in the same way as for a breakpoint.

For a simple watchpoint, you can program the settings for the other control bits as Table 11-44 shows:

Table 11-44 Values to write to WCR for a simple watchpoint

Bits	Value to write	Description
[31:29]	0b000	Reserved
[28:24]	0b00000	Watchpoint address mask
[23:21]	0b000	Reserved
[20]	0b0	Enable linking
[19:16]	0b0000	Linked BRP number
[15:13]	0b00	Reserved
[12:5]	Derived from address	Byte address select
[4:3]	0b10	Load/Store access control
[2:1]	0b11	Privileged access control
[0]	0b1	Watchpoint enable

Example 11-8 shows the code for setting a simple aligned watchpoint.

Example 11-8 Setting a simple aligned watchpoint

```
SetSimpleAlignedWatchpoint(int watch_num, uint32 address, int size)
{
    // Step 1. Disable the watchpoint being set.
    WriteDebugRegister(112 + watch_num, 0);
    // (Step 2. Write address to the WVR, leaving the bottom 3 bits zero.
    WriteDebugRegister(96 + watch_num, address & 0xFFFFFF8);
    // Step 3. Determine the byte address select value to use.
    case (size) of
    {
    when 1:
        byte_address_select := (1 << (address & 7));
    when 2:
        byte_address_select := (3 << (address & 6));
    when 4:
        byte_address_select := (15 << (address & 4));
    when 8:
        byte_address_select := 255;
    }
    // Step 4. Write the mask and control register to enable the watchpoint.
breakpoint
    WriteDebugRegister(112 + watch_num, 23 | (byte_address_select << 5));
}
```

Setting a simple unaligned watchpoint

Using the byte address select bits, certain unaligned objects up to a doubleword (64 bits) can be watched in a single watchpoint. However, this cannot cover all cases, and in many cases a second watchpoint might be required.

Table 11-45 shows some examples.

Table 11-45 Example byte address masks for watchpointed objects

Address of object	Object size in bytes	First address value	First byte address mask	Second address value	Second byte address mask
0x00008000	1	0x00008000	0b00000001	Not required	-
0x00008007	1	0x00008000	0b10000000	Not required	-
0x00009000	2	0x00009000	0b00000011	Not required	-
0x0000900c	2	0x00009000	0b11000000	Not required	-
0x0000900d	2	0x00009000	0b10000000	0x00009008	0b00000001
0x0000A000	4	0x0000A000	0b00001111	Not required	-
0x0000A003	4	0x0000A000	0b01111000	Not required	-
0x0000A005	4	0x0000A000	0b11100000	0x0000A008	0b00000001
0x0000B000	8	0x0000B000	0b11111111	Not required	-
0x0000B001	8	0x0000B000	0b11111110	0x0000B008	0b00000001

Example 11-9 shows the code for setting a simple unaligned watchpoint.

Example 11-9 Setting a simple unaligned watchpoint

```
bool SetSimpleWatchpoint(int watch_num, uint32 address, int size)
{
    // Step 1. Disable the watchpoint being set.
    WriteDebugRegister(112 + watch_num, 0x0);
    // Step 2. Write addresses to the WVRs, leaving the bottom 3 bits zero.
    WriteDebugRegister(96 + watch_num, (address & 0xFFFFFF8));
    // Step 3. Determine the byte address select value to use.
    byte_address_select := (1 << size) - 1;
    byte_address_select := (byte_address_select) << (address & 7);
    // Step 4. Write the mask and control register to enable the breakpoint.
    WriteDebugRegister (112 + watch_num, 5'b23 | ((byte_address_select & 0xFF) << 5));
    // Step 5. Set second watchpoint if required. This is the case if the byte
    // address mask is more than 8 bits.
    if (byte_address_select >= 256)
    {
        WriteDebugRegister(112 + watch_num + 1, 0);
        WriteDebugRegister(96 + watch_num + 1, (address & 0xFFFFFF8) + 8);
        WriteDebugRegister(112 + watch_num + 1 23| ((byte_address_select & 0xFF00) >> 3));
    }
    // Step 6. Return flag to caller indicating if second watchpoint was used.
    return (byte_address_select >= 256)
}
```

11.11.3 Single-stepping

You can use the breakpoint mismatch bit to implement single-stepping on the processor. Unlike high-level stepping, single-stepping implements a low-level step that executes a single instruction at a time. With high-level stepping, the instruction is decoded to determine the address of the next instruction and a breakpoint is set at that address.

Example 11-10 shows the code for single-stepping off an instruction.

Example 11-10 Single-stepping off an instruction

```
SingleStepOff(uint32 address)
{
        bkpt := FindUnusedBreakpointWithMismatchCapability();
        SetComplexBreakpoint(bkpt, address, 4 << 20);
}
```

Note

In Example 11-10, the third parameter of `SetComplexBreakpoint()` indicates the value to set BCR[22:20].

This method of single-stepping steps off the instruction that might not necessarily be the same as stepping to the next instruction executed. In certain circumstances, the next instruction executed might be the same instruction being stepped off.

The simplest example of this is a branch to a self instruction such as `(B .)`. In this case, the wanted behavior is most likely to step off the branch to self because this is often used as a means of waiting for an interrupt.

A more complex example is a return from function that returns to the same point. For example, a simple recursive function might terminate with:

```
BL    ThisFunction
POP    {saved_registers, pc}
```

In this case, the `POP` instruction loads a link register that is saved at the start of the function, and if that is the link register created by the `BL` instruction shown, it points back at the `POP` instruction. Therefore, this single step code unwinds the entire call stack to the point of the original caller, rather than stepping out a level at a time. It is not possible to single step this piece of code using either the high-level or low-level stepping methods.

11.11.4 Debug state entry

On entry to debug state, the debugger can read the processor state, including all registers and the PC, and determine the cause of the exception from the DSCR method-of-entry bits.

Example 11-11 shows the code for entry to debug state.

Example 11-11 Entering debug state

```
OnEntryToDebugState(PROCESSOR_STATE *state)
{
    // Step 1. Read the DSCR to determine the cause of debug entry.
    state->dscr := ReadDebugRegister(34);
    // Step 2. Issue a DataSynchronizationBarrier instruction if required;
    // this is not required by Cortex-R4 but is required for ARMv7
    // debug.
    if ((state->dscr & (1<<19)) == 0)
    {
        ExecuteARMInstruction(0xEE070F9A)
        // Step 3. Poll the DSCR for DSCR[19] to be set.
        repeat
        {
```

```
                dscr := ReadDebugRegister(34);
            }
            until (dscr & (1<<19));
        }
        // Step 4. Read the entire processor state. The function ReadAllRegisters
        //    reads all general-purpose registers for all processor mode, and saves
        //    the data in “state”.
        ReadAllRegisters(state);
        // Step 5. Based on the CPSR (processor state), determine the actual restart
        //    address
        if (state->cpsr & (1<<5);
        {
            // set the T bit to Thumb state
            state->pc := state->pc - 4;
        }
        elseif (state->cpsr & (1<<24))
        {
            // Set the J bit to Jazelle state. Note: ARM Cortex-R4 does not support
            // Jazelle state but ARMv7 debug does.
            state->pc := state->pc - IMPLEMENTATION DEFINED
value;
        }
        else
        {
            // ARM state
            state->pc := state->pc - 8;
        }
        // Step 6. If the method of entry was Watchpoint Occurred, read the WFAR
        // register
        method_of_debug_entry := ((state->dscr >> 2) & 0xF;
        if (method_of_debug_entry == 2 || method_of_debug_entry == 10)
        {
            state->wfar := ReadDebugRegister(6);
        }
}
```

11.11.5 Debug state exit

When exiting debug state, the program counter must always be written. If the execution state or CPSR must be changed, this must be done before writing to the PC because writing to the CPSR can affect the PC.

Having restored the program state, the debugger can restart by writing to bit [1] of the Debug Run Control Register. It must then poll bit [1] of the Debug Status and Control Register to determine if the core has restarted.

Example 11-12 shows the code for exit from debug state.

Example 11-12 Leaving debug state

```
ExitDebugState(PROCESSOR_STATE *state)
{
    // Step 1. Update the CPSR value
    WriteCPSR(state->cpsr);
    // Step 2. Restore any registers corrupted by debug state. The function
    // WriteAllRegisters restores all general-purpose registers for all
    // processor modes apart from R0.
    WriteAllRegisters(state);
    // Step 3. Write the return address.
```

```
    WritePC(state->pc);
    // Step 4. Writing the PC corrupts R0 therefore, restore R0 now.
    WriteRegister(0, state->r0);
    // Step 5. Write the restart request bit in the DRCR.
    WriteDebugRegister(36, 1<<1);
    // Step 6. Poll the RESTARTED flag in the DSCR.
    repeat
    {
        dscr := ReadDebugRegister(34);
    }
    until (dscr & (1<<1));
}
```

11.11.6 Accessing registers and memory in debug state

This section describes the following:

- *Reading and writing registers through the DCC*
- *Reading the PC in debug state* on page 11-64
- *Reading the CPSR in debug state* on page 11-64
- *Writing the CPSR in debug state* on page 11-64
- *Reading memory* on page 11-65
- *Fast register read/write* on page 11-67
- *Fast memory read/write* on page 11-68
- *Accessing coprocessor registers* on page 11-69.

Reading and writing registers through the DCC

To read a single register, the debugger can use the sequence that Example 11-13 shows. This sequence depends on two other sequences, *Executing an ARM instruction through the ITR* on page 11-54 and *Target to host data transfer (host end)* on page 11-56.

Example 11-13 Reading an ARM register

```
uint32 ReadARMRegister(int Rd)
{
    // Step 1. Execute instruction MCR p14, 0, Rd, c0, c5, 0 through the ITR.
    ExecuteARMInstruction(0xEE000E15 + (Rd<<12));
    // Step 2. Read the register value through DTRTX.
    reg_val := ReadDCC();
    return reg_val;
}
```

Example 11-14 shows a similar sequence for writing an ARM register.

Example 11-14 Writing an ARM register

```
WriteRegister(int Rd, uint32 reg_val)
{
    // Step 1. Write the register value to DTRRX.
    WriteDCC(reg_val);
    // Step 2. Execute instruction MRC p14, 0, Rd, c0, c5, 0 to the ITR.
    ExecuteARMInstruction(0xEE100E15 + (Rd<<12));
```

```
}
```

Reading the PC in debug state

Example 11-15 shows the code to read the PC.

Example 11-15 Reading the PC

```
ReadPC()
{
    // Step 1. Save R0
    saved_r0 := ReadRegister(0);
    // Step 2. Execute the instruction MOV r0, pc through the ITR.
    ExecuteARMInstruction(0xE1A0000F);
    // Step 3. Read the value of R0 that now contains the PC.
    pc := ReadRegister(0);
    // Step 4. Restore the value of R0.
    WriteRegister(0, saved_r0);
    return pc;
}
```

Note

You can use a similar sequence to write to the PC to set the return address when leaving debug state.

Reading the CPSR in debug state

Example 11-16 shows the code for reading the CPSR.

Example 11-16 Reading the CPSR

```
ReadCPSR()
{
    // Step 1. Save R0.
    saved_r0 := ReadRegister(0);
    // Step 2. Execute instruction MRS R0, CPSR through the ITR.
    ExecuteARMInstruction(0xE10F0000);
    // Step 3. Read the value of R0 that now contains the CPSR
    cpsr_val := ReadRegister(0);
    // Step 4. Restore the value of R0.
    WriteRegister(0, saved_r0);
    return cpsr_val;
}
```

Note

You can use similar sequences to read the SPSR in Privileged modes.

Writing the CPSR in debug state

Example 11-17 on page 11-65 shows the code for writing the CPSR.

Example 11-17 Writing the CPSR

```
WriteCPSR(uint32 cpsr_val)
{
    // Step 1. Save R0.
    saved_r0 := ReadRegister(0);
    // Step 2. Write the new CPSR value to R0.
    WriteRegister(0, cpsr_val);
    // Step 3. Execute instruction MSR R0, CPSR through the ITR.
    ExecuteARMInstruction(0xE12FF000);
    // Step 4. Execute a PrefetchFlush instruction through the ITR.
    ExecuteARMInstruction(9xEE070F95);
    // Step 5. Restore the value of R0.
    WriteRegister(0, saved_r0);
}
```

Reading memory

Example 11-18 shows the code for reading a byte of memory.

Example 11-18 Reading a byte of memory

```
uint8 ReadByte(uint32 address, bool &aborted)
{
    // Step 1. Save the values of R0 and R1.
    saved_r0 := ReadRegister(0);
    saved_r1 := ReadRegister(1);
    // Step 2. Write the address to R0.
    WriteRegister(0, address);
    // Step 3. Execute the instruction LDRB R1,[R0] through the ITR.
    ExecuteARMInstruction(0xE5D01000);
    // Step 4. Read the value of R1 that contains the data at the address.
    datum := ReadRegister(1);
    // Step 5. Restore the corrupted registers R0 and R1.
    WriteRegister(0, saved_r0);
    WriteRegister(1, saved_r1);
    // Step 6. Check the DSCR for a sticky abort.
    aborted := CheckForAborts();
    return datum;
}
```

Example 11-19 shows the code for checking for aborts after a memory access.

Example 11-19 Checking for an abort after memory access

```
bool CheckForAborts()
{
    // Step 1. Check the DSCR for a sticky abort.
    dscr := ReadDebugRegister(34);
    if (dscr & ((1<<6) + (1<<7))
    {
        // Step 2. Clear the sticky flag by writing DRCR[2].
        WriteDebugRegister(36, 1<<2);
        return true;
    }
    else
```

```
    {
        return false;
    }
}
```

Note

You can use a similar sequence to read a halfword of memory and to write to memory.

To read or write blocks of memory, substitute the data instruction with one that uses post-indexed addressing. For example:

```
LDRB R1, [R0],1
```

This prevents reloading the address value for each sequential word.

Example 11-20 shows the code for reading a block of bytes of memory.

Example 11-20 Reading a block of bytes of memory

```
ReadBytes(uint32 address, bool &aborted, uint8 *data, int nbytes)
{
    // Step 1. Save the value of R0 and R1.
    saved_r0 := ReadRegister(0);
    saved_r1 := ReadRegister(1);
    // Step 2. Write the address to R0
    WriteRegister(0, address);
    while (nbytes > 0)
    {
        // Step 3. Execute instruction LDRB R1,[R0],1 through the ITR.
        ExecuteARMInstruction(0xE4D01001);
            // Step 4. Read the value of R1 that contains the data at the
            // address.
        *data++ := ReadRegister(1);
        --nbytes;
    }
    // Step 5. Restore the corrupted registers R0 and R1.
    WriteRegister(0, saved_r0);
    WriteRegister(1, saved-r1);
    // Step 6. Check the DSCR for a sticky abort.
    aborted := CheckForAborts();
    return datum;
}
```

Example 11-21 shows the sequence for reading a word of memory.

Note

A faster method is available for reading and writing words using the direct memory access function of the DCC. See *Fast memory read/write* on page 11-68.

Example 11-21 Reading a word of memory

```
uint32 ReadWord(uint32 address, bool &aborted)
{
    // Step 1. Save the value of R0.
    saved_r0 := ReadRegister(0);
```

```
    // Step 2. Write the address to R0.
    WriteRegister(0, address);
    // Step 3. Execute instruction LDC p14, c5, [R0] through the ITR.
    ExecuteARMInstruction(0xED905E00);
    // Step 4. Read the value from the DTR directly.
    datum := ReadDCC();
    // Step 5. Restore the corrupted register R0.
    WriteRegister(0, saved_r0);
    // Step 6. Check the DSCR for a sticky abort.
    aborted := CheckForAborts();
    return datum;
}
```

Fast register read/write

When multiple registers must be read in succession, you can optimize the process by placing the DCC into stall mode and by writing the value 1 to the DCC access mode bits. For more information, see *CP14 c1, Debug Status and Control Register* on page 11-14.

Example 11-22 shows the sequence to change the DTR access mode.

Example 11-22 Changing the DTR access mode

```
SetDTRAccessMode(int mode)
{
    // Step 1. Write the mode value to DSCR[21:20].
    dscr := ReadDebugRegister(34);
    dscr := (dscr & ~(0x3<<20)) | (mode<<20);
    WriteDebugRegister(34, dscr);
}
```

Example 11-23 shows the sequence to read registers in stall mode.

Example 11-23 Reading registers in stall mode

```
ReadRegisterStallMode(int Rd)
{
    // Step 1. Write the opcode for MCR p14, 0, Rd, c5, c0 to the ITR.
    // Write stalls until the ITR is ready.
    WriteDebugRegister(33, 0xEE000E15 + (Rd<<12));
    // Step 2. Read the register value through the DCC. Read stalls until
    // DTRTX is ready
    reg_val := ReadDebugRegister(32);
    return reg_val;
}
```

Example 11-24 shows the sequence to write registers in stall mode.

Example 11-24 Writing registers in stall mode

```
WriteRegisterInStallMode(int Rd, uint32 value)
{
    // Step 1. Write the value to the DTRRX.
    // Write stalls until the DTRRX is ready.
```

```
    WriteDebugRegister(32, value);
    // Step 2. Write the opcode for MRC p14, 0, Rd, c5, c0 to the ITR.
    // Write stalls until the ITR is ready.
    WriteDebugRegister(33, 0xEE100E15 + (Rd<<12));
}
```

Note

To transfer a register to the processor when in stall mode, you are not required to poll the DSCR each time an instruction is written to the ITR and a value read from or written to the DTR. The processor stalls using the signal **PREADYDBG** until the previous instruction has completed or the DTR register is ready for the operation.

Fast memory read/write

This section provides example code to enable faster reads from memory by making use of the DTR access mode.

Example 11-25 shows the sequence for reading a block of words of memory.

Example 11-25 Reading a block of words of memory

```
ReadWords(uint32 address, bool &aborted, uint32 *data, int nwords)
{
    // Step 1. Write the value 0b01 to DSCR[21:20] for stall mode.
    SetDTRAccessMode(1);
    // Step 2. Save the value of R0.
    saved_r0 := ReadRegisterInStallMode(0);
    // Step 3. Write the address to read from to the DTRRX.
    // Write stalls until the DTRRX is ready.
    WriteRegisterInStallMode(0, address);
    // Step 4. Write the opcode for LDC p14, c5, [R0], 4 to the ITR.
    // Write stalls until the ITR is ready.
    WriteDebugRegister(33, 0xECB05E01);
    // Step 5. Write the value 0b10 to DSCR[21:20] for fast mode.
    SetDCCAccessMode(2);
    // Step 6. Loop reading out the data.
    // Each time a word is read from the DTRTX, the instruction is reissued.
    while (nwords > 1)
    {
        *data++ = ReadDebugRegister(35);
        --nwords;
    }
    // Step 7. Write the value 0b00 to DSCR[21:20] for non-blocking mode.
    SetDTRAccessMode(0);
    // Step 8. Need to wait for the final instruction to complete. If there
    // was an abort, this will complete immediately.
    do
    {
       dscr := ReadDebugRegister(34);
    }
    until (dscr & (1<<24));
    // Step 9: Check for aborts.
    aborted := CheckForAborts();
    // Step 10: Read the final word from the DCC.
    if (!aborted) *data := ReadDCC();
    // Step 11. Restore the corrupted register r0.
    WriteRegister(0, saved_r0);
```

```
}
```

Example 11-26 shows the sequence for writing a block of words to memory.

Example 11-26 Writing a block of words to memory (fast download)

```
WriteWords(uint32 address, bool &aborted, uint32 *data, int nwords)
{
    // Step 1. Save the value of R0.
    saved_r0 := ReadRegister(0);
    // Step 2. Write the value 0b10 to DSCR[21:20] for fast mode.
    SetDTRAccessMode(2);
    // Step 3. Write the opcode for MRC p14, 0, R0, c5, c0 to the ITR.
    // Write stalls until the ITR is ready but the instruction is not issued.
    WriteDebugRegister(33, 0xEE100E15);
    // Step 4. Write the address to read from to the DTRRX
    // Write stalls until the ITR is ready, but the instruction is not reissued.
    WriteDebugRegister(32, address);
    // Step 5. Write the opcode for STC p14, c5, [R0], 4 to the ITR.
    // Write stalls until the ITR is ready but the instruction is not issued.
    WriteDebugRegister(33, 0xECA05E01);
    // Step 6. Loop writing the data.
    // Each time a word is written to the DTRRX, the instruction is reissued.
    while (nwords > 0)
    {
        WriteDebugRegister(35, *data++);
        --nwords;
    }
    // Step 7. Write the value b00 to DSCR[21:20] for normal mode.
    SetDTRAccessMode(0);
    // Step 8. Restore the corrupted register R0.
    WriteRegister(0, saved_r0);
    // Step 9. Check the DSCR for a sticky abort.
    aborted := CheckForAborts();
}
```

Note

As the amount of data transferred increases, these functions reach an optimum performance of one debug register access per data word transferred.

After writing data to memory, you must execute a data synchronization barrier instruction to ensure that the memory window updates properly

Accessing coprocessor registers

The sequence for accessing coprocessor registers is the same for the PC and CPSR. That is, you must first execute an instruction to transfer the register to an ARM register, then read the value back through the DTR.

Example 11-27 shows the sequence for reading a coprocessor register.

Example 11-27 Reading a coprocessor register

```
uint32 ReadCPReg(int CPnum, int opc1, int CRn, int CRm, int opc2)
{
```

```
    // Step 1. Save R0.
    saved_r0 := ReadRegister(0);
    // Step 2. Execute instruction MCR p15, 0, R0, c0, c1, 0 through the ITR.
    ExecuteARMInstruction(0xEE000010 + (CPnum<<8) + (opc1<<21) + (CRn<<16) + CRm     + (opc2<<5));
    // Step 3. Read the value of R0 that now contains the CP register.
    CP15c1 := ReadRegister(0);
    // Step 4. Restore the value of R0.
    WriteRegister(0, saved_r0);
    return CP15c1;
}
```

11.12 Debugging systems with energy management capabilities

The processor offers functionality for debugging systems with energy-management capabilities. This section describes scenarios where the OS takes energy-saving measures when in an idle state.

The different measures that the OS can take to save energy during an idle state are divided into two groups:

Standby The OS takes measures that reduce energy consumption but maintain the processor state.

Power down The OS takes measures that reduce energy consumption but do not maintain the processor state. Recovery involves a reset of the processor after the power level has been restored, and reinstallation of the processor state.

Standby is the least invasive OS energy-saving state because it only implies that the core is unavailable. It does not clear any of the debug settings. For this case, the processor offers the following:

- If the processor is in standby and a halting debug event occurs, the processor:
  - leaves standby
  - retires the *Wait-For-Interrupt* (`WFI`) instruction
  - enters debug state.
- If the processor is in standby and detects an APB port access, it temporarily leaves standby state to complete the transaction. While the processor wakes up from standby, the APB access is held by keeping the **PREADYDBG** signal LOW.

11.12.1 Emulating power down

By writing to bit [0] of the PRCR, the debugger asserts the **DBGNOPWRDWN** output. The expected usage model of this signal is that it connects to the system power controller and that, when HIGH, it indicates that this controller must work in emulate mode.

On a power-down request from the processor, if the power controller is in emulate mode, it does not remove processor power or ETM power. Otherwise, it behaves exactly the same as in normal mode.

Emulating power down is ideal for debugging applications running on top of operating systems that are free of errors because the debug register settings are not lost on a power-down event. However, you must ensure that:

- **nIRQ** and **nFIQ** interrupts to the processor are externally masked as part of the emulation to prevent them from retiring the `WFI` instruction from the pipeline.
- The reset controller asserts **nRESET** on power up, rather than **nSYSPORESET**. Asserting **nSYSPORESET** on power up clears the debug registers inside the processor.
- The timing effects of power down and voltage stabilization are not factored in the power-down emulation. This is the case for systems with voltage recovery controlled by a closed loop system that monitors the processor supply voltage, rather than a fixed timed for voltage recovery.
- The emulation does not model state lost during power down, making it possible to miss errors in the state storage and recovery routines.

- Attaching the debugger for a postmortem debug session is not possible because setting the **DBGNOPWRDWN** signal to 1 might not cause the processor to power up. The effect of setting **DBGNOPWRDWN** to 1 when the processor is already powered down is implementation-defined, and is up to the system designer.

Chapter 12
FPU Programmer's Model

This chapter describes the programmer's model of the *Floating Point Unit* (FPU). The Cortex-R4F processor is a Cortex-R4 processor that includes the optional FPU. In this chapter, the generic term *processor* means only the Cortex-R4F processor.

This chapter contains the following sections:

12.1 About the FPU programmer's model

The FPU implements the VFPv3-D16 architecture and the Common VFP Sub-Architecture v2. This includes the instruction set of the VFPv3 architecture. See the *ARM Architecture Reference Manual* for information on the VFPv3 instruction set.

12.1.1 FPU functionality

The FPU is an implementation of the *ARM Vector Floating Point v3* architecture, with 16 double-precision registers (VFPv3-D16). It provides floating-point computation functionality that is compliant with the *ANSI/IEEE Std 754-1985, IEEE Standard for Binary Floating-Point Arithmetic*, referred to as the IEEE 754 standard. The FPU supports all data-processing instructions and data types in the VFPv3 architecture as described in the *ARM Architecture Reference Manual*.

The FPU fully supports single-precision and double-precision add, subtract, multiply, divide, multiply and accumulate, and square root operations. It also provides conversions between fixed-point and floating-point data formats, and floating-point constant instructions. The FPU does not support any data processing operations on vectors in hardware. Any data processing instruction that operates on a vector generates an UNDEFINED exception. The operation can then be emulated in software if necessary.

12.1.2 About the VFPv3-D16 architecture

The VFPv3-D16 architecture only includes 16 double-precision registers. VFPv3 includes 32 double-precision registers by default. An instruction which attempts to access any of the registers D16-D31 generates an UNDEFINED exception.

12.2 General-purpose registers

The FPU implements a VFP register bank. This bank is distinct from the ARM register bank.

You can reference the VFP register bank using two explicitly aliased views. Figure 12-1 shows the two views of the register bank and the way the word and doubleword registers overlap.

12.2.1 FPU views of the register bank

In the FPU, you can view the register bank as:

- Sixteen 64-bit doubleword registers, `D0-D15`.
- Thirty-two 32-bit single-word registers, `S0-S31`.
- A combination of registers from the above views.

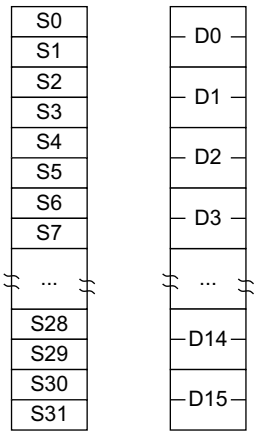


Figure 12-1 FPU register bank

The mapping between the registers is as follows:

- `S<2n>` maps to the least significant half of `D<n>`
- `S<2n+1>` maps to the most significant half of `D<n>`.

For example, you can access the least significant half of the value in `D6` by accessing `S12`, and the most significant half of the elements by accessing `S13`.

12.3 System registers

The VFPv3 architecture describes the following system registers:

- *Floating-Point System ID Register, FPSID* on page 12-5
- *Floating-Point Status and Control Register, FPSCR* on page 12-6
- *Floating-Point Exception Register, FPEXC* on page 12-7
- *Media and VFP Feature Registers, MVFR0 and MVFR1* on page 12-8.

Table 12-1 shows the VFP system registers in the Cortex-R4F FPU.

Table 12-1 VFP system registers

Register	FMXR/FMRX <reg> field	Access type	Reset state
Floating-Point System ID Register, FPSID	b0000	Read-only	0x4102314x[a]
Floating-Point Status and Control Register, FPSCR	b0001	Read/write	0x00000000
Floating-Point Exception Register, FPEXC	b1000	Read/write	0x00000000
VFP Feature Register 0, MVFR0	b0111	Read-only	0x10110221
VFP Feature Register 1, MVFR1	b0110	Read-only	0x00000001

a. Bits [3:0] of the FPSID depend on the product revision. See the FPSID register description for more information.

Note

The FPSID, MVFR0, and MVFR1 Registers are read-only. Attempts to write these registers are ignored.

Table 12-2 shows that some of the VFP system registers can only be accessed in Privileged modes.

Table 12-2 Accessing VFP system registers

	Privileged access		User access	
Register	**FPEXC EN=0**	**FPEXC EN=1**	**FPEXC EN=0**	**FPEXC EN=1**
FPSID	Permitted	Permitted	Not permitted	Not permitted
FPSCR	Not permitted	Permitted	Not permitted	Permitted
MVFR0, MVFR1	Permitted	Permitted	Not permitted	Not permitted
FPEXC	Permitted	Permitted	Not permitted	Not permitted

Table 12-2 shows that a Privileged mode is sometimes required to access a VFP system register. When a Privileged mode is required, an instruction that attempts to access a register in a nonprivileged mode takes the Undefined Instruction exception.

For a VFP system register to be accessible, it must follow the rules in Table 12-2 and the VFP must also be accessible according to the Coprocessor Access Register. See *c1, Coprocessor Access Register* on page 4-44 for more information.

Note

All hardware ID information is privileged access only:

FPSID is privileged access only

This is a change in VFPv3 compared to VFPv2.

MVFR registers are privileged access only

User code must issue a system call to determine the features that are supported.

The following sections describe the VFP system registers:

- *Floating-Point System ID Register, FPSID*
- *Floating-Point Status and Control Register, FPSCR* on page 12-6
- *Floating-Point Exception Register, FPEXC* on page 12-7
- *Media and VFP Feature Registers, MVFR0 and MVFR1* on page 12-8.

12.3.1 Floating-Point System ID Register, FPSID

The FPSID Register is a read-only register that must be accessed in Privileged mode only. It indicates which VFP implementation is being used.

Figure 12-2 shows the bit arrangement of the FPSID Register.

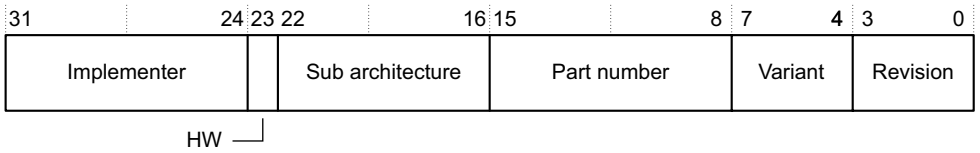


Figure 12-2 Floating-Point System ID Register format

Table 12-3 shows how the bit values correspond with the FPSID Register functions.

Table 12-3 FPSID Register bit functions

Bits	Field	Function
[31:24]	Implementer	ARM Limited: `0x41` = A
[23]	Hardware or software	0 = hardware implementation
[22:16]	Subarchitecture version	VFP architecture v3 or later with Common VFP subarchitecture v2[a]: `0x02`
[15:8]	Part number	`0x31` = Cortex-R4F
[7:4]	Variant	`0x4` = Cortex-R4F
[3:0]	Revision	See *Product revision information* on page 1-24 for details of the value of this field.

a. For details of the Common VFP subarchitecture see the *ARM Architecture Reference Manual*.

12.3.2 Floating-Point Status and Control Register, FPSCR

FPSCR is a read/write register that can be accessed in both Privileged and nonprivileged modes. All bits described as DNM in Figure 12-3 are reserved for future expansion. These bits must be initialized to zeros. To ensure that these bits are not modified, any code other than initialization code must use read-modify-write techniques when writing to FPSCR. Failure to observe this rule can cause Unpredictable results in future systems.

Figure 12-3 shows the bit arrangement of the FPSCR Register.

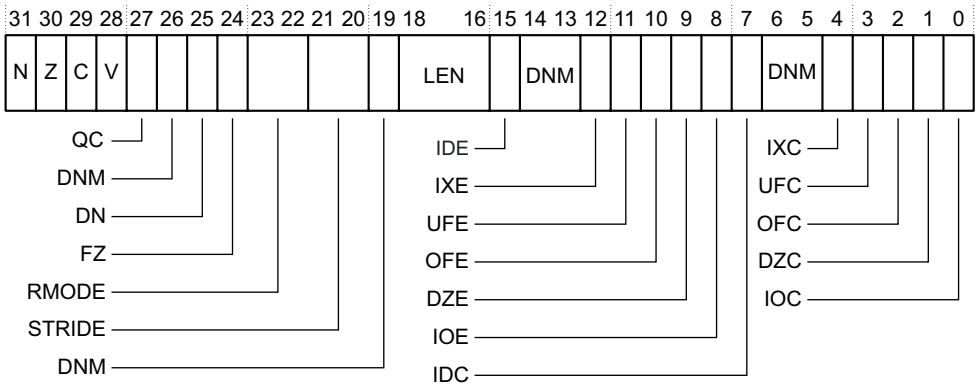


Figure 12-3 Floating-Point Status and Control Register format

Table 12-4 shows how the bit values correspond with the FPSCR Register functions.

Table 12-4 FPSCR Register bit functions

Bits	Field	Function
[31]	N	Set if comparison produces a *less than* result, resets to zero
[30]	Z	Set if comparison produces an *equal* result, resets to zero
[29]	C	Set if comparison produces an *equal*, *greater than*, or *unordered* result, resets to zero
[28]	V	Set if comparison produces an *unordered* result, resets to zero
[27]	QC	*Do Not Modify* (DNM)/*Read As Zero* (RAZ)
[26]	DNM	DNM
[25]	DN	Default NaN mode enable bit: 0 = default NaN mode disabled, this is the reset value 1 = default NaN mode enabled.
[24]	FZ	Flush-to-zero mode enable bit: 0 = flush-to-zero mode disabled, this is the reset value 1 = flush-to-zero mode enabled.
[23:22]	RMODE	Rounding mode control field: b00 = round to nearest (RN) mode, this is the reset value b01 = round towards plus infinity (RP) mode b10 = round towards minus infinity (RM) mode b11 = round towards zero (RZ) mode.
[21:20]	STRIDE	Indicates the vector stride, reset value is `0x0`

Table 12-4 FPSCR Register bit functions (continued)

Bits	Field	Function
[19]	DNM	DNM
[18:16]	LEN	Indicates the vector length, reset value is `0x0`
[15]	IDE	RAZ
[14:13]	DNM	DNM
[12]	IXE	RAZ
[11]	UFE	RAZ
[10]	OFE	RAZ
[9]	DZE	RAZ
[8]	IOE	RAZ
[7]	IDC	Input Subnormal cumulative flag, resets to zero
[6:5]	DNM	DNM
[4]	IXC	Inexact cumulative flag, resets to zero
[3]	UFC	Underflow cumulative flag, resets to zero
[2]	OFC	Overflow cumulative flag, resets to zero
[1]	DZC	Division by Zero cumulative flag, resets to zero
[0]	IOC	Invalid Operation cumulative flag, resets to zero

12.3.3 Floating-Point Exception Register, FPEXC

The FPEXC Register is a read/write register accessible in Privileged modes only.

The EN bit, FPEXC[30], is the VFP enable bit. Clearing EN disables VFP functionality, causing all VFP instructions apart from privileged system register accesses to generate an UNDEFINED exception. The EN bit is cleared on reset.

Figure 12-4 shows the bit arrangement of the FPEXC Register.

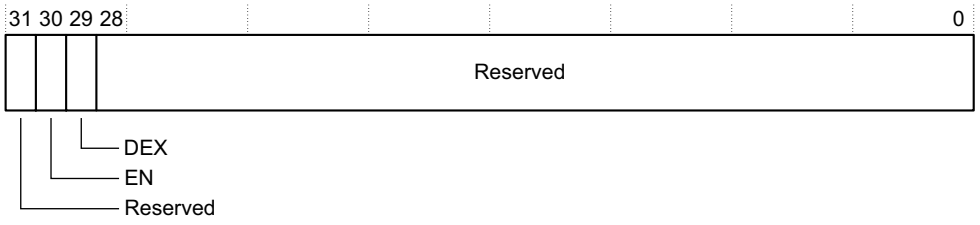


Figure 12-4 Floating-Point Exception Register format

Table 12-5 shows how the bit values correspond with the FPEXC Register functions.

Table 12-5 Floating-Point Exception Register bit functions

Bits	Field	Function
[31]	Reserved	RAZ.
[30]	EN	VFP enable bit. Setting EN enables VFP functionality. Reset clears EN.
[29]	DEX	Set when an Undefined exception is taken because of a vector instruction that would have been executed if the processor supported vectors. This field is cleared when an Undefined exception is taken for any other reason. Resets to zero.
[28:0]	Reserved	RAZ.

12.3.4 Media and VFP Feature Registers, MVFR0 and MVFR1

The VFP Feature Registers, MVFR0 and MVFR1, are read-only registers which describe the features supported by the FPU. These registers are accessible in Privileged modes only.

Figure 12-5 shows the bit arrangement of the MVFR0 Register.

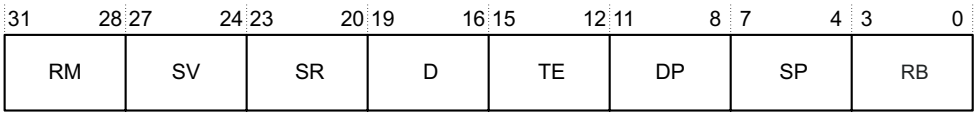


Figure 12-5 MVFR0 Register format

Table 12-6 shows how the bit values correspond with the MVFR0 Register functions.

Table 12-6 MVFR0 Register bit functions

Bits	Field	Function
[31:28]	RM	All VFP rounding modes supported: `0x1`
[27:24]	SV	VFP short vector unsupported: `0x0`
[23:20]	SR	VFP hardware square root supported: `0x1`
[19:16]	D	VFP hardware divide supported: `0x1`
[15:12]	TE	Only untrapped exception handling can be selected: `0x0`
[11:8]	DP	Double precision supported in VFPv3: `0x2`
[7:4]	SP	Single precision supported in VFPv3: `0x2`
[3:0]	RB	16x64-bit media register bank supported: `0x1`

Figure 12-6 on page 12-9 shows the bit arrangement of the MVFR1 Register.

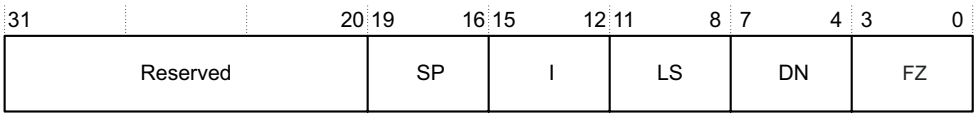


Figure 12-6 MVFR1 Register format

Table 12-7 shows how the bit values correspond with the MVFR1 Register.

Table 12-7 MVFR1 Register bit functions

Bits	Field	Function
[31:20]	-	Reserved
[19:16]	SP	Single-precision floating-point operations supported for VFP: `0b0000` = not supported
[15:12]	I	Integer operations supported for VFP: `0b0000` = not supported
[11:8]	LS	Load and store instructions supported for VFP: `0b0000` = not supported
[7:4]	DN	Propagation of NaN values supported for VFP: `0x1`
[3:0]	FZ	Full denormal arithmetic supported for VFP: `0x1`

12.4 Modes of operation

The FPU provides three modes of operation to accommodate a variety of applications:

- *Full-compliance mode*
- *Flush-to-zero mode*
- *Default NaN mode*

12.4.1 Full-compliance mode

In full-compliance mode, the FPU processes all operations according to the IEEE 754 standard in hardware.

12.4.2 Flush-to-zero mode

Setting the FZ bit, FPSCR[24], enables flush-to-zero mode. In this mode, the FPU treats all subnormal input operands of arithmetic `CDP` operations as zeros in the operation. Exceptions that result from a zero operand are signaled appropriately. `VABS`, `VNEG`, and `VMOV` are not considered arithmetic `CDP` operations and are not affected by flush-to-zero mode. A result that is *tiny*, as described in the IEEE 754 standard, for the destination precision is smaller in magnitude than the minimum normal value *before rounding* and is replaced with a zero. The IDC flag, FPSCR[7], indicates when an input flush occurs. The UFC flag, FPSCR[3], indicates when a result flush occurs.

12.4.3 Default NaN mode

Setting the DN bit, FPSCR[25], enables default NaN mode. In this mode, the result of any operation that involves an input NaN, or that generated a NaN result, returns the default NaN. Propagation of the fraction bits is maintained only by `VABS`, `VNEG`, and `VMOV` operations. All other `CDP` operations ignore any information in the fraction bits of an input NaN.

12.5 Compliance with the IEEE 754 standard

When *Default NaN* (DN) and *Flush-to-Zero* (FZ) modes are disabled, the VFP functionality is compliant with the IEEE 754 standard in hardware. No support code is required to achieve this compliance.

See the *ARM Architecture Reference Manual* for information about VFP architecture compliance with the IEEE 754 standard.

12.5.1 Complete implementation of the IEEE 754 standard

The following operations from the IEEE 754 standard are not supplied by the VFP instruction set:

- remainder
- round floating-point number to integer-valued floating-point number
- binary-to-decimal conversions
- decimal-to-binary conversions
- direct comparison of single-precision and double-precision values.

For complete implementation of the IEEE 754 standard, VFP functionality must be augmented with library functions that implement these operations. See *Application Note 98, VFP Support Code* for information on the available library functions.

12.5.2 IEEE 754 standard implementation choices

Some of the implementation choices permitted by the IEEE 754 standard and used in the VFPv3 architecture are described in the *ARM Architecture Reference Manual*.

NaN handling

All single-precision and double-precision values with the maximum exponent field value and a nonzero fraction field are valid NaNs. A most significant fraction bit of zero indicates a *Signaling NaN* (SNaN). A one indicates a *Quiet NaN* (QNaN). Two NaN values are treated as different NaNs if they differ in any bit. Table 12-8 shows the default NaN values in both single-precision and double-precision.

Table 12-8 Default NaN values

	Single-precision	Double-precision
Sign	0	0
Exponent	`0xFF`	`0x7FF`
Fraction	bit [22] = 1, bits [21:0] are all zeros	bit [51] = 1, bits [50:0] are all zeros

Processing of input NaNs for ARM floating-point functionality and libraries is defined as follows:

- In full-compliance mode, NaNs are handled as described in the *ARM Architecture Reference Manual*. The hardware processes the NaNs directly for arithmetic `CDP` instructions. For data transfer operations, NaNs are transferred without raising the Invalid Operation exception. For the non-arithmetic `CDP` instructions, `VABS`, `VNEG`, and `VMOV`, NaNs are copied, with a change of sign if specified in the instructions, without causing the Invalid Operation exception.

- In default NaN mode, arithmetic CDP instructions involving NaN operands return the default NaN regardless of the fractions of any NaN operands. SNaNs in an arithmetic CDP operation set the IOC flag, FPSCR[0]. NaN handling by data transfer and non-arithmetic CDP instructions is the same as in full-compliance mode.

Table 12-9 summarizes the effects of NaN operands on instruction execution.

Table 12-9 QNaN and SNaN handling

Instruction type	Default NaN mode	With QNaN operand	With SNaN operand
Arithmetic CDP	Off	The QNaN or one of the QNaN operands, if there is more than one, is returned according to the rules given in the *ARM Architecture Reference Manual*.	IOC[a] set. The SNaN is quieted and the result NaN is determined by the rules given in the *ARM Architecture Reference Manual*.
	On	Default NaN returns.	IOC[a] set. Default NaN returns.
Non-arithmetic CDP	Off	NaN passes to destination with sign changed as appropriate.	
	On		
FCMP(Z)	-	Unordered compare.	IOC set. Unordered compare.
FCMPE(Z)	-	IOC set. Unordered compare.	IOC set. Unordered compare.
Load/store	Off	All NaNs transferred.	
	On		

a. IOC is the Invalid Operation exception flag, FPSCR[0].

Comparisons

Comparison results modify the flags in the FPSCR Register. You can use the VMOV r15, FPSCR instruction (formerly FMSTAT) to transfer the current flags from the FPSCR Register to the CPSR Register. See the *ARM Architecture Reference Manual* for mapping of IEEE 754 standard predicates to ARM conditions. The flags used are chosen so that subsequent conditional execution of ARM instructions can test the predicates defined in the IEEE 754 standard.

Underflow

The Cortex-R4F FPU uses the *before rounding* form of *tininess* and the *inexact result* form of *loss of accuracy* as described in the IEEE 754 standard to generate Underflow exceptions.

In flush-to-zero mode, results that are tiny before rounding, as described in the IEEE 754 standard, are flushed to a zero, and the UFC flag, FPSCR[3], is set. See the *ARM Architecture Reference Manual* for information on flush-to-zero mode.

When the FPU is not in flush-to-zero mode, operations are performed on subnormal operands. If the operation does not produce a tiny result, it returns the computed result, and the UFC flag, FPSCR[3], is not set. The IXC flag, FPSCR[4], is set if the operation is inexact. If the operation produces a tiny result, the result is a subnormal or zero value, and the UFC flag, FPSCR[3], is set if the result was also inexact.

12.5.3 Exceptions

The FPU implements the VFPv3 architecture and sets the cumulative exception status flag in the FPSCR register as required for each instruction. The FPU does not support user-mode traps. The exception enable bits in the FPSCR read-as-zero, and cannot be written. The processor also has six output pins, **FPIXC**, **FPUFC**, **FPOFC**, **FPDZC**, **FPIDC**, and **FPIOC**, that each reflect the status of one of the cumulative exception flags. See *FPU signals* on page A-23 for a description of these outputs. You can mask each of these outputs masked by setting the corresponding bit in the Secondary Auxiliary Control Register.

See *Auxiliary Control Registers* on page 4-38 for more information.

Chapter 13
Integration Test Registers

This chapter describes how to use the Integration Test Registers in the processor. It contains the following sections:

13.1 About Integration Test Registers

The processor contains Integration Test Registers that enable you to verify integration of the design and enable topology detection of the design using debug tools. The *Integration Mode Control Register* (ITCTRL), which is also described in this chapter, controls the use of the Integration Test Registers.

When programming the Integration Test Registers you must enable all the changes at the same time.

For more information about the Integration Test Registers and the Integration Mode Control Register see the *ARM Architecture Reference Manual*.

13.2 Programming and reading Integration Test Registers

The Integration Test Registers are programmed using the debug APB interface. For more information on using the debug APB interface see Chapter 11 *Debug*.

13.2.1 Software access using APB

APB provides a direct method of programming:

- a stand-alone macrocell
- a macrocell in a CoreSight system.

APB provides access to the programmable control registers of peripheral devices. It has these features:

- unpipelined protocol, that is, a second transfer cannot start before the first transfer completes
- every transfer takes at least two cycles.

For more information on APB transfers see *AMBA 3 APB Protocol v1.0 Specification*.

13.3 Summary of the processor registers used for integration testing

Table 13-1 lists the processor Integration Test Registers and the *Integration Mode Control Register* (ITCTRL).

Table 13-1 Integration Test Registers summary

Register name	Base offset	Default value	Type	Clock domain	Description
Integration Test Registers					
ITETMIF	0xED8	-[a]	WO	**CLK**	See *ITETMIF Register (ETM interface)* on page 13-7
ITMISCOUT	0xEF8	n/a	WO	**CLK**	See *ITMISCOUT Register (Miscellaneous Outputs)* on page 13-8
ITMISCIN	0xEFC	-[a]	RO	**CLK**	See *ITMISCIN Register (Miscellaneous Inputs)* on page 13-8
Integration Mode Control Register					
ITCTRL	0xF00	0	R/W	**CLK**	See *Integration Mode Control Register (ITCTRL)* on page 13-9

a. See the register description for this value.

13.4 Processor integration testing

This section describes the behavior and use of the Integration Test Registers that are in the processor. It also describes the Integration Mode Control Register that controls the use of the Integration Test Registers. For more information about the ITCTRL see the *ARM Architecture Reference Manual*.

If you want to access these registers you must first set bit [0] of the Integration Mode Control Register to 1.

- You can use the write-only Integration Test Registers to set the outputs of some of the processor signals. Table 13-2 shows the signals that you can write in this way.
- You can use the read-only Integration Test Registers to read the state of some of the processor inputs. Table 13-3 on page 13-6 shows the signals that you can read in this way.

There are Integration Test Registers that you can use in conjunction with ETM-R4 integration. For more information see the *ETM-R4 Technical Reference Manual*

Table 13-2 Output signals that can be controlled by the Integration Test Registers

Signal	Register	Bit	Register description
DBGRESTARTED	ITMISCOUT	[9]	See *ITMISCOUT Register (Miscellaneous Outputs)* on page 13-8
DBGTRIGGER	ITMISCOUT	[8]	
ETMWFIPENDING	ITMISCOUT	[5]	
nPMUIRQ	ITMISCOUT	[4]	
COMMTX	ITMISCOUT	[2]	
COMMRX	ITMISCOUT	[1]	
DBGACK	ITMISCOUT	[0]	
EVNTBUS[46]	ITETMIF	[14]	See *ITETMIF Register (ETM interface)* on page 13-7
EVNTBUS[28, 0]	ITETMIF	[13:12]	
ETMCID[31, 0]	ITETMIF	[11:10]	
ETMDA[31, 0]	ITETMIF	[7:6]	
ETMDCTL[11, 0]	ITETMIF	[5:4]	
ETMDD[63, 0]	ITETMIF	[9:8]	
ETMIA[31, 1]	ITETMIF	[3:2]	
ETMICTL[13, 0]	ITETMIF	[1:0]	

Table 13-3 Input signals that can be read by the Integration Test Registers

Signal	Register	Bit	Register description
DBGRESTART	ITMISCIN	[11]	See *ITMISCIN Register (Miscellaneous Inputs)* on page 13-8
ETMEXTOUT[1:0]	ITMISCIN	[9:8]	
nETMWFIREADY	ITMISCIN	[5]	
nIRQ	ITMISCIN	[2]	
nFIQ	ITMISCIN	[1]	
EDBGRQ	ITMISCIN	[0]	

This section describes:

- *Using the Integration Test Registers*
- *Performing integration testing*
- *ITETMIF Register (ETM interface)* on page 13-7
- *ITMISCOUT Register (Miscellaneous Outputs)* on page 13-8
- *ITMISCIN Register (Miscellaneous Inputs)* on page 13-8
- *Integration Mode Control Register (ITCTRL)* on page 13-9

13.4.1 Using the Integration Test Registers

When bit [0] of the Integration Mode Control Register (ITCTRL) is set to b1:

- Values written to the write-only Integration Test Registers map onto the specified outputs of the macrocell. For example, writing `b1` to **ITMISCOUT[0]** causes **DBGACK** to be asserted HIGH.
- Values read from the read-only Integration Test Registers correspond to the values of the specified inputs of the macrocell. For example, if you read **ITMISCIN[9:8]** you obtain the value of **ETMEXTOUT[1:0]**.

13.4.2 Performing integration testing

When you perform integration testing or topology detection:

- You must ensure that the other ETM interface signals cannot change value during integration testing.
- ARM strongly recommends that the processor is halted while in debug state, because toggling input and output pins might have an unwanted effect on the operation of the processor. You must not set the ITCTRL Register until the processor has halted.

  When the ITCTRL Register is set, the ETM interface stops trace output, and outputs the data written into the relevant integration registers.

After you perform integration testing or topology detection, that is, the Integration Mode Control Register has been set, the system must be reset. This is because the signals that are toggled can have an unwanted effect on connected devices.

13.4.3 ITETMIF Register (ETM interface)

The ITETMIF Register at offset `0xED8` is write-only. Figure 13-1 shows the register bit assignments.

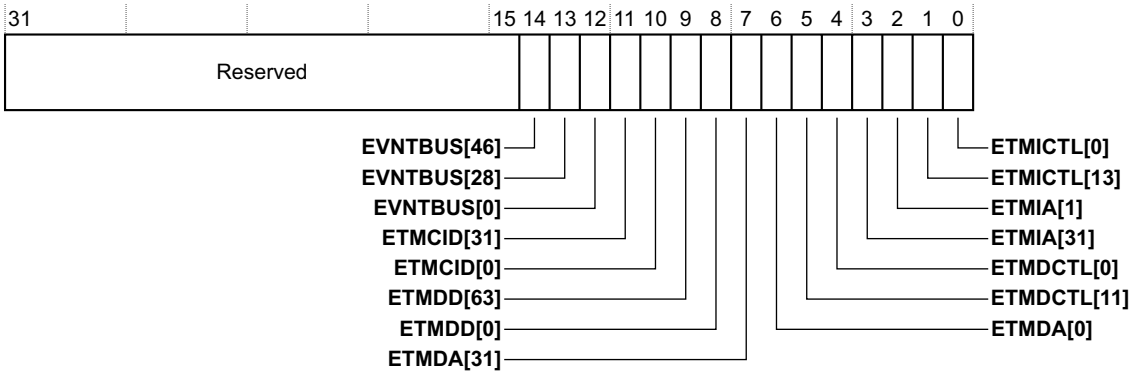


Figure 13-1 ITETMIF Register bit assignments

Table 13-4 shows the fields when writing the ITETMIF Register. When this register is written the appropriate output pins take the value written.

Table 13-4 ITETMIF Register bit assignments

Bits	Name	Function
[31:15]	-	Reserved. Write as zero.
[14]	EVNTBUS[46]	Set value of the **EVNTBUS[46]** output pin[a].
[13]	EVNTBUS[28]	Set value of the **EVNTBUS[28]** output pin.
[12]	EVNTBUS[0]	Set value of the **EVNTBUS[0]** output pin.
[11]	ETMCID[31]	Set value of the **ETMCID[31]** output pin.
[10]	ETMCID[0]	Set value of the **ETMCID[0]** output pin.
[9]	ETMDD[63]	Set value of the **ETMDD[63]** output pin.
[8]	ETMDD[0]	Set value of the **ETMDD[0]** output pin.
[7]	ETMDA[31]	Set value of the **ETMDA[31]** output pin.
[6]	ETMDA[0]	Set value of the **ETMDA[0]** output pin.
[5]	ETMDCTL[11]	Set value of the **ETMDCTL[11]** output pin.
[4]	ETMDCTL[0]	Set value of the **ETMDCTL[0]** output pin.
[3]	ETMIA[31]	Set value of the **ETMIA[31]** output pin.
[2]	ETMIA[1]	Set value of the **ETMIA[1]** output pin.
[1]	ETMICTL[13]	Set value of the **ETMICTL[13]** output pin.
[0]	ETMICTL[0]	Set value of the **ETMICTL[0]** output pin.

a. Not available on r0px revisions of the processor.

13.4.4 ITMISCOUT Register (Miscellaneous Outputs)

The ITMISCOUT Register at offset 0xEF8 is write-only. Figure 13-2 shows the register bit assignments.

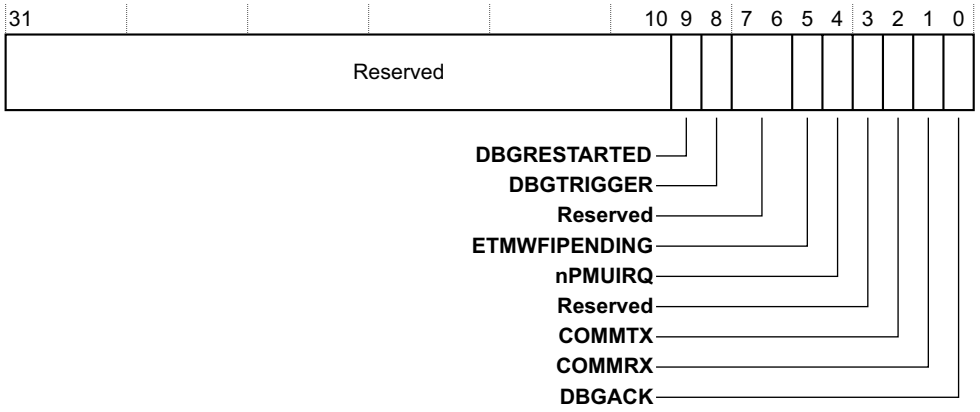


Figure 13-2 ITMISCOUT Register bit assignments

Table 13-5 shows the fields when writing the ITMISCOUT Register. When this register is written the appropriate output pins take the value written.

Table 13-5 ITMISCOUT Register bit assignments

Bits	Name	Function
[31:10]	-	Reserved. Write as zero.
[9]	DBGRESTARTED	Set value of the **DBGRESTARTED** output pin.
[8]	DBGTRIGGER	Set value of the **DBGTRIGGER** output pin.
[7:6]	-	Reserved. Write as zero.
[5]	ETMWFIPENDING	Set value of the **ETMWFIPENDING** output pin.
[4]	nPMUIRQ	Set value of **nPMUIRQ** output pin.
[3]	-	Reserved. Write as zero.
[2]	COMMTX	Set value of **COMMTX** output pin.
[1]	COMMRX	Set value of **COMMRX** output pin.
[0]	DBGACK	Set value of the **DBGACK** output pin.

13.4.5 ITMISCIN Register (Miscellaneous Inputs)

The ITMISCIN Register at offset 0xEFC is read-only. Figure 13-3 on page 13-9 shows the register bit assignments.

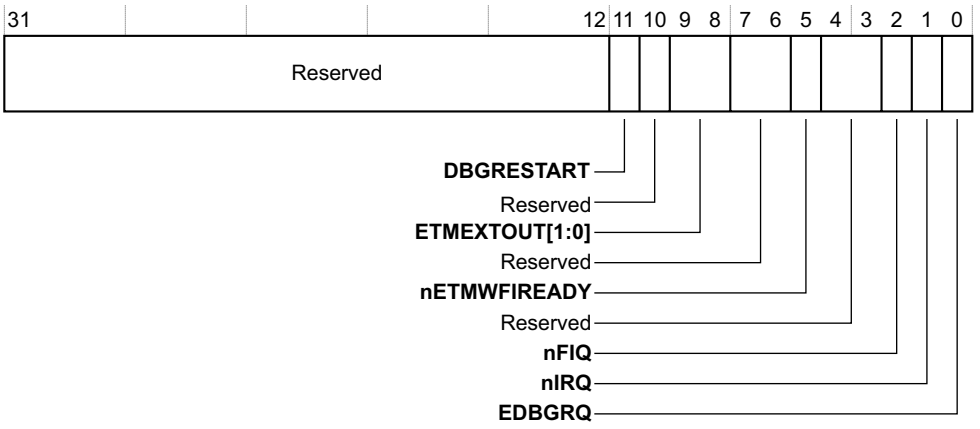


Figure 13-3 ITMISCIN Register bit assignments

Table 13-6 lists the register bit assignments for the ITMISCIN Register.

Table 13-6 ITMISCIN Register bit assignments

Bits	Name	Function
[31:12]	-	Reserved. Read Undefined.
[11]	DBGRESTART	Read value of the **DBGRESTART** input pin.
[10]	-	Reserved. Read Undefined.
[9:8]	ETMEXTOUT	Read value of the **ETMEXTOUT[1:0]** input pins.
[7:6]	-	Reserved. Read Undefined.
[5]	nETMWFIREADY	Reads the **nETMWFIREADY** input pin. Although this pin is active LOW, the value of this bit matches the physical state of the signal: 0 = input pin is LOW (asserted) 1 = input pin is HIGH (deasserted).
[4:3]	-	Reserved. Read Undefined.
[2]	nFIQ	Read value of **nFIQ** input pin.
[1]	nIRQ	Read value of **nIRQ** input pin.
[0]	EDBGRQ	Read value of **EDBGRQ** input pin.

13.4.6 Integration Mode Control Register (ITCTRL)

The ITCTRL Register, register `0x3C0` at offset `0xF00`, is read/write. Figure 13-4 shows the register bit assignments.

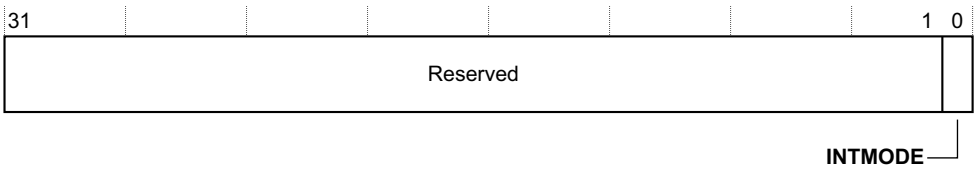


Figure 13-4 ITCTRL Register bit assignments

Table 13-7 shows the fields of the ITCTRL Register.

Table 13-7 ITCTRL Register bit assignments

Bits	Access	Reset value	Name	Function
[31:1]	RAZ/SBZP	-	-	Reserved.
[0]	R/W	0	INTMODE	Controls whether the processor is in normal operating mode or integration mode: b0 = normal operation b1 = integration mode enabled.

Writing to the ITCTRL register controls whether the processor is in its default functional mode, or in integration mode, where the inputs and outputs of the device can be directly controlled for the purpose of integration testing or topology detection. For more information see the *ARM Architecture Reference Manual*.

Chapter 14
Cycle Timings and Interlock Behavior

This chapter describes the cycle timings and interlock behavior of instructions on the processor. It contains the following sections:

14.1 About cycle timings and interlock behavior

Complex instruction dependencies and memory system interactions make it impossible to describe briefly the exact cycle timing behavior for all instructions in all circumstances. The timings described in this chapter are accurate in most cases. If precise timings are required, you must use a cycle-accurate model of the processor.

Unless stated otherwise, cycle counts and result latencies that this chapter describes are best-case numbers. They assume:

- no outstanding data dependencies between the current instruction and a previous instruction
- the instruction does not encounter any resource conflicts
- all data accesses hit in the data cache, and do not cross protection region boundaries
- all instruction accesses hit in the instruction cache.

This section describes:

- *Instruction execution overview*
- *Conditional instructions* on page 14-4
- *Flag-setting instructions* on page 14-4
- *Definition of terms* on page 14-4.
- *Assembler language syntax* on page 14-5.

14.1.1 Instruction execution overview

The instruction execution pipeline has four stages, Iss, Ex1, Ex2, and Wr.

Extensive forwarding to the end of the Iss, Ex1, and Ex2 stages enables many dependent instruction sequences to run without pipeline stalls. General forwarding occurs from the end of the Ex2 and Wr pipeline stages. In addition, the multiplier contains an internal multiply accumulate forwarding path. The address generation unit also contains an internal forwarding path.

Most instructions do not require a register until the Ex2 stage. All result latencies are given as the number of cycles until the register is available for a following instruction in the Ex2 stage. Most ALU operations require their source registers at the start of the Ex2 stage, and have a result latency of one. For example, the following sequence takes two cycles:

```
ADD R1,R3,R4              ;Result latency one
ADD R5,R2,R1              ;Register R1 required by ALU
```

The PC is the only register that result latency does not affect. An instruction that alters the PC never causes a pipeline stall because of interlocking with a subsequent instruction that reads the PC.

Most loads have a result latency of two or higher as they do not forward their results until the Wr stage. For example, the following sequence takes three cycles:

```
LDR R1, [R2]                ;Result latency two
ADD R3, R3, R1              ;Register R1 required by ALU
```

If a subsequent instruction requires the register at the end of the Iss stage then an extra cycle must be added to the result latency of the instruction producing the required register. Instructions that require a register at the end of these stages are specified by describing that register as an Early Reg. The following sequence, requiring an Early Reg, takes four cycles:

```
LDR R1, [R2]              ;Result latency two
```

```
ADD R3, R3, R1 LSL#6        ;plus one because Register R1 is Early
```

The following sequence where R1 is a Late Reg takes two cycles:

```
LDR R1, [R2]                ;Result latency two minus one cycles
STR R1, [R3]                ;no penalty because R1 is a Late register
```

The following sequence where R1 is a Very Early Reg takes four cycles:

```
ADD R3, R1, R2              ;Result latency one plus two cycles
LDR R4, [R3]                ;plus two because register R3 is Very Early
```

14.1.2 Conditional instructions

Most instructions do not take more or fewer cycles to execute if they fail their condition codes. The exceptions to this are:

- instructions that alter the PC, such as branches
- integer divide instructions, which require only one execute cycle.

The result latency of most instructions that fail their condition codes is one. The exceptions to this are:

- all load and store instructions, which have their result latency unaffected
- integer divide instructions, which have a result latency of three.

14.1.3 Flag-setting instructions

Most instructions do not take more or fewer cycles to execute if they are flag-setting. The exceptions to this are certain multiply instructions.

14.1.4 Definition of terms

Table 14-1 gives descriptions of cycle timing terms used in this chapter.

Table 14-1 Definition of cycle timing terms

Term	Description
Memory Cycles	This is the number of cycles during which an instruction sends a memory access to the cache.
Cycles	This is the minimum number of cycles required to issue an instruction. Issue cycles that produce memory accesses to the cache are included, so Cycles is always greater than or equal to Memory Cycles.
Result Latency	This is the number of cycles before the result of this instruction is available to a Normal Reg of the following instruction. When the Result Latency of an instruction is greater than Cycles and the following instruction requires the result, the following instruction stalls for a number of cycles equal to Result Latency minus Cycles. **Note** The Result Latency is counted from the first cycle of an instruction.
Normal Reg	The specified registers are required at the start of the Ex2 stage.
Late Reg	The specified registers are not required until the start of the Wr stage. Subtract one cycle from the Result Latency of the instruction producing this register.

Table 14-1 Definition of cycle timing terms (continued)

Term	Description
Early Reg	The specified registers are required at the start of the Ex1 stage. Add one cycle to the Result Latency of the instruction producing this register.
Very Early Reg	The specified registers are required at the start of the Iss stage. Add two cycles to the Result Latency of the instruction producing this register, or one cycle if the instruction producing this register is an LDM, LDR, LDRD, LDREX, or LDRT. The lower Result Latency does not apply if this register is the base register of the load instruction producing this register, or if the load instruction is an LDRB, LDRBT, LDRH, LDRSB, or LDRSH.
Interlock	There is a data dependency between two instructions in the pipeline, resulting in the Iss stage being stalled until the processor resolves the dependency.

14.1.5 Assembler language syntax

The syntax used throughout this chapter is unified assembler and the timings apply to ARM and Thumb instructions.

14.2 Register interlock examples

Table 14-2 shows register interlock examples using LDR and ADD instructions.

LDR instructions take one cycle, have a result latency of two, and require their base register as a Very Early Reg.

ADD instructions take one cycle and have a result latency of one.

Table 14-2 Register interlock examples

Instruction sequence	Behavior
`LDR R1, [R2]` `ADD R6, R5, R4`	Takes two cycles because there are no register dependencies.
`ADD R1, R2, R3` `ADD R9, R6, R1`	Takes two cycles because ADD instructions have a result latency of one.
`LDR R1, [R2]` `ADD R6, R5, R1`	Takes three cycles because of the result latency of R1.
`ADD R2, R5, R6` `LDR R1, [R2]`	Takes four cycles because of the use of the result of R2 as a Very Early Reg.
`LDR R1, [R2]` `LDR R5, [R1]`	Takes four cycles because of the result latency of R1, the use of the result of R1 as a Very Early Reg, and the use of an LDR to generate R1.

14.3 Data processing instructions

This section describes the cycle timing behavior for the ADC, ADD, ADDW, AND, ASR, BIC, CLZ, CMN, CMP, EOR, LSL, LSR, MOV, MOVT, MOVW, MVN, ORN, ORR, ROR, RRX, RSB, RSC, SBC, SUB, SUBW, TEQ, and TST instructions.

This section describes:

- *Cycle counts if destination is not PC*
- *Cycle counts if destination is the PC*
- *Example interlocks* on page 14-8

14.3.1 Cycle counts if destination is not PC

Table 14-3 shows the cycle timing behavior for data processing instructions if their destination is not the PC. You can substitute ADD with any of the data processing instructions identified in the opening paragraph of this section.

Table 14-3 Data Processing Instruction cycle timing behavior if destination is not PC

Example instruction	Cycles	Early Reg	Late Reg	Result latency	Comments
ADD <Rd>, <Rn>, #<immed>	1	-	-	1	Normal cases.
ADD <Rd>, <Rn>, <Rm>	1	-	-	1	
ADD <Rd>, <Rn>, <Rm>, LSL #<immed>	1	<Rm>	-	1	Requires a shifted source register.
ADD <Rd>, <Rn>, <Rm>, LSL <Rs>	1	<Rm>, <Rs>	-	1	Requires a register controlled shifted source register.
MOV <Rd>, <Rm>	1	-	<Rm>	1	Simple MOV case. Must not set the flags or require a shifted source register.

14.3.2 Cycle counts if destination is the PC

Table 14-4 shows the cycle timing behavior for data processing instructions if their destination is the PC. You can substitute ADD with any data processing instruction except for a CLZ. A CLZ with the PC as the destination is an Unpredictable instruction.

For condition code failing cycle counts, the cycles for the non-PC destination variants must be used.

Table 14-4 Data Processing instruction cycle timing behavior if destination is the PC

Example instruction	Cycles	Early Reg	Late Reg	Result latency	Comments
ADD pc, <Rn>, #<immed>	9	-	-	-	Normal cases to PC
ADD pc, <Rn>, <Rm>	9	-	-	-	
ADD pc, <Rn>, <Rm>, LSL #<immed>	9	<Rm>	-	-	Requires a shifted source register
ADD pc, <Rn>, <Rm>, LSL <Rs>	9	<Rm>, <Rs>	-	-	Requires a register controlled shifted source register

14.3.3 Example interlocks

Most data processing instructions are single-cycle and can be executed back-to-back without interlock cycles, even if there are data dependencies between them. The exceptions to this are when shifts are used.

Shifter

The registers that the shifter requires are Early Regs and require an additional cycle of result availability before use. For example, the following sequence introduces a 1-cycle interlock, and takes three cycles to execute:

```
ADD R1,R2,R3
ADD R4,R5,R1 LSL #1
```

The second source register, which is not shifted, does not incur an extra data dependency check. Therefore, the following sequence takes two cycles to execute:

```
ADD R1,R2,R3
ADD R4,R1,R9 LSL #1
```

Register controlled shifts

The register containing the shift distance is an Early Reg. For example, the following sequence takes three cycles to execute:

```
ADD R1, R2, R3
ADD R4, R2, R4, LSL R1
```

14.4 QADD, QDADD, QSUB, and QDSUB instructions

This section describes the cycle timing behavior for the QADD, QDADD, QSUB, and QDSUB instructions.

These instructions perform saturating arithmetic. They have a result latency of two. The QDADD and QDSUB instructions must double and saturate the register <Rn> before the addition. This register is an Early Reg.

Table 14-5 shows the cycle timing behavior for QADD, QDADD, QSUB, and QDSUB instructions.

Table 14-5 QADD, QDADD, QSUB, and QDSUB instruction cycle timing behavior

Instructions	Cycles	Early Reg	Result latency
QADD, QSUB	1	-	2
QDADD, QDSUB	1	<Rn>	2

14.5 Media data-processing

Table 14-6 shows media data-processing instructions and gives their cycle timing behavior.

All media data-processing instructions are single-cycle issue instructions. These instructions have result latencies of one or two cycles. Some of the instructions require an input register to be shifted, or manipulated in some other way before use and therefore are marked as requiring an Early Reg.

Table 14-6 Media data-processing instructions cycle timing behavior

Instructions	Cycles	Early Reg	Result latency
SADD16, SSUB16, SADD8, SSUB8	1	-	1
UADD16, USUB16, UADD8, USUB8	1	-	1
SEL	1	-	1
QADD16, QSUB16, QADD8, QSUB8	1	-	2
SHADD16, SHSUB16, SHADD8, SHSUB8	1	-	1
UQADD16, UQSUB16, UQADD8, UQSUB8	1	-	2
UHADD16, UHSUB16, UHADD8, UHSUB8	1	-	1
SSAT16, USAT16	1	<Rn>	1
SASX, SSAX	1	-	1
UASX, USAX	1	-	1
SXTAB, SXTAB16, SXTAH	1	<Rm>	1
SXTB, SXTB16, SXTH	1	<Rm>[a]	1
UXTB, UXTB16, UXTH	1	<Rm>[a]	1
UXTAB, UXTAB16, UXTAH	1	<Rm>	1
REV, REV16, REVSH, RBIT	1	<Rm>	1
PKHBT, PKHTB	1	<Rm>	1
SSAT, USAT	1	<Rm>	1
QASX, QSAX	1	-	2
SHASX, SHSAX	1	-	1
UQASX, UQSAX	1	-	2
UHASX, UHSAX	1	-	1
BFC	1	<Rd>	1
SBFX, UBFX	1	<Rn>	1
BFI	1	<Rd>, <Rn>	1

a. A shift of zero makes <Rm> a Normal Reg for these instructions.

14.6 Sum of Absolute Differences (SAD)

Table 14-7 shows SAD instructions and gives their cycle timing behavior.

Table 14-7 Sum of absolute differences instruction timing behavior

Instructions	Cycles	Early Reg	Result latency
USAD8	1	<Rn>, <Rm>	2[a]
USADA8	1	<Rn>, <Rm>	2[a]

a. Result latency is one fewer if the destination is the accumulate for a subsequent USADA8.

14.6.1 Example interlocks

Table 14-8 shows interlock examples using USAD8 and USADA8 instructions.

Table 14-8 Example interlocks

Instruction sequence	Behavior
USAD8 R1,R2,R3 ADD R5,R6,R1	Takes three cycles because USAD8 has a Result Latency of two, and the ADD requires the result of the USAD8 instruction.

USAD8 R1,R2,R3
MOV R9,R9
ADD R5,R6,R1
	Takes three cycles. The MOV instruction is scheduled during the Result Latency of the USAD8 instruction.

USAD8 R1,R2,R3 USADA8 R1,R4,R5,R1	Takes two cycles. The Result Latency is one less because the result is used as the accumulate for a subsequent USADA8 instruction.

14.7 Multiplies

Most multiply operations cannot forward their result early, except as the accumulate value for a subsequent multiply. For a subsequent multiply accumulate the result is available one cycle earlier than for all other uses of the result.

Certain multiplies require:

- more than one cycle to execute
- more than one pipeline issue to produce a result.

The multiplicand and multiplier are required as Early Regs because they are both required at the end of the Iss stage.

Flag-setting multiplies followed by a conditional instruction interlock the conditional instruction for one cycle, or two cycles if the instruction is a conditional multiply. Flag-setting multiplies followed by a flag-setting instruction interlock the flag-setting instruction for one cycle, unless the instruction is a flag-setting multiply in which case there is no interlock.

Table 14-9 shows the cycle timing behavior of example multiply instructions.

Table 14-9 Example multiply instruction cycle timing behavior

Example instruction	Cycles	Early Reg	Late Reg	Result latency
MUL(S)	2	<Rn>, <Rm>	-	3
MLA(S), MLS	2	<Rn>, <Rm>	<Ra>	3
SMULL(S)	2	<Rn>, <Rm>	-	3, 3
UMULL(S)	2	<Rn>, <Rm>	-	3, 3
SMLAL(S)	2	<Rn>, <Rm>	<RdLo>, <RdHi>	3, 3
UMLAL(S)	2	<Rn>, <Rm>	<RdLo>, <RdHi>	3, 3
SMULxy	1	<Rn>, <Rm>	-	2
SMLAxy	1	<Rn>, <Rm>	-	2
SMULWy	1	<Rn>, <Rm>	-	2
SMLAWy	1	<Rn>, <Rm>	-	2
SMLALxy	2	<Rn>, <Rm>	<RdLo>, <RdHi>	3, 3
SMUAD, SMUADX	1	<Rn>, <Rm>	-	2
SMLAD, SMLADX	1	<Rn>, <Rm>	-	2
SMUSD, SMUSDX	1	<Rn>, <Rm>	-	2
SMLSD, SMLSDX	1	<Rn>, <Rm>	-	2
SMMUL, SMMULR	2	<Rn>, <Rm>	-	3
SMMLA, SMMLAR	2	<Rn>, <Rm>	<Ra>	3
SMMLS, SMMLSR	2	<Rn>, <Rm>	<Ra>	3

Table 14-9 Example multiply instruction cycle timing behavior (continued)

Example instruction	Cycles	Early Reg	Late Reg	Result latency
SMLALD, SMLALDX	1	<Rn>, <Rm>	-	2, 2
SMLSLD, SMLSLDX	1	<Rn>, <Rm>	-	2, 2
UMAAL	2	<Rn>, <Rm>	<RdLo>, <RdHi>	3, 3

Note

Result Latency is one less if the result is used as the accumulate value for a subsequent multiply accumulate. This only applies if the result is the same width as the accumulate value, that is 32 or 64 bits.

14.8 Divide

This section describes the cycle timing behavior of the UDIV and SDIV instructions.

The divider unit is separate to the main execute pipeline so the UDIV and SDIV instructions require one cycle to issue. They execute out-of-order relative to the rest of the pipeline, and require an additional issue cycle at the end of the divide operation to write the result to the destination register. This additional cycle is not required if the divide instruction fails its condition code.

Result Latency for a UDIV instruction A divided by B is given by:

$$\text{Result latency} = 3 + \max\left(\left(\frac{\text{clz(B)} - \text{clz(A)} + 1}{2}\right), 0\right)$$

Result Latency for a SDIV instruction A divided by B is given by:

$$\text{Result latency} = 4 + \max\left(\left(\frac{\text{clz(B)} - \text{clz(A)} + 1}{2}\right), 0\right)$$

Note

- A divide instruction that fails its condition code or attempts to divide by zero has a Result Latency of three.
- The value of the (clz(B) - clz(A) + 1)/2 component of these equations must be rounded down.
- The clz(x) function counts the number of leading zeros in the 32-bit value x. If x is negative, it is negated before this count occurs.

14.9 Branches

This section describes the cycle timing behavior for the B, BL, BLX, BX, BXJ, CBNZ, CBZ, TBB, and TBH instructions. Branches are subject to dynamic and return stack predictions. Table 14-10 shows example branch instructions and their cycle timing behavior.

Table 14-10 Branch instruction cycle timing behavior

Example instruction	Cycles	Memory cycles	Comments
B<label>, BL<label>a, BLX<label>[a]	1	-	Correct dynamic prediction
	8	-	Incorrect dynamic prediction
BX <Rm>[b]	1	-	Correct return stack prediction
	9	-	Incorrect return stack prediction
BX <cond> <Rm>[b]	1	-	Correct condition prediction and correct return stack prediction
	8	-	Incorrect condition prediction
	9	-	Correct condition prediction and incorrect return stack prediction
BXJ <cond> <Rm>	1	-	Condition code fails
	9	-	Condition code passes
BLX <Rm>	9	-	-
BLX <cond> <Rm>	1	-	Condition code fails
	9	-	Condition code passes
CBZ <Rn>, <label>, CBNZ <Rn>, <label>	1	-	Correct condition prediction
	8	-	Incorrectly predicted
TBB [<Rn>, <Rm>][c]	9	1	Condition code fails
	9	1	Condition code passes
TBH [<Rn>, <Rm>, LSL#1][c]	9	1	Condition code fails
	9	1	Condition code passes

a. Return stack push.
b. Return stack pop, if condition passes.
c. <Rn> and <Rm> are Very Early Regs.

14.10 Processor state updating instructions

This section describes the cycle timing behavior for the MSR, MRS, CPS, and SETEND instructions. Table 14-11 shows processor state updating instructions and their cycle timing behavior.

Table 14-11 Processor state updating instructions cycle timing behavior

Instruction	Cycles	Comments
MRS	1	All MRS instructions
MSR	5	All other MSR instructions to the CPSR
MSR SPSR	1	All MSR instructions to the SPSR
CPS <effect> <iflags>	1	Interrupt masks only
CPS <effect> <iflags>, #<mode>	1	Mode changing
SETEND	1	-

14.11 Single load and store instructions

This section describes the cycle timing behavior for LDR, LDRHT, LDRSBT, LDRSHT, LDRT, LDRB, LDRBT, LDRSB, LDRH, LDRSH, STR, STRT, STRB, STRBT, STRH, and PLD instructions.

Table 14-12 shows the cycle timing behavior for stores and loads, other than loads to the PC. You can replace LDR with any of these single load or store instructions. The following rules apply:

- They are normally single-cycle issue. Both the base and any offset register are Very Early Regs.
- They are 3-cycle issue if pre-increment addressing with either a negative register offset or a shift other than LSL #1, 2 or 3 is used. Both the base and any offset register are Very Early Regs.
- If unaligned support is enabled then accesses to addresses not aligned to the access size that cross a 64-bit aligned boundary generate two memory accesses, and require an additional cycle to issue. This extra cycle is required if the final address is potentially unaligned, even if the final address turns out to be aligned.
- PLD (data preload hint instructions) have cycle timing behavior as for load instructions. Because they have no destination register, the result latency is not-applicable for such instructions.
- For store instructions <Rt> is always a Late Reg.

Table 14-12 Cycle timing behavior for stores and loads, other than loads to the PC

Example instruction	Cycles	Memory cycles	Result latency (LDR)	Result latency (base register)	Comments
LDR <Rt>, <addr_md_1cycle>[a]	1	1	2	1	Aligned access
LDR <Rt>, <addr_md_3cycle>[a]	3	1	4	3	Aligned access
LDR <Rt>, <addr_md_1cycle>[a]	2	2	3	2	Potentially unaligned access
LDR <Rt>, <addr_md_3cycle>[a]	4	2	5	4	Potentially unaligned access

a. See Table 14-14 on page 14-18 for an explanation of <addr_md_1cycle> and <addr_md_3cycle>.

Table 14-13 shows the cycle timing behavior for loads to the PC.

Table 14-13 Cycle timing behavior for loads to the PC

Example instruction	Cycles	Memory cycles	Result latency	Comments
LDR pc, [sp, #<imm>] (!)	1	1	-	Correctly return stack predicted, or conditional predicted correctly
LDR pc, [sp], #<imm>	1	1	-	
LDR pc, [sp, #<imm>] (!)	9	1	-	Return stack mispredicted, conditional predicted correctly
LDR pc, [sp], #<imm>	9	1	-	

Table 14-13 Cycle timing behavior for loads to the PC (continued)

Example instruction	Cycles	Memory cycles	Result latency	Comments
`LDR <cond> pc, [sp, #<imm>] (!)`	8	1	-	Conditional predicted incorrectly, but return stack predicted correctly
`LDR <cond> pc, [sp], #cns`	8	1	-	
`LDR pc, <addr_md_1cycle>`[a]	9	1	-	-
`LDR pc, <addr_md_3cycle>`[a]	11	1	-	-

a. See Table 14-14 for an explanation of `<addr_md_1cycle>` and `<addr_md_3cycle>`. For condition code failing cycle counts, you must use the cycles for the non-PC destination variants.

Only cycle times for aligned accesses are given because Unaligned accesses to the PC are not supported.

The processor includes a 4-entry return stack that can predict procedure returns. Any LDR instruction to the PC with an immediate post-indexed offset of plus four, and the stack pointer R13 as the base register is considered a procedure return.

Table 14-14 shows the explanation of `<addr_md_1cycle>` and `<addr_md_3cycle>` used in Table 14-12 on page 14-17 and Table 14-13 on page 14-17.

Table 14-14 <addr_md_1cycle> and <addr_md_3cycle> LDR example instruction explanation

Example instruction	Very Early Reg	Comments
`<addr_md_1cycle>`		
`LDR <Rt>, [<Rn>, #<imm>] (!)`	`<Rn>`	If post-increment addressing or pre-increment addressing with an immediate offset, or a positive register offset with no shift or shift LSL #1, 2 or 3, then 1-issue cycle
`LDR <Rt>, [<Rn>, <Rm>] (!)`	`<Rn>, <Rm>`	
`LDR <Rt>, [<Rn>, <Rm>, LSL #1, 2 or 3] (!)`	`<Rn>, <Rm>`	
`LDR <Rt>, [<Rn>], #<imm>`	`<Rn>`	
`LDR <Rt>, [<Rn>], +/-<Rm>`	`<Rn>, <Rm>`	
`LDR <Rt>, [<Rn>], +/-<Rm> <shift> <cns>`	`<Rn>, <Rm>`	
`<addr_md_3cycle>`		
`LDR <Rt>, [<Rn>, -<Rm>] (!)`	`<Rn>,<Rm>`	If pre-increment addressing with a negative register offset or shift other than LSL #1, 2 or 3, then 3-issue cycles
`LDR <Rt>, [Rn, +/-<Rm> <shift> <cns>] (!)`	`<Rn>,<Rm>`	

14.11.1 Base register update

The base register update for load or store instructions occurs in the ALU pipeline. To prevent an interlock for back-to-back load or store instructions reusing the same base register, there is a local forwarding path to recycle the updated base register around the address generator. This only applies when the load or store instruction with base write-back uses pre-increment addressing, and is a single load or store instruction that is not a load or store double instruction or load or store multiple instruction.

For example, with `R2` aligned the following instruction sequence take three cycles to execute:

```
LDR R5, [R2, #4]!
```

```
LDR R6, [R2, #0X10]!
LDR R7, [R2, #0X20]!
```

14.12 Load and Store Double instructions

This section describes the cycle timing behavior for the LDRD and STRD instructions.

The LDRD and STRD instructions:

- Are normally single-cycle issue. Both the base and any offset register are Very Early Regs.
- Are 3-cycle issue if offset or pre-increment addressing with a negative register offset is used. Both the base and any offset register are Very Early Regs.
- Take only one memory cycle if the address is doubleword aligned.
- Take two memory cycles if the address is not doubleword aligned.

Table 14-15 shows the cycle timing behavior for LDRD and STRD instructions.

Table 14-15 Load and Store Double instructions cycle timing behavior

Example instruction	Cycles	Cycles with base writeback	Memory cycles	Result latency (LDRD)	Result latency (base register)
Address is doubleword aligned					
LDRD R0, R1, <addr_md_1cycle>[a]	1	2	1	2, 2	2
LDRD R0, R1, <addr_md_3cycle>[a]	3	4	1	4, 4	4
Address not doubleword aligned					
LDRD R0, R1, <addr_md_1cycle>[a]	2	2	2	2, 3	2
LDRD R0, R1, <addr_md_3cycle>[a]	4	4	2	4, 5	4

a. See Table 14-16 for an explanation of <addr_md_1cycle> and <addr_md_3cycle>.

Table 14-16 shows the explanation of <addr_md_1cycle> and <addr_md_3cycle> used in Table 14-15.

Table 14-16 <addr_md_1cycle> and <addr_md_3cycle> LDRD example instruction explanation

Example instruction	Very Early Reg	Comments
<addr_md_1cycle>		
LDRD <Rt>, <Rt2>, [<Rn>, #<imm>] (!)	<Rn>	If post-increment addressing, pre-increment addressing with an immediate offset or a positive register offset, then 1-issue cycle
LDRD <Rt>, <Rt2>, [<Rn>, <Rm>] (!)	<Rn>, <Rm>	
LDRD <Rt>, <Rt2>, [<Rn>], #<imm>	<Rn>	
LDRD <Rt>, <Rt2>, [<Rn>], +/-<Rm>	<Rn>, <Rm>	
<addr_md_3cycle>		
LDRD <Rt>, <Rt2>, [<Rn>, -<Rm>] (!)	<Rn>,<Rm>	If pre-increment addressing with a negative register offset, then 3-issue cycles

14.13 Load and Store Multiple instructions

This section describes the cycle timing behavior for the LDM, STM, PUSH, and POP instructions. These instructions take multiple cycles to issue, and then use multiple memory cycles to load and store all the registers. Because the memory datapath is 64-bits wide, two registers can be loaded or stored on each cycle.

This section describes:

- *Load and Store Multiples, other than load multiples including the PC*
- *Load Multiples, where the PC is in the register list* on page 14-22
- *Example Interlocks* on page 14-22

14.13.1 Load and Store Multiples, other than load multiples including the PC

In all cases the base register, <Rn>, is a Very Early Reg.

Table 14-17 shows the cycle timing behavior of load and store multiples including the PC.

Table 14-17 Cycle timing behavior of Load and Store Multiples, other than load multiples including the PC

Example instruction	Cycles	Cycles with base register write-back	Memory cycles	Result latency (LDM)	Result latency (base register)
First address 64-bit aligned					
LDMIA <Rn>,{R1}	1	1	1	2	1
LDMIA <Rn>,{R1,R2}	1	2	1	2,2	2
LDMIA <Rn>,{R1,R2,R3}	2	2	2	2,2,3	2
LDMIA <Rn>,{R1,R2,R3,R4}	2	3	2	2,2,3,3	3
LDMIA <Rn>,{R1,R2,R3,R4,R5}	3	3	3	2,2,3,3,4	3
LDMIA <Rn>,{R1,R2,R3,R4,R5,R6}	3	4	3	2,2,3,3,4,4	4
LDMIA <Rn>,{R1,R2,R3,R4,R5,R6,R7}	4	4	4	2,2,3,3,4,4,5	4
First address not 64-bit aligned					
LDMIA <Rn>,{R1}	1	2	1	2	2
LDMIA <Rn>,{R1,R2}	2	2	2	2,3	2
LDMIA <Rn>,{R1,R2,R3}	2	3	2	2,3,3	3
LDMIA <Rn>,{R1,R2,R3,R4}	3	3	3	2,3,3,4	3
LDMIA <Rn>,{R1,R2,R3,R4,R5}	3	4	3	2,3,3,4,4	4
LDMIA <Rn>,{R1,R2,R3,R4,R5,R6}	4	4	4	2,3,3,4,4,5	4
LDMIA <Rn>,{R1,R2,R3,R4,R5,R6,R7}	4	5	4	2,3,3,4,4,5,5	5

Note

The Cycle timing behavior that Table 14-17 shows also covers PUSH and POP instructions that behave like store and load multiple instructions with base register write-back.

14.13.2 Load Multiples, where the PC is in the register list

The processor includes a 4-entry return stack that can predict procedure returns. Any LDM to the PC that does not restore the SPSR to the CPSR, is predicted as a procedure return.

In all cases the base register, <Rn>, is a Very Early Reg.

Table 14-18 shows the cycle timing behavior of Load Multiples, where the PC is in the register list.

Table 14-18 Cycle timing behavior of Load Multiples, with PC in the register list (64-bit aligned)

Example instruction	Cycles	Memory cycles	Result latency	Comments
LDMIA <Rn>,{...,pc}	m[a]	n[b]	2,…	Correct return stack prediction
LDMIA <Rn>,{...,pc}	m[a] + 8	n[b]	2,…	Incorrect return stack prediction
LDMIA <cond> <Rn>,{...,pc}	m[a]	n[b]	2,…	Correct condition prediction and correct return stack prediction
LDMIA <cond> <Rn>,{...,pc}	m[a] + 7	n[b]	2,…	Incorrect condition prediction
LDMIA <cond> <Rn>,{...,pc}	m[a] + 8	n[b]	2,…	Correct condition prediction and incorrect return stack prediction

a. Where m is the number of cycles for this instruction if the PC were treated as a normal register.
b. Where n is the number of memory cycles for this instruction if the PC were treated as a normal register.

Note

The Cycle timing behavior that Table 14-18 shows also covers PUSH and POP instructions that behave like store and load multiple instructions with base register writeback.

14.13.3 Example Interlocks

The following sequence that has an LDM instruction takes six cycles to execute, because R7 has a result latency of five cycles:

```
LDMIA R0, {R1-R7}
ADD R10, R10, R7
```

The following sequence that has an STM instruction takes five cycles to execute:

```
STMIA R0, {R1-R7}
ADD R7, R10, R11
```

The following sequence has a result latency hidden by issue cycles. It takes five cycles to execute.

```
LDMIA R0, {R1-R7}
ADD R10, R10, R3
```

The following sequence that has a POP instruction takes seven cycles to execute, because R9 has a result latency of six cycles:

```
POP {R1-R9}
ADD R10, R10, R9
```

The following sequence that has a PUSH instruction takes five cycles to execute:

```
PUSH {R1-R7}
ADD R10,R10,R7
```

Note

In the examples, R0 and sp are 64-bit aligned addresses. The instructions PUSH and POP always use the sp register for the base address.

14.14 RFE and SRS instructions

This section describes the cycle timing for the RFE and SRS instructions.

These instructions:

- return from an exception and save exception return state respectively
- take one or two memory cycles depending on doubleword alignment first address location.

In all cases the base register is a Very Early Reg.

Table 14-19 shows the cycle timing behavior for RFE and SRS instructions.

Table 14-19 RFE and SRS instructions cycle timing behavior

Example instruction	Cycles	Memory cycles
Address doubleword aligned		
RFEIA <Rn>	10	1
SRSIA #<mode>	1	1
Address not doubleword aligned		
RFEIA <Rn>	11	2
SRSIA #<mode>	2	2

14.15 Synchronization instructions

This section describes the cycle timing behavior for the CLREX, DMB, DSB, ISB, LDREX, LDREXB, LDREXD, LDREXH, STREX, STREXB, STREXD, STREXH, SWP, and SWPB instructions

In all cases the base register, Rn, is a Very Early Reg. Table 14-20 shows the synchronization instructions cycle timing behavior.

Table 14-20 Synchronization instructions cycle timing behavior

Instruction	Cycles	Memory cycles	Result latency
CLREX	1	-	-
LDREX <Rt>, [Rn]	1	1	2
LDREXB <Rt>, [Rn]	1	1	2
LDREXH <Rt>, [Rn]	1	1	2
LDREXD <Rt>, [Rn][a]	1	1	2
STREX <Rd>, <Rt>, [Rn]	1	1	2
STREXB <Rd>, <Rt>, [Rn]	1	1	2
STREXH <Rd>, <Rt>, [Rn]	1	1	2
STREXD <Rd>, <Rt>, <Rt2>, [Rn][a]	1	1	2
SWP <Rt>, <Rt2>, [Rn]	2	2	3
SWPB <Rt>, <Rt2>, [Rn]	2	2	3

a. Address must be 64-bit aligned.

The synchronization instructions DMB, DSB, and ISB stall the pipeline for a variable number of cycles, depending on the current state of the memory system.

14.16 Coprocessor instructions

This section describes the cycle timing behavior for the `MCR` and `MRC` instructions to CP14, the debug coprocessor or CP15, the system control coprocessor.

The precise timing of coprocessor instructions is tightly linked with the behavior of the relevant coprocessor. Table 14-21 shows the coprocessor instructions cycle timing behavior. Table 14-21 shows the best case numbers.

Table 14-21 Coprocessor instructions cycle timing behavior

Instruction	Cycles	Result latency	Comments
`MCR`	6	-	-
`MCR <cond>`	6	-	Condition code passes
	4	-	Condition code fails
`MRC`	6	6	-
`MRC <cond>`	6	6	Condition code passes
	4	4	Condition code fails

Note

Some instructions such as cache operations take more cycles.

14.17 SVC, BKPT, Undefined, and Prefetch Aborted instructions

This section describes the cycle timing behavior for SVC, Undefined instruction, BKPT and Prefetch Abort.

In all cases the exception is taken in the Wr stage of the pipeline. SVC and most Undefined instructions that fail their condition codes take one cycle. A small number of Undefined instructions that fail their condition codes take two cycles. Table 14-22 shows the SVC, BKPT, Undefined, prefetch aborted instructions cycle timing behavior.

Table 14-22 SVC, BKPT, Undefined, prefetch aborted instructions cycle timing behavior

Instruction	Cycles
SVC (formerly SWI)	9
BKPT	9
Prefetch Abort	9
Undefined Instruction	9

14.18 Miscellaneous instructions

Table 14-23 shows the cycle timing behavior for *If-Then* (IT) and *No OPeration* (NOP) instructions.

Table 14-23 IT and NOP instructions cycle timing behavior

Example instructions	Cycles	Early Reg	Late Reg	Result latency	Comments
`IT{<v>{<w>{<z>}}} <cond>`	1	-	-	-	-
`NOP`	1	-	-	-	-

The `DBG`, `PLI`, `SEV`, `WFE`, and `YIELD` instructions are all treated the same as `NOP`, and so have the same cycle timing behavior.

The `WFI` instruction stalls the pipeline for a variable number of cycles, depending on the current state of the memory system.

14.19 Floating-point register transfer instructions

This section describes the cycle timing behavior for the various VFP instruction which transfer data between the VFP register file and the integer register file, including the system registers.

All source operands are Normal Regs, and the result latency for non-system register transfers is always 1 cycle.

Instructions that write data from the integer register file to the VFP system registers (FMXR) are blocking, that is, no subsequent instruction can start execution before the FMXR has completed execution. Consequently, the FMXR instructions take six cycles to execute.

All transfers to and from the VFP system registers are also serializing. This means that if there are any outstanding out-of-order-completion VFP instructions, the system register transfer instruction will stall in the iss-stage until these instructions are complete.

VFP instructions that complete out-of-order are VMLA.F32, VMLS.F32, VNMLS.F32, VNMLA.F32, VDIV.F32, VSQRT.F32, VCVT.F64.F32, and double-precision arithmetic and conversion instructions.

Table 14-24 shows the floating-point register transfer instructions cycle timing behavior.

Table 14-24 Floating-point register transfer instructions cycle timing behavior

Example instruction	Cycles	Result latency	Comments
VMOV <Sn>, <Rt>	1	1	-
VMOV <Rt>, <Sn>	1	2	-
VMOV <Dn[x]>, <Rt>	1	1	-
VMOV.<dt> <Rt>, <Dn[x]>	1	2	-
VMOV <Sm>, <Sm1>, <Rt>, <Rt2>	1	1	-
VMOV <Rt>, <Rt2>, <Sm>, <Sm1>	1	2	-
VMOV <Dm>, <Rt>, <Rt2>	1	1	-
VMOV <Rt>, <Rt2>, <Dm>	1	2	-
VMSR <spec_reg>, <Rt>	6	-	Blocking and serializing
VMRS <Rt>, <spec_reg>	1	2	Serializing
VMRS APSR_nzcv, FPSCR	1	-	Serializing

14.20 Floating-point load/store instructions

This section describes the cycle timing behavior for all load and store instructions that operate on the VFP register file:

- The base address register, and any offset register are Very Early Regs for both loads and stores.
- For store instructions, the data register (Sd or Dd), or registers are always Late Regs.
- The cycle timing of load and store instructions is affected by the starting address for the transfer.

  Note

  The starting address is not always the same as the base address.

- The cycle timing of load and store multiple instructions is also affected by whether or not the base address register is updated by the instruction, that is, base register writeback.

Table 14-25 shows the number of cycles and result latencies for single load and store instructions and load multiple instructions. Values are shown for each instruction with and without base register writeback, and with different starting address alignments. Cycle counts and base register result latencies for store multiple instructions are the same as for the equivalent load multiple instruction.

Table 14-25 Floating-point load/store instructions cycle timing behavior

Example instruction	Cycles/ memory cycles	Cycles with writeback (!)	Result latency (load)	Result latency (base register, <Rn>)	Comments
VLDR.32 <Sd>, [<Rn>{, #+/-<imm>}]	1	-	1	-	-
VLDR.64 <Dd>, [<Rn>{, #+/-<imm>}]	1	-	1	-	64-bit aligned address
VLDR.64 <Dd>, [<Rn>{, #+/-<imm>}]	2	-	2	-	Not aligned
VSTR.32 <Sd>, [<Rn>{, #+/-<imm>}]	1	-	-	-	-
VSTR.64 <Dd>, [<Rn>{, #+/-<imm>}]	1	-	-	-	64-bit aligned address
VSTR.64 <Dd>, [<Rn>{, #+/-<imm>}]	2	-	-	-	Not aligned
First address 64-bit aligned					
VLDM{mode}.32 <Rn>{!}, {s1}	1	1	1	1	-
VLDM{mode}.32 <Rn>{!}, {s1,s2}	1	2	1,1	2	-
VLDM{mode}.32 <Rn>{!}, {s1-s3}	2	2	1,1,2	2	-
VLDM{mode}.32 <Rn>{!}, {s1-s4}	2	3	1,1,2,2	3	-
VLDM{mode}.64 <Rn>{!}, {d1}	1	2	1	2	-
VLDM{mode}.64 <Rn>{!}, {d1,d2}	2	3	1,2	3	-
VLDM{mode}.64 <Rn>{!}, {d1-d3}	3	4	1,2,3	4	-
VLDM{mode}.64 <Rn>{!}, {d1-d4}	4	5	1,2,3,4	5	-

Table 14-25 Floating-point load/store instructions cycle timing behavior (continued)

Example instruction	Cycles/ memory cycles	Cycles with writeback (!)	Result latency (load)	Result latency (base register, <Rn>)	Comments
First address not 64-bit aligned					
`VLDM{mode}.32 <Rn>{!}, {s1}`	1	1	1	1	-
`VLDM{mode}.32 <Rn>{!}, {s1,s2}`	2	2	1,2	2	-
`VLDM{mode}.32 <Rn>{!}, {s1-s3}`	2	3	1,2,2	3	-
`VLDM{mode}.32 <Rn>{!}, {s1-s4}`	3	3	1,2,2,3	3	-
`VLDM{mode}.64 <Rn>{!}, {d1}`	2	2	2	2	-
`VLDM{mode}.64 <Rn>{!}, {d1,d2}`	3	3	2,3	3	-
`VLDM{mode}.64 <Rn>{!}, {d1-d3}`	4	4	2,3,4	4	-
`VLDM{mode}.64 <Rn>{!}, {d1-d4}`	5	5	2,3,4,5	5	-

14.21 Floating-point single-precision data processing instructions

This section describes the cycle timing behavior for all single-precision VFP CDP instructions. This includes arithmetic instructions such as VMUL.F32, data and immediate moving instructions such as "VMOV.F32 <Sd>, #<imm>", VABS.F32, VNEG.F32, and "VMOV <Sd>, <Sm>", and comparison instructions and conversion instructions.

Table 14-26 shows the floating-point single-precision data processing instructions cycle timing behavior.

Table 14-26 Floating-point single-precision data processing instructions cycle timing behavior

Example instruction	Cycles	Early Reg	Result latency
VMLA.F32 <Sd>, <Sn>, <Sm>[a]	1[b]	<Sn>, <Sm>	5[c]
VADD.F32 <Sd>, <Sn>, <Sm>[d]	1	<Sn>, <Sm>	2
VDIV.F32 <Sd>, <Sn>, <Sm>	2	<Sn>, <Sm>	16
VSQRT.F32 <Sd>, <Sm>	2	<Sm>	16
VMOV.F32 <Sd>, #<imm>	1	-	1
VMOV.F32 <Sd>, <Sm>[e]	1	-	1
VCMP.F32 <Sd>, <Sm>[f]	1	<Sd>, <Sm>	-
VCMPE.F32 <Sd>, #0.0[f]	1	<Sd>	-
VCVT.F32.U32 <Sd>, <Sm>[g]	1	<Sm>	2
VCVT.F32.U32 <Sd>, <Sd>, #<fbits>[h]	1	<Sd>	2
VCVTR.U32.F32 <Sd>, <Sm>[i]	1	<Sm>	2
VCVT.U32.F32 <Sd>, <Sd>, #<fbits>[j]	1	<Sd>	2
VCVT.F64.F32 <Dd>, <Sn>	3	<Sm>	5

a. Also VMLS.F32, VNMLS.F32, and VNMLA.F32.
b. VMLA.F32 completes out-of-order, and can take an extra cycle (two in total) if an add instruction (VADD) or certain dual-issued instruction pairs are in the iss-stage when the instruction completes.
c. Except when the instruction dependent on the result <Sd> is another VMLA.F32 instruction, and the dependent operand is the accumulate operand, <Sd>. In this case, the result latency is reduced to 3 cycles.
d. Also VSUB.F32, VMUL.F32, and VNMUL.F32.
e. Also VABS.F32 and VNEG.F32.
f. Also VCMPE.F32.
g. Also VCVT.F32.S32.
h. Also VCVT.F32.U16, VCVT.F32.S32, and VCVT.F32.S16.
i. Also VCVT.U32.F32, VCVTR.S32.F32, and VCVT.S32.F32.
j. Also VCVT.U16.F32, VCVT.S32.F32, and VCVT.S16.F32.

14.22 Floating-point double-precision data processing instructions

This section describes the cycle timing behavior for all double-precision VFP CDP instructions. This includes arithmetic instructions such as VMUL.F64, data and immediate moving instructions such as "VMOV.F64 <Dd>, #<imm>", VABS.F64, VNEG.F64, and "VMOV <Dd>, <Dm>", and comparison instructions and conversion instructions.

Table 14-27 shows the floating-point double-precision data processing instructions cycle timing behavior

Table 14-27 Floating-point double-precision data processing instructions cycle timing behavior

Example instruction	Cycles	Early Reg	Result latency
VMLA.F64 <Dd>, <Dn>, <Dm>[a]	13	<Dn>, <Dm>	19
VADD.F64 <Dd>, <Dn>, <Dm>[b]	3	<Dn>, <Dm>	9
VDIV.F64 <Dd>, <Dn>, <Dm>	3	<Dn>, <Dm>	96
VSQRT.F64 <Dd>, <Dm>	3	<Dm>	96
VMOV.F64 <Dd>, #<imm>	1	-	1
VMOV.F64 <Dd>, <Dm>[c]	1	-	1
VCMP.F64 <Dd>, <Dm>[d]	2	<Dd>, <Dm>	-
VCMPE.F64 <Dd>, #0.0[d]	2	<Dm>	-
VCVT.F64.U32 <Dd>, <Sm>[e]	3	<Dm>	7
VCVT.F64.U32 <Dd>, <Dd>, #<fbits>[f]	3	<Dd>	7
VCVTR.U32.F64 <Sd>, <Dm>[g]	3	<Dm>	7
VCVT.U32.F64 <Dd>, <Dd>, #<fbits>[h]	3	<Dd>	7
VCVT.F32.F64 <Sd>, <Dn>	3	<Dm>	7

a. Also VMLS.F64, VNMLS.F64, and VNMLA.F64.
b. Also VSUB.F64, VMUL.F64, and VNMUL.F64.
c. Also VABS.F64 and VNEG.F64.
d. Also VCMPE.F64.
e. Also VCVT.F64.S32.
f. Also VCVT.F64.U16, VCVT.F64.S32, and VCVT.F64.S16.
g. Also VCVT.U32.F64, VCVTR.S32.F64, and VCVT.S32.F64.
h. Also VCVT.U16.F64, VCVT.S32.F64, and VCVT.S16.F64.

14.23 Dual issue

To increase instruction throughput, the processor can issue certain pairs of instructions simultaneously. This is called dual issue. When this happens, the instruction with the smaller cycle count is assumed to execute in zero cycles. If a pair of instructions can be dual-issued, they are always dual-issued unless dual-issuing is disabled, see *Auxiliary Control Registers* on page 4-38. If one instruction of the pair is interlocked, both are interlocked.

This section describes:

- *Dual issue rules*
- *Permitted combinations* on page 14-35

14.23.1 Dual issue rules

The following rules apply to dual-issue instructions:

- Both instructions must be available to the issue stage at the same time. This is unlikely if there are many branches.
- The second instruction must not use the PC as a source register unless it is B #immed.
- The first instruction must not use the PC as a destination register.
- Both instructions must belong to the same instruction set, ARM or Thumb.
- There must be no data dependency between the two instructions. That is, the second instruction must not have any source registers that are destination registers of the first instruction.

14.23.2 Permitted combinations

Table 14-28 lists the permitted instruction combinations. Any instruction can be conditional or flag-setting unless otherwise stated. Only the exact instruction combinations listed in Table 14-28 can be dual issued, provided you ensure the instruction combinations obey the rules specified in *Dual issue rules* on page 14-34.

Table 14-28 Permitted instruction combinations

Dual issue case	First instruction	Second instruction

Case A	Any instruction other than load/store multiple/double, flag-setting multiply, non-VFP coprocessor operations, miscellaneous processor control instructions[a], or floating point instructions if floating point logic is not included in the processor	`B #immed`
		`IT`
		`NOP`

Case A-F[b]	Any floating point instructions, excluding load/store multiple, double precision `CDP` instructions, `VCVT.F64.F32`, and `VMRS` and `VMSR`.	
Case B1	`LDR <Rt>, [<Rn>, #<imm>]`[c] `LDR <Rt>, [<Rn>, <Rm>]`[c] `LDR <Rt>, [<Rn>, <Rm>, LSL #1, 2 or 3]`[c]	Any data processing instruction that does not require a shift by a register value.[d] Any bitfield, saturate or bit-packing instruction.[e] Any signed or unsigned extend instruction.[f] Any `SIMD` add or subtract instruction.[g] Other miscellaneous instructions.[h]
Case B1-F[b]		Any single-precision CDP[i], excluding "`VMOV.F32 <Sd>, #<imm>`", `VNEG.F32`, `VABS.F32`, `VCVT.F64.F32`, `VDIV.F32`, and `VSQRT.F32`. 32-bit transfers to and from the floating-point register file[l].
Case B2	`STR <Rt>, [<Rn>, #<imm>]`[c]	As for Case B1.
Case B2-F[b]		As for Case B1-F
Case C	`MOV <Rd>, #immed`[j][k] `MOVW <Rd>, #immed`[j] `MOV <Rd>, <Rm>`[j]	Any data processing instruction.[d] Any bitfield, saturate or bit-packing instruction.[e] Any signed or unsigned extend instruction.[f] Any `SIMD` add or subtract instruction.[g] Other miscellaneous instructions.[h]
Case C-F[b]		32-bit transfers to and from the floating-point register file[l].
Case F1[b,m]	Any single-precision `CDP`[i], excluding "`VMOV.S32 <Sd>, #<imm>`", `VCVT.F64.F32`, `VABS.F32`, and `VNEG.F32`.	As for case C or C-F.
Case F2_ld[b]	`VLDR.F32`[n]	As for Case B1 or Case B1-F

Table 14-28 Permitted instruction combinations (continued)

Dual issue case	First instruction	Second instruction
Case F2_st[b]	VSTR.F32[n]	As for Case B1. Any single-precision CDP[i], excluding multiply-accumulate instructions[o]. 32-bit transfers to and from the floating-point register file[l].
Case F2D[b]	VLDR.F64[n]	As for Case B1.
Case F3[b]	32-bit transfers to and from the floating-point register file[l] "VMOV.F32 <Sd>, <Sd>, <Sm>", VABS.F32, and VNEG.F32.	As for Case F2_st.
Case F4[b]	Any instruction that does not set flags, other than load/store multiple/double, non-VFP coprocessor operations, multi-cycle multiply instructions[p], double precision floating point CDP instructions, VCVT.F64.F32, or a miscellaneous processor control instruction[a]	Any single-precision CDP[i], excluding "VMOV.F32 <Sd>, #<imm>", VNEG.F32, VABS.F32, VCVT.F64.F32, VDIV.F32, and VSQRT.F32. 32-bit transfers to and from the floating-point register file[l].
Case F6[b]	VMRS r15, FPSCR	As for Case A.

a. These are processor state updating instructions, synchronization instructions, SVC, BKPT, prefetch abort and Undefined instructions.
b. This case can only occur if floating-point functionality has been configured for the Cortex-R4F processor, see *Configurable options* on page 1-13.
c. You can substitute LDR with LDRB, LDRH, LDRSB, or LDRSH. You can also substitute STR with STRB or STRH.
d. Data processing instructions are ADC, ADD, ADDW, AND, ASR, BIC, CLZ, CMN, CMP, EOR, LSL, LSR, MOV, MOVT, MOVW, MVN, ORN, ORR, ROR, RRX, RSB, SBC, SUB, SUBW, TEQ, and TST.
e. Bitfield, saturate, and bit-packing instructions are BFC, BFI, PKHBT, PKHTB, QADD, QDADD, QDSUB, QSUB, SBFX, SSAT, SSAT16, UBFX, USAT, and USAT16.
f. Signed or unsigned extend instructions are SXTAB, SXTAB16, SXTAH, SXTB, SXTB16, SXTH, UXTAB, UXTAB16, UXTAH, UXTB, UXTB16, and UXTH.
g. SIMD add and subtract instructions are QADD16, QADD8, QASX, SQUB16, QSUB8, QSAX, SADD16, SADD8, SASX, SHADD16, SHADD8, SHASX, SHSUB16, SHSUB8, SHSAX, SSUB16, SSUB8, SSAX, UADD16, UADD8, UASX, UHADD16, UHADD8, UHASX, UHSUB16, UHSUB8, UHSAX, UQADD16, UQADD8, UQASX, UQSUB16, UQSUB8, UQSAX, USUB16, USUB8, and USAX.
h. Other miscellaneous instructions are RBIT, REV, REV16, REVSH, and SEL.
i. Single-precision CDPs are VABS.F32, VNEG.F32, "VMOV.F32 <Sd>, #<imm>", VMLA.F32, VMLS.F32, VNMLS.F32, VNMLA.F32, VMUL.F32, VNMUL.F32, VADD.F32, VSUB.F32, VDIV.F32, VSQRT.F32, VCMP.F32, VCMPE.F32, VCVT.F64.F32, VCVT.F32.U32, VCVT.F32.S32, VCVT.F32.U16, VCVT.F32.S16, VCVTR.U32.F32, VCVT.U32.F32, VCVTR.S32.F32, VCVT.S32.F32, VCVT.U16.F32, and VCVT.S16.F32.
j. Must not be flag-setting.
k. Immediate value must not require a shift.
l. 32-bit transfers to or from the floating point register file include single or half-double floating point register transfers, including "VMOV <Sn>, <Rt>", "VMOV <Dn[x]>, <Rt>", "VMOV <Rt>, <Dn[x]>", and "VMOV <Rt>, <Sn>", but excluding VMRS and VMSR.
m. When the first instruction is a floating point multiply-accumulate, and the second instruction is a 32-bit transfer to the floating-point register file, case F1 can only occur if the two instructions have different destination registers.
n. Any addressing modes.
o. Single-precision floating-point multiply-accumulate instructions are VMLA.F32, VMLS.F32, VNMLS.F32, and VNMLA.F32.
p. Multi-cycle multiply instructions are SMMUL, SMMLA, SMMLS, MUL, MLA, MLS, SMULL, SMLAL, UMAAL, UMULL, and UMLAL.

Chapter 15
AC Characteristics

This chapter gives the timing parameters for the processor. It contains the following sections:

15.1 Processor timing

The AXI bus interface of the processor conforms to the *AMBA AXI Specification*. For the relevant timing of the AXI write and read transfers, and the error response, see the *AMBA AXI Protocol v1.0 Specification*.

The APB debug interface of the processor conforms to the *AMBA 3 APB Protocol v1.0 Specification*. For the relevant timing of the APB write and read transfers, and the error response, see the *AMBA 3 APB Protocol v1.0 Specification*.

15.2 Processor timing parameters

This section describes the input and output port timing parameters for the processor.

The maximum timing parameter or constraint delay for each processor signal applied to the SoC is given as a percentage in Table 15-1 to Table 15-17 on page 15-11. The input and output delay columns provide the maximum and minimum time as a percentage of the processor clock cycle given to the SoC for that signal.

This section describes:

- *Input port timing parameters*
- *Output ports timing parameters* on page 15-8.

15.2.1 Input port timing parameters

Table 15-1 shows the timing parameters for the miscellaneous input ports.

Table 15-1 Miscellaneous input ports timing parameters:

Input delay minimum	Input delay maximum	Signal name
Clock uncertainty	10%	**nRESET**
Clock uncertainty	10%	**nSYSPORESET**
Clock uncertainty	10%	**PRESETDBGn**
Clock uncertainty	50%	**nCPUHALT**
Clock uncertainty	20%	**DBGNOCLKSTOP**

Table 15-2 shows the timing parameters for the configuration input port.

Table 15-2 Configuration input port timing parameters

Input delay minimum	Input delay maximum	Signal name
Clock uncertainty	20%	**VINITHI**
Clock uncertainty	20%	**CFGEE**
Clock uncertainty	20%	**CFGIE**
Clock uncertainty	20%	**INITRAMA**
Clock uncertainty	20%	**INITRAMB**
Clock uncertainty	20%	**LOCZRAMA**
Clock uncertainty	20%	**TEINIT**
Clock uncertainty	20%	**CFGNMFI**
Clock uncertainty	20%	**CFGATCMSZ[3:0]**
Clock uncertainty	20%	**CFGBTCMSZ[3:0]**
Clock uncertainty	20%	**PARECCENRAM[2:0]**
Clock uncertainty	20%	**ERRENRAM[2:0]**

Table 15-2 Configuration input port timing parameters (continued)

Input delay minimum	Input delay maximum	Signal name
Clock uncertainty	20%	**PARLVRAM**
Clock uncertainty	20%	**ENTCM1IF**
Clock uncertainty	20%	**SLBTCMSB**
Clock uncertainty	20%	**RMWENRAM[1:0]**

Table 15-3 shows the timing parameters for the interrupt input ports.

Table 15-3 Interrupt input ports timing parameters

Input delay minimum	Input delay maximum	Signal name
Clock uncertainty	60%	**nFIQ**
Clock uncertainty	60%	**nIRQ**
Clock uncertainty	10%	**INTSYNCEN**
Clock uncertainty	60%	**IRQADDRV**
Clock uncertainty	60%	**IRQADDRVSYNCEN**
Clock uncertainty	60%	**IRQADDR[31:2]**

Table 15-4 shows the input timing parameters for the AXI master port.

Table 15-4 AXI master input port timing parameters

Input delay minimum	Input delay maximum	Signal name
Clock uncertainty	50%	**ACLKENM**
Clock uncertainty	60%	**AWREADYM**
Clock uncertainty	60%	**WREADYM**
Clock uncertainty	60%	**BIDM[3:0]**
Clock uncertainty	60%	**BRESPM[1:0]**
Clock uncertainty	60%	**BVALIDM**
Clock uncertainty	60%	**ARREADYM**
Clock uncertainty	60%	**RIDM[3:0]**
Clock uncertainty	60%	**RDATAM[63:0]**
Clock uncertainty	60%	**RRESPM[1:0]**
Clock uncertainty	60%	**RLASTM**

Table 15-4 AXI master input port timing parameters (continued)

Input delay minimum	Input delay maximum	Signal name
Clock uncertainty	60%	**RVALIDM**
Clock uncertainty	60%	**BPARITYM**
Clock uncertainty	60%	**RPARITYM**

Table 15-5 shows the input timing parameters for the AXI slave port.

Table 15-5 AXI slave input port timing parameters

Input delay minimum	Input delay maximum	Signal name
Clock uncertainty	50%	**ACLKENS**
Clock uncertainty	60%	**AWIDS[7:0]**
Clock uncertainty	60%	**AWADDRS[22:0]**
Clock uncertainty	60%	**AWLENS[3:0]**
Clock uncertainty	60%	**AWSIZES[2:0]**
Clock uncertainty	60%	**AWBURSTS[1:0]**
Clock uncertainty	60%	**AWPROTS**
Clock uncertainty	60%	**AWUSERS[3:0]**
Clock uncertainty	60%	**AWVALIDS**
Clock uncertainty	60%	**WDATAS[63:0]**
Clock uncertainty	60%	**WSTRBS[7:0]**
Clock uncertainty	60%	**WLASTS**
Clock uncertainty	60%	**WVALIDS**
Clock uncertainty	60%	**BREADYS**
Clock uncertainty	60%	**ARIDS[7:0]**
Clock uncertainty	60%	**ARADDRS[22:0]**
Clock uncertainty	60%	**ARLENS[3:0]**
Clock uncertainty	60%	**ARSIZES[2:0]**
Clock uncertainty	60%	**ARBURSTS[1:0]**
Clock uncertainty	60%	**ARPROTS**
Clock uncertainty	60%	**ARUSERS[3:0]**
Clock uncertainty	60%	**ARVALIDS**
Clock uncertainty	60%	**RREADYS**

Table 15-5 AXI slave input port timing parameters (continued)

Input delay minimum	Input delay maximum	Signal name
Clock uncertainty	60%	**AWPARITYS**
Clock uncertainty	60%	**WPARITYS**
Clock uncertainty	60%	**ARPARITYS**

Table 15-6 shows the input timing parameters for the debug input ports.

Table 15-6 Debug input ports timing parameters

Input delay minimum	Input delay maximum	Signal name
Clock uncertainty	50%	**DBGEN**
Clock uncertainty	50%	**NIDEN**
Clock uncertainty	50%	**EDBGRQ**
Clock uncertainty	50%	**PCLKENDBG**
Clock uncertainty	50%	**PSELDBG**
Clock uncertainty	50%	**PADDRDBG[11:2]**
Clock uncertainty	50%	**PADDRDBG31**
Clock uncertainty	50%	**PWDATADBG[31:0]**
Clock uncertainty	50%	**PENABLEDBG**
Clock uncertainty	50%	**PWRITEDBG**
Clock uncertainty	10%	**DBGROMADDR[31:12]**
Clock uncertainty	10%	**DBGROMADDRV**
Clock uncertainty	10%	**DBGSELFADDR[31:12]**
Clock uncertainty	10%	**DBGSELFADDRV**
Clock uncertainty	50%	**DBGRESTART**

Table 15-7 shows the input timing parameters for the ETM input ports.

Table 15-7 ETM input ports timing parameters

Input delay minimum	Input delay maximum	Signal name
Clock uncertainty	50%	**ETMPWRUP**
Clock uncertainty	50%	**nETMWFIREADY**
Clock uncertainty	50%	**ETMEXTOUT[1:0]**

Table 15-8 shows the timing parameters for the test input ports.

Table 15-8 Test input ports timing parameters

Input delay minimum	Input delay maximum	Signal name
Clock uncertainty	10%	**SE**
Clock uncertainty	10%	**RSTBYPASS**
Clock uncertainty	50%	**MBTESTON**
Clock uncertainty	50%	**MBISTDIN[71:0]**
Clock uncertainty	50%	**MBISTADDR[19:0]**
Clock uncertainty	50%	**MBISTCE**
Clock uncertainty	50%	**MBISTSEL[4:0]**
Clock uncertainty	50%	**MBISTWE[7:0]**

Table 15-9 shows the timing parameters for the TCM interface input ports.

Table 15-9 TCM interface input ports timing parameters

Input delay minimum	Input delay maximum	Signal name
Clock uncertainty	65%	**ATCDATAIN[63:0]**
Clock uncertainty	65%	**ATCPARITYIN[13:0]**
Clock uncertainty	65%	**ATCERROR**
Clock uncertainty	50%	**ATCWAIT**
Clock uncertainty	40%	**ATCLATEERROR**
Clock uncertainty	50%	**ATCRETRY**
Clock uncertainty	65%	**B0TCDATAIN[63:0]**
Clock uncertainty	65%	**B0TCPARITYIN[13:0]**
Clock uncertainty	65%	**B0TCERROR**
Clock uncertainty	50%	**B0TCWAIT**
Clock uncertainty	40%	**B0TCLATEERROR**
Clock uncertainty	50%	**B0TCRETRY**
Clock uncertainty	65%	**B1TCDATAIN[63:0]**
Clock uncertainty	65%	**B1TCPARITYIN[13:0]**
Clock uncertainty	65%	**B1TCERROR**

Table 15-9 TCM interface input ports timing parameters (continued)

Input delay minimum	Input delay maximum	Signal name
Clock uncertainty	50%	**B1TCWAIT**
Clock uncertainty	40%	**B1TCLATEERROR**
Clock uncertainty	50%	**B1TCRETRY**

The timing parameters for the dual-redundant core compare logic input control buses, **DCCMINP[7:0]** and **DCCMINP2[7:0]**, are implementation-defined. Contact the implementer of the macrocell you are working with.

15.2.2 Output ports timing parameters

Most output ports have a maximum output delay of 60%, that is the SoC is enabled to use 60% of the clock cycle.

Table 15-10 shows the timing parameter for the miscellaneous output port.

Table 15-10 Miscellaneous output port timing parameter

Output delay minimum	Output delay maximum	Signal name
Clock uncertainty	10%	**STANDBYWFI**

Table 15-11 shows the timing parameters for the interrupt output ports.

Table 15-11 Interrupt output ports timing parameters

Output delay minimum	Output delay maximum	Signal name
Clock uncertainty	60%	**IRQACK**
Clock uncertainty	60%	**nPMUIRQ**

Table 15-12 shows the timing parameters for the AXI master output port.

Table 15-12 AXI master output port timing parameters

Output delay minimum	Output delay maximum	Signal name
Clock uncertainty	60%	**AWIDM[3:0]**
Clock uncertainty	60%	**AWADDRM[31:0]**
Clock uncertainty	60%	**AWLENM[3:0]**
Clock uncertainty	60%	**AWSIZEM[2:0]**
Clock uncertainty	60%	**AWBURSTM[1:0]**
Clock uncertainty	60%	**AWLOCKM[1:0]**
Clock uncertainty	60%	**AWCACHEM[3:0]**

Table 15-12 AXI master output port timing parameters (continued)

Output delay minimum	Output delay maximum	Signal name
Clock uncertainty	60%	**AWPROTM[2:0]**
Clock uncertainty	60%	**AWUSERM[4:0]**
Clock uncertainty	60%	**AWVALIDM**
Clock uncertainty	60%	**WIDM[3:0]**
Clock uncertainty	60%	**WDATAM[63:0]**
Clock uncertainty	60%	**WSTRBM[7:0]**
Clock uncertainty	60%	**WLASTM**
Clock uncertainty	60%	**WVALIDM**
Write response channel		
Clock uncertainty	60%	**BREADYM**
Clock uncertainty	60%	**ARIDM[3:0]**
Clock uncertainty	60%	**ARADDRM[31:0]**
Clock uncertainty	60%	**ARLENM[3:0**]
Clock uncertainty	60%	**ARSIZEM[2:0**]
Clock uncertainty	60%	**ARBURSTM[1:0]**
Clock uncertainty	60%	**ARLOCKM[1:0]**
Clock uncertainty	60%	**ARCACHEM[3:0**]
Clock uncertainty	60%	**ARPROTM[2:0]**
Clock uncertainty	60%	**ARUSERM[4:0]**
Clock uncertainty	60%	**ARVALIDM**
Clock uncertainty	60%	**RREADYM**
Clock uncertainty	60%	**AWPARITYM**
Clock uncertainty	60%	**WPARITYM**
Clock uncertainty	60%	**ARPARITYM**
Clock uncertainty	50%	**AXIMPARERR[1:0]**

Table 15-13 shows the timing parameters for the AXI slave output ports.

Table 15-13 AXI slave output ports timing parameters

Output delay minimum	Output delay maximum	Signal name
Clock uncertainty	60%	**AWREADYS**
Clock uncertainty	60%	**WREADYS**
Clock uncertainty	60%	**BIDS[7:0]**

Table 15-13 AXI slave output ports timing parameters (continued)

Output delay minimum	Output delay maximum	Signal name
Clock uncertainty	60%	**BRESPS[1:0]**
Clock uncertainty	60%	**BVALIDS**
Clock uncertainty	60%	**ARREADYS**
Clock uncertainty	60%	**RIDS[7:0]**
Clock uncertainty	60%	**RDATAS[63:0]**
Clock uncertainty	60%	**RRESPS[1:0]**
Clock uncertainty	60%	**RLASTS**
Clock uncertainty	60%	**RVALIDS**
Clock uncertainty	60%	**BPARITYS**
Clock uncertainty	60%	**RPARITYS**
Clock uncertainty	50%	**AXISPARERR[2:0]**

Table 15-14 shows the timing parameters for the debug interface output ports.

Table 15-14 Debug interface output ports timing parameters

Output delay minimum	Output delay maximum	Signal name
Clock uncertainty	50%	**PRDATADBG[31:0]**
Clock uncertainty	50%	**PREADYDBG**
Clock uncertainty	50%	**PSLVERRDBG**
Clock uncertainty	50%	**DBGNOPWRDWN**
Clock uncertainty	50%	**DBGACK**
Clock uncertainty	50%	**DBGTRIGGER**
Clock uncertainty	50%	**DBGRESTARTED**
Clock uncertainty	50%	**DBGRSTREQ**
Clock uncertainty	50%	**COMMTX**
Clock uncertainty	50%	**COMMRX**

Table 15-15 shows the timing parameters for the ETM interface output ports.

Table 15-15 ETM interface output ports timing parameters

Output delay minimum	Output delay maximum	Signal name
Clock uncertainty	50%	**ETMICTL[13:0]**
Clock uncertainty	50%	**ETMIA[31:1]**
Clock uncertainty	50%	**ETMDCTL[11:0]**
Clock uncertainty	50%	**ETMDA[31:0]**
Clock uncertainty	50%	**ETMDD[63:0]**
Clock uncertainty	50%	**ETMCID[31:0]**
Clock uncertainty	50%	**ETMWFIPENDING**
Clock uncertainty	50%	**EVNTBUS[46:0]**

Table 15-16 shows the timing parameters for the test output ports.

Table 15-16 Test output ports timing parameters

Output delay minimum	Output delay maximum	Signal name
Clock uncertainty	50%	**MBISTDOUT[71:0]**
Clock uncertainty	50%	**nVALIRQ**
Clock uncertainty	50%	**nVALFIQ**
Clock uncertainty	50%	**nVALRESET**
Clock uncertainty	50%	**VALEDBGRQ**

Table 15-17 shows the timing parameters for the TCM interface output ports.

Table 15-17 TCM interface output ports timing parameters

Output delay minimum	Output delay maximum	Signal name
Clock uncertainty	45%	**ATCEN0**
Clock uncertainty	45%	**ATCEN1**
Clock uncertainty	45%	**ATCADDR[22:3]**
Clock uncertainty	45%	**ATCBYTEWR[7:0]**
Clock uncertainty	45%	**ATCSEQ**
Clock uncertainty	45%	**ATCDATAOUT[63:0]**
Clock uncertainty	45%	**ATCPARITYOUT[13:0]**
Clock uncertainty	45%	**ATCACCTYPE[2:0]**
Clock uncertainty	45%	**ATCWE**

Table 15-17 TCM interface output ports timing parameters (continued)

Output delay minimum	Output delay maximum	Signal name
Clock uncertainty	45%	**ATCADDRPTY**
Clock uncertainty	45%	**B0TCEN0**
Clock uncertainty	45%	**B0TCEN1**
Clock uncertainty	45%	**B0TCADDR[22:3]**
Clock uncertainty	45%	**B0TCBYTEWR[7:0]**
Clock uncertainty	45%	**B0TCSEQ**
Clock uncertainty	45%	**B0TCDATAOUT[63:0]**
Clock uncertainty	45%	**B0TCPARITYOUT[13:0]**
Clock uncertainty	45%	**B0TCACCTYPE[2:0]**
Clock uncertainty	45%	**B0TCWE**
Clock uncertainty	45%	**B0TCADDRPTY**
Clock uncertainty	45%	**B1TCEN0**
Clock uncertainty	45%	**B1TCEN1**
Clock uncertainty	45%	**B1TCADDR[23:0]**
Clock uncertainty	45%	**B1TCBYTEWR[7:0]**
Clock uncertainty	45%	**B1TCSEQ**
Clock uncertainty	45%	**B1TCDATAOUT[63:0]**
Clock uncertainty	45%	**B1TCPARITYOUT[13:0]**
Clock uncertainty	45%	**B1TCACCTYPE[2:0]**
Clock uncertainty	45%	**B1TCWE**
Clock uncertainty	45%	**B1TCADDRPTY**

Table 15-18 shows the timing parameters for the FPU output signals.

Table 15-18 FPU output port timing parameters

Output delay minimum	Output delay maximum	Signal name
Clock uncertainty	60%	**FPIXC**
Clock uncertainty	60%	**FPOFC**
Clock uncertainty	60%	**FPUFC**
Clock uncertainty	60%	**FPIOC**
Clock uncertainty	60%	**FPDZC**
Clock uncertainty	60%	**FPIDC**

The timing parameters for the dual-redundant core compare logic output buses, **DCCMOUT[7:0]** and **DCCMOUT2[7:0]**, are implementation-defined. Contact the implementer of the macrocell you are working with.

Appendix A
Processor Signal Descriptions

This appendix describes the processor signals. It contains the following sections:

A.1 About the processor signal descriptions

The tables in this appendix list the processor signals, along with their dimensions and direction, input or output, and a high-level description. Each table also has a clocking column, that indicates by which clock a signal is sampled or driven. All signals are sampled on or driven from the rising edge of the clock. The clocking column can also contain the following information:

Any Means the input is synchronised inside the processor, so the input can be driven from any clock.

Tie-off Means the input must be tied to a fixed value.

Reset Means the input must only be changed under reset.

Clocking is listed for all outputs, though some are typically synchronized into a different clock before use.

A.2 Global signals

Table A-1 shows the processor global signals.

The free clock is ungated, with minimal insertion delay, because it clocks the clock gating circuits. Therefore, you must ensure that incoming clocks are balanced with the free clock.

Table A-1 Global signals

Signal	Direction	Clocking	Description
FREECLKIN	Input	-	Free version of the core clock.
CLKIN	Input	-	Core clock.
CLKIN2	Input	-	Core clock, in phase with **DUALCKLIN**, for configurations with dual-redundant core.[a]
nRESET	Input	Any	Core reset.
nSYSPORESET	Input	Any	System power on reset.
nCPUHALT	Input	Any	Processor halt after reset.
DBGNOCLKSTOP	Input	Any	Processor does not stop the clocks when entering WFI state.[a]
DUALCLKIN	Input	-	Clock for second, redundant, core.[a]
DUALCLKIN2	Input	-	Clock for second, redundant, core, in phase with **CLKIN**.[a]
STANDBYWFI	Output	**FREECLKIN**	Indicates that the processor is in Standby mode and the processor clock is stopped. You can use this signal for TCMs RAM clock gating.

a. Not available in r0px revisions of the processor.

A.3 Configuration signals

Table A-2 shows the processor configuration signals.

Table A-2 Configuration signals

Signal	Direction	Clocking	Description
VINITHI	Input	Tie-off, Reset	Reset V-bit value. When HIGH indicates HIVECS mode at reset. See *c1, System Control Register* on page 4-35 for more information.
CFGEE	Input	Tie-off, Reset	Reset EE-bit value. When HIGH indicates the implementation uses BE-8 mode for exceptions at reset. See *c1, System Control Register* on page 4-35 for more information.
CFGIE	Input	Tie-off, Reset	Instruction side endianness, reflected in the IE-bit. When HIGH indicates that big endian instruction fetch is used. See *c1, System Control Register* on page 4-35 for more information.
INITRAMA	Input	Tie-off, Reset	Reset value of ATCM enable bit. When HIGH indicates Tightly-Coupled Memory A, ATCM, enabled at reset. See *c9, ATCM Region Register* on page 4-58 for more information.
INITRAMB	Input	Tie-off, Reset	Reset value of BTCM bit. When HIGH indicates Tightly-Coupled Memory B, BTCM, enabled at reset. See *c9, BTCM Region Register* on page 4-57 for more information.
LOCZRAMA	Input	Tie-off, Reset	When HIGH indicates ATCM initial base address is zero and BTCM base address is implementation-defined. When LOW indicates BTCM initial base address is zero and ATCM base address is implementation-defined.
TEINIT	Input	Tie-off, Reset	Reset TE-bit value. Determines exception handling state at reset. When set to: 0 = ARM 1 = Thumb. See *c1, System Control Register* on page 4-35 for more information.
CFGATCMSZ[3:0]	Input	Tie-off	Selects the ATCM size. The encodings for the TCM sizes are: b0000 = 0KB b0011 = 4KB b0100 = 8KB b0101 = 16KB b0110 = 32KB b0111 = 64KB b1000 = 128KB b1001 = 256KB b1010 = 512KB b1011 = 1MB b1100 = 2MB b1101 = 4MB b1110 = 8MB.

Table A-2 Configuration signals (continued)

Signal	Direction	Clocking	Description
CFGBTCMSZ[3:0]	Input	Tie-off	Selects the BTCM size. The encodings for the TCM sizes are: b0000 = 0KB b0011 = 4KB b0100 = 8KB b0101 = 16KB b0110 = 32KB b0111 = 64KB b1000 = 128KB b1001 = 256KB b1010 = 512KB b1011 = 1MB b1100 = 2MB b1101 = 4MB b1110 = 8MB.
CFGNMFI	Input	Tie-off, Reset	When HIGH, enable non-maskable Fast Interrupts. Reflected in the NMFI bit. See *c1, System Control Register* on page 4-35 for more information.
ENTCM1IF	Input	Tie-off	Enable B1TCM interface. Use B0TCM only if this signal not tied HIGH.
PARECCENRAM[2:0]	Input	Tie-off, Reset	TCMs parity or ECC check enable. Tie each bit HIGH to enable parity or ECC checking on the appropriate TCM at reset. Use following values: 2:B1TCM[a] 1: B0TCM[a] 0: ATCM See *Auxiliary Control Registers* on page 4-38 for more information.
PARLVRAM	Input	Tie-off, Reset	Selects between odd and even parity for caches, TCMs, and buses. See Chapter 8 *Level One Memory System*: Tie LOW for even parity Tie HIGH for odd parity.

Table A-2 Configuration signals (continued)

Signal	Direction	Clocking	Description
ERRENRAM[2:0]	Input	Tie-off, Reset	TCMs external error enable. Tie each bit high to enable the external error signals for each TCM at reset. Use the following values: 2: B1TCM 1: B0TCM 0: ATCM See *Auxiliary Control Registers* on page 4-38 for more information.
RMWENRAM[1:0][b]	Input	Tie-off, Reset	RMW enable bits reset values. Tie each bit high to enable read-modify-write for TCM interfaces at reset.[c] Use the following values: 1: BTCM 0: ATCM See *Auxiliary Control Registers* on page 4-38 for more information.
SLBTCMSB	Input	Tie-off	Use most significant bit of BTCM address to select B1TCM if this signal is HIGH. Use bit [3] of the BTCM address if this signal is LOW.

a. If the BTCM is configured with ECC, bit[2] and bit[1] must be the same value.
b. Not used if 32-bit ECC is included.
c. Not available in r0px revisions of the processor.

A.4 Interrupt signals, including VIC interface signals

Table A-3 shows the Interrupt signals including signals used on the VIC interface.

Table A-3 Interrupt signals

Signal	Direction	Clocking	Description
nFIQ	Input	**CLKIN**[a] Any[b]	Fast interrupt[c].
nIRQ	Input	**CLKIN**[a] Any[b]	Normal interrupt[c].
INTSYNCEN	Input	Tie-off	Tie HIGH if the interrupt inputs are asynchronous to CLKIN. Tie LOW if the interrupt inputs are synchronous to CLKIN.
IRQADDRV	Input	**CLKIN**[d] Any[e]	Indicates IRQADDR is valid.
IRQADDRVSYNCEN	Input	Tie-off	Tie HIGH if the IRQADDRV input from the VIC is asynchronous to CLKIN. Tie HIGH if the IRQADDRV input from the VIC is synchronous to CLKIN.
IRQADDR [31:2]	Input	-	Address of the IRQ. This signal must be stable when IRQADDRV is asserted.
IRQACK	Output	**CLKIN**	Acknowledges interrupt.
nPMUIRQ	Output	**CLKIN**	Interrupt request by *Performance Monitor Unit* (PMU).

a. When INTSYNCEN is tied LOW
b. When INTSYNCEN is tied HIGH
c. This signal is level-sensitive and must be held LOW until a suitable interrupt response is received from the processor.
d. When IRQADDRVSYNCEN is tied LOW
e. When IRQADDRVSYCNEN is tied HIGH

A.5 L2 interface signals

This section describes the processor L2 interface AXI signals. For more information on *Advanced Microcontroller Bus Architecture* (AMBA) AXI signals see the *AMBA AXI Protocol Specification*.

Note

All the outputs listed in this section have their reset values during standby.

A.5.1 AXI master port

Table A-4 shows the AXI master port signals for the L2 interface. With the exception of the **ACLKENM**, all signals are only sampled or driven on **CLKIN** edges when **ACLKENM** is asserted, see *AXI interface clocking* on page 3-9 for more information.

Table A-4 AXI master port signals for the L2 interface

Signal	Direction	Clocking	Description
ACLKENM	Input	**CLKIN**	Clock enable for the AXI master port.
Write address channel			
AWADDRM[31:0]	Output	**CLKIN**	Transfer start address.
AWBURSTM[1:0]	Output	**CLKIN**	Write burst type.
AWCACHEM[3:0]	Output	**CLKIN**	Provides decode information for outer attributes: b0000 = Strongly Ordered. b0001 = Device. b0011 = Normal, Non-cacheable. b0110 = Normal, Cacheable. write-through. b1111 = Normal, Cacheable. write-back, write allocation. b0111 = Normal, Cacheable. write-back, no write allocation. **Note** The AXI specification describes these encodings using the pre-ARMv6 terms such as *cacheable-bufferable*. These terms are equivalent to the ARMv6 memory-type descriptions such as *Normal, Non-cacheable* used here.
AWIDM[3:0]	Output	**CLKIN**	The identification tag for the write address group of signals.
AWLENM [3:0]	Output	**CLKIN**	Write transfer burst length. The transfer burst length range is from one to 16. A 4-bit binary value minus one determines the transfer burst length.
AWLOCKM[1:0]	Output	**CLKIN**	Lock signal.
AWPROTM[2:0]	Output	**CLKIN**	Protection type. Only bit [0] is used from the 3-bit AXI bus.
AWREADYM	Input	**CLKIN**	Address ready. The slave uses this signal to indicate that it can accept the address.
AWSIZEM[2:0]	Output	**CLKIN**	Indicates the size of the transfer.
AWUSERM[4:0]	Output	**CLKIN**	Provides decode information for the write address channel. See Table 9-3 on page 9-5 for information about the encoding of this signal.

Table A-4 AXI master port signals for the L2 interface (continued)

Signal	Direction	Clocking	Description
AWVALIDM	Output	**CLKIN**	Indicates address and control are valid.
Write data channel			
WDATAM[63:0]	Output	**CLKIN**	Write data.
WIDM[3:0]	Output	**CLKIN**	The identification tag for the write data group of signals.
WLASTM	Output	**CLKIN**	Indicates the last data transfer of a burst.
WREADYM	Input	**CLKIN**	Indicates that the slave is ready to accept write data
WSTRBM[7:0]	Output	**CLKIN**	Write strobes used to indicate which byte lanes must be updated.
WVALIDM	Output	**CLKIN**	Indicates address and control are valid.
Write response channel			
BIDM [3:0]	Input	**CLKIN**	The identification tag for the write response signal.
BREADYM	Output	**CLKIN**	Indicates that the core is ready to accept write response.
BRESPM[1:0]	Input	**CLKIN**	Write response.
BVALIDM	Input	**CLKIN**	Indicates that a valid write response is available.
Read address channel			
ARADDRM[31:0]	Output	**CLKIN**	Instruction fetch burst start address.
ARBURSTM[1:0]	Output	**CLKIN**	Burst type.
ARCACHEM[3:0]	Output	**CLKIN**	Provides decode information for outer attributes: b0000 = Strongly Ordered. b0001 = Device. b0011 = Normal, Non-cacheable. b0110 = Normal, Cacheable. write-through. b1111 = Normal, Cacheable. write-back, write allocation. b0111 = Normal, Cacheable. write-back, no write allocation. **Note** The AXI specification describes these encodings using the pre-ARMv6 terms such as *cacheable-bufferable*. These terms are equivalent to the ARMv6 memory-type descriptions such as *Normal, Non-cacheable* used here.
ARIDM[3:0]	Output	**CLKIN**	Identification tag for the read address group of signals
ARLENM [3:0]	Output	**CLKIN**	Instruction fetch burst length.
ARLOCKM[1:0]	Output	**CLKIN**	Lock signal.
ARPROTM[2:0]	Output	**CLKIN**	Protection signals provide addition information about a bus access.
ARREADYM	Input	**CLKIN**	Address ready. The slave uses this signal to indicate that it can accept the address.
ARSIZEM[2:0]	Output	**CLKIN**	Indicates the size of the transfer.

Table A-4 AXI master port signals for the L2 interface (continued)

Signal	Direction	Clocking	Description
ARUSERM[4:0]	Output	**CLKIN**	Provides decode information for the read address channel. See Table 9-3 on page 9-5 for information about the encoding of this signal.
ARVALIDM	Output	**CLKIN**	Indicates address and control are valid.
Read Data Channel			
RDATAM[63:0]	Input	**CLKIN**	Read Data.
RIDM[3:0]	Input	**CLKIN**	The identification tag for the read data group of signals.
RLASTM	Input	**CLKIN**	Indicates the last transfer in a read burst.
RREADYM	Output	**CLKIN**	Read ready signal indicating that the bus master can accept read data and response information.
RRESPM[1:0]	Input	**CLKIN**	Read response.
RVALIDM	Input	**CLKIN**	Indicates that read data is available.

A.5.2 AXI master port error detection signals

Table A-5 shows the AXI master port error detection signals. these signals are only generated if the processor is configured to include AXI bus parity. See *Configurable options* on page 1-13 for more information.

Table A-5 AXI master port error detection signals

Signal	Direction	Clocking	Description
AWPARITYM	Output	**CLKIN**	Parity bit for write address channel
WPARITYM	Output	**CLKIN**	Parity bit for write data channel
BPARITYM	Input	**CLKIN**	Parity bit for write response channel
ARPARITYM	Output	**CLKIN**	Parity bit for read address channel
RPARITYM	Input	**CLKIN**	Parity bit for read data channel
AXIMPARERR[1:0]	Output	**CLKIN**	Parity error indication for read data (bit [1]) and write response (bit[0]) channels

A.5.3 AXI slave port

Table A-6 shows the AXI slave port signals for the L2 interface. With the exception of the **ACLKENS**, all signals are only sampled or driven on **CLKIN** edges when **ACLKENS** is asserted, see *AXI interface clocking* on page 3-9 for more information.

Table A-6 AXI slave port signals for the L2 interface

Signal	Direction	Clocking	Description
ACLKENS	Input	**CLKIN**	Clock enable for the AXI slave port.
Write Address Channel			
AWADDRS[22:0]	Input	**CLKIN**	Transfer start address.

Table A-6 AXI slave port signals for the L2 interface (continued)

Signal	Direction	Clocking	Description
AWBURSTS[1:0]	Input	**CLKIN**	Write burst type.
AWIDS[7:0]	Input	**CLKIN**	The identification tag for the write address group of signals.
AWLENS[3:0]	Input	**CLKIN**	Write transfer burst length. The transfer burst length range is from one to 16. A four bit binary value minus one determines the transfer burst length.
AWPROTS	Input	**CLKIN**	Protection information, privileged/normal access. **AWPROT[0]** in AXI specification.
AWREADYS	Output	**CLKIN**	Address ready. The slave uses this signal to indicate that it can accept the address.
AWSIZES[2:0]	Input	**CLKIN**	Indicates the size of the transfer.
AWUSERS[3:0]	Input	**CLKIN**	Memory type select data cache, instruction cache, BTCM or ATCM, one hot. **AWUSERS[3:0]** signal is not part of the standard AXI specification.
AWVALIDS	Input	**CLKIN**	Indicates address and control are valid.
Write Data Channel			
WDATAS[63:0]	Input	**CLKIN**	Write data.
WLASTS	Input	**CLKIN**	Indicates the last data transfer of a burst.
WREADYS	Output	**CLKIN**	Indicates that the slave is ready to accept write data.
WSTRBS[7:0]	Input	**CLKIN**	Write strobes used to indicate which byte lanes must be updated.
WVALIDS	Input	**CLKIN**	Indicates address and control are valid.
Write Response Channel			
BIDS[7:0]	Output	**CLKIN**	The identification tag for the write response signal.
BREADYS	Input	**CLKIN**	Indicates that the core is ready to accept write response.
BRESPS[1:0]	Output	**CLKIN**	Write response.
BVALIDS	Output	**CLKIN**	Indicates that a valid write response is available.
Read Address Channel			
ARADDRS[22:0]	Input	**CLKIN**	Instruction fetch burst start address.
ARBURSTS[1:0]	Input	**CLKIN**	Burst type.
ARIDS[7:0]	Input	**CLKIN**	Identification tag for the read address group of signals.
ARLENS[3:0]	Input	**CLKIN**	Instruction fetch burst length.
ARPROTS	Input	**CLKIN**	Protection information, privileged/normal access. **ARPROT[0]** in AXI specification.
ARREADYS	Output	**CLKIN**	Address ready. The slave uses this signal to indicate that it can accept the address.
ARSIZES[2:0]	Input	**CLKIN**	Indicates the size of the transfer.

Table A-6 AXI slave port signals for the L2 interface (continued)

Signal	Direction	Clocking	Description
ARUSERS[3:0]	Input	**CLKIN**	Memory type select {data cache, instruction cache, BTCM or ATCM}, one hot. **AWUSERS[3:0]** signal is not part of the standard AXI specification.
ARVALIDS	Input	**CLKIN**	Indicates address and control are valid.
Read Data Channel			
RDATAS[63:0]	Output	**CLKIN**	Read data.
RIDS[7:0]	Output	**CLKIN**	The identification tag for the read data group of signals.
RLASTS	Output	**CLKIN**	Indicates the last transfer in a read burst.
RREADYS	Input	**CLKIN**	Read ready signal indicating that the bus master can accept read data and response information.
RRESPS[1:0]	Output	**CLKIN**	Read response.
RVALIDS	Output	**CLKIN**	Indicates address and control are valid.

A.5.4 AXI slave port error detection signals

Table A-7 shows the AXI slave port error detection signals. These signals are only generated if the processor is configured to include AXI bus parity. See *Configurable options* on page 1-13 for more information.

Table A-7 AXI slave port error detection signals

Signal	Direction	Clocking	Description
AWPARITYS	Input	**CLKIN**	Parity bit for write address channel
WPARITYS	Input	**CLKIN**	Parity bit for write data channel
BPARITYS	Output	**CLKIN**	Parity bit for write response channel
ARPARITYS	Input	**CLKIN**	Parity bit for read address channel
RPARITYS	Output	**CLKIN**	Parity bit for read data channel
AXISPARERR[2:0]	Output	**CLKIN**	Parity error indication for read address (bit [2]), write data (bit [1]), and write address (bit [0]) channels.

A.6 TCM interface signals

Table A-8 shows the ATCM port signals.

Table A-8 ATCM port signals

Name	Direction	Clocking	Description
ATCDATAIN [63:0]	Input	**CLKIN**	Data from ATCM
ATCPARITYIN [13:0]	Input	**CLKIN**	Parity or ECC code from ATCM
ATCERROR	Input	**CLKIN**	Error detected by ATCM[a]
ATCWAIT	Input	**CLKIN**	Wait from ATCM
ATCLATEERROR	Input	**CLKIN**	Late error from ATCM[a]
ATCRETRY	Input	**CLKIN**	Access to ATCM must be retried[a]
ATCADDRPTY	Output	**CLKIN**	Parity formed from ATCM address output[b]
ATCEN0	Output	**CLKIN**	Enable for ATCM lower word, bit range [31:0]
ATCEN1	Output	**CLKIN**	Enable for ATCM upper word, bit range [64:32]
ATCWE	Output	**CLKIN**	Write enable for ATCM
ATCADDR [22:3]	Output	**CLKIN**	Address for ATCM data RAM
ATCBYTEWR [7:0]	Output	**CLKIN**	Byte strobes for direct write
ATCSEQ	Output	**CLKIN**	ATCM RAM access is sequential
ATCDATAOUT [63:0]	Output	**CLKIN**	Write data for ATCM data RAM
ATCPARITYOUT [13:0]	Output	**CLKIN**	Write parity or ECC code for ATCM
ATCACCTYPE[2:0]	Output	**CLKIN**	Determines access type: b001 = Load/Store b010 = Fetch b100 = DMA b100 = MBIST[c].

a. This signal is ignored when bit [0] of the Auxiliary Control Register is set to 0, see *c1, Auxiliary Control Register* on page 4-38.
b. Only generated if the processor is configured to include TCM address bus parity.
c. The MBIST interface has no way of signalling a wait. If it is accessing the TCM, and the TCM signals a wait, the AXI slave pipeline stalls and the data arrives later. However, no signal is sent to the MBIST controller to indicate this.

Table A-9 shows the B0TCM port signals.

Table A-9 B0TCM port signals

Name	Direction	Clocking	Description
B0TCDATAIN [63:0]	Input	**CLKIN**	Data from B0TCM
B0TCPARITYIN [13:0]	Input	**CLKIN**	Parity or ECC code from B0TCM
B0TCERROR	Input	**CLKIN**	Error detected by B0TCM[a]
B0TCWAIT	Input	**CLKIN**	Wait from B0TCM

Table A-9 B0TCM port signals (continued)

Name	Direction	Clocking	Description
B0TCLATEERROR	Input	**CLKIN**	Late error from B0TCM[a]
B0TCRETRY	Input	**CLKIN**	Access to B1TCM must be retried[a]
B0TCADDRPTY	Output	**CLKIN**	Parity formed from B0TCM address output[b]
B0TCWE	Output	**CLKIN**	Write enable for B0TCM
B0TCEN0	Output	**CLKIN**	Enable for B0TCM lower word, bit range [31:0]
B0TCEN1	Output	**CLKIN**	Enable for B0TCM upper word, bit range [64:32]
B0TCADDR [22:3]	Output	**CLKIN**	Address for B0TCM data RAM
B0TCBYTEWR [7:0]	Output	**CLKIN**	Byte strobes for direct write
B0TCSEQ	Output	**CLKIN**	B0TCM RAM access is sequential
B0TCDATAOUT [63:0]	Output	**CLKIN**	Write data for B0TCM data RAM
B0TCPARITYOUT [13:0]	Output	**CLKIN**	Write parity or ECC code for B0TCM
B0TCACCTYPE[2:0]	Output	**CLKIN**	Determines access type: b001 = Load/Store b010 = Fetch b100 = DMA b100 = MBIST[c].

a. This signal is ignored when bit [1] of the Auxiliary Control Register is set to 0, see *c1, Auxiliary Control Register* on page 4-38.
b. Only generated if the processor is configured to include TCM address bus parity.
c. The MBIST interface has no way of signalling a wait. If it is accessing the TCM, and the TCM signals a wait, the AXI slave pipeline stalls and the data arrives later. However, no signal is sent to the MBIST controller to indicate this.

Table A-10 shows the B1TCM port signals.

Table A-10 B1TCM port signals

Name	Direction	Clocking	Description
B1TCDATAIN [63:0]	Input	**CLKIN**	Data from B1TCM
B1TCPARITYIN [13:0]	Input	**CLKIN**	Parity or ECC code from B1TCM
B1TCERROR	Input	**CLKIN**	Error detected by B1TCM[a]
B1TCRETRY	Input	**CLKIN**	Access to B1TCM must be retried[a]
B1TCLATEERROR	Input	**CLKIN**	Late error from B1TCM[a]
B1TCWAIT	Input	**CLKIN**	Wait from B1TCM
B1TCADDRPTY	Output	**CLKIN**	Parity formed from B1TCM address output[b]
B1TCWE	Output	**CLKIN**	Write enable for B1TCM
B1TCEN0	Output	**CLKIN**	Enable for B1TCM lower word, bit range [31:0]
B1TCEN1	Output	**CLKIN**	Enable for B1TCM upper word, bit range [64:32]

Table A-10 B1TCM port signals (continued)

Name	Direction	Clocking	Description
B1TCADDR [22:3]	Output	**CLKIN**	Address for B1TCM data RAM
B1TCBYTEWR [7:0]	Output	**CLKIN**	Byte strobes for direct write
B1TCSEQ	Output	**CLKIN**	B1TCM RAM access is sequential
B1TCDATAOUT [63:0]	Output	**CLKIN**	Write data for B1TCM data RAM
B1TCPARITYOUT [13:0]	Output	**CLKIN**	Write parity or ECC code for B1TCM
B1TCACCTYPE[2:0]	Output	**CLKIN**	Determines access type: b001 = Load/Store b010 = Fetch b100 = DMA b100 = MBIST[c].

a. This signal is ignored when bit [2] of the Auxiliary Control Register is set to 0, see *c1, Auxiliary Control Register* on page 4-38.
b. Only generated if the processor is configured to include TCM address bus parity.
c. The MBIST interface has no way of signalling a wait. If it is accessing the TCM, and the TCM signals a wait, the AXI slave pipeline stalls and the data arrives later. However, no signal is sent to the MBIST controller to indicate this.

A.7 Dual core interface signals

Table A-11 shows the dual redundant core interface signals.

Table A-11 Dual core interface signals

Signal	Direction	Clocking	Description
DCCMINP[7:0]	Input	-[a]	Dual core compare logic input control bus
DCCMOUT[7:0]	Output	-[a]	Dual core compare logic output control bus
DCCMINP2[7:0]	Input	-[a]	Dual core compare logic extra input control bus[b]
DCCMOUT2[7:0]	Output	-[a]	Dual core compare logic extra output control bus[b]

a. Implementation-defined.
b. Not available in r0px revisions of the processor.

A.8 Debug interface signals

Table A-12 shows the debug interface signals. With the exception of **PCLKDBG**, **PCLKENDBG** and **PRESETDBGn**, all these signals are only sampled or driven on **PCLKDBG** edges when **PCLKENDBG** is asserted.

Table A-12 Debug interface signals

Signal	Direction	Clocking	Description
PCLKDBG	Input	-	Debug clock.
PCLKENDBG	Input	**PCLKDBG**	Clock enable for **PCLKDBG**.
PSELDBG	Input	**PCLKDBG**	Selects the external debug interface.
PADDRDBG[11:2]	Input	**PCLKDBG**	Programming address.
PADDRDBG31	Input	**PCLKDBG**	Programming address.
PRDATADBG[31:0]	Output	**PCLKDBG**	Read data bus.
PWDATADBG[31:0]	Input	**PCLKDBG**	Write data bus.
PENABLEDBG	Input	**PCLKDBG**	Indicates second, and subsequent, cycle of a transfer.
PREADYDBG	Output	**PCLKDBG**	Extends a APB transfer by the inserting wait states.
PSLVERRDBG	Output	**PCLKDBG**	Slave-generated error response.
PWRITEDBG	Input	**PCLKDBG**	Indicates access is a write transfer. Distinguishes between a read, LOW, and a write, HIGH.
PRESETDBGn	Input	Any	Reset debug logic.

Table A-13 shows the debug miscellaneous signals.

Table A-13 Debug miscellaneous signals

Name	Direction	Clocking	Description
DBGEN	Input	Any	Debug enable
NIDEN	Input	Any	Non-invasive debug enable
EDBGRQ	Input	Any	External debug request
DBGACK	Output	**CLKIN**	Debug acknowledge
DBGRSTREQ[a]	Output	**PCLKDBG**	Request for reset from debug logic
DBGTRIGGER	Output	**CLKIN**	External debug request taken
COMMRX	Output	**CLKIN**	Write-DTR full
COMMTX	Output	**CLKIN**	Read-DTR empty
DBGRESTART	Input		External restart request
DBGRESTARTED	Output	**CLKIN**	Handshake for **DBGRESTART**
DBGNOPWRDWN	Output	**PCLKDBG**	No power-down request
DBGROMADDR[31:12]	Input	Tie-off	Debug ROM physical address

Table A-13 Debug miscellaneous signals (continued)

Name	Direction	Clocking	Description
DBGROMADDRV	Input	Tie-off	Debug ROM physical address valid
DBGSELFADDR[31:12]	Input	Tie-off	Debug self-address offset
DBGSELFADDRV	Input	Tie-off	Debug self-address offset valid

a. Not available in r0px revisions of the processor.

A.9 ETM interface signals

Table A-14 shows the ETM interface signals.

Table A-14 ETM interface signals

Signal	Direction	Clocking	Description
ETMICTL[13:0]	Output	**CLKIN**	ETM instruction control bus
ETMIA[31:1]	Output	**CLKIN**	ETM instruction address
ETMDCTL[11:0]	Output	**CLKIN**	ETM data control bus
ETMDA[31:0]	Output	**CLKIN**	ETM data address
ETMDD[63:0]	Output	**CLKIN**	ETM data-data
ETMCID[31:0]	Output	**CLKIN**	Current value of processor CID register
ETMWFIPENDING	Output	**CLKIN**	Core is attempting to enter WFI state
EVNTBUS[46:0]	Output	**CLKIN**	Performance monitor unit output
ETMPWRUP	Input	**CLKIN**	Power up ETM interface
nETMWFIREADY	Input	**CLKIN**	ETM FIFO is empty, core can enter WFI state
ETMEXTOUT[1:0]	Input	**CLKIN**	ETM detected events

A.10 Test signals

Table A-15 shows the test signals.

Table A-15 Test signals

Signal	Direction	Clocking	Description
SE	Input	-[a]	Scan Enable
RSTBYPASS	Input	-[a]	Bypass pipelined reset

a. Design for test only.

A.11 MBIST signals

Table A-16 shows the MBIST signals.

Table A-16 MBIST signals

Signal	Direction	Clocking	Description
MBTESTON	Input	**CLKIN**	MBIST test is enabled
MBISTDIN[77:0]	Input	**CLKIN**	MBIST data in
MBISTADDR[19:0]	Input	**CLKIN**	MBIST address
MBISTCE	Input	**CLKIN**	MBIST chip enable
MBISTSEL[4:0]	Input	**CLKIN**	MBIST chip select
MBISTWE [7:0]	Input	**CLKIN**	MBIST write enable
MBISTDOUT[77:0]	Output	**CLKIN**	MBIST data out

A.12 Validation signals

Table A-17 shows the validation signals.

Table A-17 Validation signals

Signal	Direction	Clocking	Description
VALEDBGRQ	Output	**CLKIN**	Debug request
nVALIRQ	Output	**CLKIN**	Request for an interrupt
nVALFIQ	Output	**CLKIN**	Request for a Fast Interrupt
nVALRESET	Output	**CLKIN**	Request for a reset

A.13 FPU signals

Table A-18 shows the FPU signals. These signals are only driven if the processor is configured to include the floating-point logic.

Table A-18 FPU signals

Signal	Direction	Clocking	Description
FPIXC	Output	**CLKIN**	Masked floating-point inexact exception
FPOFC	Output	**CLKIN**	Masked floating-point overflow exception
FPUFC	Output	**CLKIN**	Masked floating-point underflow exception
FPIOC	Output	**CLKIN**	Masked floating-point invalid operation exception
FPDZC	Output	**CLKIN**	Masked floating-point divide-by-zero exception
FPIDC	Output	**CLKIN**	Masked floating-point input denormal exception

Appendix B
ECC Schemes

This appendix describes some of the advantages and disadvantages of the different *Error Checking and Correction* (ECC) schemes for the TCMs. It contains the following section:

- *ECC scheme selection guidelines* on page B-2.

B.1 ECC scheme selection guidelines

When deciding to implement a Cortex-R4 processor with an ECC scheme on one or both of the TCM interfaces, give careful consideration between using 32-bit or 64-bit ECC. To calculate or check the ECC code for data, the processor must know the value of all bytes in the data chunk protected by the scheme. Therefore, when using these schemes, the processor must perform additional read accesses to calculate and check the ECC code stored with the data.

For example, if the ATCM is implemented with 32-bit ECC and a program performs an aligned `STR` to the memory, the processor can calculate the error correction code using only the data stored by the program.

If the same memory was implemented with 64-bit ECC, the processor cannot calculate the ECC code for the doubleword memory chunk being written using only the data stored by the program. To calculate the ECC code and store the data, the processor must first perform a read of the other word in that memory chunk. This increases the number of memory accesses required to execute the program. This increases power consumption, and can also lead to a decrease in performance.

Use the following guidelines to decide which scheme to use. If you are in any doubt, benchmark your system running typical software to find the best balance between area, power, and performance for your application.

- For a TCM interface that contains mainly instructions, use 64-bit ECC. The vast majority of reads requested by the prefetch unit are doubleword.
- Use 64-bit ECC when a TCM contains data that is accessed using:
  - `LDRD` or `STRD` instructions where the start address is doubleword aligned
  - `LDM` or `STM` instructions where the start address is doubleword aligned and there are an even number of registers in the register list.

  64-bit ECC requires less RAM area, and does not provide any performance loss or increased power consumption over 32-bit ECC in these cases.
- When `LDM` and `STM` instructions are used to access many registers, the majority of TCM accesses do not require additional reads with 64-bit ECC.
- 32-bit ECC provides better power consumption and generally better performance compared to 64-bit ECC when:
  - a program performs many unaligned accesses to data in a TCM
  - a program performs many byte, halfword, and word accesses to data in a TCM.

You might be able to obtain optimal results by using a different error detection scheme on each TCM interface, and allocating instructions and data to each interface based on the guidelines given above.

Appendix C
Revisions

This appendix describes the technical changes between released issues of this book.

Table C-1 Differences between issue B and issue C

Change	Location
Clarified the description of Thumb-2 technology and Thumb instructions	• *About the programmer's model* on page 2-2 • *Abort exceptions* on page 8-9
Clarified byte-invariant big-endian format	*Byte-invariant big-endian format* on page 2-6
Clarified little-endian format	*Little-endian format* on page 2-6
nCPUHALT removed from timing diagram	Figure 3-1 on page 3-7
Added sections	• *AXI interface clocking* on page 3-9 • *Clock gating* on page 3-9

Table C-1 Differences between issue B and issue C (continued)

Change	Location
Updated reset value information for: • Cache Type Register • MPU Type Register • Instruction Set Attributes Register 1 • Instruction Set Attributes Register 4 • Current Cache Size Identification Register • Current Cache Level ID Register • MPU Region Base Address Registers • MPU Region Size and Enable Register • MPU Region Access Control Register • MPU Memory Region Number • ATCM Region Register • BTCM Region Register • TCM selection Register • Performance Monitor Control Register • Software Increment Register • User read/write Thread and Process ID Register • User read-only Thread and Process ID Register • Privileged-only Thread and Process ID Register • Secondary Auxiliary Control Register • Build Options 1 Register • Build Options 2 Register • Correctable Fault Location Register	Table 4-2 on page 4-9
Updated Type information for the Coprocessor Access Register	Table 4-2 on page 4-9
Clarified the description of the Instruction Set Attributes Register 3	• Figure 4-22 on page 4-30 • Table 4-17 on page 4-30
Clarified functions for bits [31], [30], [29], and 28]	Table 4-24 on page 4-38
Clarified functions for bits [20], [19], [18], [17], [16], [3], and [2]	Table 4-25 on page 4-42
Clarified instructions that the PFU recognizes as procedure calls and procedure returns	*Return stack* on page 5-5
Added reference to Application Note 204	*Memory types* on page 7-7
Added section	*Using memory types* on page 7-7
Clarified the description of region attributes	*Region attributes* on page 7-9
Clarified the description of store buffer draining	*Store buffer draining* on page 8-19
Clarified the encodings for some signals	*AXI master interface* on page 9-3
Clarified the number of Identifiers used for AXI bus accesses	*Identifiers for AXI bus accesses* on page 9-4
Clarified the description of the handling of TCM external faults	*External TCM errors* on page 9-21
Added dormant mode description	*Power management* on page 1-12

Table C-1 Differences between issue B and issue C (continued)

Change	Location
Added section	*Dormant mode* on page 10-3
Updated the permitted instruction combinations	Table 14-28 on page 14-35
Updated the descriptions for **COMMRX** and **COMMTX** signals	Table A-13 on page A-17

Table C-2 Differences between issue C and issue D

Change	Location
No technical changes	-

Glossary

This glossary describes some of the terms and abbreviations used in this manual. Where terms can have several meanings, the meaning presented here is intended.

Abort
A mechanism that indicates to a processor that the value associated with a memory access is invalid. An abort can be caused by the external or internal memory system as a result of attempting to access invalid instruction or data memory. An abort is classified as either a Prefetch or Data Abort, and an internal or External Abort.

See also Data Abort, External Abort and Prefetch Abort.

Abort model
An abort model is the defined behavior of an ARM processor in response to a Data Abort exception. Different abort models behave differently with regard to load and store instructions that specify base register write-back.

Addressing modes
A mechanism, shared by many different instructions, for generating values used by the instructions. For four of the ARM addressing modes, the values generated are memory addresses (which is the traditional role of an addressing mode). A fifth addressing mode generates values to be used as operands by data-processing instructions.

Advanced eXtensible Interface (AXI)
This is a bus protocol that supports separate address/control and data phases, unaligned data transfers using byte strobes, burst-based transactions with only start address issued, separate read and write data channels to enable low-cost DMA, ability to issue multiple outstanding addresses, out-of-order transaction completion, and easy addition of register stages to provide timing closure. The AXI protocol also includes optional extensions to cover signaling for low-power operation.

AXI is targeted at high performance, high clock frequency system designs and includes a number of features that make it very suitable for high speed sub-micron interconnect.

Advanced High-performance Bus (AHB)
The AMBA Advanced High-performance Bus system connects embedded processors such as an ARM core to high-performance peripherals, DMA controllers, on-chip memory, and interfaces. It is a high-speed, high-bandwidth bus that supports multi-master bus management to maximize system performance.

See also Advanced Microcontroller Bus Architecture.

Advanced Microcontroller Bus Architecture (AMBA)
AMBA is the ARM open standard for multi-master on-chip buses, capable of running with multiple masters and slaves. It is an on-chip bus specification that details a strategy for the interconnection and management of functional blocks that make up a *System-on-Chip* (SoC). It aids in the development of embedded processors with one or more CPUs or signal processors and multiple peripherals. AMBA complements a reusable design methodology by defining a common backbone for SoC modules. AHB, APB, and AXI conform to this standard.

Advanced Peripheral Bus (APB)
The AMBA Advanced Peripheral Bus is a simpler bus protocol than AHB. It is designed for use with ancillary or general-purpose peripherals such as timers, interrupt controllers, UARTs, and I/O ports. Connection to the main system bus is through a system-to-peripheral bus bridge that helps to reduce system power consumption.

See also Advanced High-performance Bus.

AHB *See* Advanced High-performance Bus.

Aligned A data item stored at an address that is divisible by the number of bytes that defines the data size is said to be aligned. Aligned words and halfwords have addresses that are divisible by four and two respectively. The terms word-aligned and halfword-aligned therefore stipulate addresses that are divisible by four and two respectively.

AMBA *See* Advanced Microcontroller Bus Architecture.

APB *See* Advanced Peripheral Bus.

Application Specific Integrated Circuit (ASIC)
An integrated circuit that has been designed to perform a specific application function. It can be custom-built or mass-produced.

Architecture The organization of hardware and/or software that characterizes a processor and its attached components, and enables devices with similar characteristics to be grouped together when describing their behavior, for example, Harvard architecture, instruction set architecture, ARMv6 architecture.

ARM instruction A word that specifies an operation for an ARM processor to perform. ARM instructions must be word-aligned.

ARM state A processor that is executing ARM (32-bit) word-aligned instructions is operating in ARM state.

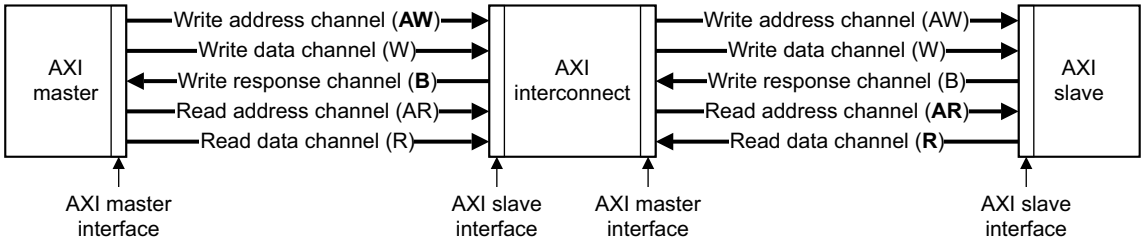
ASIC *See* Application Specific Integrated Circuit.

AXI *See* Advanced eXstensible Interface.

AXI channel order and interfaces
The block diagram shows:

- the order in which AXI channel signals are described

- the master and slave interface conventions for AXI components.



AXI terminology The following AXI terms are general. They apply to both masters and slaves:

Active read transaction

A transaction for which the read address has transferred, but the last read data has not yet transferred.

Active transfer

A transfer for which the **xVALID**[1] handshake has asserted, but for which **xREADY** has not yet asserted.

Active write transaction

A transaction for which the write address and/or leading write data has transferred, but the write response has not yet transferred.

Completed transfer

A transfer for which the **xVALID**/**xREADY** handshake is complete.

Payload The non-handshake signals in a transfer.

Transaction An entire burst of transfers, comprising an address, one or more data transfers and a response transfer (writes only).

Transmit An initiator driving the payload and asserting the relevant **xVALID** signal.

Transfer A single exchange of information. That is, with one **xVALID**/**xREADY** handshake.

The following AXI terms are master interface attributes. To obtain optimum performance, they must be specified for all components with an AXI master interface:

Combined issuing capability

The maximum number of active transactions that a master interface can generate. This is specified instead of write or read issuing capability for master interfaces that use a combined storage for active write and read transactions.

Read ID capability

The maximum number of different **ARID** values that a master interface can generate for all active read transactions at any one time.

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1. The letter **x** in the signal name denotes an AXI channel as follows:

AW Write address channel.
W Write data channel.
B Write response channel.
AR Read address channel.
R Read data channel.

Read ID width

The number of bits in the **ARID** bus.

Read issuing capability

The maximum number of active read transactions that a master interface can generate.

Write ID capability

The maximum number of different **AWID** values that a master interface can generate for all active write transactions at any one time.

Write ID width

The number of bits in the **AWID** and **WID** buses.

Write interleave capability

The number of active write transactions for which the master interface is capable of transmitting data. This is counted from the earliest transaction.

Write issuing capability

The maximum number of active write transactions that a master interface can generate.

The following AXI terms are slave interface attributes. To obtain optimum performance, they must be specified for all components with an AXI slave interface

Combined acceptance capability

The maximum number of active transactions that a slave interface can accept. This is specified instead of write or read acceptance capability for slave interfaces that use a combined storage for active write and read transactions.

Read acceptance capability

The maximum number of active read transactions that a slave interface can accept.

Read data reordering depth

The number of active read transactions for which a slave interface can transmit data. This is counted from the earliest transaction.

Write acceptance capability

The maximum number of active write transactions that a slave interface can accept.

Write interleave depth

The number of active write transactions for which the slave interface can receive data. This is counted from the earliest transaction.

Banked registers

Those physical registers whose use is defined by the current processor mode. The banked registers are R8 to R14.

Base register

A register specified by a load/store instruction that is used to hold the base value for the instruction's address calculation. Depending on the instruction and its addressing mode, an offset can be added to or subtracted from the base register value to form the virtual address that is sent to memory.

Base register write-back
Updating the contents of the base register used in an instruction target address calculation so that the modified address is changed to the next higher or lower sequential address in memory. This means that it is not necessary to fetch the target address for successive instruction transfers and enables faster burst accesses to sequential memory.

Beat
Alternative word for an individual transfer within a burst. For example, an INCR4 burst comprises four beats.

See also Burst.

BE-8
Big-endian view of memory in a byte-invariant system.

See also BE-32, LE, Byte-invariant and Word-invariant.

BE-32
Big-endian view of memory in a word-invariant system.

See also BE-8, LE, Byte-invariant and Word-invariant.

Big-endian
Byte ordering scheme in which bytes of decreasing significance in a data word are stored at increasing addresses in memory.

See also Little-endian and Endianness.

Big-endian memory
Memory in which:- a byte or halfword at a word-aligned address is the most significant byte or halfword within the word at that address - a byte at a halfword-aligned address is the most significant byte within the halfword at that address.

See also Little-endian memory.

Block address
An address that comprises a tag, an index, and a word field. The tag bits identify the way that contains the matching cache entry for a cache hit. The index bits identify the set being addressed. The word field contains the word address that can be used to identify specific words, halfwords, or bytes within the cache entry.

See also Cache terminology diagram on the last page of this glossary.

Branch prediction
The process of predicting if conditional branches are to be taken or not in pipelined processors. Successfully predicting if branches are to be taken enables the processor to prefetch the instructions following a branch before the condition is fully resolved. Branch prediction can be done in software or by using custom hardware. Branch prediction techniques are categorized as static, in which the prediction decision is decided before run time, and dynamic, in which the prediction decision can change during program execution.

Breakpoint
A breakpoint is a mechanism provided by debuggers to identify an instruction at which program execution is to be halted. Breakpoints are inserted by the programmer to enable inspection of register contents, memory locations, variable values at fixed points in the program execution to test that the program is operating correctly. Breakpoints are removed after the program is successfully tested.

See also Watchpoint.

Burst
A group of transfers to consecutive addresses. Because the addresses are consecutive, there is no requirement to supply an address for any of the transfers after the first one. This increases the speed at which the group of transfers can occur. Bursts over AHB or AXI buses are controlled using the **xBURST** signals to specify if transfers are single, four-beat, eight-beat, or 16-beat bursts, and to specify how the addresses are incremented.

See also Beat.

Byte
An 8-bit data item.

Byte invariant
In a byte-invariant system, the address of each byte of memory remains unchanged when switching between little-endian and big-endian operation. When a data item larger than a byte is loaded from or stored to memory, the bytes making up that data item are arranged into the correct order depending on the endianness of the memory access. The ARM architecture supports byte-invariant systems in ARMv6 and later versions. When byte-invariant support is selected, unaligned halfword and word memory accesses are also supported. Multi-word accesses are expected to be word-aligned.

See also Word-invariant.

Byte lane strobe
An AXI signal, **WSTRB**, that is used for unaligned or mixed-endian data accesses to determine which byte lanes are active in a transfer. One bit of **WSTRB** corresponds to eight bits of the data bus.

Byte swizzling
The reverse ordering of bytes in a word.

Cache
A block of on-chip or off-chip fast access memory locations, situated between the processor and main memory, used for storing and retrieving copies of often used instructions and/or data. This is done to greatly increase the average speed of memory accesses and so improve processor performance.

See also Cache terminology diagram on the last page of this glossary.

Cache contention
When the number of frequently-used memory cache lines that use a particular cache set exceeds the set-associativity of the cache. In this case, main memory activity increases and performance decreases.

Cache hit
A memory access that can be processed at high speed because the instruction or data that it addresses is already held in the cache.

Cache line
The basic unit of storage in a cache. It is always a power of two words in size (usually four or eight words), and is required to be aligned to a suitable memory boundary.

See also Cache terminology diagram on the last page of this glossary.

Cache line index
The number associated with each cache line in a cache set. Within each cache set, the cache lines are numbered from 0 to (set associativity) -1.

See also Cache terminology diagram on the last page of this glossary.

Cache miss
A memory access that cannot be processed at high speed because the instruction/data it addresses is not in the cache and a main memory access is required.

Cache set
A cache set is a group of cache lines (or blocks). A set contains all the ways that can be addressed with the same index. The number of cache sets is always a power of two. All sets are accessed in parallel during a cache look-up.

See also Cache terminology diagram on the last page of this glossary.

Cache set associativity
The maximum number of cache lines that can be held in a cache set.

See also Set-associative cache and Cache terminology diagram on the last page of this glossary.

Cache way
A group of cache lines (or blocks). It is 2 to the power of the number of index bits in size.

See also Cache terminology diagram on the last page of this glossary.

Cast out
See Victim.

Clean A cache line that has not been modified while it is in the cache is said to be clean. To clean a cache is to write dirty cache entries into main memory. If a cache line is clean, it is not written on a cache miss because the next level of memory contains the same data as the cache.

See also Dirty.

Clock gating Gating a clock signal for a macrocell with a control signal (such as **PWRDOWN**) and using the modified clock that results to control the operating state of the macrocell.

Clocks Per Instruction (CPI)
See Cycles Per Instruction (CPI).

Coherency *See* Memory coherency.

Cold reset Also known as power-on reset. Starting the processor by turning power on. Turning power off and then back on again clears main memory and many internal settings. Some program failures can lock up the processor and require a cold reset to enable the system to be used again. In other cases, only a warm reset is required.

See also Warm reset.

Communications channel
Software running on an ARM processor uses this to communicate with an external host through the debug interface. It can also be called the Debug Communications Channel. It is architecture-defined. See the *ARM Architecture Reference Manual* and your product technical reference manual for specific information.

Condition field A 4-bit field in an instruction that is used to specify a condition under which the instruction can execute.

Conditional execution
If the condition code flags indicate that the corresponding condition is true when the instruction starts executing, it executes normally. Otherwise, the instruction does nothing.

Context The environment that each process operates in for a multitasking operating system. In ARM processors, this is limited to mean the physical address range that it can access in memory and the associated memory access permissions.

See also Fast context switch.

Control bits The bottom eight bits of a Program Status Register (PSR). The control bits change when an exception arises and can be altered by software only when the processor is in a Privileged mode.

Coprocessor A processor that supplements the main processor. It carries out additional functions that the main processor cannot perform. Usually used for floating-point math calculations, signal processing, or memory management.

Copy back *See* Write-back.

Core module In the context of an ARM Integrator, a core module is an add-on development board that contains an ARM processor and local memory. Core modules can run standalone, or can be stacked onto Integrator motherboards.

Core reset *See* Warm reset.

CPI *See* Cycles per instruction.

CPSR *See* Current Program Status Register.

Current Program Status Register (CPSR)
The register that holds the current operating processor status.

Cycles Per instruction (CPI)
Cycles per instruction (or clocks per instruction) is a measure of the number of computer instructions that can be performed in one clock cycle. This figure of merit can be used to compare the performance of different CPUs that implement the same instruction set against each other. The lower the value, the better the performance.

CoreSight The infrastructure for monitoring, tracing, and debugging a complete system on chip.

Data Abort An indication from a memory system to the processor of an attempt to access an illegal data memory location. An exception must be taken if the processor attempts to use the data that caused the abort.

See also Abort, External Abort, and Prefetch Abort.

Data cache A block of on-chip fast access memory locations, situated between the processor and main memory, used for storing and retrieving copies of often used data. This is done to greatly increase the average speed of memory accesses and so improve processor performance.

Debugger A debugging system that includes a program, used to detect, locate, and correct software faults, together with custom hardware that supports software debugging.

Default NaN mode A mode in which all operations that result in a NaN return the default NaN, regardless of the cause of the NaN result. This mode is compliant with the IEEE 754 standard but implies that all information contained in any input NaNs to an operation is lost.

Denormalized value See Subnormal value.

Dirty A cache line in a write-back cache that has been modified while it is in the cache is said to be dirty. A cache line is marked as dirty by setting the dirty bit. If a cache line is dirty, it must be written to memory on a cache miss because the next level of memory contains data that has not been updated. The process of writing dirty data to main memory is called cache cleaning.

See also Clean.

Disabled exception An exception is disabled when its exception enable bit in the FPCSR is not set. For these exceptions, the IEEE 754 standard defines the result to be returned. An operation that generates an exception condition can bounce to the support code to produce the result defined by the IEEE 754 standard. The exception is not reported to the user trap handler.

DNM *See* Do Not Modify.

Do Not Modify (DNM)
In Do Not Modify fields, the value must not be altered by software. DNM fields read as Unpredictable values, and must only be written with the same value read from the same field on the same processor. DNM fields are sometimes followed by RAZ or RAO in parentheses to show which way the bits should read for future compatibility, but programmers must not rely on this behavior.

Double-precision value
Consists of two 32-bit words that must appear consecutively in memory and must both be word-aligned, and that is interpreted as a basic double-precision floating-point number according to the IEEE 754-1985 standard.

Doubleword A 64-bit data item. The contents are taken as being an unsigned integer unless otherwise stated.

Embedded Trace Macrocell (ETM)
A hardware macrocell that, when connected to a processor core, outputs instruction and data trace information on a trace port. The ETM provides processor driven trace through a trace port compliant to the ATB protocol.

EmbeddedICE-RT The JTAG-based hardware provided by debuggable ARM processors to aid debugging in real-time.

Enabled exception An exception is enabled when its exception enable bit in the FPCSR is set. When an enabled exception occurs, a trap to the user handler is taken. An operation that generates an exception condition might bounce to the support code to produce the result defined by the IEEE 754 standard. The exception is then reported to the user trap handler.

Endianness Byte ordering. The scheme that determines the order in which successive bytes of a data word are stored in memory. An aspect of the system's memory mapping.

See also Little-endian and Big-endian

ETM See *Embedded Trace Macrocell*.

Event

1. (Simple) An observable condition that can be used by an ETM to control aspects of a trace.
2. (Complex) A boolean combination of simple events that is used by an ETM to control aspects of a trace.

Exception A fault or error event that is considered serious enough to require that program execution is interrupted. Examples include attempting to perform an invalid memory access, external interrupts, and Undefined instructions. When an exception occurs, normal program flow is interrupted and execution is resumed at the corresponding exception vector. This contains the first instruction of the interrupt handler to deal with the exception.

Exception service routine
See Interrupt handler.

Exception vector *See* Interrupt vector.

Exponent The component of a floating-point number that normally signifies the integer power to which two is raised in determining the value of the represented number.

External Abort An indication from an external memory system to a core that the value associated with a memory access is invalid. An external abort is caused by the external memory system as a result of attempting to access invalid memory.

See also *See also* Abort, Data Abort and Prefetch Abort

Halfword A 16-bit data item.

Halt mode One of two mutually exclusive debug modes. In halt mode all processor execution halts when a breakpoint or watchpoint is encountered. All processor state, coprocessor state, memory and input/output locations can be examined and altered by the JTAG interface.

See also Monitor mode.

High vectors Alternative locations for exception vectors. The high vector address range is near the top of the address space, rather than at the bottom.

Hit-Under-Miss (HUM)
A buffer that enables program execution to continue, even though there has been a data miss in the cache.

Host A computer that provides data and other services to another computer. Especially, a computer providing debugging services to a target being debugged.

HUM *See* Hit-Under-Miss.

IEEE 754 standard *IEEE Standard for Binary Floating-Point Arithmetic, ANSI/IEEE Std 754-1985*. The standard that defines data types, correct operation, exception types and handling, and error bounds for floating-point systems. Most processors are built in compliance with the standard either in hardware or in a combination of hardware and software.

Illegal instruction An instruction that is architecturally Undefined.

Implementation-defined

Means that the behavior is not architecturally defined, but should be defined and documented by individual implementations.

Implementation-specific

Means that the behavior is not architecturally defined, and does not have to be documented by individual implementations. Used when there are a number of implementation options available and the option chosen does not affect software compatibility.

Infinity In the IEEE 754 standard format to represent infinity, the exponent is the maximum for the precision and the fraction is all zeros.

Input exception An exception condition in which one or more of the operands for a given operation are not supported by the hardware. The operation bounces to support code for processing.

Instruction cache A block of on-chip fast access memory locations, situated between the processor and main memory, used for storing and retrieving copies of often used instructions. This is done to greatly increase the average speed of memory accesses and so improve processor performance.

Instruction Synchronization Barrier (ISB)

An operation to ensure that the prefetch buffer is flushed of all out-of-date instructions.

Intermediate result An internal format used to store the result of a calculation before rounding. This format can have a larger exponent field and fraction field than the destination format.

Interrupt handler A program to which control of the processor is passed when an interrupt occurs.

Interrupt vector One of a number of fixed addresses in low memory, or in high memory if high vectors are configured, that contains the first instruction of the corresponding interrupt handler.

Invalidate To mark a cache line as being not valid by clearing the valid bit. This must be done whenever the line does not contain a valid cache entry. For example, after a cache flush all lines are invalid.

ISB *See* Instruction Synchronization Barrier.

LE Little endian view of memory in both byte-invariant and word-invariant systems. See also Byte-invariant, Word-invariant.

Line *See* Cache line.

Little-endian Byte ordering scheme in which bytes of increasing significance in a data word are stored at increasing addresses in memory.

See also Big-endian and Endianness.

Little-endian memory

Memory in which:

- a byte or halfword at a word-aligned address is the least significant byte or halfword within the word at that address
- a byte at a halfword-aligned address is the least significant byte within the halfword at that address.

See also Big-endian memory.

Load/store architecture

A processor architecture where data-processing operations only operate on register contents, not directly on memory contents.

Load Store Unit (LSU)
The part of a processor that handles load and store transfers.

LSU *See* Load Store Unit.

Macrocell A complex logic block with a defined interface and behavior. A typical VLSI system comprises several macrocells (such as a processor, an ETM, and a memory block) plus application-specific logic.

Memory coherency A memory is coherent if the value read by a data read or instruction fetch is the value that was most recently written to that location. Memory coherency is made difficult when there are multiple possible physical locations that are involved, such as a system that has main memory, a write buffer and a cache.

Memory Protection Unit (MPU)
Hardware that controls access permissions to blocks of memory. Unlike an MMU, an MPU does not translate virtual addresses to physical addresses.

Microprocessor *See* Processor.

Miss *See* Cache miss.

Monitor debug-mode
One of two mutually exclusive debug modes. In Monitor debug-mode the processor enables a software abort handler provided by the debug monitor or operating system debug task. When a breakpoint or watchpoint is encountered, this enables vital system interrupts to continue to be serviced while normal program execution is suspended.

See also Halt mode.

MPU *See* Memory Protection Unit.

NaN Not a number. A symbolic entity encoded in a floating-point format that has the maximum exponent field and a nonzero fraction. An SNaN causes an invalid operand exception if used as an operand and a most significant fraction bit of zero. A QNaN propagates through almost every arithmetic operation without signaling exceptions and has a most significant fraction bit of one.

Penalty The number of cycles in which no useful Execute stage pipeline activity can occur because the instruction flow is different from that assumed or predicted.

Power-on reset *See* Cold reset.

Prefetching In pipelined processors, the process of fetching instructions from memory to fill up the pipeline before the preceding instructions have finished executing. Prefetching an instruction does not mean that the instruction has to be executed.

Prefetch Abort An indication from a memory system to the processor that an instruction has been fetched from an illegal memory location. An exception must be taken if the processor attempts to execute the instruction. A Prefetch Abort can be caused by the external or internal memory system as a result of attempting to access invalid instruction memory.

See also Data Abort, External Abort and Abort.

Processor A contraction of microprocessor. A processor includes the CPU or core, plus additional components such as memory, and interfaces. These are combined as a single macrocell, that can be fabricated on an integrated circuit.

Read Reads are defined as memory operations that have the semantics of a load. That is, the ARM instructions `LDM`, `LDRD`, `LDC`, `LDR`, `LDRT`, `LDRSH`, `LDRH`, `LDRSB`, `LDRB`, `LDRBT`, `LDREX`, `RFE`, `STREX`, `SWP`, and `SWPB`, and the Thumb instructions `LDM`, `LDR`, `LDRSH`, `LDRH`, `LDRSB`, `LDRB`, and `POP`.

Region A partition of instruction or data memory space.

Reserved
A field in a control register or instruction format is reserved if the field is to be defined by the implementation, or produces Unpredictable results if the contents of the field are not zero. These fields are reserved for use in future extensions of the architecture or are implementation-specific. All reserved bits not used by the implementation must be written as 0 and are to be read as 0.

Rounding mode
The IEEE 754 standard requires all calculations to be performed as if to an infinite precision. For example, a multiply of two single-precision values must accurately calculate the significand to twice the number of bits of the significand. To represent this value in the destination precision, rounding of the significand is often required. The IEEE 754 standard specifies four rounding modes.

In round-to-nearest mode, the result is rounded at the halfway point, with the tie case rounding up if it would clear the least significant bit of the significand, making it even.
Round-towards-zero mode chops any bits to the right of the significand, always rounding down, and is used by the C, C++, and Java languages in integer conversions.
Round-towards-plus-infinity mode and round-towards-minus-infinity mode are used in interval arithmetic.

Saved Program Status Register (SPSR)
The register that holds the CPSR of the task immediately before the exception occurred that caused the switch to the current mode.

SBO
See Should Be One.

SBZ
See Should Be Zero.

Scan chain
See Boundary scan chain.

Set
See Cache set.

Set-associative cache
In a set-associative cache, lines can only be placed in the cache in locations that correspond to the modulo division of the memory address by the number of sets. If there are *n* ways in a cache, the cache is termed *n*-way set-associative. The set-associativity can be any number greater than or equal to 1 and is not restricted to being a power of two.

Short vector operation
An operation involving more than one destination register and perhaps more than one source register in the generation of the result for each destination.

Should Be One (SBO)
Should be written as 1 (or all 1s for bit fields) by software. Writing a 0 produces Unpredictable results.

Should Be Zero (SBZ)
Should be written as 0 (or all 0s for bit fields) by software. Writing a 1 produces Unpredictable results.

Should Be Zero or Preserved (SBZP)
Should be written as 0 (or all 0s for bit fields) by software, or preserved by writing the same value back that has been previously read from the same field on the same processor.

Significand
The component of a binary floating-point number that consists of an explicit or implicit leading bit to the left of the implied binary point and a fraction field to the right.

SPSR
See Saved Program Status Register

Stride The stride field, FPSCR[21:20], specifies the increment applied to register addresses in short vector operations. A stride of 00, specifying an increment of +1, causes a short vector operation to increment each vector register by +1 for each iteration, while a stride of 11 specifies an increment of +2.

Subnormal value A value in the range ($-2^{Emin} < x < 2^{Emin}$), except for 0. In the IEEE 754 standard format for single-precision and double-precision operands, a subnormal value has a zero exponent and a nonzero fraction field. The IEEE 754 standard requires that the generation and manipulation of subnormal operands be performed with the same precision as normal operands.

Support code Software that must be used to complement the hardware to provide compatibility with the IEEE 754 standard. The support code has a library of routines that performs supported functions, such as divide with unsupported inputs or inputs that might generate an exception, and as well as operations beyond the scope of the hardware. The support code has a set of exception handlers to process exceptional conditions in compliance with the IEEE 754 standard.

Synchronization primitive

The memory synchronization primitive instructions are those instructions that are used to ensure memory synchronization. That is, the `LDREX`, `STREX`, `SWP`, and `SWPB` instructions.

Tag The upper portion of a block address used to identify a cache line within a cache. The block address from the CPU is compared with each tag in a set in parallel to determine if the corresponding line is in the cache. If it is, it is said to be a cache hit and the line can be fetched from cache. If the block address does not correspond to any of the tags, it is said to be a cache miss and the line must be fetched from the next level of memory.

See also Cache terminology diagram on the last page of this glossary.

TAP *See* Debug test access port.

Thumb state A processor that is executing Thumb (16-bit and 32-bit) instructions is operating in Thumb state.

Tightly coupled memory (TCM)

An area of low latency memory that provides predictable instruction execution or data load timing in cases where deterministic performance is required. TCMs are suited to holding:

- critical routines (such as for interrupt handling)
- scratchpad data
- data types whose locality is not suited to caching
- critical data structures (such as interrupt stacks).

Tiny A nonzero result or value that is between the positive and negative minimum normal values for the destination precision.

Trace port A port on a device, such as a processor or ASIC, used to output trace information.

Trap A exceptional condition that has the respective exception enable bit set in the FPSCR register. The user trap handler is executed.

Unaligned A data item stored at an address that is not divisible by the number of bytes that defines the data size is said to be unaligned. For example, a word stored at an address that is not divisible by four.

Undefined Indicates an instruction that generates an Undefined instruction trap. See the *ARM Architecture Reference Manual* for more information on ARM exceptions.

UNP *See* Unpredictable.

Unpredictable The result of an instruction or control register field value that cannot be relied upon. Unpredictable instructions or results must not represent security holes, or halt or hang the processor, or any parts of the system.

Unsupported values Specific data values that are not processed by the hardware but bounced to the support code for completion. These data can include infinities, NaNs, subnormal values, and zeros. An implementation is free to select which of these values is supported in hardware fully or partially, or requires assistance from support code to complete the operation. Any exception resulting from processing unsupported data is trapped to user code if the corresponding exception enable bit for the exception is set.

Victim A cache line, selected to be discarded to make room for a replacement cache line that is required as a result of a cache miss. The way in which the victim is selected for eviction is processor-specific. A victim is also known as a cast out.

Warm reset Also known as a core reset. Initializes the majority of the processor excluding the debug controller and debug logic. This type of reset is useful if you are using the debugging features of a processor.

Watchpoint A watchpoint is a mechanism provided by debuggers to halt program execution when the data contained by a particular memory address is changed. Watchpoints are inserted by the programmer to enable inspection of register contents, memory locations, and variable values when memory is written to test that the program is operating correctly. Watchpoints are removed after the program is successfully tested. *See also* Breakpoint.

Way *See* Cache way.

WB *See* Write-back.

Word A 32-bit data item.

Word-invariant In a word-invariant system, the address of each byte of memory changes when switching between little-endian and big-endian operation, in such a way that the byte with address A in one endianness has address A EOR 3 in the other endianness. As a result, each aligned word of memory always consists of the same four bytes of memory in the same order, regardless of endianness. The change of endianness occurs because of the change to the byte addresses, not because the bytes are rearranged. The ARM architecture supports word-invariant systems in ARMv3 and later versions. When word-invariant support is selected, the behavior of load or store instructions that are given unaligned addresses is instruction-specific, and is in general not the expected behavior for an unaligned access.

See also Byte-invariant.

Write Writes are defined as operations that have the semantics of a store. That is, the ARM instructions `SRS`, `STM`, `STRD`, `STC`, `STRT`, `STRH`, `STRB`, `STRBT`, `STREX`, `SWP`, and `SWPB`, and the Thumb instructions `STM`, `STR`, `STRH`, `STRB`, and `PUSH`.

Write-back (WB) In a write-back cache, data is only written to main memory when it is forced out of the cache on line replacement following a cache miss. Otherwise, writes by the processor only update the cache. Also known as copyback.

Write buffer A block of high-speed memory, arranged as a FIFO buffer, between the data cache and main memory, whose purpose is to optimize stores to main memory.

Write completion The memory system indicates to the processor that a write has been completed at a point in the transaction where the memory system is able to guarantee that the effect of the write is visible to all processors in the system. This is not the case if the write is associated with a memory synchronization primitive, or is to a Device or Strongly Ordered region. In these cases the memory system might only indicate completion of the write when the access has affected the state of the target, unless it is impossible to distinguish between having the effect of the write visible and having the state of target updated. This stricter requirement for some types of memory ensures that any side-effects of the memory access can be guaranteed by the processor to have taken place. You can use this to prevent the starting of a subsequent operation in the program order until the side-effects are visible.

Write-through (WT) In a write-through cache, data is written to main memory at the same time as the cache is updated.

WT *See* Write-through.

Cache terminology diagram

The figure below illustrates the following cache terminology:

- block address
- cache line
- cache set
- cache way
- index
- tag.