GR716

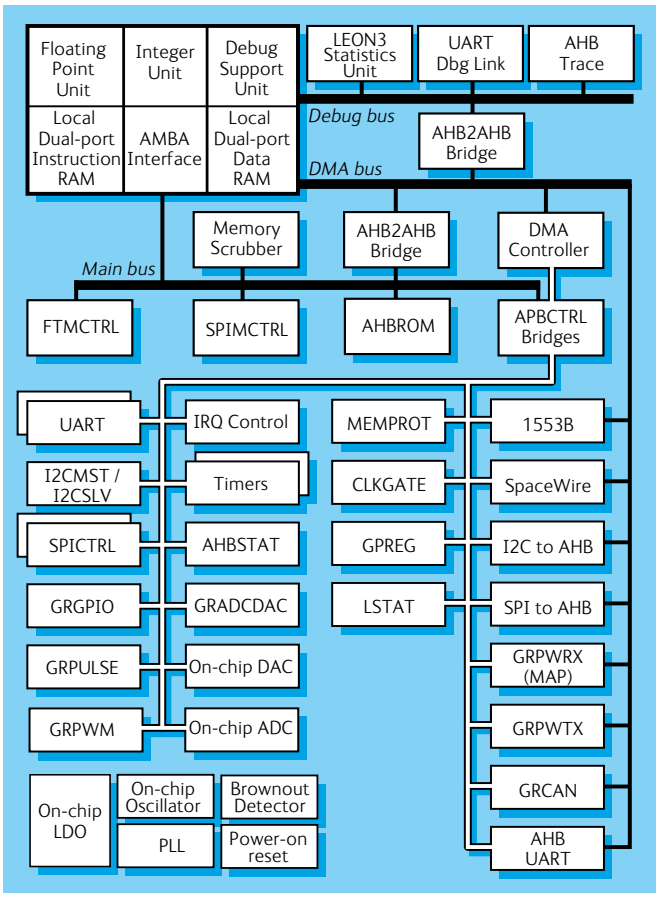
LEON3FT Microcontroller

2020 Advanced Data Sheet and User's Manual

The most important thing we build is trust

Features

- Fault-tolerant SPARC V8 processor with 31 register windows, 192KiB EDAC protected tightly coupled memory and support for reduced instruction set.
- Double precision IEEE-754 floating point unit
- Advanced on-chip debug support unit
- Memory protection units
- 8-bit external PROM/SRAM interface with BCH EDAC protection
- Boot from external SRAM/PROM, SPI or I^2C memory protected by EDAC and dual memory redundancy
- SpaceWire interface with time distribution support
- SPI for Space master and slave interface
- MIL-STD-1553B interface
- CAN 2.0B controller interface
- PacketWire with CRC acceleration support
- On-chip 12-bit DAC and two 11-bit ADC
- Programmable PWM interface
- UARTs, SPI, I^2C, GPIO, Timers with Watchdog, Interrupt controller, Status registers, UART debug, etc.
- Configurable I/O switch matrix



Description

The GR716 device is a fault-tolerant LEON3 SPARC V8 processor with various communication interfaces and on-chip ADC, DAC, Power-on-Reset, Oscillator, Brown-out detection, LVDS transceivers, regulators to support single 3.3V supply, ideally suited for space and other high-rel applications.

Specification

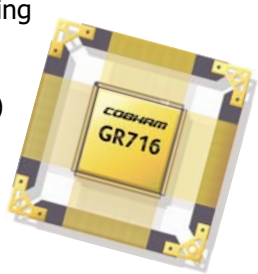
- System frequency up-to 50 MHz
- SpaceWire links up-to 100 Mbps
- CQFP132 hermetically sealed ceramic package
- Total Ionizing Dose (TID) up to 300 krad (Si)
- Single-Event Latch-up Immunity (SEL) to LET_{TH} > 118 MeV-cm^2mg
- Single-Event Upset (SEU) below 10^{-6} errors per device and day in space environment
- Support for single 3.3V supply

Applications

The GR716 microcontroller is an advanced microcontroller, targeting high reliability space and aeronautics applications.

Support for many different standard interfaces makes the GR716 microcontroller ideal for supervision, monitoring and control in a satellite, such as:

- propulsion system control
- sensor bus control
- robotics applications control
- simple motor control
- mechanism control
- power control
- particle detector instrumentation
- radiation environment monitoring
- thermal control
- antenna pointing control
- AOCS / GNC (Gyro, IMU, MTM)
- remote terminal unit control
- simple instrument control
- wireless networking



Availability

The GR716 microcontroller is currently available as engineering samples. Contact Cobham Gaisler for information on flight model schedule.

1 Introduction 9
1.1 Scope 9
1.2 Data sheet limitations 9
1.3 Updates and feedback 9
1.4 Software support 9
1.5 Development board 9
1.6 Reference documents 9
1.7 Document revision history 10
1.8 Acronyms 11
1.9 Definitions 12
1.10 Register descriptions 13
2 Architecture 14
2.1 Key features 15
2.2 Digital Architecture Overview 18
2.3 Analog Architecture Overview 26
2.4 Signal Overview 31
2.5 I/O switch matrix overview 31
2.6 I/O switch default configurations for bootstraps 34
2.7 I/O switch matrix options, considerations and limitations 37
2.8 I/O switch matrix pin validation script 38
2.9 I/O switch matrix scenario examples 41
2.10 Cores 47
2.11 Memory map 48
2.12 Atomic access 51
2.13 Interrupts 53
3 Signals 55
3.1 Bootstrap signals 55
3.2 Configuration for flight 62
3.3 Complete signal list 63
4 Clocking 65
4.1 PLL Configuration and Status 66
4.2 Clock Source and divisor 66
4.3 System clock 67
4.4 SpaceWire clock 67
4.5 MIL-STD-1553B clock 67
4.6 PacketWire RX Clock 67
4.7 ADC Clock 67
4.8 DAC Clock 68
4.9 PWM Clock 68
4.10 Clock gating unit 68
4.11 Debug AHB bus clocking 68
4.12 Test mode clocking 68
5 Reset 69
5.1 IO Reset 69
6 Technical notes 70
6.1 GRLIB AMBA plug&play scanning 70
6.2 Software portability 70
7 System Startup Status and General Configuration 71

7.1 Configuration Registers ... 71
7.2 Boot Strap information register ... 76
7.3 Special Configuration Registers ... 77
8 Reset Generation and Brownout Detection ... 85
8.1 Overview ... 85
8.2 Operation ... 85
8.3 Registers ... 86
9 Crystal (XO) Oscillator ... 90
9.1 Overview ... 90
9.2 Operation ... 90
10 PLL ... 93
10.1 Overview ... 93
10.2 Operation ... 93
10.3 Registers ... 94
11 Voltage and Current References ... 100
11.1 Overview ... 100
11.2 Operation ... 100
12 Internal ADC, Pre-Amplifier and Analog MUX ... 101
12.1 Overview ... 101
12.2 Operation ... 102
12.3 Registers ... 107
13 LDO ... 112
13.1 Overview ... 112
13.2 Operation ... 112
14 Temperature Sensor ... 113
14.1 Overview ... 113
14.2 Operation ... 113
15 Internal DAC ... 114
15.1 Overview ... 114
15.2 Operation ... 115
15.3 Registers ... 116
16 LEON3/FT - High-performance SPARC V8 32-bit Processor ... 119
16.1 Overview ... 119
16.2 LEON3 integer unit ... 120
16.3 Local instruction and data RAM ... 128
16.4 Floating-point unit ... 128
16.5 AMBA interface ... 129
16.6 Configuration registers ... 130
16.7 Software considerations ... 136
17 IEEE-754 Floating-Point Unit ... 137
17.1 Overview ... 137
17.2 Functional Description ... 137
18 UART Serial Interface ... 140
18.1 Overview ... 141
18.2 Operation ... 141
18.3 Baud-rate generation ... 142

18.4 Loop back mode 143
18.5 FIFO debug mode 143
18.6 Interrupt generation 143
18.7 Registers 144
19 Hardware Debug Support Unit 147
19.1 Overview 147
19.2 Operation 147
19.3 AHB trace buffer 148
19.4 Instruction trace buffer 150
19.5 Using the DSU trace buffer 151
19.6 DSU memory map 151
19.7 DSU registers 152
20 On-chip Dual-port Memory with EDAC Protection 158
20.1 Overview 158
20.2 Local Memory memory map and register 161
21 Fault Tolerant PROM/SRAM Memory Interface 165
21.1 Overview 165
21.2 PROM access 166
21.3 SRAM access 168
21.4 Memory EDAC 168
21.5 Bus Ready signalling 169
21.6 Access errors 171
21.7 Registers 172
22 Fault Tolerant NVRAM Memory Interface 176
23 MIL-STD-1553B / AS15531 Interface 177
23.1 Overview 177
23.2 Electrical interface 178
23.3 Operation 178
23.4 Bus Controller Operation 180
23.5 Remote Terminal Operation 185
23.6 Bus Monitor Operation 189
23.7 Registers 190
24 ADC / DAC Interface 202
24.1 Overview 202
24.2 Operation 204
24.3 Registers 206
25 CAN 2.0 Controller 211
25.1 Overview 212
25.2 Interface 213
25.3 Protocol 213
25.4 Status and monitoring 214
25.5 Transmission 214
25.6 Reception 217
25.7 Global reset and enable 220
25.8 Registers 221
25.9 Memory mapping 230
26 Clock gating unit (Primary) 232

26.1 Overview 232
26.2 Operation 232
26.3 Registers 233
27 Clock gating unit (Secondary) 236
27.1 Overview 236
27.2 Operation 236
27.3 Registers 237
28 DMA Controller with internal AHB/APB bridge 240
28.1 Overview 240
28.2 Configuration 241
28.3 Operation 250
28.4 AHB transfers 252
28.5 Interrupts 252
28.6 Errors 252
28.7 Internal Buffer Readout Interface 253
28.8 Registers 253
28.9 DMA Transfer Example 259
29 General Purpose I/O Port 263
29.1 Overview 264
29.2 Operation 264
29.3 Pulse command 264
29.4 Pulse sequencer 264
29.5 Pulse sampler 266
29.6 Registers 266
30 Pulse Width Modulation Generator 277
30.1 Overview 278
30.2 Operation 278
30.3 Registers 280
31 PacketWire Receiver 285
31.1 Overview 285
31.2 PacketWire interface 285
31.3 Operation 286
31.4 Operation 286
31.5 Registers 288
32 PacketWire Transmitter 291
32.1 Overview 291
32.2 PacketWire interface 291
32.3 Operation 292
32.4 Registers 293
33 SpaceWire Interface and RMAP target 296
33.1 Overview 296
33.2 Operation 297
33.3 Link interface 298
33.4 Time-code distribution 301
33.5 Interrupt distribution 301
33.6 Receiver DMA channels 304
33.7 Transmitter DMA channels 309

33.8 RMAP ... 312
33.9 AMBA interface ... 316
33.10 SpaceWire Plug-and-Play ... 317
33.11 Registers ... 323
34 SpaceWire - Time Distribution Protocol ... 341
34.1 Overview ... 341
34.2 Protocol ... 341
34.3 Functionality ... 341
34.4 Data formats ... 347
34.5 Registers ... 348
35 General Purpose Timer Unit with Watchdog ... 364
35.1 Overview ... 364
35.2 Operation ... 364
35.3 Registers ... 366
36 General Purpose Timer Unit (Secondary) ... 370
36.1 Overview ... 370
36.2 Operation ... 370
36.3 Registers ... 371
37 I2C to AHB bridge ... 375
37.1 Overview ... 375
37.2 Operation ... 376
37.3 Registers ... 380
38 I2C master ... 383
38.1 Overview ... 383
38.2 Operation ... 384
38.3 Registers ... 387
39 I2C slave ... 390
39.1 Overview ... 390
39.2 Operation ... 391
39.3 Registers ... 393
40 Interrupt Controller ... 397
40.1 Overview ... 397
40.2 Operation ... 398
40.3 Registers ... 402
41 LEON3 Statistics Unit ... 414
41.1 Overview ... 414
41.2 Using the LEON3 statistics unit ... 416
41.3 Registers ... 416
42 Memory Scrubber and Status Register ... 419
42.1 Overview ... 420
42.2 Operation ... 420
42.3 Registers ... 422
43 SPI to AHB bridge ... 427
43.1 Overview ... 427
43.2 Transmission protocol ... 428
43.3 System clock requirements and sampling ... 429

43.4 SPI instructions 429
43.5 Registers 431
44 SPI Controller 433
44.1 Overview 433
44.2 Operation 434
44.3 Registers 437
45 SPI for Space Slave Controller 444
45.1 Overview 444
45.2 Implementation of SPI protocols 445
45.3 Transmission 445
45.4 Operation 446
45.5 SPI 2 Protocol Handler 446
45.6 Message Header - Command Token 447
45.7 Redundancy 453
45.8 Registers 454
46 SPI Memory Controller 459
46.1 Overview 460
46.2 Operation 460
46.3 Registers 463
47 AMBA Protection Unit 466
47.1 Overview 466
47.2 Operation 467
47.3 Registers 467
47.4 Example of configure and use the Memory protection 483
48 Serial Debug and remote access Interface 485
48.1 Overview 486
48.2 Operation 486
48.3 Registers 487
49 AHB Status Registers 489
49.1 Overview 489
49.2 Operation 489
49.3 Registers 490
50 Trace buffer 492
50.1 Overview 492
50.2 Operation 493
50.3 Using the AHB trace buffer 494
50.4 Registers 495
51 Boot ROM 498
51.1 Overview 498
51.2 ROM Architecture 499
51.3 Loader description 504
51.4 Standby description 504
51.5 State at handover to application software 505
51.6 Boot source requirements 506
51.7 Protection schemes 506
52 Electrical description 509
52.1 Absolute maximum ratings 509

52.2 Recommended operating conditions 511
52.3 Power supplies characteristics 512
52.4 Input voltages, leakage currents and capacitances 513
52.5 Output voltages, leakage currents and capacitances 514
52.6 Simplified IO buffer schematics 516
52.7 DAC Electrical Characteristics 518
52.8 ADC Electrical Characteristics 519
52.9 Reference Voltages and Currents Electrical Characteristics 522
52.10 Reset and Brownout-Detector Electrical Characteristics 522
52.11 AC characteristics 524
53 Mechanical description 538
53.1 Component and package 538
53.2 Pin assignment 538
53.3 Mechanical package drawings 542
54 Ordering information 544
54.1 Silicon and mask information 545
55 Errata 546
55.1 Overview 546
55.2 Errata description 546
56 Planned Features 550
56.1 Overview 550
56.2 Feature description 550

1 Introduction

1.1 Scope

This document is the advanced data sheet and user's manual for the GR716 LEON3FT microcontroller. The GR716 microcontroller has been developed in an activity initiated by the European Space Agency under ESTEC contract 40001117749/14/NL/AK.

1.2 Data sheet limitations

Note that this document is an advanced data sheet:

- Advanced data sheet - Product in development
- Preliminary data sheet - Shipping prototype
- Data sheet - Shipping space-grade product

1.3 Updates and feedback

Updates are available at https://www.gaisler.com/gr716

Feedback can be sent to Cobham Gaisler AB support: support@gaisler.com

For commercial questions please contact sales@gaisler.com

1.4 Software support

The GR716 LEON3FT microcontroller design is supported by standard toolchains provided by Cobham Gaisler. Toolchains can be downloaded from https://www.gaisler.com.

1.5 Development board

Development boards with GR716 device is available. Please see https://www.gaisler.com/gr716-boards

1.6 Reference documents

[AMBA]	AMBA Specification, Rev 2.0, ARM Limited
[GRLIB]	GRLIB IP Library User's Manual, Cobham Gaisler, www.cobham.com/gaisler
[GRIP]	GRLIB IP Core User's Manual, Cobham Gaisler, www.cobham.com/gaisler
[SPARC]	The SPARC Architecture Manual, Version 8, SPARC International Inc.
[LEON-REX]	LEON-REX Instruction Set Extension, Cobham Gaisler
[GRMON3]	GRMON3 User's Manual, Cobham Gaisler
[V8E]	SPARC-V8 Supplement, SPARC-V8 Embedded (V8E) Architecture Specification, SPARC-V8E, Version 1.0, SPARC International Inc.
[CCSDS]	Time Code Formats, CCSDS 301.0-B-4, www.CCSDS.org
[SPW]	Space engineering: SpaceWire - Links, nodes, routers and networks, ECSS-E-ST-50-12C
[RMAP]	Space engineering: SpaceWire - Remote memory access protocol, ECSS-E-ST-50-52C

1.7 Document revision history

Change record information is provided in table 1.

Table 1. Change record

Version	Date	Note
1.29	May 2019	First public release
1.30	March 2020	Updated reference documents in section 1.6 Crystal recommendations and examples added to section 9.2.3 and 9.2.5 Updated ordering section 54 Errata section 55.1 updated for XO and GRDMAC errata
1.31	April 2020	Ordering information section
1.32	May 2020	Errata section 55.1 workaround update for XO Errata section 55.1 added Errata for Lower ESD tolerance on supply pins Added note for analogue supply VDDA in section 52.2 Added note for Power On Reset release delay in section 52.10
1.33	Jun 2020	Updated GR716 Crystal configuration examples
1.34	July 2020	Updated drawings in architecture section

1.8 Acronyms

Table 2. Acronyms

Acronym	Comment
AHB	Advanced High-performance bus, part of [AMBA]
AMBA	Advanced Microcontroller Bus Architecture
APB	Advanced Peripheral Bus, part of [AMBA]
BCH	Bose–Chaudhuri–Hocquenghem, class of error-correcting codes
CAN	Controller Area Network, bus standard
CPU	Central Processing Unit, used to refer to one LEON3FT processor core.
DMA	Direct Memory Access
DSU	Debug Support Unit
EDAC	Error Detection and Correction
FIFO	First-In-First-Out, refers to buffer type
FPU	Floating Point Unit
Gb	Gigabit, 10^9 bits
GB	Gigabyte, 10^9 bytes
GiB	Gibibyte, gigabinary byte, 2^{30} bytes, unit defined in IEEE 1541-200
I/O	Input/Output
ISR	Interrupt Service Routine
JTAG	Joint Test Action Group (developer of IEEE Standard 1149.1-1990)
kB	Kilobyte, 10^3 bytes
KiB	Kibibyte, 2^{10} bytes, unit defined in IEEE 1541-2002
Mb, Mbit	Megabit, 10^6 bits
MB, Mbyte	Megabyte, 10^6 bytes
MiB	Mebibyte, 2^{20} bytes, unit defined in IEEE 1541-2002
PROM	Programmable Read Only Memory
RAM	Random Access Memory
SEE	Single Event Effects
SEL/SEU/ SET	Single Event Latchup/Upset/Transient
SPARC	Scalable Processor ARChitecture
SW	Software
UART	Universal Asynchronous Receiver/Transmitter

1.9 Definitions

This section and the following subsections define the typographic and naming conventions used throughout this document.

1.9.1 Bit numbering

The following conventions are used for bit numbering:

- The most significant bit (MSb) of a data type has the leftmost position
- The least significant bit of a data type has the rightmost position
- Unless otherwise indicated, the MSb of a data type has the highest bit number and the LSb the lowest bit number

1.9.2 Radix

The following conventions is used for writing numbers:

- Binary numbers are indicated by the prefix "0b", e.g. 0b1010.
- Hexadecimal numbers are indicated by the prefix "0x", e.g. 0xF00F
- Unless a radix is explicitly declared, the number should be considered a decimal.

1.9.3 Data types

Byte (BYTE)	8 bits of data
Halfword (HWORD)	16 bits of data
Word (WORD)	32 bits of data

1.10 Register descriptions

An example register, showing the register layout used throughout this document, can be seen in table 3. The values used for the reset value fields are described in table 4, and the values used for the field type fields are described in table 5. Fields that are named RESERVED, RES, or R are read-only fields. These fields can be written with zero or with the value read from the same register field.

Table 3. <Address> - <Register acronym> - <Register name>

31 24	23 16	15 8	7 0
EF3	EF2	EF1	EF0
<Reset value for EF3>	<Reset value for EF2>	<Reset value for EF1>	<Reset value for EF0>
<Field type for EF3>	<Field type for EF2>	<Field type for EF1>	<Field type for EF0>

31: 24 Example field 3 (EF3) - <Field description>
23: 16 Example field 2 (EF2) - <Field description>
15: 8 Example field 1 (EF1) - <Field description>
7: 0 Example field 0 (EF0) - <Field description>

Table 4. Reset value definitions

Value	Description
0	Reset value 0.
1	Reset value 1. Used for single-bit fields.
0xNN	Hexadecimal representation of reset value. Used for multi-bit fields.
0bNN	Binary representation of reset value. Used for multi-bit fields.
NR	Field not reset
*	Special reset condition, described in textual description of the field. Used for example when reset value is taken from a pin.
-	Don’t care / Not applicable

Table 5. Field type definitions

Value	Description
r	Read-only. Writes have no effect.
w	Write-only. Used for a writable field in a register where the field’s read-value has no meaning.
rw	Readable and writable.
rw*	Readable and writable. Special condition for write, described in textual description of field.
wc	Write-clear. Readable, and cleared when written with a 1
cas	Readable, and writable through compare-and-swap. Only applies to SpaceWire Plug-and-Play registers.

2 Architecture

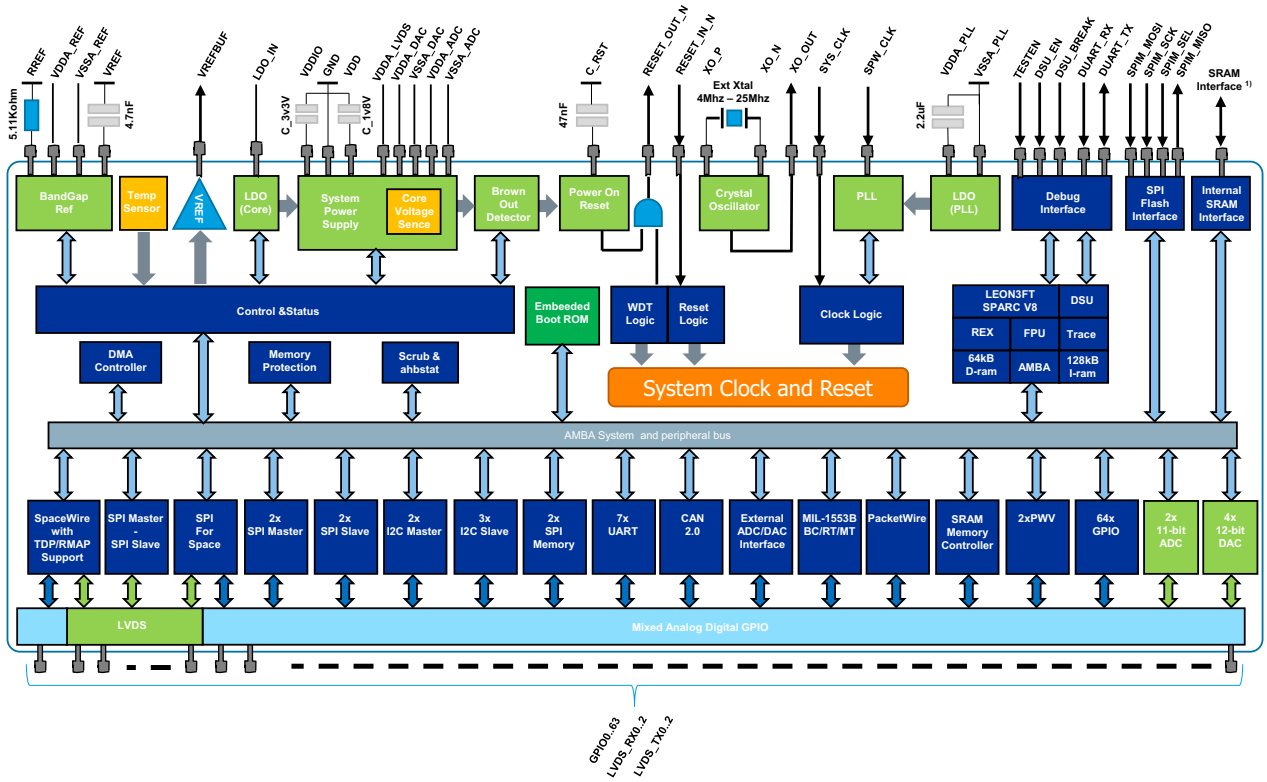


Figure 1. GR716 block diagram

The microcontroller is a single core LEON3FT SPARC V8 processor, with advanced interface protocols, that has been optimized for real-time systems and deterministic software execution. Features such as SPARC V8E Alternate Window Pointer, interrupt zero jitter latency, SPARC V8E multiply step instructions and the possibility to run software (including interrupt handlers) from local RAM are supported to increase the determinism and responsiveness in the system. The LEON-REX instruction set extension is also supported by the microcontroller and is further described in [LEON-REX].

The architecture is centered around multiple instances of the AMBA Advanced High-speed Bus (AHB), to which the LEON3FT processor and other high-bandwidth units are connected. Low bandwidth peripherals/functions are connected to the AMBA Advanced Peripheral Bus (APB) which is accessed through an AHB to APB bridge. The use of multiple processor buses also enables non-intrusive debugging and the possibility to have direct access to on-board memory without interrupting or involving the LEON3FT processor.

64 external CMOS pins and six LVDS transceivers are configurable from software via configuration registers. Pre-defined pin configurations are defined in the boot software and can be enabled by using pull-up/pull-down resistors on external pins during reset. Pre-defined configuration of external pins are useful in cases when the microcontroller should boot from external memories or remote controlled via SpaceWire, UART, SPI or I2C after reset. The program controlling the microcontroller needs to set appropriate direction and functionality on all pins after reset depending on the environment that the microcontroller is used in. On-chip LVDS transceivers for SpaceWire and SPI for Space and dedicated pins for external SPI boot ROM boot are available and can optionally be used.

The microcontroller has a high level of integrated analog functions. Analog function integrated on-chip includes Analog to digital converters, Brown out detection, Crystal Oscillator, Digital to Analog Converters, Power-on and reset functionality and Linear Voltage Regulators for single 3.3V supply.

2.1 Key features

- Core
  - Fault-tolerant SPARC V8 processor with 31 register windows and support for LEON-REX.
  - Double precision IEEE-754 floating point unit.
  - Memory protection units with 8 zones and individual access control of APB peripherals for memory protection.
  - Advanced on-chip debug support unit with trace buffers and statistic unit for software profiling.
  - Single cycle instructions execution and data fetch from tightly coupled memory.
  - Deterministic instruction execution and interrupt latency.
  - Fast context switching (Partial write %PSR, AWP, Register file partitioning, interrupt mapping, MVT).
  - Single Vector Trap support.
  - Interrupt zero jitter delay.
- Memories
  - 192KiB EDAC protected tightly coupled memory with single cycle access from processor and ATOMIC bit operations.
  - Embedded ROM with boot loader for initializing and remote access.
  - Dedicated SPI memory interface with boot ROM capability.
  - I2C memory interface with boot ROM capability.
  - 8-bit SRAM/ROM (FTMCTRL) with support up to 16 MB ROM and 256 MB SRAM.
  - Support for package option with embedded SRAM/PROM (FTMCTRL).
  - Scrubber with programmable scrub rate for all embedded memories and external PROM/SRAM and SPI memories.
- System
  - On-chip voltage regulators for single supply support. Capability to sense core voltage for trimming of the embedded voltage regulator for low power applications.
  - Power-on-reset, brownout detection and dual watchdogs for safe operation. External reset signal generation for reseting companion chips.
  - Crystal oscillator support.
  - PLL for System and SpaceWire clock generation. In-application programming of system clock and peripheral clocks. System and SpaceWire clocks switches glitch free.
  - Low power mode and individual clock gating of functions and peripherals.
  - Temperature and core voltage sensor.
  - External precision voltage reference for precision measurement.
  - Four programmable DMA controllers with up to 16 individual channels. DMA transfers can be triggered on events such as interrupts or bits/register changing value.
  - Timer units with seven 32-bit timers including watchdog.
  - Multiple bus structures for non-intrusive debug, DMA transfers and memory scrubbers.
  - Atomic access support for all APB registers (AND, OR, XOR, Set&Clear).

  - Support for NVRAM (SRAM and/or PROM) embedded in package. Support for software boot and execution from embedded RAM for future package options.
  - Peripheral access control.
  - Embedded trace and statistics unit for profiling of the system.
- Peripherals
  - SpaceWire with support for RMAP and Time Distribution Protocol.
  - Redundant MIL-STD-1553B BRM (BC/RT/BM) interface.
  - Two CAN 2.0B bus controllers.
  - Six UART ports, with 16-byte FIFO.
  - Two SPI master/slave serial ports.
  - SPI4SPACE - hardware support for SPI protocol 0,1 and 2 in HW for SPI for SPI4SPACE.
  - Two I2C master/slave serial ports.
  - PacketWire interface.
  - PWM with up to 16 channels. PWM clock support up to 200 MHz.
  - Up to 64 general purpose input and outputs (GPIO) with external interrupt capability, pulse generation and sampling.
  - Four single ended Digital to Analog Converters (DAC), 12-bit at 3MS/s.
  - Four differential or eight single ended Analog to Digital Converters (ADC) 11-bit at 200KS/s with programmable pre-amplifier and support for oversampling. Dual sample and hold circuit integrated for simultaneously sampling.
  - External ADC and DAC support up to 16-bit at 1MS/s.
- I/O
  - Configurable I/O selection matrix with support for mixed signals, internal pull-up/pull-down resistors.
  - LVDS transceivers for SpaceWire or SPI4SPACE.
  - Dedicated SPI boot ROM support for configuration.
- Supply
  - Single 3.3V±0.3V supply or separate Core Voltage 1.8V±0.18V, I/O voltage 3.3V±0.3V.
- Radiation tolerance
  - Technology: 180 nm process, UMC Taiwan
  - Library: DARE+ Library version 5.5, IMEC
  - TID: up to 300 Krad(Si)
  - SEL: > 118 MeV-cm2/mg
  - SEU: Proven tolerance with hardened flip-flops and error corrections on all on-chip and external memories
- Package
  - 132-lead CQFP, 0.635 mm pitch, 24mm x 24mm, hermetically sealed with flat pins and insulating lead-frame for customer trim and form.
- Software
  - Supported by standard tools-chains and debug tools provided by Cobham Gaisler. Tool-chains, simulators and debug software is available at https://www.gaisler.com.

- Boot ROM and boot options
  - Remote boot directly via SpaceWire, UART, SPI or I2C.
  - Direct software execution from onchip RAM, external SRAM, PROM or SPI memory.
  - Direct software execution from in package embedded memory.
  - Application Software Container (ASW) for boot software integrity check.
  - Boot via ASW from external SRAM, PROM, SPI memory or I2C memory.
  - Boot from redundant memory.
  - Fast boot option.
- System configuration
  - Reset and boot status.
  - Individual reset and clock control for digital and analog peripherals.
  - Remote reset and boot control.
  - Clock source and divide control for the system, SpaceWire, SPI4S, ADC, DAC, 1553 and PWM clock domain.
  - Support for external system reset.
  - Support for external clock source for the system, SpaceWire, SPI4S, 1553 and PWM.
  - Automatic oscillator shutdown if oscillator not used.
  - Individual programmable brown-out levels.
  - Protection for erroneous I/O configuration during power-up and power-down.
  - Programmable LDO output level for low power mode.

2.2 Digital Architecture Overview

The system is built around three 32-bit AMBA AHB buses; one 32-bit Main AHB bus, one 32-bit DMA AHB buses and one 32-bit Debug AHB bus. The main bus connects the LEON3FT core with all other peripheral cores in the design as well as the external memory controllers. Several peripherals are connected through AMBA AHB/APB bridges where one of the bridges is integrated with the DMA controller.

The debug AMBA AHB bus connects a UART serial debug communications link to the debug support unit and also to the rest of the system through an AMBA AHB bridge.

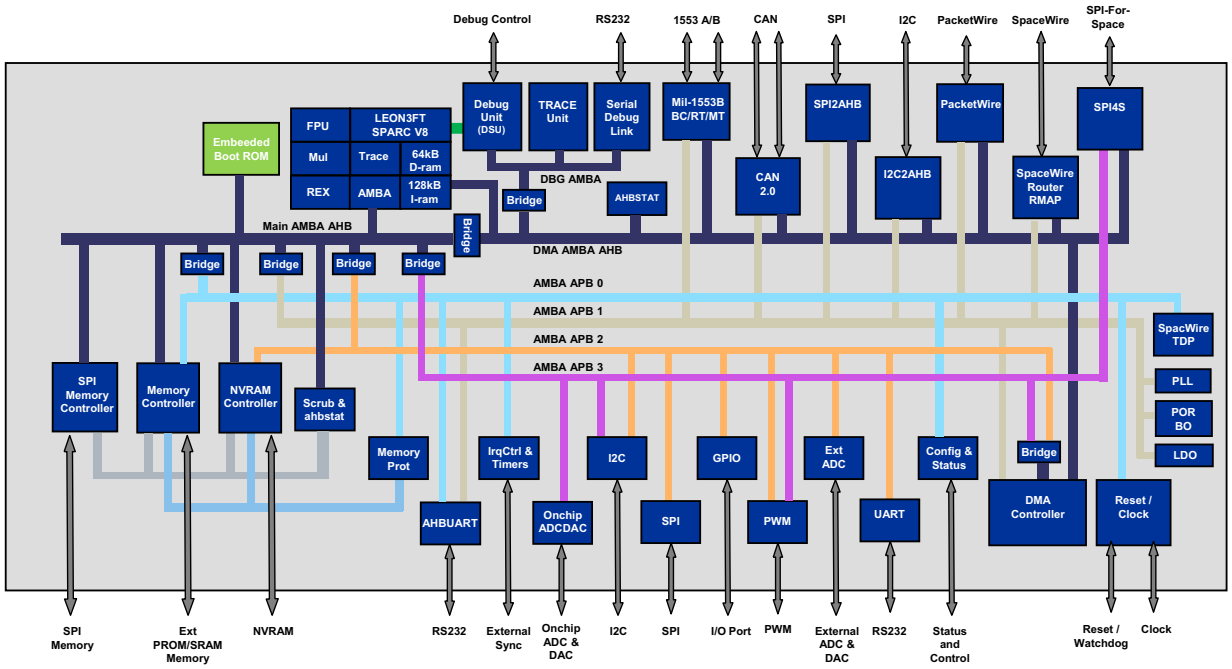


Figure 2. Simplified architecture and functional block diagram of the microcontroller

2.2.1 Processor core and memory subsystem

The microcontroller implements a LEON3FT 32-bit processor core conforming to the IEEE-1754 (SPARC V8) architecture. The microcontroller is designed for embedded applications, combining high performance with low complexity and low power consumption. The LEON3FT core has the following main features: 7-stage pipeline with Harvard architecture, hardware multiplier and divider and on-chip debug support. The LEON3FT processor is enhanced with fault tolerance against SEU errors. The fault tolerance is focused on the protection of the on-chip RAM, processor register file and protection of external memory interfaces.

The LEON3FT integer pipeline is implemented with 31 register windows, SEU protection of register file with zero impact on software timing, and hardware multiply and divide units. The multiplier is a 16x16 hardware multiplier that is iterated four times. Floating-point operations are supported by integration of a hardware floating-point unit (GRFPU-lite).

Memory protection units are located on the AMBA system bus and on AMBA DMA bus. Each protection unit monitors access on the AHB bus. When an access is made to a protected area then the protection unit will assert a signal to the memory controller that will annul the operation and respond to the AMBA access with an AMBA ERROR response. Four areas can be protected on the system bus and four areas can be protected on the DMA bus.

Exclusive write permission can be enforced for individual APB peripherals to protect interfaces from erroneous writes during normal operations.

To protect tightly coupled instruction and data memory directly connected to the processor core from software the LEON3FT hardware watchpoints (located within the processor integer unit) can function as memory protection registers for both the instruction and data RAM.

Several features are supported in the architecture in order to enhance it for embedded microcontroller applications:

- Support for SPARC V8E write partial %psr
- Support for SPARC V8E Alternative Window Pointer
- Support of the SPARC V8E Multiply step instructions

The microcontroller program execution is deterministic due to the microcontroller being cache-less, and AMBA accesses made by the processor being unaffected by other AMBA masters in the microcontroller. The processor uses separate EDAC protected instruction and data memories with fixed latencies. The instruction memory latency is 1 system clock and the delay for the data memory is 1 system clock. The local instruction and data memory in the system have the same latency and behaviour in the corrected as in the uncorrected case. This also applies to the CPU, so dynamic SEU handling schemes such as the LEON3FT pipeline restart on error options is not be used.

The microcontroller has 64 KiB of shared data RAM and 128 KiB of tightly coupled instruction memory connected to the processor. The tightly coupled instruction and data RAM can be accessed via the AMBA buses. This AMBA access can be used to upload new software into the instruction memory or read/write data to/from any AMBA master in the system. The access to the data memory will not affect or delay any access made by the processor on the AMBA bus.

The processor or any AMBA master can access the external PROM/SRAM or SPI memory controller for program execution or reading/writing data. The external SRAM memory can be protected by the scrubber located on the main system bus. The scrubber connected to the main system bus will block access for the processor to the external memories during scrub execution. The scrub rate can be configured and should be set to an acceptable rate for the mission. The scrubber access will not block the AMBA bus since masters and slaves on the main system bus support split transactions.

2.2.2 DMA controller

The microcontroller has four parallel DMA controllers. The GRDMAC core provides a flexible direct memory access controller. The DMA controller can perform burst transfers of data between AHB and APB peripherals at aligned or unaligned memory addresses. The GRDMAC core has multiple AHB master interfaces for access to AHB peripheral bus and direct access to all APB slaves. The GRDMAC is able to perform programmable sequences of data transfers between any slaves in AMBA address space. The IP core is able to transfer data between peripherals and memory and between memory areas. If the accessed memory is internal or external does not matter, as long as the memory is mapped into AMBA address space reachable from the AHB bus where the DMA controller is mapped.

The DMA controller configuration registers are accessible through an APB interface. Each DMA controller can be flexibly configured by means of two descriptor chains residing in main memory: a Memory to Buffer (M2B) chain and a Buffer to Memory (B2M) chain. Each chain is composed of a linked list of descriptors, where each descriptor specifies an AHB address and the size of the data to read/write, supporting a scatter/gather behavior.

Once enabled, the DMA controller will proceed in reading the descriptor chains, then reading memory mapped addresses specified by the M2B chain and filling its internal buffer. It will then write the content of the buffer back to memory-mapped addresses by elaborating the B2M descriptor chain.

The DMA controller supports a simplified mode of operation, with only one channel. In this mode of operation only one descriptor is present for each of the M2B and B2M chains. These two descriptors are written directly in the core's register via APB.

The DMA controller will offload the CPU and provide DMA capabilities to IP cores in the microcontroller design that do not have an internal DMA engine. The DMA controller can be programmed to initiate DMA transfers on events, such as interrupts, to the GRDMAC core to achieve timely readouts of values. An example of use can be found the detailed description of the DMA controller in section 28.

2.2.3 Interrupt handling

The microcontroller supports interrupt time stamping and interrupt handling mechanism to ensure that a fixed number of clock cycles occurs between the assertion of an interrupt and the processor's jump to the trap table. Depending on the software application, several types of time stamping can be of interest:

- Timestamp when interrupt line is raised from peripheral IP core. This time is of particular importance when time needs to be synchronized with an external event.
- Timestamp when processor acknowledges the interrupt. This stamp is primarily of interest in system characterization where users may want to measure the time it takes for the processor to divert execution flow to the interrupt service routine after the processor has discovered the pending interrupt.
- Timestamp when software enters ISR. This timestamp is typically taken by software by reading a timer register when the ISR is entered.

Interrupt time stamping is controlled via the Interrupt Timestamp Control register(s) described in section 40. Each Interrupt Timestamp Control register contains a field (TSTAMP) that contains the number of timestamp register sets that the core implements. A timestamp register sets consist of one Interrupt Timestamp Counter register, one Interrupt Timestamp Control register, one Interrupt Assertion Timestamp register and one Interrupt Acknowledge Timestamp register.

Software enables time stamping for a specific interrupt via an Interrupt Timestamp Control Register. When the selected interrupt line is asserted, software will save the current value of the interrupt timestamp counter into the Interrupt Assertion Timestamp register. When the processor acknowledges the interrupt, the Interrupt Timestamp Control register will be set and the current value of the timestamp

counter will be saved in the Interrupt Acknowledge Timestamp Register. The difference between the Interrupt Assertion timestamp and the Interrupt Acknowledge timestamp is the number of system clock cycles that was required for the processor to react to the interrupt and divert execution to the trap handler.

2.2.4 Reset and software boot

The reset default behavior for all included cores, except the LEON3FT processor, is to enter an idle state upon reset. The internal reset signal will be asserted as a result of power-on. In the idle state the cores do not initiate any transactions nor keep any output signals in an idle state. This is of particular concern for bidirectional signals to prevent contention.

The LEON3FT processor will normally start executing from a predefined start address 0x0000000 at reset. The start of execution can be prevented by assertion of an external break signal. If the break signal is asserted then the processor will enter power-down mode after reset. This will allow software upload from an external entity that can then start the processor at a dynamically specified address, by writing to the interrupt controller's register interface. Processor can optionally be forced via bootstraps to be forced to start from external PROM, SRAM, MRAM, SPI or I2C memory. This mode could be used if the application requires separate boot code than the one existing in the LEON3FT microcontroller boot ROM. Boot addresses for external PROM and SPI memory are defined in section 2.11.

A boot ROM application is placed at address 0x00000000 and is normally executed after reset. The boot application supports system functions controllability via external bootstrap registers. The application always starts executing after reset and checking the value of external bootstrap signals. Based on these signals the processor performs tasks such as load software to internal RAM from an external memory device, enable remote access via SpaceWire, SPI, UART or I2C. See section 3.1 for more information about bootstrap options for the boot ROM.

In the case of boot from I2C, the boot ROM application will copy the content of the I2C into the onboard memory and start to execute the software setup by application.

A protocol to guard against the system trying to boot using a corrupt boot image is implemented using a protected image format containing an image header, boot code, data checksum and header checksum, see section 51. Extra protection can be enabled via bootstraps by reading identical images from redundant memories but needs to be configured before booting via an external boot strap.

Self-test and diagnostic test of the CPU and internal RAMs can be enabled via bootstraps. The internal ROM will check for Stuck-At and Transition errors in local instruction and data ram. Stuck-At or Transition error(s) will result an error reported in the boot report, see 51.2.5.

2.2.5 Direct boot from external memory

Custom boot options are supported via bootstrap options to bypass the internal boot ROM code. The LEON3FT microcontroller can be configured to boot directly from external ROM, external SRAM, external SPI Memory or internal NVRAM in package (GR716 with internal NVRAM is currently not available).

2.2.6 Atomic access

The microcontroller supports atomic bit and bit field access for all APB peripherals and in internal data memory when accessed from the LEON3FT processor. The atomic access is supported via address mirrors of the peripheral and local data ram. The microcontroller supports the following atomic operations:

- Configuration register will 'or' data written from processor with contents of control register
- Configuration register will 'and' data written from processor with contents of control register
- Configuration register will 'xor' data written from processor with contents of control register

- Configuration register will set and cleared using a double store from the processor written from the processor.

The actual bit field operation is performed in the APB bridge and in the local on-chip data RAM and will have no impact on the instruction execution or delay of data fetch. Atomic accesses are further described in section 2.12.

2.2.7 Remote access and control

The microcontroller can be accessed and controlled by an external control unit via SpaceWire (RMAP), UART, SPI or I2C without using processor support. Full access, except for debug features on the debug AMBA bus, will be granted to SpaceWire, UART, SPI or I2C if enabled at startup via bootstraps after reset:

- SpaceWire: Remote Memory Access Protocol (RMAP) provides full remote access to the entire AMBA address space of the microcontroller. See section for GRSPW2 for more information
- UART: Support for reading and writing to register via special protocol over UART provides full remote access to the entire AMBA address space of the microcontroller. See section for AHBUART for more information
- SPI: Support for reading and writing to register via special protocol over SPI provides full remote access to the entire AMBA address space of the microcontroller. See section for SPI2AHB for more information
- I2C: Support for reading and writing to register via special protocol over I2C provides full remote access to the entire AMBA address space of the microcontroller. See section for I2C2AHB for more information

All the communication interfaces above can be implemented to be functional directly after the microcontroller leaves reset, no initialisation from the processor is required. The communication links can also be disabled by the processor, a feature that can be required for safety.

When debugging the microcontroller, the DSU is used to load software and initiate the program counter. In the case when new software is remotely updated via SpaceWire, UART, SPI or I2C, a special feature in the interrupt handler is implemented to restart the system and to start execution of new software. For more information see section 40.2.7 to 40.2.9.

2.2.8 Pin sharing

A I/O switch matrix allows most of the GR716 microcontroller pins functionality to be configurable and to be shared between several peripherals. The I/O switch matrix provides a flexible solution where enabling one core changes the I/O switch matrix so that the current core gets connected to I/O pads.

The microcontroller comprises on-chip ADC/DAC. The on-chip ADC/DAC requires special mixed digital and analog I/Os. The mixed digital and analog I/O is controlled via configuration registers and needs to be set to analog mode when an ADC or DAC is going to be used.

SPI4SPACE supports on-chip LVDS transceivers and CMOS I/Os. The redundant SPI4SPACE channel can be accessed via CMOS pins and the primary SPI4SPACE channel is accessed via on-chip LVDS.

2.2.9 Integrated ADC and DAC

The ADC digital control logic supports functions to control the on-chip ADC and to offload the processor. Support for automatic oversampling on all channels, sample sequencer and digital level comparators are examples of features integrated to offload the processor. The integrated DMA controller can also be used to off-load the processor by automatic transfers of sample values to/from the integrated data and ADC/DAC.

2.2.10 Debug and statistics

An external debug host can access the microcontroller Debug Support Unit (DSU) via UART (RS232). The DSU can be used to access instruction trace buffers and registers of the LEON3FT processor. The DSU has also support for tracing AHB accesses that can be used for performance monitoring. For more information about the functionality see section 19. Since the DSU is connected to an AMBA AHB bus and is accessed via debug communication links also connected to AMBA AHB, all debug accesses will generate traffic over AMBA AHB. In order for the debugging to be completely non-intrusive this debug traffic is separated from the non-debug AHB traffic.

The microcontroller includes a LEON3 statistics unit that allows the debugger to count a wide range of events without interrupting or controlling execution. See section 41 for more information about the LEON3 statistics unit.

The GR716 microcontroller have one dedicated Serial Debug interface. The Serial Debug unit is directly connected to the AMBA debug bus. The Serial Debug unit have a unique AMBA address described in chapter 2.11.

The debug interface is intended to be used during software development and have direct access to the internal state of the processor and trace buffers. This interface can be disabled during mission via external pin configuration i.e. tie DSU_EN to low.

The Serial Debug interface unit is fully described in section 48

2.2.11 AMBA Error detection

The microcontroller includes status registers to store information about AMBA AHB accesses triggering an error response on the Main and DMA AMBA bus. Error response on the AMBA main bus is stored in either the memory scrubber unit or AHB Status unit 2. Error response triggered on the DMA bus is stored in the AHB Status unit 1.

The Main AMBA bus can be configured to fetch all AMBA error responses in the memory scrubber, see chapter 7.3.3. The system default configuration is to only fetch AMBA errors from the external memory controllers in the memory scrubber. All other AMBA error responses on the Main bus will be fetched in the AHB Status unit 2.

2.2.12 Internal communication

Triggers, events and synchronization signals that require immediate response are distributed outside the internal AMBA bus structure. This section explains the different connections next to the internal AMBA structure.

Signal connections are visually shown in figure 3 and described in table 6 in this section.

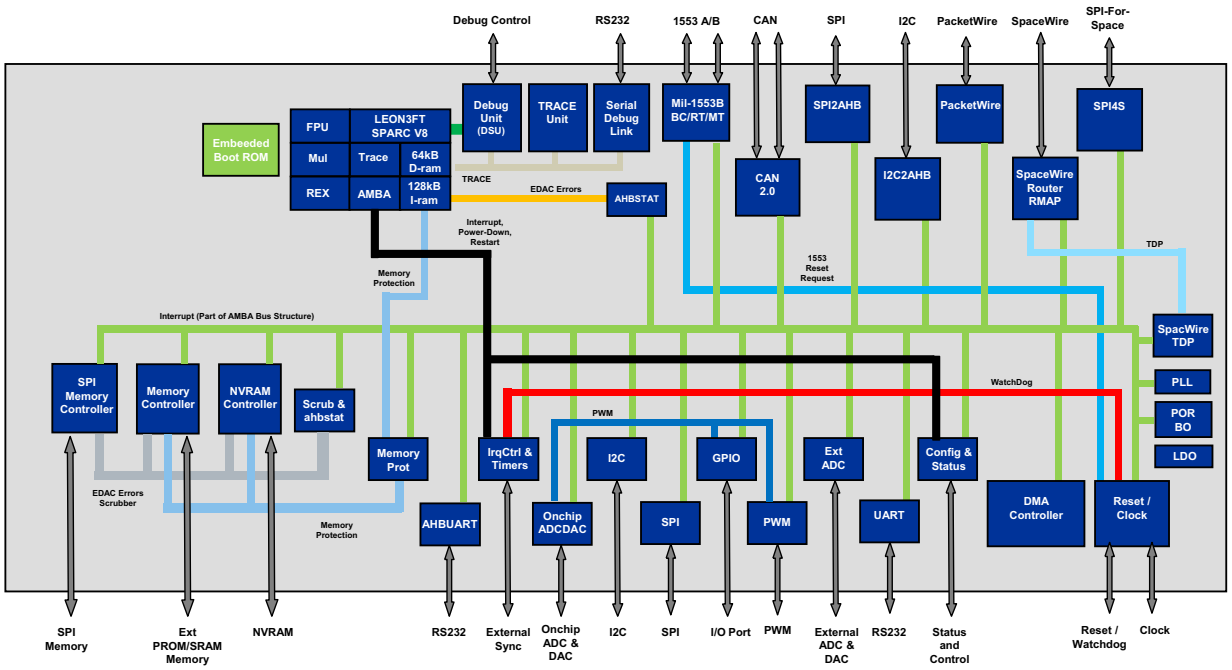


Figure 3. Internal communication paths outside AMBA bus structure

Table 6. Internal communication paths outside the AMBA bus structure

Internal bus name	Connecting functional blocks	Description
EDAC Error	AMBA status, local instruction memory and local data memory	Connection for monitoring of correctable errors signaled from the internal data and instruction memory.
EDAC Error Scrubber	AMBA status functionality in scrubber, external memory controller and NVRAM controller	Connection for monitoring of correctable errors signaled from the memory controller and NVRAM controller.
Interrupt Bus	All blocks connected to the internal AMBA structure	Connection for distributing events from/to all peripherals and digital functionality. The internal interrupt bus distributes all 64 unique interrupts IDs in table 29. The interrupt bus is used to program event driven functions e.g. the DMA channel 0 to respond to a specific Interrupt ID in table 29.
Memory protection	Protection unit, external memory controller, NVRAM controller, local instruction memory and local data memory	Connection for blocking write access to protected areas. Protection unit grants or denies the ongoing AMBA access via the memory protection bus.

Table 6. Internal communication paths outside the AMBA bus structure

Internal bus name	Connecting functional blocks	Description
Processor Interrupt, Power Down and Restart	LEON3FT, Interrupt controller and Primary Clock gating unit.	The interrupts generated on the interrupt bus are all forwarded to the interrupt controller. The interrupt controller prioritizes, masks and propagates the interrupt with the highest priority to the processor. This bus is also used for request for Power-Down of the processor and restart of the processor. Power down request from the processor is described in section 16.2.16 and reboot is described in section 40.2.7.
Watch Dog	Timer unit 0 and reset request logic	Watch dog timer unit drives a watchdog signal on this bus to request restart of the system. Watch dog functionality is described in section 35. User can override reset request with control register described in section 7.3.
1553 Reset Request	MIL-1553 peripheral interfaces and reset request logic	MIL-1553B codec request for reset of MIL-1553B interface support.
TDP	MIL-1553B and SpaceWire	Internal bus for communication between the SpaceWire Time Distribution Protocol core and the SpaceWire interface or the MIL-1553B interface. For more information see section 34.
DSU	DSU and LEON3FT	Debug interface for direct access and control of the LEON3FT processor from debug interface.
PWM	PWM, GPIO, DAC and ADC	PWM synchronization tick outputs. Ticks or events can be programmed individually for each PWM to be generated at PWM compare points, PWM period match, or not generated at all. PWM ticks are distributed in the system to synchronize events to the PWM output.
L3STAT	To LEON3 Statistical Unit	Connection for counting events in the system defined in table 558 under section "Implementation specific events" and in section "Events generated from REQ/GNT signals". Bus is only passively listening.
TRACE	From AMBA infrastructure to Trace buffer	Main and DMA AMBA buses are routed to the trace buffer. Trace buffer is passively listening to signals.

2.3 Analog Architecture Overview

The analog/mixed and power-supply IP blocks are presented here. In figure 4, a simplified block diagram shows these blocks and their analog and power interconnections in the GR716 microcontroller.

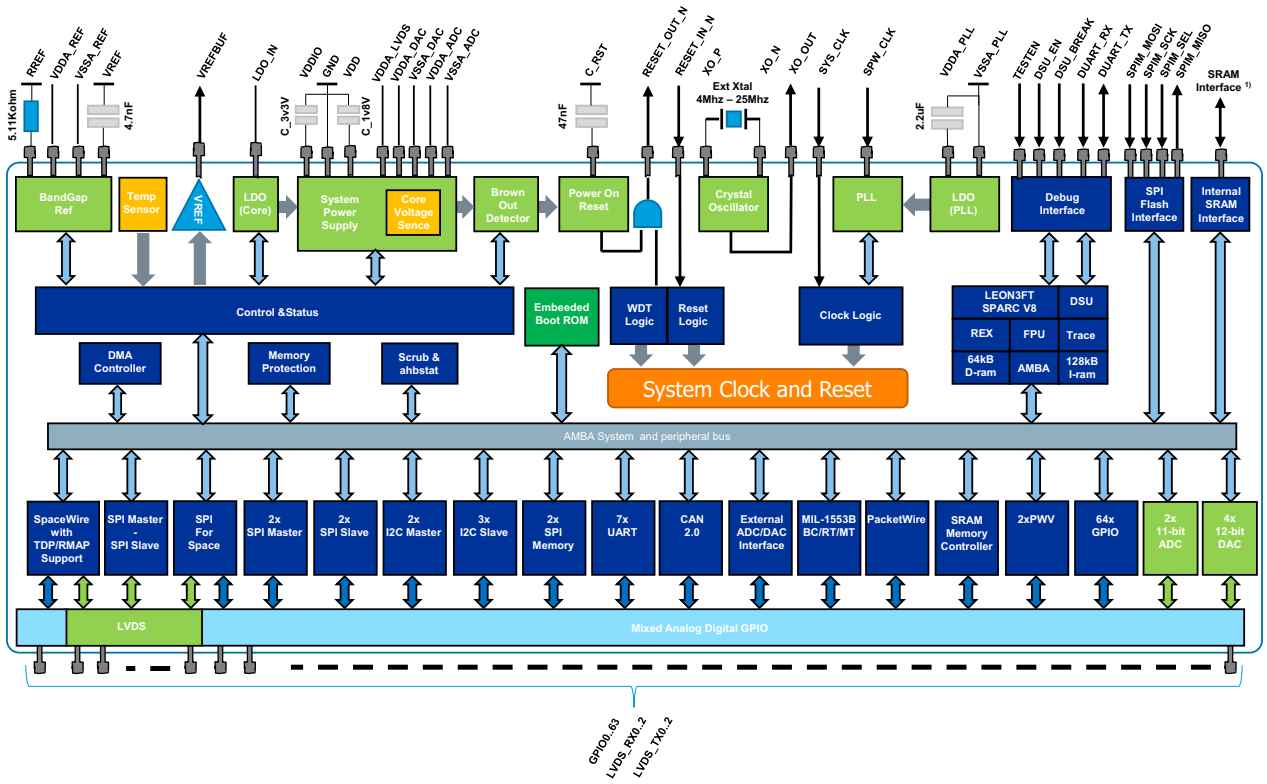


Figure 4. Simplified block diagram of the analog/mixed and power-supply IPs in the GR716 microcontroller.

Generally, note that when the XO-oscillator and PLL are used to generate the GR716 microcontroller clocks, these two blocks must be correctly connected and configured to obtain correct digital functionality of the GR716 microcontroller. Moreover, to obtain correct analog functionality of the GR716 microcontroller, the voltage and current references, set by Vref and Rref, must be correctly connected and configured, since they provide the GR716 microcontroller with the internal references and bias currents required by several other IPs in Figure 4.

2.3.1 Reset and Brownout-detector

The RESET and Brownout-detector blocks supervise the supply voltages as shown in Figure 4. The RESET block provides reset of the internal GR716 microcontroller logic. The internal reset signal, IntRST_N, is available externally as a 3.3V CMOS output, RESET_OUT_N. The IntRST_N and RESET_OUT_N signals are low when VDD_CORE is too low. There is also a reset release delay at power up, starting to count when VDD_CORE goes above its reset threshold level. The Brownout detectors are intended to be used as pre-warnings to the GR716 microcontroller that some supply voltage(s) has started to go down, so the CPU can perform a well-controlled system shutdown before any reset detectors are activated. The Brownout detectors are implemented as one detector block on each supply to be supervised, and each of them has a programmable threshold level that can be set individually. Each Brownout-detector output signal can be programmed by an interrupt mask bit to generate an interrupt, and typically, the interrupt routine can be used to shut down the system in a controlled way.

2.3.2 XO oscillator

The oscillator (XO) is supplied by the LEON3FT microcontroller core voltage, VDD_CORE (1.8V). The oscillator output is a 3.3V CMOS output and is available on an external pin.

2.3.3 PLL

The PLL is supplied by 1.8V from an internal LDO, which should have an external decoupling capacitor on the PLL supply pin (1.8V). This supply pin shall be left open, with exception of this decoupling capacitor. The PLL provides several internal clock outputs, typically used as clock for the SpaceWire interface, etc. The PLL reference-clock input is a 3.3V CMOS input, to which the XO-oscillator clock output can be directly connected, or any other clock signal generated on PCB fulfilling the electrical specification of this input. The PLL reference-clock input is allowed to be asynchronous to any other clocks in the GR716 microcontroller.

2.3.4 Voltage reference

The reference blocks are supplied by VDDA_REF. This supply needs to have the best voltage integrity on the chip. Therefore, no fast load-current steps are present in any of the on-chip blocks using this supply. It is essential that especially this supply has good PCB decoupling/filtering (across VDDA_REF and VSSA_REF) in order to not feed external disturbances from PCB supplies into this supply. The analog internal references are generated in two steps. First, a reference voltage is generated by an on-chip band-gap reference, which should have an external decoupling capacitor on the VREF pin. Alternatively, the on-chip reference block can be turned off; then, an external reference voltage must be applied to this pin (including the right decoupling capacitance needed in that voltage-reference implementation). Second, this reference voltage is buffered and put out on the VREFBUF pin. This reference voltage is also used by an internal current generator, which puts this voltage across an external reference resistor, RREF on PCB, to generate a precision reference current. Since this reference current is used to generate both the current reference to each DAC and the internal bias currents required by several other on-chip blocks, RREF can *not* be chosen arbitrarily to get any desired DAC full-scale value; it shall be 5.11kohm (or 4.64kohm + 464ohm).

2.3.5 On-chip ADC

There are two independent ADC blocks. Each ADC is a 11bit/200kSps SAR converter, and has an analog MUX in-front of it, which means that one MUX channel at a time can be measured.

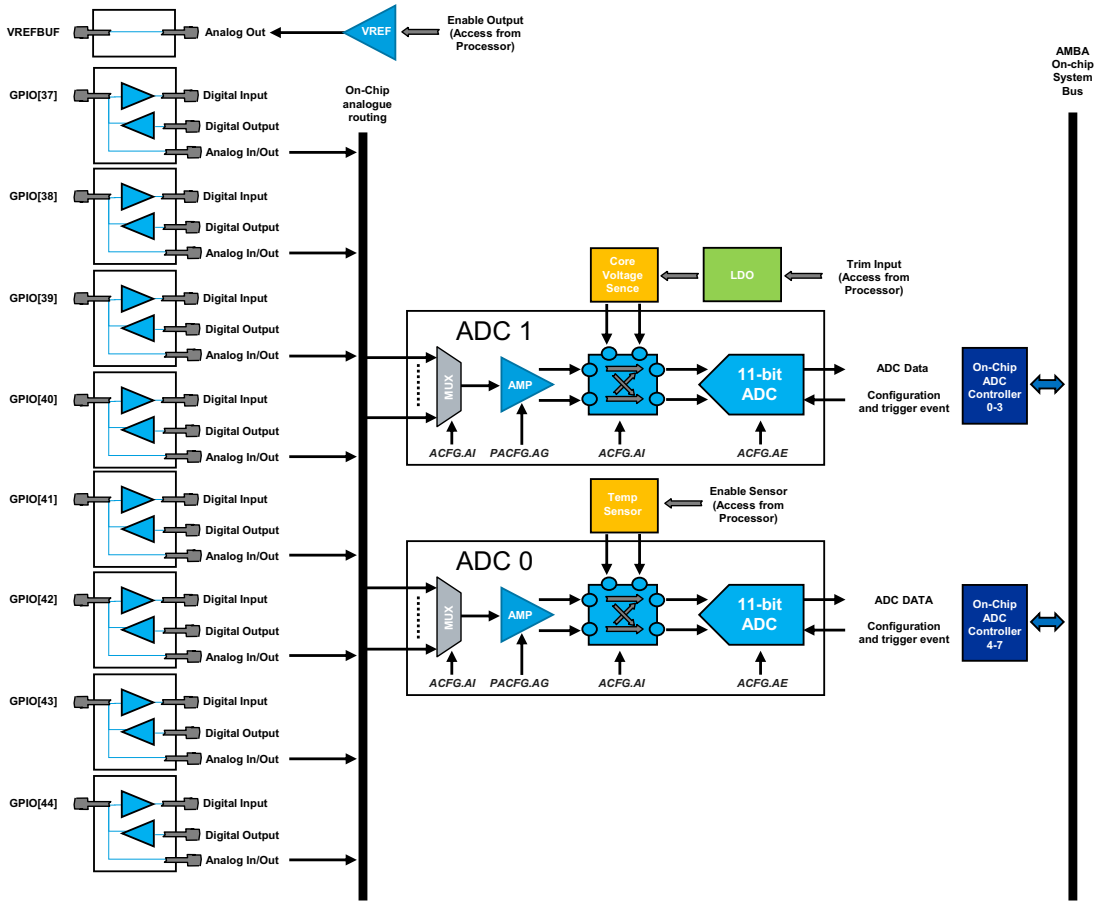


Figure 5. Shared external connections for ADC0 and ADC1

Each ADC can be programmed to single-ended 11-bit range (0 - VREF) using one input pin per channel, or to differential-input 11-bit range (-VREF to VREF) using two input pins per channel. In-between the ADC and MUX, there is a fully differential pre-amplifier, which has three programmable gain-settings (x1, x2, x4). It is to be used together with the fully-differential ADC setting. The input impedance is in the order of 5-20 kohm (TBC) when the pre-amplifier is in use. The pre-amplifier can be by-passed by programming; then, the DC input impedance is high (dominated by MUX leakage currents). These three blocks are supplied by VDDA_ADC and VSSA_ADC. This supply is not the analog reference for ADC measurements; however, it must still be really well decoupled/filtered at high frequencies (>~1MHz) to not degrade the ADC performance.

The ADC supply ground, VSSA_ADC, must always be hardwired to the same PCB ground point as VSSA_REF, directly outside the Microcontroller package. Otherwise, the ADC measurement range will be incorrect, since the reference voltage from the on-chip band-gap reference is a single-ended signal referred to VSSA_REF, whereas the reference input of the on-chip ADC is a single-ended input referred to VSSA_ADC.

2.3.6 On-chip DAC

There are four independent 12bit/3MSps DAC blocks.

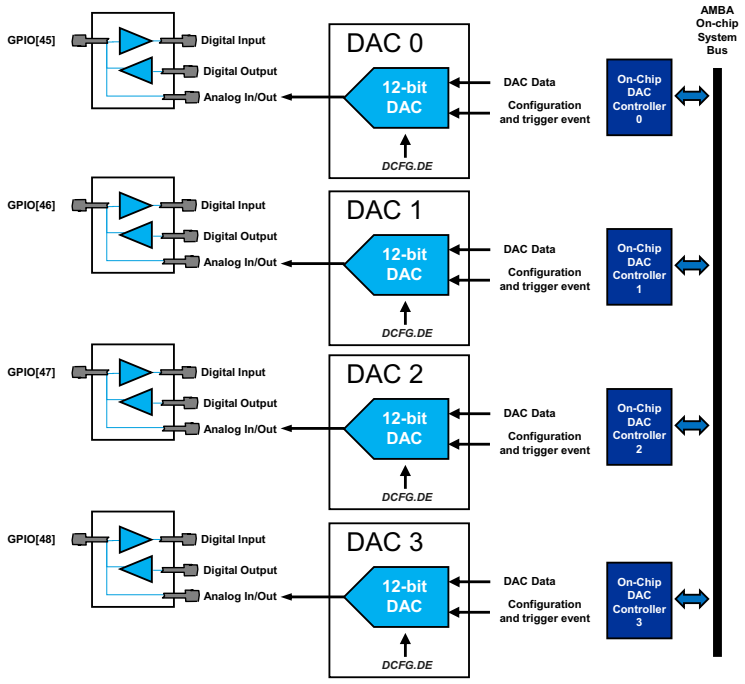


Figure 6. DAC connections to external pin

The DAC output is a sourcing-current single-ended output, typically to be loaded by virtual ground generated by an op-amp on PCB, or by a passive impedance connected to PCB ground providing the output voltage directly across this impedance. These four DAC blocks are supplied by VDDA_DAC and VSSA_DAC. In the same way as for the ADC, it is enough to provide really good decoupling/filtering at high frequencies (>~1MHz).

2.3.7 LDO

The LDO provides VDD_CORE with a regulated 1.8V, and needs a 3.3V input supply. The LDO can be by-passed and, then, the VDD_CORE pins are directly fed with 1.8V regulated supply voltage from PCB. In this case, the 3.3V LDO input pins must not be connected to any low-impedance node other than VDD_CORE; one other possibility is to leave the LDO input pins open (non-connected), but the recommendation is to connect them directly to VDD_CORE. In any case, all VDD_CORE pins must be decoupled on PCB with a small capacitor (in the order of 10nF) directly at each VDD_CORE/GND pin pair. When in use, the LDO is always capable of supplying the full maximum current consumption needed by VDD_CORE. However, the LDO will cause additional on-chip power dissipation - the core average current times the LDO voltage drop - which will further increase the junction temperature. Therefore, when running the core logic such that the core current is high, it is critical to carefully check that the maximum allowed junction temperature is never exceeded in the thermal situation at hand. This should of course be checked in all application implementations with the GR716 microcontroller, but is especially important to do carefully when the LDO is in use at the same time as core current can be high.

2.3.8 Temperature Sensor

There is a temperature sensor implemented on the GR716 microcontroller chip. Its output signal is a monotonic voltage versus temperature, and is measured by the on-chip ADC in the same way as any other MUX channel. Its output is not threshold detected or used in any other on-chip block, so if a chip over-temperature protection is desired, the user needs to measure the sensor and take adequate actions in the system application at hand.

2.3.9 Core Voltage (VDD_CORE) Monitor

The core voltage level can be monitored via the on-chip ADC. The voltage measured can be used by the application to trim the core voltage when the on-chip LDO is active. Default Core voltage trim value is to have maximum core voltage to always guarantee functionality in worst case corners at maximum supported clock frequency. For low power applications the core voltage can be decreased to optimum level in order to minimize power consumption.

2.3.10 External precision voltage reference and monitor

A precession voltage reference can be enabled and used to facilitate applications such as thermistor measurements in a loop with the on-board ADC or reference for virtual ground amplifier in combination with the on-board DAC.

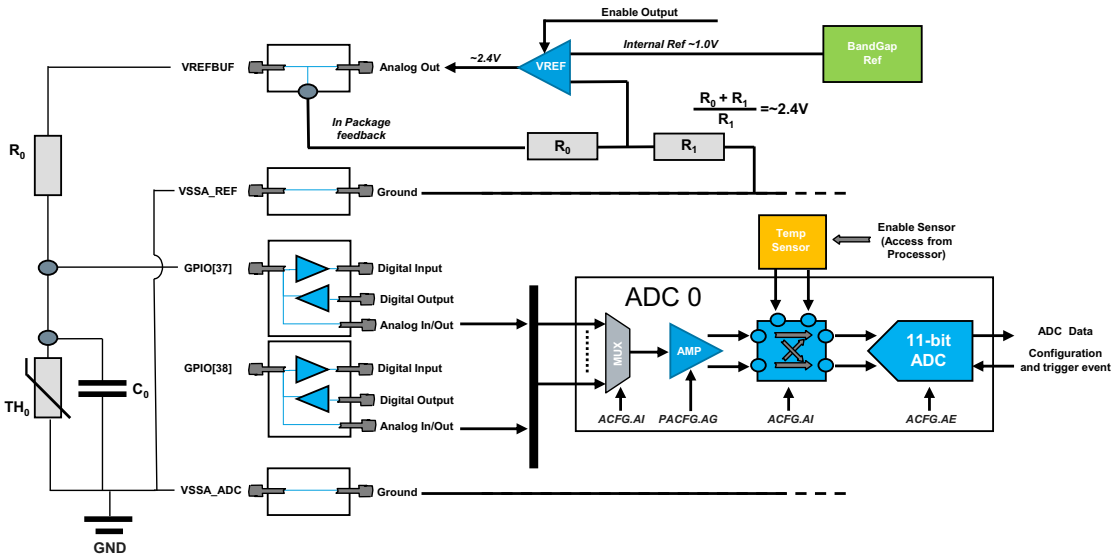


Figure 7. Schematic view of thermistor force sense implementation using on-board ADC and precision reference

2.4 Signal Overview

The GR716 microcontroller has 64 external general purpose user input and outputs, 6 LVDS transceivers and dedicated SPI memory interface. Almost all 64 external inputs and outputs and LVDS transceivers have multiple functionality. Functionality is selected by the application software during startup and configuration. During startup i.e. after reset all user input and outputs are configured as inputs.

LVDS transmitters are disabled after reset and only enabled if SpaceWire or SPI for Space is enabled.

2.5 I/O switch matrix overview

This section provides a introduction to the I/O switch matrix and gives a presentation to the pre-defined set of pin configuration.

The I/O switch matrix provides access to several I/O units. When an interface is not activated, its pins automatically become general purpose I/O. After reset, all I/O switch matrix pins are defined as inputs until programmed otherwise. Configuration and assigning of functions to external I/O is flexible and is controlled by software via registers described in section 7.1.

Figure 8 shows an overview of how the various I/O units are connected to the I/O switch matrix.

Figure 8. Architectural block diagram showing connections to the I/O switch matrix

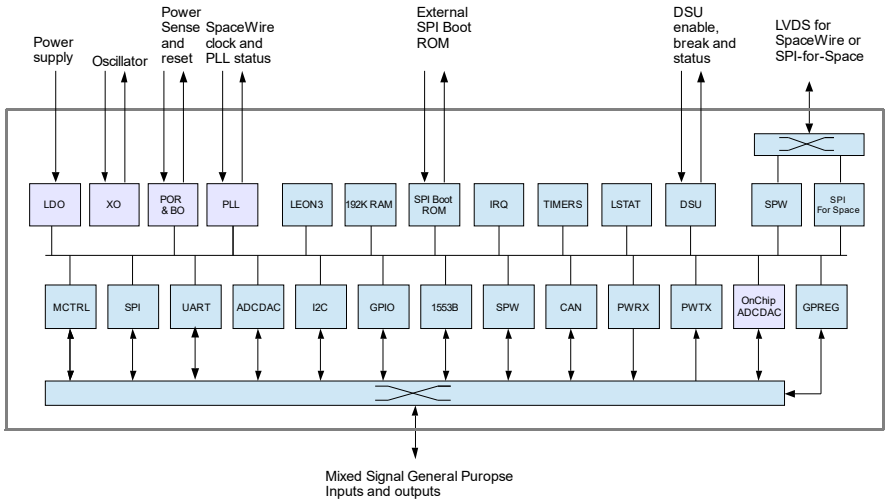


Table 2.6 shows a listing of all external CMOS pins in the I/O switch matrix and what functions can be assign to external pins. Table 2.6 also shows configuration registers to assign specific function or pin to external I/O. To assign a specific function or pin to an external interface the “column” value should be written into the table ’row’ I/O configuration register and bit field. E.g. n register SYS.CFG.GP0.GP5 described in section 7.1.

Table 7. IO configuration option table 1

	0x0	0x1	0x2	0x3	0x4	0x5	0x6	0x7	0x8	0x9	0xA	0xB	0xC	0xD	0xE
SYS.CFG.GP0	GPIO0	UART_RTSN0	MEM_ADDR0	1553_RXENA	PWRX_BUSYN	CAN_TX0		SPIM_SLV1		ADC-DAC_A0	PWM0				
	GPIO1	UART_CTNS0	MEM_ADDR1	1553_TXA	PWRX_CLK	CAN_RX0		SPIM_SCK1		ADCDAC_A1	PWM1				
	GPIO2	UART_TX0	MEM_ADDR2	1553_RXA	PWRX_DATA	CAN_SEL0	I2CM_SDA0	SPIM_MOSI1		ADCDAC_A2	PWM2				
	GPIO3	UART_RX0	MEM_ADDR3	1553_RXNA	PWRX_ABORT	CAN_RX1	I2CM_SCL0	SPIM_MISO1		ADCDAC_A3	PWM3				
	GPIO4	UART_CTSN1	MEM_ADDR4	1553_TXNA	PWRX_VALID	CAN_TX1	I2CM_SDA1	SPI_SCK0		ADCDAC_A4	PWM4				
	GPIO5	UART_RTSN1	MEM_ADDR5	1553_TXINHA	PWRX_RDY	CAN_SEL1	I2CM_SCL1	SPI_MISO0		ADCDAC_A5	PWM5				
	GPIO6	UART_TX1	MEM_ADDR6	1553_RXB	PWTX_VALID		I2CS_SDA0	SPI_MOSI0		ADCDAC_A6	PWM6				
	GPIO7	UART_RX1	MEM_ADDR7	1553_RXNB	PWTX_CLK		I2CS_SCL0	SPI_SEL0		ADCDAC_A7	PWM7				
SYS.CFG.GP1	GPIO8	UART_CTSN2	MEM_ADDR8	1553_RXENB	PWTX_BUSYN		I2CS_SDA1	SPI_SLV0_0			PWM8				
	GPIO9	UART_RTSN2	MEM_ADDR9	1553_TXB	PWTX_READY		I2CS_SCL1	SPI_SLV0_1			PWM9				
	GPIO10	UART_TX2	MEM_ADDR10	1553_CLK	PWTX_DATA		I2CS_SDA2	SPI_SLV0_2			PWM10				
	GPIO11	UART_RX2	MEM_ADDR11	1553_TXNB	PWTX_ABORT		I2CS_SCL2	SPI_SLV0_3			PWM11				
	GPIO12		MEM_ADDR12	1553_TXINHB							PWM12				
	GPIO13	UART_CTSN3	MEM_ADDR13			CAN_TX0		SPI_SCK1		ADCDAC_D0	PWM13				
	GPIO14	UART_RTSN3	MEM_ADDR14			CAN_RX0		SPI_MISO1		ADCDAC_D1	PWM14				
	GPIO15	UART_TX3	MEM_ADDR15			CAN_SEL0		SPI_MOSI1		ADCDAC_D2	PWM15				
SYS.CFG.GP2	GPIO16	UART_RX3	MEM_ADDR16			CAN_RX1		SPI_SEL1		ADCDAC_D3					
	GPIO17	UART_RTSN4	MEM_ADDR17			CAN_TX1		SPI_SLV1_0		ADCDAC_A0					
	GPIO18	UART_TX4	MEM_ADDR18			CAN_SEL1		SPI_SLV1_1		ADCDAC_A1					
	GPIO19	UART_RX4	RAM_CSN0							ADCDAC_D4				TDP_SETET	
	GPIO20	UART_CTSN4	RAM_CSN1							ADCDAC_D5				TDP_E_ET_I	
	GPIO21	UART_CTSN5	RAM_CSN2					SPI_SLV1_2		ADCDAC_D6	PWM12	SPW_RXS			
	GPIO22	UART_RTSN5	RAM_CSN3					SPI_SLV1_3		ADCDAC_D7	PWM13	SPW_RXD			
	GPIO23	UART_TX5	ROM_CSN0							ADCDAC_D8	PWM14	SPW_TXS			
SYS.CFG.GP3	GPIO24	UART_RX5	ROM_CSN1							ADCDAC_D9	PWM15	SPW_TXD			
	GPIO25		MEM_DATA0		PWRX_VALID		I2CM_SDA0	SPI_SCK0		ADCDAC_D10	PWM0				
	GPIO26		MEM_DATA1		PWRX_CLK		I2CM_SCL0	SPI_MISO0		ADCDAC_D11	PWM1				
	GPIO27		MEM_DATA2		PWRX_DATA		I2CM_SDA1	SPI_MOSI0		ADCDAC_D12	PWM2				
	GPIO28		MEM_DATA3		PWRX_ABORT		I2CM_SCL1	SPI_SEL0		ADCDAC_D13	PWM3				
	GPIO29		MEM_DATA4		PWRX_BUSYN		I2CS_SDA0	SPI_SLV0_0		ADCDAC_D14	PWM4				
	GPIO30		MEM_DATA5		PWRX_RDY		I2CS_SCL0	SPI_SLV0_1		ADCDAC_D15	PWM5				
	GPIO31		MEM_DATA6		PWTX_VALID		I2CS_SDA1	SPI_SLV0_2		ADC_RC	PWM6				
SYS.CFG.GP4	GPIO32		MEM_DATA7		PWTX_CLK		I2CS_SCL1	SPI_SLV0_3		DAC_WR	PWM7				
	GPIO33	UART_CTSN3	MEM_OEN		PWTX_BUSYN		I2CM_SDA0			ADC_CS	PWM8				
	GPIO34	UART_RTSN3	MEM_WRN		PWTX_READY		I2CM_SCL0			ADC_RDY	PWM9				
	GPIO35	UART_TX3	ROM_CSN0		PWTX_DATA		I2CS_SDA0			ADC_TRIG	PWM10	MEM_BRDYN			
	GPIO36	UART_RX3	ROM_CSN1		PWTX_ABORT		I2CS_SCL0			ADCDAC_D6	PWM11	MEM_BEXCN			
	GPIO37	UART_RTSN4		1553_RXENA	PWRX_VALID	CAN_TX0		SPI_SLV0_3	ADC0	ADCDAC_D7	PWM0				
	GPIO38	UART_TX4		1553_TXA	PWRX_CLK	CAN_RX0		SPI_SLV0_2	ADC1		PWM1				
	GPIO39	UART_RX4		1553_RXA	PWRX_DATA	CAN_SEL0	I2CS_SDA1	SPI_SLV0_1	ADC2		PWM2				

	0x0	0x1	0x2	0x3	0x4	0x5	0x6	0x7	0x8	0x9	0xA	0xB	0xC	0xD	0xE
SYS.CFG.GP5	GPIO40	UART_CTSN4		1553_RXNA	PWRX_ABORT		I2CS_SCL1	SPI_SLV0_0	ADC3	ADC_RC	PWM3				
	GPIO41	UART_CTSN5	RAM_CSN2	1553_TXNA	PWRX_BYN	CAN_TX0	I2CM_SDA0	SPI_SCK0	ADC4	DAC_WR	PWM0				
	GPIO42	UART_RTSN5	RAM_CSN3	1553_TXINHA	PWRX_RDY	CAN_RX0	I2CM_SCL0	SPI_MISO0	ADC5	ADC_CS	PWM1				
	GPIO43	UART_TX5	ROM_CSN0	1553_RXB	PWTX_VALID	CAN_SEL0	I2CS_SDA0	SPI_MOSI0	ADC6	ADC_RDY	PWM2				
	GPIO44	UART_RX5	ROM_CSN1	1553_RXNB	PWTX_CLK	CAN_RX1	I2CS_SCL0	SPI_SEL0	ADC7	ADC_TRIG	PWM3				
	GPIO45	UART_RX0		1553_RXENB	PWTX_BUSYN	CAN_RX1		SPI_SLV1_1	DAC0		PWM4				
	GPIO46	UART_TX0		1553_TXB	PWTX_RDY			SPI_SLV1_0	DAC1	ADCDAC_D15	PWM5				
	GPIO47	UART_CTSN0		1553_CLK	PWTX_DATA	CAN_TX1	I2CM_SDA1	SPI_SCK1	DAC2	ADCDAC_D14	PWM6				
SYS.CFG.GP6	GPIO48	UART_RTSN0		1553_TXNB	PWTX_ABORT	CAN_SEL1	I2CM_SCL1	SPI_MISO1	DAC3	ADCDAC_D13	PWM15				
	GPIO49	UART_CTSN0	MEM_ADDR19	1553_TXINHB			I2CS_SDA2	SPI_MOSI1		ADCDAC_D0	PWM0	SPIM_SLV1	AHBUART_TX	TDP_SETET	
	GPIO50	UART_TX0	MEM_ADDR20				I2CS_SCL2	SPI_SEL1		ADCDAC_D1	PWM1	SPIM_SCK1	AHBUART_RX	TDP_E_ET_I	
	GPIO51	UART_RX0	MEM_ADDR21	1553_RXENA				SPI_MOSI1		ADCDAC_D2	PWM2	SPIM_MOSI1		TDP_PULSE0	
	GPIO52	UART_CTSN1	MEM_ADDR22	1553_TXA	PWRX_VALID		I2CM_SDA0	SPI_SEL1		ADCDAC_D3	PWM3	SPIM_MISO1		TDP_PULSE1	
	GPIO53	UART_RTSN1		1553_RXA	PWRX_CLK		I2CM_SCL0	SPIS_SCK0		ADCDAC_D4	PWM4	SPI4S_SCK0			
	GPIO54	UART_TX1		1553_RXNA	PWRX_DATA		I2CM_SDA1	SPIS_MISO0		ADCDAC_D5	PWM5	SPI4S_MISO0			
	GPIO55	UART_RX1		1553_TXNA	PWRX_ABORT		I2CM_SCL1	SPIS_MOSI0		ADCDAC_D6	PWM6	SPI4S_MOSI0			
SYS.CFG.GP7	GPIO56	UART_CTSN2		1553_TXINHA	PWRX_BSYN		I2CS_SDA0	SPIS_SLV0		ADCDAC_D7	PWM7	SPI4S_SLV0			
	GPIO57	UART_RTSN2		1553_RXB	PWRX_RDY		I2CS_SCL0	SPI_SCK0		ADCDAC_D8	PWM8				
	GPIO58	UART_TXN2		1553_RXNB	PWTX_VALID	CAN_TX0	I2CS_SDA1	SPI_MISO0		ADCDAC_D9	PWM9				
	GPIO59	UART_RXN2		1553_RXENB	PWTX_CLK	CAN_RX0	I2CS_SCL1	SPI_MOSI0		ADCDAC_D10	PWM10				
	GPIO60	UART_CTSN3		1553_TXB	PWTX_BUSYN	CAN_SEL0	I2CS_SDA2	SPI_SEL0		ADCDAC_D11	PWM11			TDP_PULSE2	
	GPIO61	UART_RXN3		1553_CLK	PWTX_RDY	CAN_RX1	I2CS_SCL2	SPI_SLV0_0		ADCDAC_D12	PWM12			TDP_PULSE3	
	GPIO62	UART_TX3	ROM_CSN0	1553_TXNB	PWTX_DATA	CAN_TX1		SPI_SLV0_1		ADCDAC_A0	PWM13			TDP_PULSE4	
	GPIO63	UART_RTSN3	ROM_CSN1	1553_TXINHB	PWTX_ABORT	CAN_SEL1		SPI_SLV0_2		ADCDAC_A1	PWM14			TDP_PULSE5	

2.6 I/O switch default configurations for bootstraps

This chapter lists external pin connection for all valid boot strap options.

2.6.1 External pin configuration for SpaceWire remote access

This section describes valid bootstrap configuration for SpaceWire remote access.

Table 8. Remote SpaceWire pin configurations

Pin Name	Interface Name	Functional description
LVDS_RX[0]	RXD	SpaceWire receiver data interface
LVDS_RX[1]	RXS	SpaceWire receiver strobe interface
LVDS_TX[0]	TXD	SpaceWire transmitter data interface
LVDS_TX[1]	TXS	SpaceWire transmitter strobe interface

Note 1: Remote SpaceWire interface uses LVDS type interface

2.6.2 External pin configuration for UART remote access

This section describes valid bootstrap configuration for UART remote access.

Table 9. Remote UART access pin configurations

Pin Name	Interface Name	Functional description
GPIO[49]	TX	UART transmitter interface
GPIO[50]	RX	UART receiver interface

Note 1: Interface uses CMOS type interface

2.6.3 External pin configuration for I2C remote access

This section describes valid bootstrap configuration for I2C remote access.

Table 10. Remote I2C access pin configurations

Pin Name	Interface Name	Functional description
GPIO[49]	SDA	I2C Serial Data interface
GPIO[50]	SCL	I2C Serial Clock interface

Note 1: Interface uses CMOS type interface

2.6.4 External pin configuration for SPI remote access

This section describes valid bootstrap configuration for SPI remote access.

Table 11. Remote SPI access pin configurations

Pin Name	Interface Name	Functional description
GPIO[53]	SCK	SPI Slave Clock interface
GPIO[54]	MISO	SPI Master input Slave output interface
GPIO[55]	MOSI	SPI Master output Slave input interface
GPIO[56]	SLV	SPI Slave Select interface

Note 1: Interface uses CMOS type interface

2.6.5 External pin configuration for external SPI boot memory

This section describes valid bootstrap configuration for external SPI memory.

Table 12. SPI memory pin configurations

Pin Name	Interface Name	Functional description
SPIM_MOSI	MOSI	SPI Memory master output slave input
SPIM_SCK	SCK	SPI Memory master clock output
SPIM_SEL	SEL	SPI Memory slave select output
SPIM_MISO	MISO	SPI Memory master input slave output
GPIO[2]	MOSI	Redundant SPI Memory master output slave input
GPIO[1]	SCK	Redundant SPI Memory master clock output
GPIO[0]	SEL	Redundant SPI Memory slave select output
GPIO[3]	MISO	Redundant SPI Memory master input slave output

Note 1: Interface uses CMOS type interface

2.6.6 External pin configuration for external SRAM boot memory

This section describes valid bootstrap configuration for external SRAM.

Table 13. SRAM memory pin configurations

Pin Name	Interface Name	Functional description
GPIO[0]	ADDR[0]	Memory address interface
GPIO[1]	ADDR[1]	
GPIO[2]	ADDR[2]	
GPIO[3]	ADDR[3]	
GPIO[4]	ADDR[4]	
GPIO[5]	ADDR[5]	
GPIO[6]	ADDR[6]	
GPIO[7]	ADDR[7]	
GPIO[8]	ADDR[8]	
GPIO[9]	ADDR[9]	
GPIO[10]	ADDR[10]	
GPIO[11]	ADDR[11]	
GPIO[12]	ADDR[12]	
GPIO[13]	ADDR[13]	
GPIO[14]	ADDR[14]	
GPIO[15]	ADDR[15]	
GPIO[16]	ADDR[16]	
GPIO[17]	ADDR[17]	
GPIO[18]	ADDR[18]	
GPIO[33]	OEN	Output interface
GPIO[34]	WRN	Writen enable interface

Table 13. SRAM memory pin configurations

Pin Name	Interface Name	Functional description
GPIO[25]	DATA[0]	Data interface
GPIO[26]	DATA[1]	
GPIO[27]	DATA[2]	
GPIO[28]	DATA[3]	
GPIO[29]	DATA[4]	
GPIO[30]	DATA[5]	
GPIO[31]	DATA[6]	
GPIO[32]	DATA[7]	
GPIO[19]	CSN[0]	Chip Select
GPIO[20]	CSN[1]	Redundant Chip Select

Note 1: Interface uses CMOS type interface

2.6.7 External pin configuration for external PROM/FLASH boot memory

This section describes valid bootstrap configuration for external PROM/FLASH.

Table 14. PROM/FLASH memory pin configurations

Pin Name	Interface Name	Functional description
GPIO[0]	ADDR[0]	Memory address interface
GPIO[1]	ADDR[1]	
GPIO[2]	ADDR[2]	
GPIO[3]	ADDR[3]	
GPIO[4]	ADDR[4]	
GPIO[5]	ADDR[5]	
GPIO[6]	ADDR[6]	
GPIO[7]	ADDR[7]	
GPIO[8]	ADDR[8]	
GPIO[9]	ADDR[9]	
GPIO[10]	ADDR[10]	
GPIO[11]	ADDR[11]	
GPIO[12]	ADDR[12]	
GPIO[13]	ADDR[13]	
GPIO[14]	ADDR[14]	
GPIO[15]	ADDR[15]	
GPIO[16]	ADDR[16]	
GPIO[17]	ADDR[17]	
GPIO[18]	ADDR[18]	
33	OEN	Output interface
34	WRN	Writen enable interface

Table 14. PROM/FLASH memory pin configurations

Pin Name	Interface Name	Functional description
GPIO[25]	DATA[0]	Data interface
GPIO[26]	DATA[1]	
GPIO[27]	DATA[2]	
GPIO[28]	DATA[3]	
GPIO[29]	DATA[4]	
GPIO[30]	DATA[5]	
GPIO[31]	DATA[6]	
GPIO[32]	DATA[7]	
GPIO[35]	CSN[0]	Chip Select
GPIO[36]	CSN[1]	Redundant Chip Select

Note 1: Interface uses CMOS type interface

2.6.8 External pin configuration for external I2C boot memory

This section describes valid bootstrap configuration for external I2C memory.

Table 15. I2C memory pin configurations

Pin Name	Interface Name	Functional description
GPIO[2]	SDA	I2C Serial Data interface
GPIO[3]	SCL	I2C Serial Clock interface
GPIO[4]	SDA	Redundant I2C Serial Data interface
GPIO[5]	SCL	Redundant I2C Serial Clock interface

Note 1: Interface uses CMOS type interface

2.7 I/O switch matrix options, considerations and limitations

This chapter lists options and limitations when using different interfaces in the IO switch.

2.7.1 SPI interfaces

The SPI interface can switch from being a Master to Slave interface and vice versa. In general this is not a problem and adds flexibility to the I/O mux concept except for the ’slave select’ signal. The ’slave select’ signal will change direction when switching from Slave i.e. slave select input signal to Master interface i.e. slave select output. In the worst scenario this can permanently damage the internal driver and receiver. To mitigate this problem the Master Slave select output and Slave Select input has been assigned to different I/Os.

In a situation where the application board only requires the SPI interface to either be Slave or Master the option is given to the designer to assign the extra pin to another system interface.

2.7.2 External Memory interface

The external PROM/SRAM interface occupies many external I/Os due parallel data and address buses. The system should only allocate the number of address and chip-select pins needed for the application. E.g. a system that only requires 256KiB of memory only need to allocate and use 18 external address lines and 1 chip-select i.e. the system can assign 4 pins to another system interface.

There is also a potential saving to make if the functionality ’bus ready’ and ’bus exception’ isn’t used.

2.7.3 External ADC and DAC interface

The number of pins used for the external ADC and DAC interface depends upon the number of external ADC and DAC channel the application shall support. The interface can use up to 8 address lines in order to address and control multiple ADC and DAC outside the GR716 microcontroller. On the other hand, if very few or only one ADC or DAC is used the 8 address lines can be assigned to another system interface.

2.8 I/O switch matrix pin validation script

This an introduction to the validation script provided upon request in order to validate pin configurations and to generate constants for the I/O switch configuration registers. The intention of the script is to help the user of the GR716 microcontroller to validate a configuration according to table 2.6 and to quickly setup a system for test. The script should not be used for any other purpose than test and debug of systems using the GR716 microcontroller.

2.8.1 Functional pin mapping sections

The I/O configuration script is written in TCL and contains lists for mapping functional pins to physical pins on the GR716 microcontroller as described in table 2.6. Each functional group maps individual functional pins to physical external pins. Example of UART0 configuration description are shown in table 16.

Table 16. UART0 functional pin mapping to external pins of the GR716 microcontroller

```
set uart0_cfg0 { {uart0_cfg0} {
  { 1 1 uart_ctsn(0) in}
  { 0 1 uart_rtsn(0) out}
  { 2 1 uart_tx(0)   out}
  { 3 1 uart_rx(0)   in}
} }
```

Table 16 specifies the following for the configuration UART0_CFG0:

- functional pin UART_CTSN(0) of UART0 to mapped to external physical pin GPIO(0)
- functional pin UART_RTSN(0) of UART0 to mapped to external physical pin GPIO(1)
- functional pin UART_TX(0) of UART0 to mapped to external physical pin GPIO(2)
- functional pin UART_RX(0) of UART0 to mapped to external physical pin GPIO(3)

Functions can have multiple I/O configurations and are then differentiated by adding a consecutive number to the name of the configuration. All interface options described in table 2.6 are described in the I/O mux script.

2.8.2 I/O configuration sections

The I/O configuration section specifies all functional groups to be available on physical pins. The functions and configurations are listed and named in this section. Example of using UART0, UART1 and UART3 are listed in table 16.

Table 17. Example of mapping UART0, UART1 and UART2 to external pins of the GR716 microcontroller

```
set iomx_uart0_cfg [list \
$auart_cfg0 $uart2_cfg0 $uart3_cfg1 \
]
```

2.8.3 Usage of the pin validation script

Script needs to be modified and loaded into GRMON. After script been loaded the TCL command gen_config can be run to generate the external I/O configuration register settings.

Table 18. Example of executing I/O configuration script

```
grmon2> source iomx.tcl
grmon2> gen_config $iomx_uart0_cfg
 ...
grmon2>
```

2.8.4 Output of the pin validation script

The I/O script can be executed from within GRMON using the build-in TCL support. Here is an example of running the script for setting up the system using with SpaceWire, 1 UART and external SPI memory.

Table 19. Example of output from running the pin validation script when successful

```
grmon2> source iomx.tcl
grmon2> gen_config $iomx_apw_uart0_spi0_cfg
  # Pin list
  pin[0]: uart_ctsn(0)
  pin[1]: uart_rtsn(0)
  pin[2]: uart_tx(0)
  pin[3]: uart_rx(0)
  pin[12]: spim_sck(0)
  pin[13]: spim_miso(0)
  pin[14]: spim_mosi(0)
  pin[15]: spim_slv(0)
  pin[16]: spw_rxd
  pin[17]: spw_rxs
  pin[18]: spw_txs
  pin[19]: spw_txd

 // C constant
 const int iomx[8] = {
  0x00001111,
  0x11110000,
  0x00002222,
  0x00000000,
  0x00000000,
  0x00000000,
  0x00000000,
  0x00000000};

 grmon2>
```

The script outputs:

- A section specifying all pins that are dedicated to specific interface. (All other pins are considered as GPIOs)
- A section that can be imported directly to standard 'C' program for configuration of I/O mux registers, see section 7.1.

2.8.5 Erroneous pin configuration

Script checks for conflicting pins and a third section will be printed when running the scripts.

Table 20. Example of output from running the pin validation script when conflicting pins are detected

```
grmon2> source iomx.tcl
  ...
Error: conflicting pin config


Double-mapped signal:
uart_ctsn(3) uart_rtsn(3) uart_tx(3) uart_rx(3)


grmon2>
```

The last printed section will print the pins violating the selected pins configuration.

2.8.6 Validation of custom pin configuration

The supplied validation scripts contains variables for valid pin placement of each interface specified in table 2.6. See script for valid names.

2.8.7 Script limitations

The script is provided "as-is" and only checks for valid configurations according to pre-defined pin allocations for specific interfaces defined in the script.

The script will not check pins placement or direction selected is correct according to target system or PCB board.

2.9 I/O switch matrix scenario examples

This chapter gives examples of how to configure the GR716 microcontroller and the I/O mux for following scenarios:

- Sensor / Actuator Node using external SRAM to store data
- Bus bridge using external SRAM to store data
- Bus bridge booting from external serial ROM

This chapter presents examples of I/O mux configuration tables. The configuration tables e.g. table 22 should be interpreted as follow:

- Each row represent an external I/O on the GR716 microcontroller device
- The first column states the register and bits used to control the external I/O
- The columns marked with a hexadecimal number states the value the function are selected with. For reference see table 2.6.
- The columns marked with <namn>.<index> are a combined user scenarios and gives the fixed functions and pins for the scenario
- Empty entries in columns marked with <namn>.<index> indicates that the user can assign any valid function to the external pin according to table 2.6.

2.9.1 Scenario #1 - Sensor / Actuator Node

This chapter describes how to configure the I/O mux to node bus either via SPW, CAN or MIL-1553B and at the same run internal or external ADC.

The following assumptions are made for the system:

- All on-chip ADCs and DACs is used (or external ADC / DAC).
- External RAM needs to be greater than 128KiB. (If the application needs less than that the internal on-chip memory should be used in order to utilize the pins on the device more efficiently). For this example we assume 256KiB is needed.
- Boot from external PROM is required.

In table 21 options of I/O configuration for using SPW, MIL-1553B and CAN as node bus are depicted. Note that SpaceWire is connected on dedicated pins.

Table 21. Examples of I/O configuration for using SPW, MIL-1553B and CAN as node bus

	MIL1553		CAN		SpaceWire	
IO Config Register	MIL.CFG1	MIL.CFG2	CAN.CFG1	CAN.CFG2	SPW.CFG1	SPW.CFG2
SYS.CFG.GP0.GP0	MEM_ADDR0	MEM_ADDR0	MEM_ADDR0	MEM_ADDR0	MEM_ADDR0	MEM_ADDR0
SYS.CFG.GP0.GP1	MEM_ADDR1	MEM_ADDR1	MEM_ADDR1	MEM_ADDR1	MEM_ADDR1	MEM_ADDR1
SYS.CFG.GP0.GP2	MEM_ADDR2	MEM_ADDR2	MEM_ADDR2	MEM_ADDR2	MEM_ADDR2	MEM_ADDR2
SYS.CFG.GP0.GP3	MEM_ADDR3	MEM_ADDR3	MEM_ADDR3	MEM_ADDR3	MEM_ADDR3	MEM_ADDR3
SYS.CFG.GP0.GP4	MEM_ADDR4	MEM_ADDR4	MEM_ADDR4	MEM_ADDR4	MEM_ADDR4	MEM_ADDR4
SYS.CFG.GP0.GP5	MEM_ADDR5	MEM_ADDR5	MEM_ADDR5	MEM_ADDR5	MEM_ADDR5	MEM_ADDR5
SYS.CFG.GP0.GP6	MEM_ADDR6	MEM_ADDR6	MEM_ADDR6	MEM_ADDR6	MEM_ADDR6	MEM_ADDR6
SYS.CFG.GP0.GP7	MEM_ADDR7	MEM_ADDR7	MEM_ADDR7	MEM_ADDR7	MEM_ADDR7	MEM_ADDR7
SYS.CFG.GP1.GP0	MEM_ADDR8	MEM_ADDR8	MEM_ADDR8	MEM_ADDR8	MEM_ADDR8	MEM_ADDR8
SYS.CFG.GP1.GP1	MEM_ADDR9	MEM_ADDR9	MEM_ADDR9	MEM_ADDR9	MEM_ADDR9	MEM_ADDR9
SYS.CFG.GP1.GP2	MEM_ADDR10	MEM_ADDR10	MEM_ADDR10	MEM_ADDR10	MEM_ADDR10	MEM_ADDR10
SYS.CFG.GP1.GP3	MEM_ADDR11	MEM_ADDR11	MEM_ADDR11	MEM_ADDR11	MEM_ADDR11	MEM_ADDR11
SYS.CFG.GP1.GP4	MEM_ADDR12	MEM_ADDR12	MEM_ADDR12	MEM_ADDR12	MEM_ADDR12	MEM_ADDR12
SYS.CFG.GP1.GP5	MEM_ADDR13	MEM_ADDR13	MEM_ADDR13	MEM_ADDR13	MEM_ADDR13	MEM_ADDR13
SYS.CFG.GP1.GP6	MEM_ADDR14	MEM_ADDR14	MEM_ADDR14	MEM_ADDR14	MEM_ADDR14	MEM_ADDR14
SYS.CFG.GP1.GP7	MEM_ADDR15	MEM_ADDR15	MEM_ADDR15	MEM_ADDR15	MEM_ADDR15	MEM_ADDR15
SYS.CFG.GP2.GP0	MEM_ADDR16	MEM_ADDR16	MEM_ADDR16	MEM_ADDR16	MEM_ADDR16	MEM_ADDR16
SYS.CFG.GP2.GP1	MEM_ADDR17	ADCDAC_A0	MEM_ADDR17	ADCDAC_A0	MEM_ADDR17	ADCDAC_A0
SYS.CFG.GP2.GP2	MEM_ADDR18	ADCDAC_A1	MEM_ADDR18	ADCDAC_A1	MEM_ADDR18	ADCDAC_A1
SYS.CFG.GP2.GP3	RAM_CSN0	RAM_CSN0	RAM_CSN0	RAM_CSN0	RAM_CSN0	RAM_CSN0
SYS.CFG.GP2.GP4	RAM_CSN1	ADCDAC_D5	RAM_CSN1	RAM_CSN1	RAM_CSN1	RAM_CSN1
SYS.CFG.GP2.GP5	RAM_CSN2	ADCDAC_D6	RAM_CSN2		RAM_CSN2	SPW_RXD
SYS.CFG.GP2.GP6	RAM_CSN3	ADCDAC_D7	RAM_CSN3		RAM_CSN3	SPW_RXS
SYS.CFG.GP2.GP7	ROM_CSN0	ADCDAC_D8	ROM_CSN0		ROM_CSN0	SPW_TXS
SYS.CFG.GP3.GP0	ROM_CSN1	ADCDAC_D9	ROM_CSN1		ROM_CSN1	SPW_TXD
SYS.CFG.GP3.GP1	MEM_DATA0	MEM_DATA0	MEM_DATA0	MEM_DATA0	MEM_DATA0	MEM_DATA0
SYS.CFG.GP3.GP2	MEM_DATA1	MEM_DATA1	MEM_DATA1	MEM_DATA1	MEM_DATA1	MEM_DATA1
SYS.CFG.GP3.GP3	MEM_DATA2	MEM_DATA2	MEM_DATA2	MEM_DATA2	MEM_DATA2	MEM_DATA2
SYS.CFG.GP3.GP4	MEM_DATA3	MEM_DATA3	MEM_DATA3	MEM_DATA3	MEM_DATA3	MEM_DATA3
SYS.CFG.GP3.GP5	MEM_DATA4	MEM_DATA4	MEM_DATA4	MEM_DATA4	MEM_DATA4	MEM_DATA4
SYS.CFG.GP3.GP6	MEM_DATA5	MEM_DATA5	MEM_DATA5	MEM_DATA5	MEM_DATA5	MEM_DATA5
SYS.CFG.GP3.GP7	MEM_DATA6	MEM_DATA6	MEM_DATA6	MEM_DATA6	MEM_DATA6	MEM_DATA6
SYS.CFG.GP4.GP0	MEM_DATA7	MEM_DATA7	MEM_DATA7	MEM_DATA7	MEM_DATA7	MEM_DATA7
SYS.CFG.GP4.GP1	MEM_OEN	MEM_OEN	MEM_OEN	MEM_OEN	MEM_OEN	MEM_OEN
SYS.CFG.GP4.GP2	MEM_WRN	MEM_WRN	MEM_WRN	MEM_WRN	MEM_WRN	MEM_WRN
SYS.CFG.GP4.GP3		ROM_CSN0		ROM_CSN0		ROM_CSN0
SYS.CFG.GP4.GP4		ROM_CSN1		ROM_CSN1		ROM_CSN1
SYS.CFG.GP4.GP5	ADC0	1553_RXENA	ADC0	CAN_TX0		
SYS.CFG.GP4.GP6	ADC1	1553_TXA	ADC1	CAN_RX0		
SYS.CFG.GP4.GP7	ADC2	1553_RXA	ADC2	CAN_SEL0		
SYS.CFG.GP5.GP0	ADC3	ADC_RC	ADC3	ADC_RC		ADC_RC
SYS.CFG.GP5.GP1	ADC4	DAC_WR	ADC4	DAC_WR		DAC_WR
SYS.CFG.GP5.GP2	ADC5	ADC_CS	ADC5	ADC_CS		ADC_CS
SYS.CFG.GP5.GP3	ADC6	ADC_RDY	ADC6	ADC_RDY		ADC_RDY
SYS.CFG.GP5.GP4	ADC7	ADC_TRIG	ADC7	ADC_TRIG		ADC_TRIG
SYS.CFG.GP5.GP5	DAC0	1553_RXENB	DAC0	CAN_RX1		
SYS.CFG.GP5.GP6	DAC1	1553_TXB	DAC1	ADCDAC_D15		ADCDAC_D15
SYS.CFG.GP5.GP7	DAC2	1553_CLK	DAC2	ADCDAC_D14		ADCDAC_D14
SYS.CFG.GP6.GP0	DAC3	ADCDAC_D13	DAC3	ADCDAC_D13		ADCDAC_D13
SYS.CFG.GP6.GP1		ADCDAC_D0		ADCDAC_D0		ADCDAC_D0
SYS.CFG.GP6.GP2		ADCDAC_D1		ADCDAC_D1		ADCDAC_D1
SYS.CFG.GP6.GP3	1553_RXENA	ADCDAC_D2		ADCDAC_D2		ADCDAC_D2
SYS.CFG.GP6.GP4	1553_TXA	ADCDAC_D3		ADCDAC_D3		ADCDAC_D3
SYS.CFG.GP6.GP5	1553_RXA	ADCDAC_D4		ADCDAC_D4		ADCDAC_D4
SYS.CFG.GP6.GP6	1553_RXNA	1553_RXNA		ADCDAC_D5		ADCDAC_D5
SYS.CFG.GP6.GP7	1553_TXNA	1553_TXNA		ADCDAC_D6		ADCDAC_D6
SYS.CFG.GP7.GP0	1553_TXINHA	1553_TXINHA		ADCDAC_D7		ADCDAC_D7
SYS.CFG.GP7.GP1	1553_RXB	1553_RXB		ADCDAC_D8		ADCDAC_D8
SYS.CFG.GP7.GP2	1553_RXNB	1553_RXNB	CAN_TX0	ADCDAC_D9		ADCDAC_D9
SYS.CFG.GP7.GP3	1553_RXENB	ADCDAC_D10	CAN_RX0	ADCDAC_D10		ADCDAC_D10
SYS.CFG.GP7.GP4	1553_TXB	ADCDAC_D11	CAN_SEL0	ADCDAC_D11		ADCDAC_D11
SYS.CFG.GP7.GP5	1553_CLK	ADCDAC_D12	CAN_RX1	ADCDAC_D12		ADCDAC_D12
SYS.CFG.GP7.GP6	1553_TXNB	1553_TXNB	CAN_TX1	CAN_TX1		
SYS.CFG.GP7.GP7	1553_TXINHB	1553_TXINHB	CAN_SEL1	CAN_SEL1		

2.9.2 Scenario #2 - Bus bridge

This chapter describes how to configure the I/O mux for a node bus bridge.

The following assumptions are made for the system:

- External RAM needs to be greater than 128KiB. (If the application needs less than that the internal on-chip memory should be used in order to utilize the pins on the device more efficiently). For this example we assume at least 256KiB is needed.
- Boot from external PROM is required.
- Connects to spacecraft bus either via 1553B or SpaceWire, and on the other side to node bus via CAN.

In table 22 two example of I/O configurations for Node bus bridge are shown.

Note that SpaceWire is assumed to be connected on dedicated pins see BRIDGE.CFG1 in table 22. If SpaceWire redundancy is required configuration BRIDGE.CFG2 in table 22 should be used.

Table 22. Examples of I/O MUX configurations for Node bus bridges when using the external parallel memory

	Bridge	
IO Config Register	BRIDGE.CFG1	BRIDGE.CFG2
SYS.CFG.GP0.GP0	MEM_ADDR0	MEM_ADDR0
SYS.CFG.GP0.GP1	MEM_ADDR1	MEM_ADDR1
SYS.CFG.GP0.GP2	MEM_ADDR2	MEM_ADDR2
SYS.CFG.GP0.GP3	MEM_ADDR3	MEM_ADDR3
SYS.CFG.GP0.GP4	MEM_ADDR4	MEM_ADDR4
SYS.CFG.GP0.GP5	MEM_ADDR5	MEM_ADDR5
SYS.CFG.GP0.GP6	MEM_ADDR6	MEM_ADDR6
SYS.CFG.GP0.GP7	MEM_ADDR7	MEM_ADDR7
SYS.CFG.GP1.GP0	MEM_ADDR8	MEM_ADDR8
SYS.CFG.GP1.GP1	MEM_ADDR9	MEM_ADDR9
SYS.CFG.GP1.GP2	MEM_ADDR10	MEM_ADDR10
SYS.CFG.GP1.GP3	MEM_ADDR11	MEM_ADDR11
SYS.CFG.GP1.GP4	MEM_ADDR12	MEM_ADDR12
SYS.CFG.GP1.GP5	MEM_ADDR13	MEM_ADDR13
SYS.CFG.GP1.GP6	MEM_ADDR14	MEM_ADDR14
SYS.CFG.GP1.GP7	MEM_ADDR15	MEM_ADDR15
SYS.CFG.GP2.GP0	MEM_ADDR16	MEM_ADDR16
SYS.CFG.GP2.GP1	MEM_ADDR17	MEM_ADDR17
SYS.CFG.GP2.GP2	MEM_ADDR18	MEM_ADDR18
SYS.CFG.GP2.GP3	RAM_CSN0	RAM_CSN0
SYS.CFG.GP2.GP4	RAM_CSN1	RAM_CSN1
SYS.CFG.GP2.GP5	RAM_CSN2	SPW_RXD
SYS.CFG.GP2.GP6	RAM_CSN3	SPW_RXS
SYS.CFG.GP2.GP7	ROM_CSN0	SPW_TXS
SYS.CFG.GP3.GP0	ROM_CSN1	SPW_TXD
SYS.CFG.GP3.GP1	MEM_DATA0	MEM_DATA0
SYS.CFG.GP3.GP2	MEM_DATA1	MEM_DATA1
SYS.CFG.GP3.GP3	MEM_DATA2	MEM_DATA2
SYS.CFG.GP3.GP4	MEM_DATA3	MEM_DATA3
SYS.CFG.GP3.GP5	MEM_DATA4	MEM_DATA4
SYS.CFG.GP3.GP6	MEM_DATA5	MEM_DATA5
SYS.CFG.GP3.GP7	MEM_DATA6	MEM_DATA6
SYS.CFG.GP4.GP0	MEM_DATA7	MEM_DATA7
SYS.CFG.GP4.GP1	MEM_OEN	MEM_OEN
SYS.CFG.GP4.GP2	MEM_WRN	MEM_WRN
SYS.CFG.GP4.GP3		ROM_CSN0
SYS.CFG.GP4.GP4		ROM_CSN1
SYS.CFG.GP4.GP5	1553_RXENA	1553_RXENA
SYS.CFG.GP4.GP6	1553_TXA	1553_TXA
SYS.CFG.GP4.GP7	1553_RXA	1553_RXA
SYS.CFG.GP5.GP0	1553_RXNA	1553_RXNA
SYS.CFG.GP5.GP1	1553_TXNA	1553_TXNA
SYS.CFG.GP5.GP2	1553_TXINHA	1553_TXINHA
SYS.CFG.GP5.GP3	1553_RXB	1553_RXB
SYS.CFG.GP5.GP4	1553_RXNB	1553_RXNB
SYS.CFG.GP5.GP5	1553_RXENB	1553_RXENB
SYS.CFG.GP5.GP6	1553_TXB	1553_TXB
SYS.CFG.GP5.GP7	1553_CLK	1553_CLK
SYS.CFG.GP6.GP0	1553_TXNB	1553_TXNB
SYS.CFG.GP6.GP1	1553_TXINHB	1553_TXINHB
SYS.CFG.GP6.GP2		
SYS.CFG.GP6.GP3		
SYS.CFG.GP6.GP4		
SYS.CFG.GP6.GP5		
SYS.CFG.GP6.GP6		
SYS.CFG.GP6.GP7		
SYS.CFG.GP7.GP0		
SYS.CFG.GP7.GP1		
SYS.CFG.GP7.GP2	CAN_TX0	CAN_TX0
SYS.CFG.GP7.GP3	CAN_RX0	CAN_RX0
SYS.CFG.GP7.GP4	CAN_SEL0	CAN_SEL0
SYS.CFG.GP7.GP5	CAN_RX1	CAN_RX1
SYS.CFG.GP7.GP6	CAN_TX1	CAN_TX1
SYS.CFG.GP7.GP7	CAN_SEL1	CAN_SEL1

2.9.3 Scenario #3 - Bus bridge booting from external serial ROM

This chapter shows how to make use of more I/O and describes how to configure the I/O mux for a node bus bridge.

The following assumptions are made for the system:

- System boots and runs software from external serial memory. (Software can also execute from internal instruction memory).
- Connects to spacecraft bus either via MIL-1553B or SpaceWire, and on the other side to node bus via CAN.

In table 23 two example of I/O configurations for Node bus bridge are depicted. Note that the external SPI configuration ROM and SpaceWire are connected on dedicated pins.

Table 23. Examples of I/O MUX configurations for Node bus bridges when using the external serial memory

	Bridge	
IO Config Register	BRIDGE.CFG1	BRIDGE.CFG2
SYS.CFG.GP0.GP0		
SYS.CFG.GP0.GP1		
SYS.CFG.GP0.GP2		
SYS.CFG.GP0.GP3		
SYS.CFG.GP0.GP4		
SYS.CFG.GP0.GP5		
SYS.CFG.GP0.GP6		
SYS.CFG.GP0.GP7		
SYS.CFG.GP1.GP0		
SYS.CFG.GP1.GP1		
SYS.CFG.GP1.GP2		
SYS.CFG.GP1.GP3		
SYS.CFG.GP1.GP4		
SYS.CFG.GP1.GP5		
SYS.CFG.GP1.GP6		
SYS.CFG.GP1.GP7		
SYS.CFG.GP2.GP0		
SYS.CFG.GP2.GP1		
SYS.CFG.GP2.GP2		
SYS.CFG.GP2.GP3		
SYS.CFG.GP2.GP4		
SYS.CFG.GP2.GP5		SPW_RXD
SYS.CFG.GP2.GP6		SPW_RXS
SYS.CFG.GP2.GP7		SPW_TXS
SYS.CFG.GP3.GP0		SPW_TXD
SYS.CFG.GP3.GP1		
SYS.CFG.GP3.GP2		
SYS.CFG.GP3.GP3		
SYS.CFG.GP3.GP4		
SYS.CFG.GP3.GP5		
SYS.CFG.GP3.GP6		
SYS.CFG.GP3.GP7		
SYS.CFG.GP4.GP0		
SYS.CFG.GP4.GP1		
SYS.CFG.GP4.GP2		
SYS.CFG.GP4.GP3		
SYS.CFG.GP4.GP4		
SYS.CFG.GP4.GP5	1553_RXENA	1553_RXENA
SYS.CFG.GP4.GP6	1553_TXA	1553_TXA
SYS.CFG.GP4.GP7	1553_RXA	1553_RXA
SYS.CFG.GP5.GP0	1553_RXNA	1553_RXNA
SYS.CFG.GP5.GP1	1553_TXNA	1553_TXNA
SYS.CFG.GP5.GP2	1553_TXINHA	1553_TXINHA
SYS.CFG.GP5.GP3	1553_RXB	1553_RXB
SYS.CFG.GP5.GP4	1553_RXNB	1553_RXNB
SYS.CFG.GP5.GP5	1553_RXENB	1553_RXENB
SYS.CFG.GP5.GP6	1553_TXB	1553_TXB
SYS.CFG.GP5.GP7	1553_CLK	1553_CLK
SYS.CFG.GP6.GP0	1553_TXNB	1553_TXNB
SYS.CFG.GP6.GP1	1553_TXINHB	1553_TXINHB
SYS.CFG.GP6.GP2		
SYS.CFG.GP6.GP3		
SYS.CFG.GP6.GP4		
SYS.CFG.GP6.GP5		
SYS.CFG.GP6.GP6		
SYS.CFG.GP6.GP7		
SYS.CFG.GP7.GP0		
SYS.CFG.GP7.GP1		
SYS.CFG.GP7.GP2	CAN_TX0	CAN_TX0
SYS.CFG.GP7.GP3	CAN_RX0	CAN_RX0
SYS.CFG.GP7.GP4	CAN_SEL0	CAN_SEL0
SYS.CFG.GP7.GP5	CAN_RX1	CAN_RX1
SYS.CFG.GP7.GP6	CAN_TX1	CAN_TX1
SYS.CFG.GP7.GP7	CAN_SEL1	CAN_SEL1

2.10 Cores

The design is based on the following cores from the GRLIB IP Library:

Table 24. Used IP cores

Core	Function	Vendor	Device
AHB2AHB	Bi-directional AHB/AHB bridge	0x01	0x020
AHBROM	Generic AHB ROM	0x01	0x1B
AHBSTAT	AHB Status Register	0x01	0x052
AHBTRACE	AHB trace buffer	0x01	0x017
AHBUART	Serial/AHB Debug interface	0x01	0x007
APBCTRL	AHB/APB bridge	0x01	0x006
APBUART	8-bit UART with FIFO	0x01	0x00C
DSU3	LEON3 Debug Support Unit	0x01	0x004
LRAM	Local on-chip SRAM with EDAC and AHB interface	0x01	0x0A3
FTMCTRL	8/16/32-bit memory controller with EDAC	0x01	0x054
GPTIMER	Modular timer unit with watchdog	0x01	0x038
GR1553B	MIL-STD-1553B / AS15531 interface	0x01	0x04D
GRADCDAC	ADC/DAC Interface	0x01	0x036
GRCAN	CAN 2.0 controller with DMA	0x01	0x03D
GRCLKGATE	Clock gating unit	0x01	0x02C
GRDMAC	DMA Controller with internal AHB/APB bridge	0x01	0x095
GRGPIO	General Purpose I/O Port	0x01	0x01A
GRGPIO_SEQ	General Purpose Sequencer	0x01	0x1F8
GRGPREG	General purpose register	0x01	0x087
GRMEMPROT	Memory protection	0x01	0x1F1
GRPWM	PWM controller	0x01	0x04A
GRPWRX	PacketWire receiver	0x01	0x08D
GRPWTX	PacketWire transmitter	0x01	0x08E
GRSPW2	SpaceWire codec with AHB host interface and RMAP	0x01	0x029
I2C2AHB	I2C to AHB bridge	0x01	0x00B
I2CMST	I2C master	0x01	0x028
I2CSLV	I2C slave	0x01	0x03E
IRQ(A)MP	Multiprocessor interrupt controller with AMP extensions	0x01	0x00D
L3STAT	LEON3 statistical unit	0x01	0x098
LEON3FT	LEON3 SPARC V8 32-bit processor	0x01	0x053
MEMSCRUB	Memory scrubber	0x01	0x057
RSTGEN	Reset generator	N/A	N/A
SPI2AHB	SPI to AHB bridge	0x01	0x05C
SPICTRL	SPI controller	0x01	0x02D
SPIMCTRL	SPI memory controller	0x01	0x045
SPISLAVE	SPI for space slave	0x01	0x0A7

The information in the last two columns is available via plug'n'play information in the system and is used by software to detect peripherals and to initialize software drivers.

2.11 Memory map

The memory map of the internal AHB and APB buses as seen from the processor cores can be seen below.

The column 'DMA Access' in the Memory map table indicates if the AMBA peripheral is accessible by a DMA controller.

Table 25. AMBA memory map, as seen from processors

Core		Address range	Area	DMA Access
AHBROM		0x00000000 - 0x000FFFFF	Internal Boot PROM	Yes
FTMCTRL		0x01000000 - 0x01FFFFFF	External PROM	Yes
SPIMCTRL		0x02000000 - 0x03FFFFFF	SPI Memory 0 mapped area	Yes
SPIMCTRL		0x04000000 - 0x05FFFFFF	SPI Memory 1 mapped area	Yes
DLRAM		0x30000000 - 0x300FFFFF	Processor local data memory	Yes
ILRAM		0x31000000 - 0x310FFFFF	Processor local instruction memory	Yes
FTMCTRL		0x40000000 - 0x4FFFFFFF	External SRAM Memory	Yes
NVRAM		0x50000000 - 0x50FFFFFF	Reserved space for internal NVRAM	Yes
	FTMCTRL	0x80000000 - 0x800000FF	Memory controller with EDAC	No
	DLRAM	0x80001000 - 0x800010FF	On-chip Data memory control registers	No
	IRQAMP	0x80002000 - 0x800023FF	Multi-processor Interrupt Ctrl.	No
	GPTIMER	0x80003000 - 0x800030FF	Modular Timer Unit 0 with Watchdog support	No
A	GPTIMER	0x80004000 - 0x800040FF	Modular Timer Unit 1	No
P	MEMPROT	0x80005000 - 0x800051FF	Memory Protection Unit for system bus	No
B	GRCLKGATE	0x80006000 - 0x800060FF	Clock gating configuration register unit 0	No
B	GRCLKGATE	0x80007000 - 0x800070FF	Clock gating configuration register unit 1	No
C	GRGPREG	0x80008000 - 0x800080FF	Configuration and test registers	No
T	L3STAT	0x80009000 - 0x800093FF	LEON3 Statistics Unit	No
R	AHBSTAT	0x8000A000 - 0x8000A0FF	AHB Status Register for DMA AMBA bus	No
L	ILRAM	0x8000B000 - 0x8000B0FF	On-chip Instruction memory control registers	No
0	GRSPWTDP	0x8000C000 - 0x8000C1FF	CCSDS TDP / SpaceWire I/F	No
	GRGPRBANK	0x8000D000 - 0x8000D0FF	IO Mux configuration register	No
	GRGPREG	0x8000E000 - 0x8000E0FF	Test register and system control register	No
	AHBUART	0x8000F000 - 0x8000F0FF	Slave UART configuration for remote access	No

Table 25. AMBA memory map, as seen from processors

Core		Address range	Area	DMA Access
APBCTRL1	GRSPW2	0x80100000 - 0x801000FF	GRSPW2 SpaceWire Serial Link	No
	GR1553B	0x80101000 - 0x801010FF	MIL-STD-1553B Interface	No
	GRCAN	0x80102000 - 0x801023FF	CAN Controller with DMA	No
	GRCAN	0x80103000 - 0x801033FF	CAN Controller with DMA	No
	SPI2AHB	0x80104000 - 0x801040FF	SPI to AHB Bridge	No
	I2C2AHB	0x80105000 - 0x801050FF	I2C to AHB Bridge	No
	GRDMAC	0x80106000 - 0x801061FF	Stand alone DMA unit 0	No
	GRDMAC	0x80107000 - 0x801071FF	Stand alone DMA unit 1	No
	GRDMAC	0x80108000 - 0x801081FF	Stand alone DMA unit 2	No
	GRDMAC	0x80109000 - 0x801091FF	Stand alone DMA unit 3	No
	MEMPROT	0x8010A000 - 0x8010A0FF	Memory protection for DMA bus	No
	BANDGAP	0x8010B000 - 0x8010B0FF	Bandgap control registers	No
	BO	0x8010C000 - 0x8010C0FF	Brown-Out detection control registers	No
	PLL	0x8010D000 - 0x8010D0FF	PLL control registers	No
	PWRX	0x8010E000 - 0x8010E0FF	PacketWire Receiver with DMA	No
	PWTX	0x8010F000 - 0x8010F0FF	PacketWire Transmitter with DMA	No
APBCTRL2	APBUART [1)]	0x80300000 - 0x803000FF	Generic UART 0	Yes
	APBUART [1)]	0x80301000 - 0x803010FF	Generic UART 1	Yes
	APBUART [1)]	0x80302000 - 0x803020FF	Generic UART 2	Yes
	APBUART [1)]	0x80303000 - 0x803030FF	Generic UART 3	Yes
	APBUART [1)]	0x80304000 - 0x803040FF	Generic UART 4	Yes
	APBUART [1)]	0x80305000 - 0x803050FF	Generic UART 5	Yes
	AHBSTAT [1)]	0x80306000 - 0x803060FF	AHB Status Register for MAIN AMBA bus	Yes
	NVRAM [1)]	0x80307000 - 0x803070FF	Memory controller with EDAC (NVRAM)	Yes
	GRADCDAC [1)]	0x80308000 - 0x803080FF	External ADC / DAC Interface	Yes
	SPICTRL [1)]	0x80309000 - 0x803090FF	SPI Controller 0	Yes
	SPICTRL [1)]	0x8030A000 - 0x8030A0FF	SPI Controller 1	Yes
		0x8030B000 - 0x8030BFFF	Unused	-
	GRGPIO [1)]	0x8030C000 - 0x8030CFFF	General Purpose I/O port 0 to 31	Yes
	GRGPIO [1)]	0x8030D000 - 0x8030DFFF	General Purpose I/O port 32 to 64	Yes
	I2CMST [1)]	0x8030E000 - 0x8030E0FF	I2C-master 0	Yes
	I2CMST [1)]	0x8030F000 - 0x8030F0FF	I2C-master 1	Yes
	GRPWM0 [1)]	0x80310000 - 0x803100FF	PWM generator 0	Yes

Table 25. AMBA memory map, as seen from processors

Core		Address range	Area	DMA Access
APBCTRL3	ADC [1)]	0x80400000 - 0x804000FF	On-chip ADC interface 0	Yes
	ADC [1)]	0x80401000 - 0x804010FF	On-chip ADC interface 1	Yes
	ADC [1)]	0x80402000 - 0x804020FF	On-chip ADC interface 2	Yes
	ADC [1)]	0x80403000 - 0x804030FF	On-chip ADC interface 3	Yes
	ADC [1)]	0x80404000 - 0x804040FF	On-chip ADC interface 4	Yes
	ADC [1)]	0x80405000 - 0x804050FF	On-chip ADC interface 5	Yes
	ADC [1)]	0x80406000 - 0x804060FF	On-chip ADC interface 6	Yes
	ADC [1)]	0x80407000 - 0x804070FF	On-chip ADC interface 7	Yes
	DAC [1)]	0x80408000 - 0x804080FF	On-chip DAC interface 0	Yes
	DAC [1)]	0x80409000 - 0x804090FF	On-chip DAC interface 1	Yes
	DAC [1)]	0x8040A000 - 0x8040A0FF	On-chip DAC interface 2	Yes
	DAC [1)]	0x8040B000 - 0x8040B0FF	On-chip DAC interface 3	Yes
	I2CSLV [1)]	0x8040C000 - 0x8040C0FF	I2C-slave 0	Yes
	I2CSLV [1)]	0x8040D000 - 0x8040D0FF	I2C-slave 1	Yes
	GRSPI4 [1)]	0x8040E000 - 0x8040E0FF	SPI for Space Slave	Yes
	GRPWM1 [1)]	0x80410000 - 0x804100FF	PWM generator 1	Yes

Table 25. AMBA memory map, as seen from processors

Core		Address range	Area	DMA Access
APBCTRL DBG	AHBUART	0x94000000 - 0x940000FF	AHB Debug UART	Yes
	L3STAT	0x94001000 - 0x940013FF	LEON3 Statistics Unit	Yes
	GRGPREG	0x94002000 - 0x940020FF	Analog test control	Yes
		0x94003000 - 0x94003FFF	Unused	-
		0x94004000 - 0x94004FFF	Unused	-
		0x94005000 - 0x94005FFF	Unused	-
		0x94006000 - 0x94006FFF	Unused	--
		0x94007000 - 0x94007FFF	Unused	-
		0x94008000 - 0x94008FFF	Unused	-
		0x94009000 - 0x94009FFF	Unused	-
		0x9400A000 - 0x9400AFFF	Unused	-
		0x9400B000 - 0x9400BFFF	Unused	-
		0x9400C000 - 0x9400CFFF	Unused	-
		0x9400D000 - 0x9400DFFF	Unused	-
		0x9400E000 - 0x9400EFFF	Unused	-
		0x9400F000 - 0x9400FFFF	Unused	-
DSU3		0x90000000 - 0x907FFFFF	LEON3 Debug Support Unit	Yes
-		0x94000000 - 0x940FFFFF	APB bus DBG address space	Yes
AHBTRACE1		0x9ff20000 - 0x9ff3FFFF	AHB Trace Buffer	Yes
-		0x9FFFF000 - 0x9FFFFFFF	Configuration area for Debug bus	Yes
MEMSCRUB		0xFFF00000 - 0xFFF000FF	Memory scrubber registers	Yes
SPIMCTRL		0xFFF00100 - 0xFFF001FF	SPIMCTRL control registers 0	Yes
SPIMCTRL		0xFFF00200 - 0xFFF002FF	SPIMCTRL control registers 1	Yes
-		0xFFFFF000 - 0xFFFFFFFF	Configuration area for system main bus	Yes

Note 1: CPU and DMA controller accesses specified memory areas using different APB interfaces. The CPU and DMA can access different APB peripherals at the same time without conflict

Accesses to unused AMBA AHB address space will result in an AMBA ERROR response, this applies to the memory areas that are marked as "Unused" in the table above. Accesses to unused areas located on one of the AHB/APB bridges will not have any effect, note that these unoccupied address ranges are not marked as "Unused" in the table above. No AMBA ERROR response will be given for memory allocated to one of the APB bridges.

2.12 Atomic access

This chapter describes how atomic read and modify operations are performed in the GR716 microcontroller. The GR716 microcontroller supports atomic read-modify-write operations in hardware by mirroring the address space of the peripheral and internal data memory for different atomic operations. Atomic operations supported are OR, AND, XOR and Set&Clear.

Atomic operations are performed by adding an atomic operation offset to the destination register address of the normal write operation of a atomic bit mask:

Table 26. For atomic operations in local processor data memory

*(DEST_ADDR + ATOMIC_OP_OFFSET) = ATOMIC_MASK;

Local data memory use the following atomic offset:

- OR operation offset: 0x10000
- AND operation offset 0x20000
- XOR operation offset 0x30000
- Set and clear operation offset: 0x40000

APB peripheral registers use the following atomic offset:

- AND operation offset: 0x20000
- OR operation offset 0x40000
- XOR operation offset 0x60000
- Set and clear operation offset: 0x80000

When using the atomic set and clear function, some extra precautions have to be taken. In order to be able to both set and clear a 32 bit register two consecutive 32-bit writes need to be performed. The access will not be executed and an error response will be given if a non-related access appears in between the 2 writes to the same slave. To guarantee no non-related access in between the 2 atomic set and clear write accesses the LEON3FT processors ability to perform a double store should be used. [SPARC]

All addresses in the atomic set and clear address space have been aligned to 0x8 i.e. local write address in processor data memory or APB peripheral needs to be modified in order to avoid exception from the LEON3FT processor. The shifted address is automatically decoded in the local memory or the APB peripheral.

Table 27. Set and clear atomic operation address definition

$$(ADDR + OP) \& 0xFFFFF000) + ((ADDR \& 0x00000FFF) << 1)$$

For simplicity and to guarantee the use of a double store it is recommended to include a function that forces the usage of the double store operation. An example of such a function for using atomic set and clear function to register in APB peripherals is included in this chapter:

Table 28. Example of Atomic set and clear function using SPARC V8 double store operation

```
// Atomic set and clear for aliging write address and setting operation offset
// function need set and clear mask and address to peripheral
void SetAndClear (unsigned int _set, unsigned int _clr, unsigned int *addr)
{
    unsigned long long a = ((unsigned long long int) _set << 32) | _clr;      // Concatenate set and clear
                                                                              // mask
    unsigned int b = (unsigned int)addr & 0xFFFFF000;                         // Keep base address
    b += 0x80000;                                                             // Add atomic offset for op.
    b |= (((unsigned int) addr & 0x00000FFF) << 1);                           // Align local address to 0x8
    __asm__ volatile ("std %1, [%0]"::"r"(b),"r"(a));                         // Insert double store op
}
```

2.13 Interrupts

The table below indicates the interrupt default assignments. All interrupts are handled by the interrupt controller and forwarded to the LEON3 processors. For more configuration and option see chapter 40

Table 29. Bus Interrupt line assignments

Interrupt ID	Interrupt Line	Core	Comment
	0	n/a	not used
1	1	Extended	Extended Interrupts for primary interrupt controller
2	2	GRPWRX	Interrupt from PacketWire RX controller
3	3	GRPWTX	Interrupt from PacketWire TX controller
4	4	GR1553	Interrupt from GR1553 controller
5	5	GRSPW2	Interrupt from SpaceWire controller
6	6	GRDMAC	DMA controller interrupt 0 - 3
7	7	I2CS/2AHB/SPI2AHB	Interrupt from I2C Slave 0 and 1 / I2C2AHB / SPI2AHB
8	8	GRPWM	Interrupt from PWM controller
9	9	GPTIMER0	Interrupt 1 from timer block 0
10	10	GPTIMER0	Interrupt 2 from timer block 0
11	11	GPTIMER0	Interrupt 3 from timer block 0
12	12	GPTIMER0	Interrupt 4 from timer block 0
13	13	GPTIMER0	Interrupt 5 from timer block 0
14	14	GPTIMER0	Interrupt 6 from timer block 0
15	15	GPTIMER0	Interrupt 7 from timer block 0 (WDOG)
16	16	GRADCDAC	External ADC interface
17	17	GRGPIO	Interrupt from GPIO controller 0 / External DAC
18	18	GRGPIO	(Interrupt from GPIO controller 0)
19	19	GRGPIO	(Interrupt from GPIO controller 0)
20	20	GRGPIO	(Interrupt from GPIO controller 0)
21	21	GRCAN0&1	Interrupt from CAN controller
22	22	GRCAN0&1	Interrupt from CAN RX controller
23	23	GRCAN0&1	Interrupt from CAN TX controller
24	24	APBUART	APBUART interface interrupt 0
25	25	APBUART	APBUART interface interrupt 1
26	26	DAC	on-chip DAC 0 interrupt
27	27	DAC	on-chip DAC 1 interrupt
28	28	ADC0	on-chip ADC interrupt 0
29	29	ADC1	on-chip ADC interrupt 1
30	30	ADC2	on-chip ADC interrupt 2
31	31	ADC3	on-chip ADC interrupt 3
28	32	ADC4	on-chip ADC interrupt 4
29	33	ADC5	on-chip ADC interrupt 5
30	34	ADC6	on-chip ADC interrupt 6

Table 29. Bus Interrupt line assignments

Interrupt ID	Interrupt Line	Core	Comment
31	35	ADC7	on-chip ADC interrupt 7
26	36	DAC	on-chip DAC 2 interrupt
27	37	DAC	on-chip DAC 3 interrupt
16	38	GRGPIO	Interrupt from GPIO controller 1
17	39	GRGPIO	(Interrupt from GPIO controller 1)
18	40	GRGPIO	(Interrupt from GPIO controller 1)
19	41	GRGPIO	(Interrupt from GPIO controller 1)
3	42	APBUART	APBUART interface interrupt 2
4	43	GRSPWTDP	SpaceWire TDP
5	44	APBUART	APBUART interface interrupt 3
6	45	APBUART	APBUART interface interrupt 4
7	46	APBUART	APBUART interface interrupt 5
8	47	I2CSLV1 / I2C2AHB	I2C Slave Interface 0 and/or I2C2AHB
11	48	SPICTRL	Interrupt from SPI controller 0
12	49	SPICTRL	Interrupt from SPI controller 1
13	50	I2CM	Interrupt from I2C master controller 0
14	51	I2CM	Interrupt from I2C master controller 1
2	52	SPIMCTRL	Interrupt from SPI memory controller 0 and 1
20	53	GPTIMER1	Interrupt 1 from timer block 1
21	54	GPTIMER1	Interrupt 2 from timer block 1
22	55	GPTIMER1	Interrupt 3 from timer block 1
23	56	GPTIMER1	Interrupt 4 from timer block 1
24	57	GPTIMER1	Interrupt 5 from timer block 1
25	58	GPTIMER1	Interrupt 6 from timer block 1
26	59	GPTIMER1	Interrupt 7 from timer block 1
16	60	GRGPIOSEQ0	GPIO sequencer 0
17	61	GRGPIOSEQ1	GPIO sequencer 1
18	62	PLL	PLL interrupt, Power On Reset and Brown Out interrupt
19	63	AHBSTAT/DLRAM, ILRAM/GRGPRBANK/ MEMSCRUB	AHB status, Scrubbers and I/O mux interrupt

3 Signals

3.1 Bootstrap signals

The power-up and initialisation state is affected by several external signals as shown in table 30.The bootstrap signals taken via GPIO, DUART and SPIM signals are saved when the on-chip system reset is released. This occurs after deassertion of the internal power-on-reset or RESET_IN_N input and valid input clock on the SYS_CLK pin. The state of the signals are sampled and stored in a bootstrap register. See section 7.2 for boot strap register description.

Note that some pins used for bootstrapping have dual purpose can be used for normal operations after reset has been released.

Table 30. Bootstrap signals

Pin	Functional description
DSU_EN	Enables the Debug Support Unit (DSU) and other members connected to the Debug AHB bus. If DSU_EN is HIGH the DSU and the Debug AHB bus will be clocked. If DSU_EN is LOW the DSU and all members on the Debug AHB bus will be clock gated off
DSU_BREAK	Puts processor in debug mode when asserted while DSU_EN is HIGH. When DSU_EN is LOW, BREAK is assigned to the timer enable bit of the watchdog timer and also controls if the processor starts executing after reset.
GPIO[17]	Enable bypass of internal boot ROM. Boot strapping this signal 'high' will force the processor NOT to execute the internal boot software. Normally the processor starts executing from address 0x0. But if this bootstrap is 'high' the processor will start execute from software from address selected by bootstrap signals SPIM_MOSI & SPIM_SCK & SPIM_SEL.
GPIO[0]	Determines the use of EDAC for external boot RAM when the GR716 microcontroller shall boot from external memory. Set to low for enabling EDAC and to high for disabling EDAC. Determine the use of PLL when the GR716 microcontroller shall boot via a remote source.
GPIO[62]	Enable test of internal memories at startup. The processor starts checking internal memory for bit errors during boot if this bootstrap is set to 'high'. Setting this to 'high' will slow down the boot processes since the check is software based.
GPIO[63]	Enables extra protection of external boot source or setting SpaceWire clock frequency If boot from external RAM/ROM this pin enable the use of redundant memory if primary boot memory fails. If remote access via SPW this pin together with DUART_TXD are used to set the SpaceWire default speed.
DUART_TXD	If boot from external SRAM/ROM/SPI-ROM this pin are used for selecting to copy ASW image from selected external boot RAM/ROM (If not set for this option. The GR716 microcontroller will start execute from the selected external memory) If remote access via SPW is selected this pin together with GPIO[63] are used to set the SPW default speed. Set DUART_TXD & GPIO[63] accordingly depending on external SpaceWire frequency: "00" - For 5Mhz external frequency source "01" - For 10Mhz external frequency source "10" - For 20Mhz external frequency source "11" - For 25Mhz external frequency source
SPIM_MOSI	Enable remote access. When remote access is disabled processor will start from selected external boot memory.

Table 30. Bootstrap signals

Pin	Functional description
SPIM_SCK & SPIM_SEL	This pin together with the pin SPIM_MOSI selects which source the LEON3FT microcontroller should boot from: When copy ASW boot from external source is selected (SPIM_MOSI is low) "00" - Copy software image from SPI Memory "01" - Copy software image from external SRAM "10" - Copy software image from external ROM "11" - Copy software image from external I2C When boot from external source is selected (SPIM_MOSI is low) "00" - Boot from SPI Memory "01" - Boot from external SRAM "10" - Boot from external ROM "11" - Unused Enable for remote access interfaces (SPIM_MOSI is high) "00" - SPI remote access "01" - SpaceWire RMAP enable "10" - I2C remote access "11" - UART remote access

Note 1: User should use weak pull-up/pull-downs for configuration of the GR716 microcontroller. A weak resistor is defined as resistor which require low current from the drive circuitry. The resistance should be greater or equal to 10K ohm.

Note 2: Bootstrap signals determine state of GR716 microcontroller after reset has been released.

Note 3: The LEON3FT processor is always enabled after reset has been released.

Note 4: Remote access request will force the processor to power down according to 16.2.16 after initialization has been completed.

Note 5: Remote access will enable clocks according to table:

1. SpaceWire option will enable SpaceWire core and external SpaceWire interface
2. SPI option will enable SPI for Space Slave and external SPI for Space interface
3. I2C option will enable I2C2AHB bridge and external I2C interface
4. UART option will enable AHBUART1 and external UART interface

Note 6: Only requested memory interface will have clock and pins enabled.

Note 7: Watchdog timer will always be enabled and not controllable from bootstraps.

3.1.1 Boot strap configuration for remote access

This section describes valid bootstrap configuration for remote access:

Table 31. Remote bootstrap configurations

Pin								
Remote Access	Source		SpaceWire Divisor		**PLL** [4) 5)]	Boot Bypass	Memory test	
SPIM_MOSI	SPIM_SCK	SPIM_SEL	DUART_TXD	GPIO[63]	GPIO[0]	GPIO[17]	GPIO[62]	**Functional description**
high	low	high	low	low	low	low	low	Enable SpaceWire remote access using a 5 MHz input clock after initialization of the processor
high	low	high	low	low	low	low	high	Enable SpaceWire remote access using a 5 MHz input clock after initialization of the processor and internal memory test.
high	low	high	low	high	low	low	low	Enable SpaceWire remote access using a 10 MHz input clock after initialization of the processor
high	low	high	low	high	low	low	high	Enable SpaceWire remote access using a 10 MHz input clock after initialization of the processor and internal memory test.
high	low	high	high	low	low	low	low	Enable SpaceWire remote access using a 20 MHz input clock after initialization of the processor
high	low	high	high	low	low	low	high	Enable SpaceWire remote access using a 20 MHz input clock after initialization of the processor and internal memory test.
high	low	high	high	low	low	low	low	Enable SpaceWire remote access using a 25 MHz input clock after initialization of the processor
high	low	high	high	low	low	low	high	Enable SpaceWire remote access using a 25 MHz input clock after initialization of the processor and internal memory test.
high	low	high	x [2)]	x [2)]	high	low	low	Enable SpaceWire remote access using the clock direct from the SpaceWire input pin after initialization of the processor

Table 31. Remote bootstrap configurations

Pin								
Remote Access	Source		SpaceWire Divisor		**PLL** [4) 5)]	Boot Bypass	Memory test	
SPIM_MOSI	SPIM_SCK	SPIM_SEL	DUART_TXD	GPIO[63]	GPIO[0]	GPIO[17]	GPIO[62]	**Functional description**
high	low	high	x [2)]	x [2)]	high	low	high	Enable SpaceWire remote access using the clock direct from the SpaceWire input pin after initialization of the processor and internal memory test.
high	low	low	x [2)]	x [2)]	x [2)]	low	low	Enable SPI remote access after initialization of the processor.
high	low	low	x [2)]	x [2)]	x [2)]	low	high	Enable SPI remote access after initialization of the processor and internal memory test.
high	high	low	x [2)]	x [2)]	x [2)]	low	low	Enable I2C remote access after initialization of the processor.
high	high	low	x [2)]	x [2)]	x [2)]	low	high	Enable I2C remote access after initialization of the processor and internal memory test.
high	high	high	x [2)]	x [2)]	x [2)]	low	low	Enable UART remote access after initialization of the processor.
high	high	high	x [2)]	x [2)]	x [2)]	low	high	Enable UART remote access after initialization of the processor and internal memory test.

Note 1: To enable remote access SPIM_MOSI must be bootstrapped to high.

Note 2: Configuration pin has no effect or not used for bootstrap configuration. It recommend to tie the pin to either low or high.

Note 3: Processor are forced into power down mode after processor and memory test has been completed.

Note 4: Enable internal PLL by bootstrap signal to low. When using the internal PLL the link speed will be set to 10 Mbps after reset and maximum link speed after auto negotiation of link speed is 100 Mbps.

Note 5: Disable internal PLL by bootstrap signal to high. When bypassing the internal PLL the speed will be set to input frequency of the SpaceWire clock. The PLL will be in power down mode.

3.1.2 Boot strap configuration for external SPI memory

This section describes valid bootstrap configuration for use of external memory options:

Table 32. External SPI memory bootstrap configurations

Pin								
Remote Access	Source		ASW [3]	Red [4]	EDAC [5]	Bypass [6]	Memory test	
SPIM_MOSI	SPIM_SCK	SPIM_SEL	DUART_TXD	GPIO[63]	GPIO[0]	GPIO[17]	GPIO[62]	**Functional description**
low	low	low	low	low	[5]	low	[7]	Enable external SPI memory boot. Processor will start execute application software direct from memory after initialization of the processor.
low	low	low	low	low	[5]	high	[7]	Enable external SPI memory boot. Processor will start execute application software direct from memory.
low	low	low	high	low	[5]	low	low	Enable external ASW SPI memory boot after initialization of the processor. Processor will copy and extract ASW container before executing application software.
low	low	low	high	high	[5]	low	low	Enable external ASW SPI memory with DMR protection boot after initialization of the processor. Processor will copy and extract ASW container before executing application software.

Note 1: To enable external memory access SPIM_MOSI must be bootstrapped to low.

Note 2: Configuration pin has no effect or not used for bootstrap configuration. It recommend to tie the pin either to low or high.

Note 3: Enable ASW protection. ASW protection usage is described in section 51.

Note 4: Enable dual module redundancy protection. Option only valid in combination with ASW protection. Redundant memory is expected to located at 0x04000000.

Note 5: Enable BCH EDAC protection. EDAC can be enabled and used in combination with all other options. When configuration is used external memory must included BCH check bits.

Note 6: Enable bypass of the internal boot ROM. When enabled the processor will start execute code directly from the primary memory at 0x02000000. Processor or internal memory is initialized after reset when this option is used.

Note 7: Enable memory test. Memory test configuration can be used in combination with all other options. Memory test have no affect when internal boot ROM is bypassed.

3.1.3 Boot strap configuration for external SRAM memory

This section describes valid bootstrap configuration for use of external memory options:

Table 33. External SRAM memory bootstrap configurations

Pin								
Remote Access	Source		ASW [3]	Red [4]	EDAC [5]	Bypass [6]	Memory test	
SPIM_MOSI	SPIM_SCK	SPIM_SEL	DUART_TXD	GPIO[63]	GPIO[0]	GPIO[17]	GPIO[62]	**Functional description**
low	low	high	low	low	[5]	low	[7]	Enable external SRAM memory boot. Processor will start execute application software direct from memory after initialization of the processor.
low	low	high	low	low	[5]	high	[7]	Enable external SRAM memory boot. Processor will start execute application software direct from memory.
low	low	high	high	low	[5]	low	low	Enable external ASW SRAM memory boot after initialization of the processor. Processor will copy and extract ASW container before executing application software.
low	low	high	high	high	[5]	low	low	Enable external ASW SRAM memory with DMR protection boot after initialization of the processor. Processor will copy and extract ASW container before executing application software.

Note 1: To enable external memory access SPIM_MOSI must be bootstrapped to low.

Note 2: Configuration pin has no effect or not used for bootstrap configuration. It recommend to tie the pin either to low or high.

Note 3: Enable ASW protection. ASW protection usage is described in section 51.

Note 4: Enable dual module redundancy protection. Option only valid in combination with ASW protection. Redundant memory is expected to be located at address allocated for external chip select signal 1.

Note 5: Enable BCH EDAC protection. EDAC can be enabled and used in combination with all other options. When configuration is used external memory must included BCH check bits.

Note 6: Enable bypass of the internal boot ROM. When enabled the processor will start execute code directly from the primary memory at 0x40000000. Processor or internal memory is initialized after reset when this option is used.

Note 7: Enable memory test. Memory test configuration can be used in combination with all other options. Memory test have no affect when internal boot ROM is bypassed.

3.1.4 Boot strap configuration for external PROM/FLASH memory

This section describes valid bootstrap configuration for use of external memory options:

Table 34. External PROM/FLASH memory bootstrap configurations

Pin								
Remote Access	Source		ASW [3]	Red [4]	EDAC [5]	Bypass [6]	Memory test	
SPIM_MOSI	SPIM_SCK	SPIM_SEL	DUART_TXD	GPIO[63]	GPIO[0]	GPIO[17]	GPIO[62]	**Functional description**
low	high	low	low	low	[5]	low	[7]	Enable external PROM/FLASH memory boot. Processor will start execute application software direct from memory after initialization of the processor.
low	high	low	low	low	[5]	high	[7]	Enable external PROM/FLASH memory boot. Processor will start execute application software direct from memory.
low	high	low	high	low	[5]	low	low	Enable external ASW PROM/FLASH memory boot after initialization of the processor. Processor will copy and extract ASW container before executing application software.
low	high	low	high	high	[5]	low	low	Enable external ASW PROM/FLASH memory with DMR protection boot after initialization of the processor. Processor will copy and extract ASW container before executing application software.

Note 1: To enable external memory access SPIM_MOSI must be bootstrapped to low

Note 2: Configuration pin has no effect or not used for bootstrap configuration. It recommend to tie the pin either to low or high.

Note 3: Enable ASW protection. ASW protection usage is described in section 51.

Note 4: Enable dual module redundancy protection. Option only valid in combination with ASW protection. Redundant memory is expected to be located at address allocated for external chip select signal 1.

Note 5: Enable BCH EDAC protection. EDAC can be enabled and used in combination with all other options. When configuration is used external memory must included BCH check bits.

Note 6: Enable bypass of the internal boot ROM. When enabled the processor will start execute code directly from the primary memory at 0x01000000. Processor or internal memory is initialized after reset when this option is used.

Note 7: Enable memory test. Memory test configuration can be used in combination with all other options. Memory test have no affect when internal boot ROM is bypassed.

3.1.5 Boot strap configuration for external I2C memory

This section describes valid bootstrap configuration for use of external memory options:

Table 35. External SPI memory bootstrap configurations

Pin								
Remote Access	Source		ASW 3)	Red 4)	EDAC 5)	Bypass 6)	Memory test	
SPIM_MOSI	SPIM_SCK	SPIM_SEL	DUART_TXD	GPIO[63]	GPIO[0]	GPIO[17]	GPIO[62]	**Functional description**
low	high	high	high	low	5)	low	7)	Enable external ASW I2C memory boot after initialization of the processor. Processor will copy and extract ASW container before executing application software.
low	high	high	high	high	5)	low	7)	Enable external ASW I2C memory with DMR protection boot after initialization of the processor. Processor will copy and extract ASW container before executing application software.

Note 1: To enable external memory access SPIM_MOSI must be bootstrapped to low

Note 2: Configuration pin has no effect or not used for bootstrap configuration. It recommend to tie the pin either to low or high.

Note 3: Enable ASW protection. ASW protection usage is described in section 51.

Note 4: Enable dual module redundancy protection. Option only valid in combination with ASW protection. Redundant memory is expected to located at I2C master unit 1.

Note 5: Configuration pin has no effect or not used for bootstrap configuration. It recommend to tie the pin either to low or high.

Note 6: Bypass boot ROM must always be strapped to low when I2C option is used.

Note 7: Enable memory test. Memory test configuration can be used in combination with all other options.

3.2 Configuration for flight

To achieve the intended radiation tolerance in flight, certain bootstrap signals must be held at a fixed configuration:

- DSU_EN must be held low (disabling debug interfaces)

3.3 Complete signal list

The design has the external signals shown in table 36.

Table 36: Complete signal list for the design

Name	Usage				Pin sharing	Direction	Polarity
RESET_OUT_N	Reset signal generated from the Power On Reset or Software controlled reset. This signal will also indicate an error or watchdog event has occurred.				No	Out	Low
RESET_IN_N	System input reset				No	In	Low
C_RST	Internal system release delay control				No	-	Analog
XO_P	Crystal oscillator positive input				No	-	Analog
XO_N	Crystal oscillator negative input				No	-	Analog
XO_OUT	Digital clock output				No	Out	-
SYS_CLK	System clock				No	In	-
SPW_CLK	SpaceWire clock				No	In	-
DSU_EN	Debug Support Unit enable signal				No	In	High
DSU_BREAK	Debug Support Unit break signal				No	In	High
DUART_TXD	Debug UART, transmit data				Yes	Out	-
DUART_RXD	Debug UART, receive data				Yes	In	-
SPIM_MOSI	SPI Memory master output slave input				Yes	Out	-
SPIM_SCK	SPI Memory master clock output				Yes	Out	-
SPIM_SEL	SPI Memory slave select output				Yes	Out	-
SPIM_MISO	SPI Memory master input slave output				No	In	-
	SPI Slave	***SPI4S Slave***	***SPI Master***	***Space-Wire***			
LVDS_RX[0]p	SCK	SCK	MISO	RXD	Yes	In	High
LVDS_RX[0]n					Yes	In	Low
LVDS_RX[1]p	MOSI	MOSI	-	RXS	Yes	In	High
LVDS_RX[1]n					Yes	In	Low
LVDS_RX[2]p	SEL	SEL	-	-	Yes	In	High
LVDS_RX[2]n					Yes	In	Low
LVDS_TX[0]p	-	-	SCK	TXD	Yes	Out	High
LVDS_TX[0]n					Yes	Out	Low
LVDS_TX[1]p	-	-	SEL	TXS	Yes	Out	High
LVDS_TX[1]n					Yes	Out	Low
LVDS_TX[2]p	MISO	MISO	MOSI	-	Yes	Out	High
LVDS_TX[2]p					Yes	Out	Low
GPIO[63:0][2)]	General Purpose I/O				Yes	Bidir	-
TESTEN	Test enable signal				No	-	High
VDDA_LVDS	Analog LVDS Supply				No	-	Analog
VDDA_ADC	Analog ADC supply				No	-	Analog
VSSA_ADC	Analog ADC ground				No	-	Analog
VDDA_DAC	Analog DAC supply				No	-	Analog
VSSA_DAC	Analog DAC ground				No	-	Analog
VDDA_PLL	Analog PLL supply				No	-	Analog
VSSA_PLL	Analog PLL ground				No	-	Analog

Table 36: Complete signal list for the design

Name	Usage	Pin sharing	Direction	Polarity
VDDA_REF	Analog BandGap supply	No	-	Analog
VSSA_REF	Analog BandGap ground	No	-	Analog
VREFBUF	External Precision Voltage reference	No	-	Analog
VREF	External BandGap reference	No	-	Analog
RREF	External BandGap reference. Connect to ground via resistance of 5.11 Kohm.	No	-	Analog
LDO_IN	LDO voltage supply	No	-	Analog
VDDIO[1)]	Digital IO supply	No	-	Analog
VDD[1)]	Core supply	No	-	Analog
GND	Ground	No	-	Analog

Note 1: Connect to ground via decoupling capacitors when internal LDO is used

Note 2: See chapter 2.5 for IO definition selection

4 Clocking

Up to six unique external clock sources connected on five external input pins: SYS_CLK, SPW_CLK, PWRX_CLK, GR1553_CLK, SPI4S_CLK, PWM_CLK sources can be used for generating different clocks in the GR716 Microcontroller. Internal ADC and DAC clock generation is also supported to control asynchronous interface for the ADC and DAC. Note that external PacketWire clock is only accessible via the IO switch matrix

Table 37. Clock inputs

Clock input	Description	Frequency Range
ADC_CLK	ADC clock generated from internal logic used for clocking and control of internal ADC	up to 2 MHz
DAC_CLK	DAC clock generated from internal logic used for clocking and control of the internal DAC	up to 3 MHz
SYS_CLK	System clock input	1 - 50 MHz 5)
SPW_CLK	SpaceWire clock	4 - 100 MHz 2)
GR1553_CLK	MIL-STD-1553B interface clock (Only valid via PIN muxing)	20 MHz 3)
SPI4S_CLK	SPI for Space clock	up to 25 MHz 3)
PWRX_CLK	PacketWire receive clock	up to 12.5 MHz 1)
PWTX_CLK	PacketWire loop-back clock for test purpose	up to 12.5 MHz 1)
PWM_CLK	PWM clock	up to 100MHz

Note 1: Frequency shall be equal or lesser than system clock frequency divided by 4

Note 2: Duty cycle for SpaceWire clock shall be set to 50/50 for best jitter performance

Note 3: Duty cycle for MIL-STD-1553B clock shall be at least 40%

Note 4: Frequency shall be equal or lesser than system clock frequency divided by 2

Note 5: System clock must at all time be supplied to the system

The internal ADC_CLK is generated via control registers for the internal ADC, see chapter 12.

There are four internal DAC_CLK clocks. Each DAC_clock is generated individually via control registers, see chapter 15.

The SYS_CLK pin is used as the main system clock, and can be selected to directly drive the clock network without PLL. The SYS_CLK is selected by default as system clock. The system clocks shall always be running during reset and normal operation.

The SPW_CLK pin is the external SpaceWire clock, and it can be used to generate the internal clocks directly or multiplied with a PLL, depending on the value of the configuration registers in PLL configuration block, see chapter 10.

The GR1553_CLK pin is the external MIL-1553B 20 MHz clock and can be used if MIL-1553B interface requires external clock.

The PWRX_CLK pin is the external PacketWire Reciever clock and is used if PacketWirer receiver interface is enabled.

The microcontroller PLL can be used to generate frequencies required for SpaceWire, 1553B or the system. The lowest frequency to be used with the integrated PLL is 4 MHz to be able to meet jitter performance for SpaceWire (with ideal supply).

Clock distribution and configuration in the microcontroller is shown in figure 9. In figure 9 the ’blue’, ’green’ and ’grey’ boxes represents logic. External pins are marked with ’names’ for cross reference to the pin list in section 3.3. Control registers accessible via software or external boot-straps in order to setup and configure clocks in the system are named using the format <*register name*>.<*bitfield*>.

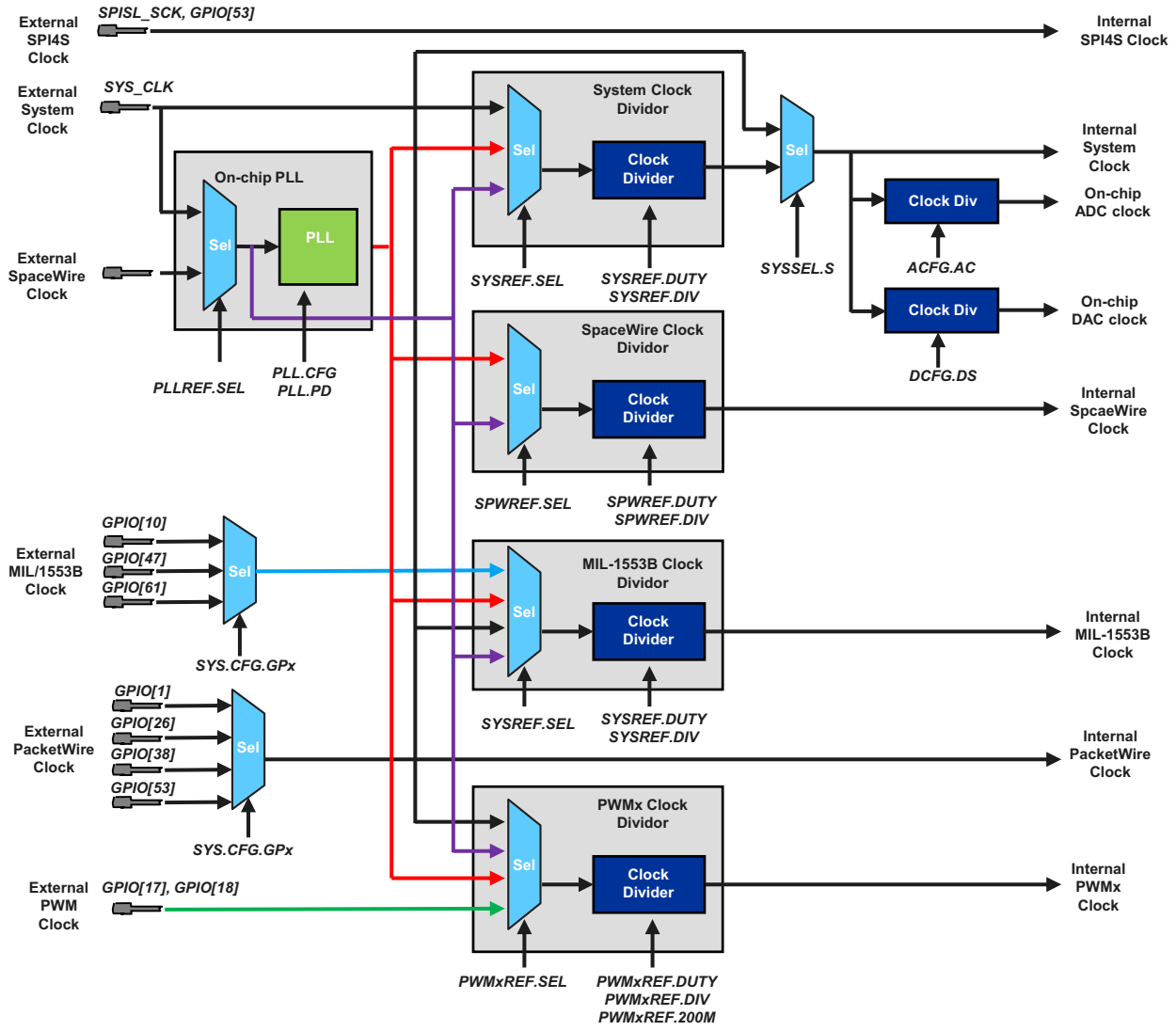


Figure 9. LEON3FT microcontroller clock distribution scheme and control register.

4.1 PLL Configuration and Status

The PLL is designed to mitigate radiation effects and to always output 400 MHz. In order to lock and generate a 400 MHz output clock the PLL needs to be programmed with the input clocks frequency. The input clock frequency is set via PLL control and status registers, see section 10.

When the GR716 Microcontroller is configured to be controlled via remote access the PLL is configured automatically after reset by the hardware. The setup used is determined by configuration bootstraps specified in chapter 3.1. The input frequency needs to be known by the hardware in order to properly setup and synchronize the remote access link.

4.2 Clock Source and divisor

The system clock, SpaceWire clock, PWM and GR1553B clock can be generated internally from internal or external sources, see figure 9 and section 10. Clock source and divisor is selected via configuration registers described in section 10.

The clock source and divisor needs to be chosen carefully depended upon the application requirements for clock frequency, clock jitter and clock duty cycle.

4.3 System clock

The system clock is used to clock the processors, the AMBA buses, and all on-chip cores. The system clock can be derived directly from input pin SYS_CLK or from the external pins SPWCLK via the internal PLL.

The microcontroller includes an on-chip oscillator able to provide a 5 - 25 MHz internal clock. This clock can optionally be used to generate other on-chip clocks for the processor system, SpaceWire and MIL-STD-1553B. To be able to provide a high-accuracy reference clock a crystal oscillator is implemented, where the active oscillator part is implemented on-chip and the crystal is to be connected externally. Alternatively, any arbitrary clock source can be applied as a logic-level clock signal on one of the crystal-interface input pins.

The output from the on-chip oscillator needs to be connected outside the microcontroller device if to used.

4.3.1 System clock source selection

By selecting a system clock source and/or system clock divisor for the system. The core system can be configured to run slower or faster than the external system clock. Special care needs to be taken when switching system clock source in order to switch to a existing clock source.

The device will automatically switch back to use the default system input clock during reset and if the system tries to switch to a disabled clock source.

4.4 SpaceWire clock

The clock used for the SpaceWire link receiver and transmitter logic is taken from the dedicated SpaceWire clock pin SPW_CLK either directly, or multiplied with a PLL, depending on the value of the configuration register for the SpaceWire clock mux and PLL. See chapter 10 for more information.

4.5 MIL-STD-1553B clock

The 20 MHz clock for the MIL-STD-1553B codec is taken from the dedicated pin gr1553b_clk or from the external SPWCLK signal configured via the internal register.

4.5.1 Using PLL clock as input clock for 1553B interface

The PLL output clock frequency can be used to generate a MIL-STD-1553B clock. The MIL-STD-1553B clock can be generated by divide the PLL frequency by 20, see section 10 for details on the MIL-STD-1553B clock divisor registers.

4.6 PacketWire RX Clock

The external clock input for the PacketWire clock receiver is available via the IO mux, see table 2.6. For more information about the PacketWire see section 31.

The PacketWire RX clock can also be generated from internal PacketWire TX clock. The PacketWire TX clock is selected as input to the PacketWire RX clock when the PacketWire is deselected in the IO mux.

4.7 ADC Clock

ADC clock shall match the sampling speed required by the application. Maximum sampling speed is 200 Ksps i.e. maximum ADC clock frequency is 2 MHz. The ADC clock is configured via registers, see 12.

4.8 DAC Clock

DAC clock shall match the sampling speed required by the application. Maximum sampling speed is 3 Msps i.e. maximum DAC clock frequency is 3 MHz. The DAC clock is configured via registers, see 15.

4.9 PWM Clock

The PWM clock shall match the resolution required by the application. The PWM clock can be generated from the an external pin, from the system clock or from the PLL. The PWM frequency can be up to 200 MHz.

4.10 Clock gating unit

The design has a clock gating unit through which individual cores can have their clocks enabled/disabled and resets driven.

The LEON3 processor core will automatically be clock gated when the processor enters power-down or halt state. The floating-point units (GRFPU) will be clock gated when the corresponding processor has disabled FPU operations by setting the %psr.ef bit to zero, or when the processor has entered power-down/halt mode.

For more information see the chapter about the clock gating unit section 26.

4.11 Debug AHB bus clocking

All cores on the Debug AHB bus will be gated off when the DSU_EN signal is set to low.

4.12 Test mode clocking

When in test mode (TESTEN signal = 1) all clocks in the design are connected to the SYS_CLK test clock.

5 Reset

The device has an on-chip reset generator that creates a reset signal that is fed to the rest of the system. The reset is asynchronously set and synchronously released after a delay. The delay can be controlled by connecting a external capacitance to the external pin C_RST input.

All peripherals can be reset independently while the processor continues execution. Thus giving the option to force the full device into a known state during reset mode or just applying a hard reset to selected peripherals. Peripherals are reset independently via register accessible from the processor in the microcontroller or via remote accesses via UART, I2C, SPI, CAN, MIL-STD-1553B or SpaceWire interface. Remote access via CAN and MIL-STD-1553B requires external boot ram. For more information about individual reset control see chapter 26.2.

The microcontroller includes a brown-out detector to supervise the external power supply for the system to shutdown in a controlled manor. A system shutdown is requested via an interrupt to the processor by the brown-out detector in case the supply voltage falls below a specific value. The voltage level is programmable and is always set to the lowest possible value by default after reset.

5.1 IO Reset

The 64 General purpose IO described in chapter 2.4 and 2.5 will set to high impedance mode during power-up/down, Brown detection or if a failure has been detected in the IO configuration registers described in chapter 7.1.

6 Technical notes

6.1 GRLIB AMBA plug&play scanning

The bus structure in this design requires some special consideration with regard to plug&play scanning. The default behavior of GRLIB AMBA plug&play scanning routines is to start scanning at address 0xFFFF0000. If any AHB/AHB bridges or APB bridges are detected during the scan, the general scanning routine traverses the bridge and reads the plug&play information from the bus behind the bridge. In this design, the default 0xFFFF0000 address gives plug&play information only for the Processor AHB bus. For the plug&play scanning routine to get plug&play information from all AHB buses the start address 0x9FFF0000 need to be used.

6.2 Software portability

6.2.1 Instruction set architecture

The LEON3FT processor used in this design implements the SPARC V8 instruction set architecture. This means that any compiler that produces valid SPARC V8 executables can be used. Full instruction set compatibility is kept with LEON2FT and LEON3FT applications.

6.2.2 Peripherals

Standard GRLIB software drivers can be used.

For software driver development, this document describes the capabilities offered by the LEON3FT microcontroller system. In order to write a generic driver for a GRLIB IP core, that can be used on all systems based on GRLIB, please also refer to the generic IP core documentation in GRLIB IP Core User's Manual [GRIP]. Note, however, that the generic documentation may describe functionality not present in this implementation and that this data sheet supersedes any documentation found in [GRIP] for this system.

6.2.3 Plug and play

Standard GRLIB AMBA plug&play layout is used. The same software routines used for typical LEON/GRLIB systems can be used.

7 System Startup Status and General Configuration

This section describes general status register and control registers for LEON3FT microcontroller system. General status and configuration register described in this section are be used for IO function selection and peripheral configuration. GPIOs are sampled during RESET and stored in register for configuration of IO switch matrix and peripherals.

This section also describes how to get access to control signal to analog functions from external pins and how to enable memory build test and interrupt test.

7.1 Configuration Registers

The registers are mapped into AMBA address space. The register layout used for configuration of GPIO is explained in section 2.5.

Table 38. System IO configuration register

AMBA address	Register	Acronym
0x8000D000	System IO configuration for GPIO 0 to 7	SYS.CFG.GP0
0x8000D004	System IO configuration for GPIO 8 to 15	SYS.CFG.GP1
0x8000D008	System IO configuration for GPIO 16 to 23	SYS.CFG.GP2
0x8000D00C	System IO configuration for GPIO 24 to 31	SYS.CFG.GP3
0x8000D010	System IO configuration for GPIO 32 to 39	SYS.CFG.GP4
0x8000D014	System IO configuration for GPIO 40 to 47	SYS.CFG.GP5
0x8000D018	System IO configuration for GPIO 48 to 55	SYS.CFG.GP6
0x8000D01C	System IO configuration for GPIO 56 to 63	SYS.CFG.GP7
0x8000D020	System IO Pullup configuration for GPIO 0 to 31	SYS.CFG.PULLUP0
0x8000D024	System IO Pullup configuration for GPIO 32 to 64	SYS.CFG.PULLUP1
0x8000D028	System IO Pulldown configuration for GPIO 0 to 31	SYS.CFG.PULLDOWN0
0x8000D02C	System IO Pulldown configuration for GPIO 32 to 64	SYS.CFG.PULLDOWN1
0x8000D030	LVDS configuration	SYS.CFG.LVDS
0x8000D040	System IO configuration register protection	SYS.CFG.PROT
0x8000D044	System IO configuration register error interrupt	SYS.CFG.EIRQ
0x8000D048	System IO configuration register error status	SYS.CFG.ESTAT

Table 39. 0x8000D000 - SYS.CFG.GP0 - System GPIO configuration register0

31 30 29 28	27 26 25 24	23 22 21 20	19 18 17 16	15 14 13 12	11 10 9 8	7 6 5 4	3 2 1 0
GP7	GP6	GP5	GP4	GP3	GP2	GP1	GP0
0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0
rw	rw	rw	rw	rw	rw	rw	rw

31: 28 GPIO7 functional select (GP7) - Select functionality for GPIO pin 7. For functionality see Table 2.6.

27: 24 GPIO6 functional select (GP6) - Select functionality for GPIO pin 6. For functionality see Table 2.6.

23: 20 GPIO5 functional select (GP5) - Select functionality for GPIO pin 5. For functionality see Table 2.6.

19: 16 GPIO4 functional select (GP4) - Select functionality for GPIO pin 4. For functionality see Table 2.6.

15: 12 GPIO3 functional select (GP3) - Select functionality for GPIO pin 3. For functionality see Table 2.6.

11: 8 GPIO2 functional select (GP2) - Select functionality for GPIO pin 2. For functionality see Table 2.6.

7: 4 GPIO1 functional select (GP1) - Select functionality for GPIO pin 1. For functionality see Table 2.6.

3: 0 GPIO0 functional select (GP0) - Select functionality for GPIO pin 0. For functionality see Table 2.6.

Table 40. 0x8000D004 - SYS.CFG.GP1 - System GPIO configuration register1

31 30 29 28	27 26 25 24	23 22 21 20	19 18 17 16	15 14 13 12	11 10 9 8	7 6 5 4	3 2 1 0
GP7	GP6	GP5	GP4	GP3	GP2	GP1	GP0
0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0
rw	rw	rw	rw	rw	rw	rw	rw

31: 28 GPIO15 functional select (GP7) - Select functionality for GPIO pin 15. For functionality see Table 2.6.
27: 24 GPIO14 functional select (GP6) - Select functionality for GPIO pin 14. For functionality see Table 2.6.
23: 20 GPIO13 functional select (GP5) - Select functionality for GPIO pin 13. For functionality see Table 2.6.
19: 16 GPIO12 functional select (GP4) - Select functionality for GPIO pin 12. For functionality see Table 2.6.
15: 12 GPIO11 functional select (GP3) - Select functionality for GPIO pin 11. For functionality see Table 2.6.
11: 8 GPIO10 functional select (GP2) - Select functionality for GPIO pin 10. For functionality see Table 2.6.
7: 4 GPIO9 functional select (GP1) - Select functionality for GPIO pin 9. For functionality see Table 2.6.
3: 0 GPIO8 functional select (GP0) - Select functionality for GPIO pin 8. For functionality see Table 2.6.

Table 41. 0x8000D008 - SYS.CFG.GP2 - System GPIO configuration register2

31 30 29 28	27 26 25 24	23 22 21 20	19 18 17 16	15 14 13 12	11 10 9 8	7 6 5 4	3 2 1 0
GP7	GP6	GP5	GP4	GP3	GP2	GP1	GP0
0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0
rw	rw	rw	rw	rw	rw	rw	rw

31: 28 GPIO23 functional select (GP7) - Select functionality for GPIO pin 23. For functionality see Table 2.6.
27: 24 GPIO22 functional select (GP6) - Select functionality for GPIO pin 22. For functionality see Table 2.6.
23: 20 GPIO21 functional select (GP5) - Select functionality for GPIO pin 21. For functionality see Table 2.6.
19: 16 GPIO20 functional select (GP4) - Select functionality for GPIO pin 20. For functionality see Table 2.6.
15: 12 GPIO19 functional select (GP3) - Select functionality for GPIO pin 19. For functionality see Table 2.6.
11: 8 GPIO18 functional select (GP2) - Select functionality for GPIO pin 18. For functionality see Table 2.6.
7: 4 GPIO17 functional select (GP1) - Select functionality for GPIO pin 17. For functionality see Table 2.6.
3: 0 GPIO16 functional select (GP0) - Select functionality for GPIO pin 16. For functionality see Table 2.6.

Table 42. 0x8000D00C - SYS.CFG.GP3 - System GPIO configuration register 3

31 30 29 28	27 26 25 24	23 22 21 20	19 18 17 16	15 14 13 12	11 10 9 8	7 6 5 4	3 2 1 0
GP7	GP6	GP5	GP4	GP3	GP2	GP1	GP0
0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0
rw	rw	rw	rw	rw	rw	rw	rw

31: 28 GPIO31 functional select (GP7) - Select functionality for GPIO pin 31. For functionality see Table 2.6.
27: 24 GPIO30 functional select (GP6) - Select functionality for GPIO pin 30. For functionality see Table 2.6.
23: 20 GPIO29 functional select (GP5) - Select functionality for GPIO pin 29. For functionality see Table 2.6.
19: 16 GPIO28 functional select (GP4) - Select functionality for GPIO pin 28. For functionality see Table 2.6.
15: 12 GPIO27 functional select (GP3) - Select functionality for GPIO pin 27. For functionality see Table 2.6.
11: 8 GPIO26 functional select (GP2) - Select functionality for GPIO pin 26. For functionality see Table 2.6.
7: 4 GPIO25 functional select (GP1) - Select functionality for GPIO pin 25. For functionality see Table 2.6.
3: 0 GPIO24 functional select (GP0) - Select functionality for GPIO pin 24. For functionality see Table 2.6.

Table 43. 0x8000D010 - SYS.CFG.GP4 - System GPIO configuration register 4

31 30 29 28	27 26 25 24	23 22 21 20	19 18 17 16	15 14 13 12	11 10 9 8	7 6 5 4	3 2 1 0
GP7	GP6	GP5	GP4	GP3	GP2	GP1	GP0
0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0
rw	rw	rw	rw	rw	rw	rw	rw

31: 28 GPIO39 functional select (GP7) - Select functionality for GPIO pin 39. For functionality see Table 2.6.
27: 24 GPIO38 functional select (GP6) - Select functionality for GPIO pin 38. For functionality see Table 2.6.
23: 20 GPIO37 functional select (GP5) - Select functionality for GPIO pin 37. For functionality see Table 2.6.
19: 16 GPIO36 functional select (GP4) - Select functionality for GPIO pin 36. For functionality see Table 2.6.
15: 12 GPIO35 functional select (GP3) - Select functionality for GPIO pin 35. For functionality see Table 2.6.
11: 8 GPIO34 functional select (GP2) - Select functionality for GPIO pin 34. For functionality see Table 2.6.
7: 4 GPIO33 functional select (GP1) - Select functionality for GPIO pin 33. For functionality see Table 2.6.
3: 0 GPIO32 functional select (GP0) - Select functionality for GPIO pin 32. For functionality see Table 2.6.

Table 44. 0x8000D014 - SYS.CFG.GP5 - System GPIO configuration register 5

31 30 29 28	27 26 25 24	23 22 21 20	19 18 17 16	15 14 13 12	11 10 9 8	7 6 5 4	3 2 1 0
GP7	GP6	GP5	GP4	GP3	GP2	GP1	GP0
0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0
rw	rw	rw	rw	rw	rw	rw	rw

31: 28 GPIO47 functional select (GP7) - Select functionality for GPIO pin 47. For functionality see Table 2.6.
27: 24 GPIO46 functional select (GP6) - Select functionality for GPIO pin 46. For functionality see Table 2.6.
23: 20 GPIO45 functional select (GP5) - Select functionality for GPIO pin 45. For functionality see Table 2.6.
19: 16 GPIO44 functional select (GP4) - Select functionality for GPIO pin 44. For functionality see Table 2.6.
15: 12 GPIO43 functional select (GP3) - Select functionality for GPIO pin 43. For functionality see Table 2.6.
11: 8 GPIO42 functional select (GP2) - Select functionality for GPIO pin 42. For functionality see Table 2.6.
7: 4 GPIO41 functional select (GP1) - Select functionality for GPIO pin 41. For functionality see Table 2.6.
3: 0 GPIO40 functional select (GP0) - Select functionality for GPIO pin 40. For functionality see Table 2.6.

Table 45. 0x8000D018 - SYS.CFG.GP6 - System GPIO configuration register 6

31 30 29 28	27 26 25 24	23 22 21 20	19 18 17 16	15 14 13 12	11 10 9 8	7 6 5 4	3 2 1 0
GP7	GP6	GP5	GP4	GP3	GP2	GP1	GP0
0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0
rw	rw	rw	rw	rw	rw	rw	rw

31: 28 GPIO55 functional select (GP7) - Select functionality for GPIO pin 55. For functionality see Table 2.6.
27: 24 GPIO54 functional select (GP6) - Select functionality for GPIO pin 54. For functionality see Table 2.6.
23: 20 GPIO53 functional select (GP5) - Select functionality for GPIO pin 53. For functionality see Table 2.6.
19: 16 GPIO52 functional select (GP4) - Select functionality for GPIO pin 52. For functionality see Table 2.6.
15: 12 GPIO51 functional select (GP3) - Select functionality for GPIO pin 51. For functionality see Table 2.6.
11: 8 GPIO50 functional select (GP2) - Select functionality for GPIO pin 50. For functionality see Table 2.6.
7: 4 GPIO49 functional select (GP1) - Select functionality for GPIO pin 49. For functionality see Table 2.6.
3: 0 GPIO48 functional select (GP0) - Select functionality for GPIO pin 48. For functionality see Table 2.6.

Table 46. 0x8000D01C - SYS.CFG.GP7 - System GPIO configuration register 7

31 30 29 28	27 26 25 24	23 22 21 20	19 18 17 16	15 14 13 12	11 10 9 8	7 6 5 4	3 2 1 0
GP7	GP6	GP5	GP4	GP3	GP2	GP1	GP0
0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0
rw	rw	rw	rw	rw	rw	rw	rw

31: 28 GPIO63 functional select (GP7) - Select functionality for GPIO pin 63. For functionality see Table 2.6.

27: 24 GPIO62 functional select (GP6) - Select functionality for GPIO pin 62. For functionality see Table 2.6.

23: 20 GPIO61 functional select (GP5) - Select functionality for GPIO pin 61. For functionality see Table 2.6.

19: 16 GPIO60 functional select (GP4) - Select functionality for GPIO pin 60. For functionality see Table 2.6.

15: 12 GPIO59 functional select (GP3) - Select functionality for GPIO pin 59. For functionality see Table 2.6.

11: 8 GPIO58 functional select (GP2) - Select functionality for GPIO pin 58. For functionality see Table 2.6.

7: 4 GPIO57 functional select (GP1) - Select functionality for GPIO pin 57. For functionality see Table 2.6.

3: 0 GPIO56 functional select (GP0) - Select functionality for GPIO pin 56. For functionality see Table 2.6.

Table 47. 0x8000D020 - SYS.CFG.PULLUP0 - System GPIO pullup configuration register for GPIO 0 to 31

31 30 29 28 27 26 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
UP
0x00000000
rw

31: 0 Select and configure inputs using internal pullup resistor (PULLUP) - Each bit in register bitfield corresponds to one input pin.

Table 48. 0x8000D024 - SYS.CFG.PULLUP1 - System GPIO pullup configuration register for GPIO 32 to 63

31 30 29 28 27 26 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
UP
0x00000000
rw

31: 0 Select and configure inputs using internal pullup resistor (PULLUP) - Each bit in register bitfield corresponds to one input pin.

Table 49. 0x8000D028 - SYS.CFG.PULLDOWN0 - System GPIO pulldown configuration register for GPIO 0 to 31

31 30 29 28 27 26 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
DOWN
0xFFFFFFFF
rw

31: 0 Select and configure inputs using internal pulldown resistor (DOWN) - Each bit in register bitfield corresponds to one input pin.

Table 50. 0x8000D02C - SYS.CFG.PULLDOWN1 - System GPIO pulldown configuration register for GPIO 32 to 63

31 30 29 28 27 26 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
DOWN
0xFFFFFFFF
rw

31: 0 Select and configure inputs using internal pulldown resistor (DOWN) - Each bit in register bitfield corresponds to one input pin.

Table 51. 0x8000D030 - SYS.CFG.LVDS - System LVDS configuration register

31 30 29 28 27 26 25 24 23 22 21 20 19 18 17 16	15 14 13 12	11 10 9 8	7 6 5 4	3 2 1 0
R	RX2	RX1	RX0	TX2	TX1	TX0
0x0	0x0	0x0	0x0	0x0	0x0	0x0
r	rrw	rrw	rrw	rw	rw	rw

31: 16 Not used

23: 20 LVDS Reciever 2 (RX2) - Select functionality for LVDS receiver 0

0x8 - LVDS receiver disable

19: 16 LVDS Reciever 1 (RX1) - Select functionality for LVDS receiver 0

0x8 - LVDS receiver disable

15: 12 LVDS Reciever 0 (RX0) - Select functionality for LVDS receiver 0

0x8 - LVDS receiver disable

11: 8 LVDS Transmitter 2 (TX2) - Select functionality for LVDS transmitter 2

0x1 - SPI for Space Slave MISO
0x2 - SPI Master MOSI
0x3 - SPI Slave MISO
0x8 - LVDS transmitter disable

7: 4 LVDS Transmitter 1 (TX1) - Select functionality for LVDS transmitter 1

0x0 - SpaceWire Strobe Transmission
0x2 - SPI Master
0x8 - LVDS transmitter disable

3: 0 LVDS Transmitter 0 (TX0) - Select functionality for LVDS transmitter 0

0x0 - SpaceWire Data Transmission
0x2 - SPI Master SCLK
0x8 - LVDS transmitter disable

Note 1: Transmitter configuration not listed will force the transmitter to output a logic ’0’

The connections listed below are always active:

LVDS Receiver 0 -> SpaceWire Data Receiver

LVDS Receiver 1 -> SpaceWire Strobe Receiver, SPI for Space Slave MOSI

LVDS Receiver 2 -> SPI for Space Slave Select

The connections listed below are active only if a GPIO is not employed for the relevant signal:

LVDS Receiver 0 -> SPI Master MISO, SPI Slave SCLK

LVDS Receiver 1 -> SPI Slave MOSI

LVDS Receiver 2 -> SPI Slave SEL

Table 52. 0x8000D034 - SYS.CFG.PROT - System IO configuration protection register

31 30 29 28 27 26 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4	3	2	1	0
R	DI	EC	IR	EN
0x0	0	0	0	0
r	rw	rw	rw	rw

31: 4 Not used

3 Disable configuration (DI) - Disable configuration at multiple configuration error.

0x1 - Enable disable IO when multiple errors has been detected
0x0 - Disable disable IO when multiple errors has been detected

Table 52. 0x8000D034 - SYS.CFG.PROT - System IO configuration protection register

2 Enable Correction (EC) - Generate interrupt at error event

0x1 - Enable correction of single error
0x0 - Disable correction of single error

1 Enable Protection interrupt (IR) - Generate interrupt at error event

0x1 - Enable interrupt
0x0 - Disable interrupt

0 Enable System IO Register Protection (EN) - Enables BCH protection of all IO configuration registers

0x1 - Enable protection
0x0 - Disable protection

Table 53. 0x8000D03C - SYS.CFG.EIRQ- System IO configuration interrupt protection register

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
R																														M	E
0x0																														0	0
r																														wc	wc

31: 2 Not used

1 Multiple error interrupt (M)

0 Single Error interrupt (E)

Table 54. 0x8000D03C - SYS.CFG.ESTAT - System IO configuration status protection register

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
R																			ESTAT													
0x0																			0													
r																			r													

31: 13 Not used

12: 0 Error status (ESTAT) BCH error status for individual register banks

7.2 Boot Strap information register

The register shows the current status of the external boot strap configuration used. The register can be modified in order to trigger a reboot and re-configuration of the microcontroller using the internal on-chip boot ROM

Table 55. Boot strap register

AMBA address	Register	Acronym
0x80008000	Internal boot ROM configuration register. Register gets default value from external bootstrap pins after reset.	SYS.CFG.BOOT

Table 56. 0x80008000 - SYS.CFG.BOOT - Internal boot ROM configuration register

31	30	29	28	27	25	24	21	20	16	15	14	13	9	8	5	4	2	1	0
EM	DE	RE	BY	-	SEL		DIV			NB	NV	-		REM		SRC		AS	-
-	-	-	-	-	-		-			1	1			-		-		-	1
rw	rw	rw	rw	rw	rw		rw			rw	rw	rw		rw		rw		rw	r

31 Enable Memory test (Set to zero for fast re-boot). Default settings is determined by GPIO[62]. For more information see table 30 in section 3.1

30 Disable EDAC for external memory. Default settings is determined by GPIO[0]. For more information see table 30 in section 3.1

Table 56. 0x80008000 - SYS.CFG.BOOT - Internal boot ROM configuration register

29	Redundant memory available. Default settings is determined by GPIO[63]. For more information see table 30 in section 3.1
28	Bypass of internal boot ROM. This will force the microcontroller to boot from external selected source. Default settings is determined by GPIO[17]. For more information see table 30 in section 3.1
27: 25	Not used
24: 21	PLL Divisor startup value 0 - Input frequency to PLL is 50 Mhz 1 - Input frequency to PLL is 25 Mhz 2 - Input frequency to PLL is 20 Mhz 3 - Input frequency to PLL is 12.5 Mhz 4 - Input frequency to PLL is 10 Mhz 5 - Input frequency to PLL is 5 Mhz All other values assume input frequency is set to 50 MHz. Default settings is determined by GPIO[63] and DUART_TX. For more information see table 30 in section 3.1
20: 16	SpaceWire clock divisor The register field set the reset value of register CLKDIV.CLKDIVSTART in SpaceWire. The register CLKDIV.CLKDIVSTART determines the link-rate during initialization (all states up to and including the connecting-state). For more information see 33.3.5. Default settings is determined by GPIO[63] and DUART_TX. For more information see table 30 in section 3.1
15	Boot from NVRAM when bit is to '0'. Only available in package option with embedded NVRAM. Pin strapped to '1' by default in package without NVRAM in package.
14	Internal NVRAM exists in package when bit is to '0'. Pin strapped to '1' by default in package without NVRAM in package.
13: 9	Not used
8: 5	Enable remote access interface: 0x0 - None 0x1 - SpaceWire 0x2 - SPI2AHB 0x4 - I2C 0x8 - UART All other values are reserved for future boot options. Default settings is determined by SPIM_MOSI, SPIM_SCK and SPIM_SEL. For more information see table 30 in section 3.1
4: 2	Select external memory to boot from 0x0 - External SPI ROM 0x1 - External SRAM/MRAM 0x2 - External ROM/PROM/EEPROM 0x3 - External I2C ROM 0x4 - Reserved for future boot options 0x5 - Reserved for future boot options 0x6 - Reserved for future boot options 0x7 - Reserved for future boot options Default settings is determined by SPIM_MOSI, SPIM_SCK and SPIM_SEL. For more information see table 30 in section 3.1
1:	Configure boot ROM to check and use ASW container. Default settings is determined by DUART_TX. For more information see table 30 in section 3.1
0:	Not used

7.3 Special Configuration Registers

The special registers are used for getting access to special functions in the LEON3FT microcontroller.

Special functions accessible via special configuration registers:

- Make digital control and status signals for on-chip analog functionality available on the external general inputs and outputs.
- Enable and run Production test on individual embedded memories
- Trigger interrupt test
- Enable external voltage reference

7.3.1 On-chip analog functions

Access to digital control and status signals for integrated analog functionality. Access to control and status for individual analog functions can be configured in the register SYS.CFG.ANA1 and SYS.CFG.ANA2. Register described in this section is only available in debug mode. Please contact Cobham Gaisler support if for more information is needed.

Table 57. Analog access configuration register

AMBA address	Register	Acronym
0x94002000	Configuration register for access of analog digital control and status interface on external pins	SYS.CFG.ANA1
0x94002004	Configuration register for access of analog digital control and status interface on external pins	SYS.CFG.ANA2

Table 58. 0x94002000 - SYS.CFG.ANA1 - Analog access configuration register

31	0
ANA1	
0x0	
rw	

31 Enable PLL_FB output on internal analog test bus 4
30 Enable PLL_LOCK output on internal analog test bus 4
29 Enable PLL_OUT output on internal analog test bus 5 output on internal analog test bus 4
28 Enable VMON33LVDS_BG33_OK output on internal analog test bus 4
27 Enable VMON33LVDS_SUPPLY33_OK output on internal analog test bus 4
26 Enable VMON33LVDS_COMPIN output on internal analog test bus 4
25 Enable VMON33DAC_BG33_OK output on internal analog test bus 4
24 Enable VMON33DAC_SUPPLY33_OK output on internal analog test bus 4
23 Enable VMON33DAC_COMPIN output on internal analog test bus 4
22 Enable VMON33BG_BG33_OK output on internal analog test bus 3
21 Enable VMON33BG_SUPPLY33_OK output on internal analog test bus 3
20 Enable VMON33BG_COMPIN output on internal analog test bus 3
19 Enable VMON33ADC_BG33_OK output on internal analog test bus 3
18 Enable VMON33ADC_SUPPLY33_OK output on internal analog test bus 3
17 Enable VMON33ADC_COMPIN output on internal analog test bus 3
16 Enable VMON33IO_BG33_OK output on internal analog test bus 3
15 Enable VMON33IO_SUPPLY33_OK output on internal analog test bus 3
14 Enable VMON33IO_COMPIN output on internal analog test bus 3
13 Enable ADC0_OUTN_CROSS output on internal analog test bus 2
12 Enable ADC0_OUTN output on internal analog test bus 2
11 Enable ADC0_VREFN output on internal analog test bus 2
10 Enable ADC0_AGND output on internal analog test bus 2

Table 58. 0x94002000 - SYS.CFG.ANA1 - Analog access configuration register

9	Enable Buffered VPTAT output on internal analog test bus 2
8	Enable ip_hipo_23u<7> output on internal analog test bus 2
7	Enable ip_ref_10u<42> output on internal analog test bus 2
6	Enable ADC0_OUTP_CROSS output on internal analog test bus 1
5	Enable ADC0_OUTP output on internal analog test bus 1
4	Enable ADC0_VREFP output on internal analog test bus 1
3	Enable CompOut33 output on internal analog test bus 1
2	Enable Buffered bandgap VREF output on internal analog test bus 1
1	Enable Unbuffered VPTAT output on internal analog test bus 1
0	Enable GND3V3_REF_C output on internal analog test bus 1

Table 59. 0x94002004 - SYS.CFG.ANA2 - Analog access configuration register

31	30	29	23	22	0
ADC		Reserved		ANA2	
0x0		0x0		0x0	
rw		rw		rw	

31	Enable control of ADC0 from external GPIO signals
30	Enable observability of ADC0 output signals on external GPIO signals
29: 23	Reserved
22	Select external resistor reference (sel_VMON18_INT_COMPIN) for VMON18 1
21	Select external resistor reference (sel_VMON33_INT_COMPIN5) for VMON33 5
20	Select external resistor reference (sel_VMON33_INT_COMPIN4) for VMON33 4
19	Select external resistor reference (sel_VMON33_INT_COMPIN3) for VMON33 3
18	Select external resistor reference (sel_VMON33_INT_COMPIN2) for VMON33 2
17	Select external resistor reference (sel_VMON33_INT_COMPIN1) for VMON33 1
16	Enable (ena_TEST) test buffer 5
15	Enable (ena_TEST) test buffer 4
14	Enable (ena_TEST) test buffer 3
13	Enable (ena_TEST) test buffer 2
12	Enable (ena_TEST) test buffer 1
11	Enable bypass (byp_TEST) measurement for test buffer 5
10	Enable bypass (byp_TEST) measurement for test buffer 4
9	Enable bypass (byp_TEST) measurement for test buffer 3
8	Enable bypass (byp_TEST) measurement for test buffer 2
7	Enable bypass (byp_TEST) measurement for test buffer 1
6	Enable offset (i_TEST) measurement for test buffer 5
5	Enable offset (i_TEST) measurement for test buffer 4
4	Enable offset (i_TEST) measurement for test buffer 3
3	Enable offset (i_TEST) measurement for test buffer 2
2	Enable offset (i_TEST) measurement for test buffer 1
1	Enable VMON18PLL_SUPPLY_OK output on internal analog test bus 5
0	Enable VMON18PLL_COMPIN output on internal analog test bus 5

Access to specific functionality are granted on the following general purpose input and output signals only if corresponding configuration bit is set in the register SYS.CFG.ANA1 and SYS.CFG.ANA2.

Table 60. External access of integrated Analog digital configuration and status signals

Pin	Mode	Functional description
GPIO[0-36]	Analog Mode	GPIO[0] - ADC Select internal reference (active high) input GPIO[1] - ADC Start conversion (active high) input GPIO[2] - ADC Clock input GPIO[3] - ADC enable (active high) input GPIO[4] - ADC Pre-AMP Bypass input GPIO[5] - ADC Select single ended mode (active high) input GPIO[7:6] - ADC Pre-AMP Pair select input GPIO[9:8] - ADC Pre-AMP Gain select input GPIO[10] - ADC Pre-AMP Cross GPIO[11] - ADC Pre-AMP Select On Chip Temperature sensor GPIO[22:12] - ADC digital output GPIO[23] - ADC End of conversion output
	User Mode	User IO
GPIO[37-48]	Analog Mode	When external access to analog digital control and status signals are enabled the mixed GPIO signals are used as analog inputs and outputs to the integrated ADC and DAC. Analog values inserted should respect the limits specified in chapter 52. GPIO[37-44] are used as ADC inputs and GPIO[45-48] are used as DAC outputs. Internal test buffers can be enabled on following pins in analog mode: GPIO[39] - Test buffer 1 output (Internal test bus 1) GPIO[40] - Test buffer 2 output (Internal test bus 2) GPIO[42] - Test buffer 3 output (Internal test bus 3) GPIO[48] - Test buffer 4 output (Internal test bus 4) External test voltage references can be enabled on following pins in analog mode: GPIO[44] - Analog test input reference voltage for ADC domain GPIO[47] - Analog test input reference voltage for IO and Core domain
	User Mode	Mixed Analog Digital user GPIO.
GPIO[49-63]	Analog Mode	Internal test buffer can be enabled on following pins in analog mode: GPIO[49] - Test buffer 5 output External test voltage reference can be enabled on following pins in analog mode: GPIO[50] - Analog test input reference voltage for PLL domain
	User Mode	User GPIO pin 63. Note that the GPIO pin #63 can only be configured as output

7.3.2 Memory Test

All memory entities have a build-in test structure for automatic testing. The automatic testing is triggered from software and can only be enabled when the external DSU_EN signal is high. The test is destructive and all memory contents will be overwritten.

The memory test algorithm used is a March C- (evolved March C). The advantage of using the March C- test algorithm is that the algorithm covers many faults models without knowing the internal structure or the layout of the memory. The covered fault models includes Stuck-At, Transition, Coupling, Neighborhood Sensitivity and Address decoding fault.

The disadvantage of using the March C- algorithm is that it is very time consuming due to its nature of checking bit by bit multiple times.

March C- algorithm implemented {↑(w0);↑(r0,w1);↑(r1,w0);↓(r0,w1);↓(r1,w0);↓(r0)}

Notation of the algorithm:

↑ : address 0 bit 0 to address n-1 bit m

↓ : address n-1 bit m to address n bit 0

w0 : write 0 to bit (memory cell) location

w1 : write 1 to bit (memory cell) location

r0 : read a bit (memory cell) value should be 0

r1 : read a bit (memory cell) value should 1

The March C- test algorithm is enabled per memory instantiation by writing to the configuration register SYS.CFG:MEMTEST.

Table 61. Memory test configuration register

AMBA address	Register	Acronym
0x80008004	Configuration register for memory test	SYS.CFG.MEMTEST

Table 62. 0x80008004 - SYS.CFG.MEMTEST - Memory test configuration register

31 30	29 28	27 26	25 24	23 22	21 20	19 18	17 16	15 14	13 12	11 10	9 8	7 6	5 4	3 2	1 0
DM	IM	DBG5	DBG4	DBG3	DBG2	DBG1	DBG0	DSU5	DSU4	DSU3	DSU2	DSU1	DSU0	RW1	RW0
0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

31: 30 On-chip data memory test control bits (DM):

0x0 - Not used (Memory bit for memory is kept in reset state)
0x1 - Enable March C- test algorithm
0x2 - Write 0x0 to all locations in memory
0x3 - Not used

29: 28 On-chip Instruction memory test control bits (IM):

0x0 - Not used (Memory bit for memory is kept in reset state)
0x1 - Enable March C- test algorithm
0x2 - Write 0x0 to all locations in memory
0x3 - Not used

27: 26 Trace Memory on MAIN AHB bus (DBG0 - DBG5):

25: 24
23: 22
21: 20
19: 18
17: 16

0x0 - Not used (Memory bit for memory is kept in reset state)
0x1 - Enable March C- test algorithm
0x2 - Write 0x0 to all locations in memory
0x3 - Not used

15: 14 Trace Memory on MAIN AHB bus (DSU0 - DSU5):

13: 12
11: 10
9: 8
7: 6
5: 4

0x0 - Not used (Memory bit for memory is kept in reset state)
0x1 - Enable March C- test algorithm
0x2 - Write 0x0 to all locations in memory
0x3 - Not used

Table 62. 0x80008004 - SYS.CFG.MEMTEST - Memory test configuration register

3: 2 LEON3FT register Window 1 memory (RW1):

0x0 - Not used (Memory bit for memory is kept in reset state)
0x1 - Enable March C- test algorithm
0x2 - Write 0x0 to all locations in memory
0x3 - Not used

1: 0 LEON3FT register Window 0 memory (RW0):

0x0 - Not used (Memory bit for memory is kept in reset state)
0x1 - Enable March C- test algorithm
0x2 - Write 0x0 to all locations in memory
0x3 - Not used

To minimize the power consumption all memory tests should be executed in sequence. It is still possible to execute all tests in parallel to shorten the test time. The run time is depended upon the number of memory cells in the memory entity. The largest memory entity's are the data (64Kib) and instruction memory (128KiB).

The results and current status can be read in the status register SYS.STAT:MEMTEST. The status register indicates if test is running and if any error was detected during the memory test per memory entity in the LEON3FT microcontroller.

Table 63. Memory test status register

AMBA address	Register	Acronym
0x8000E004	Status register for memory test	SYS.STAT.MEMTEST

Table 64. 0x8000E004 - SYS.STAT.MEMTEST - Memory test status register

31 30	29 28	27 26	25 24	23 22	21 20	19 18	17 16	15 14	13 12	11 10	9 8	7 6	5 4	3 2	1 0
DM	IM	DBG5	DBG4	DBG3	DBG2	DBG1	DBG0	DSU5	DSU4	DSU3	DSU2	DSU1	DSU0	RW1	RW0
0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

31: 30 On-chip data memory test control bits (DM):

0x0 - No error detected during last test (If test has been run)
0x1 - Enable March C- test algorithm
0x2 - Error during last scan
0x3 - Invalid state and test result

29: 28 On-chip Instruction memory test control bits (IM):

0x0 - No error detected during last test (If test has been run)
0x1 - Enable March C- test algorithm
0x2 - Error during last scan
0x3 - Invalid state and test result

27: 26 Trace Memory on MAIN AHB bus (DBG0 - DBG5):

25: 24
23: 22
21: 20
19: 18
17: 16

0x0 - No error detected during last test (If test has been run)
0x1 - Enable March C- test algorithm
0x2 - Error during last scan
0x3 - Invalid state and test result

Table 64. 0x8000E004 - SYS.STAT.MEMTEST - Memory test status register

15: 14	Trace Memory on MAIN AHB bus (DSU0 - DSU5):
13: 12	0x0 - No error detected during last test (If test has been run)
11: 10	0x1 - Enable March C- test algorithm
9: 8	0x2 - Error during last scan
7: 6	0x3 - Invalid state and test result
5: 4	
3: 2	LEON3FT register Window 1 memory (RW1):
	0x0 - No error detected during last test (If test has been run) 0x1 - Enable March C- test algorithm 0x2 - Error during last scan 0x3 - Invalid state and test result
1: 0	LEON3FT register Window 0 memory (RW0):
	0x0 - No error detected during last test (If test has been run) 0x1 - Enable March C- test algorithm 0x2 - Error during last scan 0x3 - Invalid state and test result

7.3.3 System configuration register

This register can be used to test system, change system error behavior or enable special system functions e.g. interface loopback functionality or to enable external voltage refernce.

The interrupt test is accessible to the system in all functional modes. Protection scheme has been added to the interrupt test functionality in order to prevent erroneous accesses to the functionality. The generated interrupt event will be inserted into the interrupt controller and the intention is to test interrupt controller and interrupt software.

The interrupt test control register contains a interrupt number bit field and two protection bits. The two protection bits are used as protection and enable bits for the interrupt test. When the protection bits are toggled an interrupt event is asserted to the interrupt controller.

Table 65. Interrupt test configuration register

AMBA address	Register	Acronym
0x8000E000	Configuration register for memory test, LVDS reference and Main bus configuration	SYS.CFG.SCFG

Table 66. 0x8000E000 - SYS.CFG.SCFG - Interrupt test configuration register

31 21	20 18	17 16	15	14 13	12	11	10 9	8 3	2	1	0
R	VREF	SPW	LL	LS	LE	FS	PR	IRQ	MR	WE	EE
0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0
r	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

31: 18 Not used

20: 18 Enable and control of external voltage reference

Bit #20 - Enable external voltage reference
Bit #19 - Input external voltage reference (Only for test purpose during production)
Bit #18 - Bypass buffer, this bit should normally be set to 0 in order to get a full scale ADC reference output.

To enable and output a reference for precision measurements using internal ADC set VREF bits to 100b.

Table 66. 0x8000E000 - SYS.CFG.SCFG - Interrupt test configuration register

17: 16	SpaceWire Loop-back control (SPW) - Control of SpaceWire loop-back production test. Bit #17 - Enable internal loop-back for SpaceWire PHY 0 (LVDS) Bit #16 - Enable internal loop-back for SpaceWire PHY 1 (CMOS) Internal loop-back means that the ports internal data and strobe signals are not mapped to the corresponding external SpaceWire I/O pins. They are instead routed back to the port internally (transmit data to receive data, transmit strobe to receive strobe).
15	LVDS External Loop (LL) - Enable LVDS external loop-back. External loop-back means that the external LVDS I/O pins are not routed to the corresponding port. Instead they are routed back out on the external pins (LVDS_RXp/n to LVDS_TXp/n). Enable of external loop-back forces the LVDS receiver and transmitter to be enabled. LVDS external loop-back mode enables external test of voltage input and low level detection.
14: 13	SpaceWire External Loop (LS) - SpaceWire external loop-back 0x0 - Normal operation 0x1 - External loop-back mode routed back via rising edge clocked flip-flops 0x2 - External loop-back mode routed back via falling edge clocked flip-flops 0x3 - External loop-back mode routed back via rising or falling edge clocked flip-flops SpaceWire External loop-back means that the external SpaceWire I/O pins are routed via SpaceWire-Phy to the corresponding port. Pins are routed back via SpaceWire-Phy out on the external pins (SPW_RXDp/n to SPW_TXDp/n and SPW_RXSp/n to SPW_TXSp/n). Test option 0x1 and 0x2 are used for setup and hold measurements for respective clock edge. Test option 0x3 is used for minimum pulse width detection.
12	Locken (LE) - Support Locked transfers in SCRUBBER.
11	Force Scrubber (FS) - Force Scrubber to function as AHBSTAT unit on main AMBA bus.
10: 9	Interrupt test protection bits (PROT) - Protection and generation of interrupt test for specified interrupt source. The protection bits needs to be toggled in-order to generate a test interrupt i.e.both PROT bits needs to be read and bitwise inverted before written back to the PROT bit-field to generate a interrupt.
8:3	Interrupt source (IRQ) - An event will be generated on the interrupt source
2	MIL-1553B reset disable (MR) - Disable reset signal from MIL-1553B core
1	Override watchdog error generation (WE) - Disables reset request. To be used during debug of the system
0	Override error generation (EE) - Disables reset generation when processor error is detected. To be used during debug of the system

8 Reset Generation and Brownout Detection

8.1 Overview

The Reset Generation and Brownout detection provides the system with a reset signal, deterministic startup behavior during power-on of the system and detection of power supply failure on board level.

The generated reset is output on a 3.3V IO to be used in the system.

8.2 Operation

8.2.1 System overview

The Reset generation and Brownout detection consists of two analog functions: The Power On Reset (POR) and the Brownout detection (BO).

The Brownout detectors will monitor the 1.8V and all 3.3V supplies. At the event of crossing a Brownout threshold, an interrupt will be generated. When such an interrupt is detected, the software needs to take action, typically shutting down critical parts of the system in a well controlled way. The time from detection of supply brownout to activation of system reset is determined by the external power supplies capability to maintain the supply voltages (the amount of decoupling capacitance on PCB).

8.2.2 Detailed description

An internal reset signal is generated from level detection of the core supply voltage, VDD_CORE. When this supply is below the detector threshold, the internal reset signal is low. When the supply goes above the threshold, the internal reset is still kept low until the reset release time has pasted; then, it goes high.

There is an external input reset signal, RESET_IN_N, which forces start of a reset cycle when it goes active (low). This reset cycle includes a full reset release time delay before the internal reset is released (before it goes high).

The internal reset signal and the external reset input signal RESET_IN_N input are asynchronous. However, note that the reset of all internal Microcontroller logic is synchronous with the system clock. Therefore, a positive edge on this clock is required after the internal reset is activated (after it goes low), for the reset to start taking effect on the internal Microcontroller logic, and to complete the internal Microcontroller reset state, 5 clock cycles are needed.

The RESET_OUT_N output is a buffered copy of the internal reset signal, and the output is a standard CMOS 3.3V driver.

The reset release time or pulse width is set by the combination of an internal capacitor (400pF) and an external capacitor C_RST.

The sum of power-on-reset capacitor must be large enough to keep the device in reset until power and system clock is stable. The external power-on-reset capacitor, connected to C_RST, is recommend to be at least 47nF and must be greater or equal to 5nF. The power-on-reset pulse width can be estimated using the formula: Tpw = 755000*Crst. For example Tpw_47nF = 755000*47nF=~35ms.

The internal reset detection threshold has a hysteresis of at least 100mV(TBC). This is to ensure that noise on VDD_CORE power-up/down ramp does not cause spurious toggling of the interal reset signal. The hysteresis also ensures that the delay circuitry, which generates the reset release time, functions properly (that the internal delay circuit is ensured to have enough time for proper discharge before VDD_CORE can cross the threshold again).

The Brownout detector on the supplies, VDD_CORE, VDD_IO, VDDA_PLL, VDDA_ADC, VDDA_DAC, VDD_LVDS, VDDA_REF, have individually programmable threshold levels. The threshold selected for each supply must, in worst case, be set below the guaranteed minimum supply

voltage instant peak level provided on the package pins for each supply, respectively. Otherwise, undesired Brownout detections giving inadvertent system shutdowns can result. Note however that the Brownout detectors have a spurious-pulse rejection filter of about 5us.

Furthermore, for any supply voltage in the system that is equipped with a reset threshold detection, such as the on-chip VDD_CORE detector or any arbitrary supply detector on PCB, the Brownout level must be set with a certain margin higher than the reset level, such that there is enough time to ensure that the Brownout interrupt routine can be executed before the reset is activated. Therefore, the selection of the Brownout threshold levels should be extra carefully co-designed with the power-supply and reset designs on PCB, in Microcontroller applications that will utilize the Brownout detectors on supply voltages that are also reset detected (which the VDD_CORE always is).

The Brownout detection is latched in the interrupt handling logic, and the detected event can then be taken care of by the interrupt service routine.

After power-on reset, the Microcontroller starts with all Brownout interrupt mask bits set to enable.

8.2.3 Reset IO control

The 64 General purpose IO described in chapter 2.4 and 2.5 is forced to high impedance mode when core voltage supply is lower than the threshold for releasing the system reset.

8.2.4 Brownout IO control

The control register for the 64 General purpose IO described in chapter 2.4 and 2.5 described in chapter Configuration Registers can be forced by the system to keep its state when Brown Out has been detected for at least one of the external voltage supplies, VDD_CORE, VDD_IO, VDDA_PLL, VDDA_ADC, VDDA_DAC, VDD_LVDS, VDDA_REF.

The system can force all 64 General purpose IO by disabling clock source #23 described in section 26

8.2.5 Access control

The reset release time is programmable by an external capacitor, C_RST. Capacitor value and release time is specified in section 52.10

Brown Out detection level and interrupt generation can be controlled via registers.

8.3 Registers

The Reset Generation and Brownout Detection is programmed through registers mapped into APB address space.

Table 67. Reset Generation and Brownout Detection status and control registers

APB address offset	Register
0x00	Configuration register
0x04	Status register
0x08	Interrupt register
0x0C	Interrupt mask register
0x10	LDO trim register
0x14	Voltage monitor delay register
0x18	Voltage monitor powerdown register
0x1C	Unused
0x20	Power control, XO and LVDS driver enable register
0x24	Brown Out disable IO from local register

Table 68. 0x00 - CFG - Reset Generation and Brownout Detection Configuration register

31 21	20 18	17 15	14 12	11 9	8 6	5 3	2 0
R	BLI	BLC	BLA	BLD	BLB	BLL	BLP
0	b000	b000	b000	b000	b000	b000	b000
	rw	rw	rw	rw	rw	rw	rw

31: 21 Reserved
20: 18 Brown Out Level for 3.3 V power supply (BLI)
17: 15 Brown Out Level for 1.8 V power supply (BLC)
14: 12 Brown Out Level for Analog ADC supply (BLA)
11: 9 Brown Out Level for Analog DAC supply (BLD)
8: 6 Brown Out Level for BandGap supply (BLB)
5: 3 Brown Out Level for LVDS power supply (BLL)
2: 0 Brown Out Level for PLL power supply (BLP)

000 sets the minimum value for the threshold, 111 the maximum

Table 69. 0x04 - STS - Reset Generation and Brownout Detection status register

31 6	5	4	3	2	1	0
RESERVED	BI	BC	BA	BD	BB	BL	BP
0x00000000	0	0	0	0	0	0	0
r	r	r	r	r	r	r	r

31: 7 RESERVED
6 Brown Out Detected (BI) - Faulty 3.3 V power supply detected
5 Brown Out Detected (BC) - Faulty 1.8 V power supply detected
4 Brown Out Detected (BA) - Faulty ADC power supply
3 Brown Out Detected (BD) - Faulty DAC power supply
2 Brown Out Detected (BB) - Faulty BandGap power supply
1 Brown Out Detected (BL) - Faulty LVDS power supply detected
0 Brown Out Detected (BP) - Faulty PLL power supply detected

Table 70. 0x08 - IRQ - Reset Generation and Brownout Detection Interrupt Flags

31 6	5	4	3	2	1	0
RESERVED	II	IB	ID	IA	IC	IL	IR
0x00000000	0	0	0	0	0	0	0
r	wc	wc	wc	wc	wc	wc	wc

31: 7 RESERVED
6 Interrupt Flag for Brown Out Detection (II)
5 Interrupt Flag for Brown Out Detection (IC)
4 Interrupt Flag for Brown Out Detection (IA)
3 Interrupt Flag for Brown Out Detection (ID)
2 Interrupt Flag for Brown Out Detection (IB)
1 Interrupt Flag for Brown Out Detection (IL)
0 Interrupt Flag for Brown Out Detection (IP)

Table 71. 0x0C - MSK - Reset Generation and Brownout Detection Interrupt Mask

31	6	5	4	3	2	1	0
RESERVED	MI	MB	MD	MA	MC	ML	MR
0x00000000	0	0	0	0	0	0	0
r	rw	rw	rw	rw	rw	rw	rw

31: 7 RESERVED

6 Interrupt Mask for Brown Out Detection (MI) - Set to 0 to mask interrupt generation for 3.3V power supply detection interrupt from Brown Out detection

5 Interrupt Mask for Brown Out Detection (MC) - Set to 0 to mask interrupt generation for 1.8 V power supply detection interrupt from Brown Out detection

4 Interrupt Mask for Brown Out Detection (MA) - Set to 0 to mask interrupt generation for ADC power supply detection interrupt from Brown Out detection

3 Interrupt Mask for Brown Out Detection (MD) - Set to 0 to mask interrupt generation for DAC power supply detection interrupt from Brown Out detection

2 Interrupt Mask for Brown Out Detection (MB) - Set to 0 to mask interrupt generation for faulty BandGap power supply detection interrupt from Brown Out detection

1 Interrupt Mask for Brown Out Detection (ML) - Set to 0 to mask interrupt generation for faulty LVDS power supply detection interrupt from Brown Out detection

0 Interrupt Mask for Brown Out Detection (MP) - Set to 0 to mask interrupt generation for faulty PLL power supply detection interrupt from Brown Out detection

Table 72. 0x10 - LDOTRM - LDO Trimmer

31	3	2	0
RESERVED		TRM	
0		b011	
r		rw	

31: 3 RESERVED

0: 2 LDO trimmer value (TRM):

b000 -> 0mV
b001 -> +22mV
b010 -> +44mV
b011 -> +66mV (Default)
b100 -> -88mV
b101 -> -66mV
b110 -> -44mV
b111 -> -22mV

Table 73. 0x14 - VDEL - Voltage monitor delay register

31	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
R		BDI		BDC		BDA		BDD		BDB		BDL		BDP	
0		b00		b00		b00		b00		b00		b00		b00	
		rw		rw		rw		rw		rw		rw		rw	

31: 14 Reserved

13: 12 Brown Out Delay for 3.3 V power supply (BDI)

11: 10 Brown Out Delay for 1.8 V power supply (BDC)

9: 8 Brown Out Delay for Analog ADC supply (BDA)

7: 6 Brown Out Delay for Analog DAC supply (BDD)

Table 73. 0x14 - VDEL - Voltage monitor delay register

5: 4 Brown Out Delay for BandGap supply (BDB)

3: 2 Brown Out Delay for LVDS power supply (BDL)

1: 0 Brown Out Delay for PLL power supply (BDP)

Table 74. 0x18 - VPD - Voltage monitor powerdown register

31	6	5	4	3	2	1	0
RESERVED	BI	BC	BA	BD	BB	BL	BP
0x00000000	0	0	0	0	0	0	0
r	rw	rw	rw	rw	rw	rw	rw

31: 7 RESERVED

6 Brown Out Powerdown (BI) - Powerdown 3.3 V power supply detected

5 Brown Out Powerdown (BC) - Powerdown 1.8 V power supply detected

4 Brown Out Powerdown (BA) - Powerdown ADC power supply

3 Brown Out Powerdown (BD) - Powerdown DAC power supply

2 Brown Out Powerdown (BB) - Powerdown BandGap power supply

1 Brown Out Powerdown (BL) - Powerdown LVDS power supply detected

0 Brown Out Powerdown (BP) - Powerdown PLL power supply detected

Table 75. 0x20 - XEN - Power control, XO and LVDS driver enable register

31	3	2	1	0
RESERVED		LP	PP	XP
0x00000000		0	0	0
r		rw	rw	rw

31: 3 RESERVED

2 Power down LVDS (LP) - Power down LVDS power supply

1 Power down POR (PP) - Power Down POR power supply

0 Power down XO (XP) - Power down XO power supply

Note: Register is protected by password. Contact supportgasiler.com

Table 76. 0x24 - BDI - Brown Out disable IO from local register

31	1	0
RESERVED		D
0x00000000		0
r		rw

31: 2 RESERVED

0 Disable IO (D) - Brown Out disable IO from local register

Note: Register is protected by password. Contact supportgasiler.com

9 Crystal (XO) Oscillator

9.1 Overview

The on-chip crystal oscillator (XO) contains all *active* oscillator parts, and a crystal (XTAL) is added on PCB. It provides a clock output signal as a 3.3V CMOS square-wave output.

9.2 Operation

9.2.1 System overview

The on-chip XO supports generation of an accurate XTAL-based oscillator clock signal, where its output signal can be directly connected to the system clock input on the LEON3FT microcontroller. This clock signal can also be arbitrarily used on PCB. If a precision XO on PCB is needed, the on-chip XO can then be made to draw negligible power if desired.

9.2.2 Detailed description

The XO block is supplied by the Microcontroller core voltage, VDD_CORE (1.8V). The oscillator output is a 3.3V CMOS output and is available on an external pin. The XO block requires an external crystal on PCB (parallel-resonant fundamental-tone AC-cut XTAL). The XTAL two terminals are to be connected directly to XO pins (XO_X1, XO_X2), and a capacitor to ground on each of these XO pins are. The range of supported XTAL frequencies is 5 to 25 MHz, where 5MHz is recommended for low-power applications and up to 25MHz for high-performance applications. See chapter 9.2.3 for the details how to implement the XO interface in PCB design.

In applications where an external high-precision oscillator on PCB needs to be used (TCXO, OCXO, etc), a 3.3V CMOS-compatible oscillator signal should be fed into the system clock input. To minimize the on-chip XO current consumption, a detector is build-in to disable the XO when the XO pins are connected according to the following figure.

Figure 11. Connection diagram to disable the XO, for minimum current consumption.

9.2.3 Crystal recommendations and examples

This section specifies crystal recommendations for proper functionality and lists a number of typical crystal configurations for the GR716 device.

The frequency of the crystal should be 5, 10, 12.5, 16, 20 or 25 MHz, optimum for different applications. The crystal type should be parallel-resonant fundamental-tone AC-cut XTAL.

Recommended values on C_{X1} and C_{X2} range (ceramic NP0), at 20 MHz:

- Minimum recommended value for C_{X1} and C_{X2} is 10 pF_nom.
- Max recommended value for C_{X1} and C_{X2} is 22 pF_nom, for worst-case max ESR of 100 ohm.
- Max recommended value for C_{X1} and C_{X2} is 33 pF_nom, for worst-case max ESR of 50 ohm.
- Max recommended value for C_{X1} and C_{X2} is 47 pF_nom, for worst-case max ESR of 25 ohm.

Lower frequencies than 20 MHz allow for higher crystal ESR values, e.g. half the frequency allows for at least double the ESR.

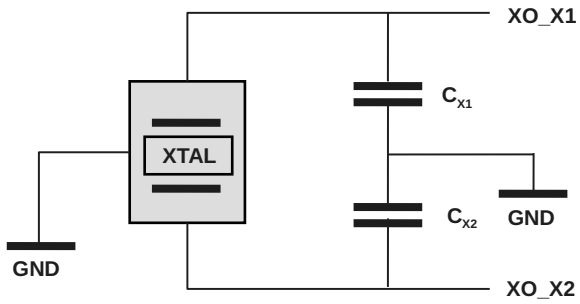


Figure 13. Connection diagram for C_{X1} and C_{X2} on PCB, where XO_X1 and XO_X2 are the XO connections on GR716.

Table 77. GR716 Crystal configuration examples

Crystal	Frequency [MHz]	Max ESR @ 25°C [Ω]	Load Cap [1] [pF]	Typical C_{X1}, C_{X2} [pF]
HC49US / U-Sxxx (Citizen)	5 25	150 50	20 15	33 22
ABMM2 (Abracon)	10 25	50 50	18 18	33 22
JXS32-WA (Jauch)	20	45	10	15
T1507 ESCC 3501/019 (Rakon)	5 10	20 15	50 50	100 100
T807 ESCC 3501/018 (Rakon)	16 25	15 10	30 30	47 47

Note 1: The total crystal load capacitance should take into account the PCB stray capacitance and the input capacitance of the GR716 device on XO pins to ground. The XO input pins to ground are typically 4 pF. E.g. Assuming a crystal with load capacitance of 20pF and PCB stray capacitance of 3pF would require $C_{X1} = C_{X2} = 33$ pF

9.2.4 PCB Design Considerations

This section lists PCB considerations for use of external crystal:

- Signal traces between GR716, the crystal (XTAL), the external capacitors must be as short as possible to minimize the parasitic capacitive crosstalk and field disturbance.
- Route XOUT with ground shield to X1 and X2 to minimize the crosstalk.
- Route the whole signal path between the XTAL and the load capacitors as short as possible i.e. XTAL to C_{X1} and C_{X2} to XTAL. Keep ground connection for C_{X1} and C_{X2} together.
- Use a ground plan and ground guard ring to protect crystal traces. This ground must be clean i.e. no current should be flowing through it. It should be connected to the GR716 ground of plane, close to the XO package pins.

Figure 15. Example of layout using a ground guard ring.

9.2.5 Access control

N/A

10 PLL

10.1 Overview

The Phase-Lock-Loop (PLL) is capable of generating an phase locked output clock of 400MHz to the system. The input reference clock is multiplied by 16, 20, 32, 40 or 80.

10.2 Operation

10.2.1 System overview

The PLL provides a 400MHz internal clock, typically used as SpaceWire clock, etc. The PLL reference-clock input is a 3.3V CMOS input, to which the XO-oscillator clock output can be directly connected, or any other clock signal generated on PCB fulfilling the electrical specification of this input. The PLL reference-clock input is allowed to be asynchronous to any other clocks in the GR716 LEON3FT microcontroller.

10.2.2 Detailed description

For more information about using the PLL in the system see section 4.

10.2.3 Access control

PLL status and configuration can be accessed via registers

10.2.4 Configuration protection

The PLL control registers are provided with an BCH EDAC that can correct and detect errors for the PLL and clock configuration. When an correctable or uncorrectable error is detected an interrupt can optionally be generated to the system.

In case of a uncorrectable error was detected the default configuration will be selected i.e. system clock source is the external SYS_CLK pin

The protection scheme needs to be enabled by system to be active.

10.3 Registers

Table 78. PLL control and status registers

APB address offset	Register
0x00	Configuration register
0x04	Status register
0x08	PLL reference clock and divider
0x0C	Select SpaceWire clock source and divisor
0x10	Select 1553B clock source and divisor
0x14	Select SYS clock source and divisor
0x18	Switch to selected system clock
0x1C	Control register
0x20	Protection register
0x24	Test clock enable
0x28	Select PWM0 clock source and divisor
0x2C	Select PWM1 clock source and divisor

Table 79. 0x00 - CFG - PLL configuration registers

31	30	3	2	0
PD	RESERVED		CFG	
0*	0x00000000		0*	
rw	r		rw	

31 PLL power down (PD) - If this bit is written to 1, the PLL is powerdown. The PLL should always be in power down mode when not used, i.e.,when the PLL is bypassed.

30: 3 RESERVED

2: 0 PLL configuration (CFG) - Internal PLL multiplier depended upon the input frequency of the PLL

011b - when input frequency 25MHz (division by 16)
101b - when input frequency 20MHz(division by 20)
100b - when input frequency 12.5MHz(division by 32)
110b - when input frequency 10MHz (division by 40)
111b - when input frequency 5MHz (division by 80)
000b - not used
001b - not used

* This register can be changed after reset due to bootstrap pins

Table 80. 0x04 - STS - PLL status register

31	2	1	0
RESERVED		LL	CL
0x00000000		wc	-
r		rw	r

31: 2 RESERVED

1 Lost lock (LL) - This bit is a sticky bit that indicates if the lock bit from the SpaceWire clock PLL has gone low. This bit can be cleared by writing a 1 to the PLL clear lost lock bit.

0 PLL clock lock (CL) - Shows the current value of the PLL lock output.

Table 81. 0x08 - PLLREF - Select reference for PLL clock

31 24	23 16	15 10	9 8	7 0
RESERVED	Not used	RESERVED	SEL	Not used
0x0	0x0	0x0	0*	0
r	rw	r	rw	r

31: 24 RESERVED

23: 16 Not used

15: 10 RESERVED

9: 8 PLL Reference Clock (SEL) - Select SpaceWire reference clock

0x0 - Clock source from external signal SYS_CLK

0x1 - Clock source from external signal SPW_CLK

All other values will result in the external signal SYS_CLK to be used as reference

* This register can be changed after reset due to bootstrap pins

7: 0 Not used

Table 82. 0x0C - SPWREF - Select reference for SpaceWire clock

31 24	23 16	15 10	9 8	7 0
RESERVED	DUTY	RESERVED	SEL	DIV
0x0	0x0	0x0	0*	0
r	rw	r	rw	rw

31: 24 RESERVED

23: 16 DUTY cycle for generated clock frequency - The duty cycle bitfield specifies how many of the total clock cycles specified in the DIV bitfield the generated clock shall be high. IF this register is set to 0x0 the duty cycle will be set to clock cycles defined in DIV and the clock period to 2xDIV.

15: 10 RESERVED

Table 82. 0x0C - SPWREF - Select reference for SpaceWire clock

9: 8 SpaceWire Reference Clock (SEL) - Select SpaceWire reference clock

0x0 - Bypass when PLL is in power down mode (Clock source from external signal SYS_CLK or SPW_CLK)

0x1 - Clock generated from PLL

All other values will result in the clock generated from the PLL to be used.

The output from the PLL is always 400 MHz

* This registers default value can be changed after reset due to bootstrap pins

7: 0 SpaceWire Reference Clock Divisor (DIV) - Set the divisor for input reference clock. Zero (default) bypass the divisor.

When bitfield DUTY period is set to 0x0 or 0x1. The input clock frequency will be divided by 2xDIV clock cycles with the duty cycle set to 50%. Valid configurations when DUTY period is set to 0 or 1:

0x00 - Bypass i.e. input frequency is divided by 1
0x02 - Divide input frequency by 4
0x04 - Divide input frequency by 8
0x06 - Divide input frequency by 12
0x08 - Divide input frequency by 16
0x0A - Divide input frequency by 20
0x0C - Divide input frequency by 24
0x0E - Divide input frequency by 28
0x10 - Divide input frequency by 32
0x14 - Divide input frequency by 40
0x16 - Divide input frequency by 44
0x18 - Divide input frequency by 48
0x1A - Divide input frequency by 52
0x1C - Divide input frequency by 56
0x1E - Divide input frequency by 60

All other combinations is not valid.

When bitfield DUTY period is equal or greater then 0x2.The DIV bifield will divide the input frequency by DIV clock cycles and with the duty cycle defined in the DUTY bitfield.

0x04 - Divide input frequency by 4
0x06 - Divide input frequency by 6
0x08 - Divide input frequency by 8
0x0A - Divide input frequency by 10
0x0C - Divide input frequency by 12
0x0E - Divide input frequency by 14
0x10 - Divide input frequency by 16
0x14 - Divide input frequency by 20
0x16 - Divide input frequency by 22
0x18 - Divide input frequency by 24
0x1A - Divide input frequency by 26
0x1C - Divide input frequency by 28
0x1E - Divide input frequency by 30

All other combinations is not valid

Table 83. 0x10 - MILREF - Select reference for 1553B clock

31 24	23 16	15 10	9 8	7 0
RESERVED	DUTY	RESERVED	SEL	DIV
0x0	0x0	0x0	0	0
r	rw	r	rw	rw

31: 24 RESERVED

23: 16 DUTY cycle for generated clock frequency - The duty cycle bitfield specifies how many of the total clock cycles specified in the DIV bitfield the generated clock shall be high. IF this register is set to 0x0 the duty cycle will be set to clock cycles defined in DIV and the clock period to 2xDIV.

Table 83. 0x10 - MILREF - Select reference for 1553B clock

15: 10 RESERVED

9: 8 1553B Reference Clock (SEL) - Select 1553B reference clock and source

0x0 - Clock source from external signal SYS_CLK

0x1 - External 1553B clock pin selected by the IO mux

0x2 - Clock source from external signal SPW_CLK

0x3 - Clock generated from PLL

External or active 1553B clock is selected via IO mux configuration

7: 0 1553B reference Clock Divisor (DIV) - Set the divisor for input reference clock. Zero (default) bypass the divisor.

When bitfield DUTY period is set to 0x0. The input clock frequency will be divided by 2xDIV clock cycles with the duty cycle set to 50%
When bitfield DUTY period is larger then 0x1.The DIV bifield will divide the input frequency by DIV clock cycles and with the duty cycle defined in the DUTY bitfield

Table 84. 0x14 - SYSREF - Select SYS clock source and divisor

31 24	23 16	15 10	9 8	7 0
RESERVED	DUTY	RESERVED	SEL	DIV
0x0	0x0	0x0	0	0
r	rw	r	rw	rw

31: 24 RESERVED

23: 16 DUTY cycle for generated clock frequency - The duty cycle bitfield specifies how many of the total clock cycles specified in the DIV bitfield the generated clock shall be high. IF this register is set to 0x0 the duty cycle will be set to clock cycles defined in DIV and the clock period to 2xDIV.

15: 10 RESERVED

9: 8 System Reference Clock (SEL) - Select system clock frequency and source

0x0 - Clock source from external signal SYS_CLK input pin

0x1 - Clock source from external signal SPW_CLK input pin

0x2 - Clock generated from PLL

All other values will result in the clock generated from the external signal SYS_CLK to be used

7: 0 System Reference Clock Divisor (DIV) - Set the divisor for input reference clock. Zero (default) bypass the divisor.

When bitfield DUTY period is set to 0x0. The input clock frequency will be divided by 2xDIV clock cycles with the duty cycle set to 50%
When bitfield DUTY period is larger then 0x1.The DIV bifield will divide the input frequency by DIV clock cycles and with the duty cycle defined in the DUTY bitfield

Table 85. 0x18 - SYSSEL - Select system clock source

31 1	0
RESERVED	S
0x0	0
r	rw

31: 1 RESERVED

0 Select new system clock source (S) - Writing to this register will force the system clock selected in register SYSREF to be selected and used.as system clock.

Table 86. 0x1C - CTRL - Enable interrupt generation from PLL and clock logic

31	1	0
RESERVED		IE
0x0		0
r		rw

31: 1 RESERVED

0 Interrupt Enable (IE) - Writing to this register will enable interrupt generation from PLL and clock logic

Table 87. 0x20 - PROT - Clock configuration protection registers

31 28	27 24	23	22	21 20	19	18	17 16	15	14 8	7	6 0
RESERVED	ECTRL	R	R	ESTAT			EIRQ	R	REGE1	R	REGE0
0x0	0x0	0	0	0x0			0x0	0	-	0	-
r	rw	r	r	wc			wc	r	r	r	r

31: 28 RESERVED

27: 24 Error control (ECTRL) - Enable error detection and correction of clock control registers

b0000 - Disable all error detection and correction
b1111 - Enable error detection and correction

21: 20 Error status (ESTAT) -Error status register

bx1 - Error detected in bitfields for PD, ECTRL, TCTRL, CFG or system clock configuration register
b1x - Error detected in bitfields for PLL, SPW or 1553B clock configuration registers

17: 16 Enable error interrupt generation (EIRQ) - Register for enabling error interrupt generation

b00 - No interrupt generation
b11 - Enable interrupt generation

14: 8 Register debug register 1 (REGE1) - Debug register displaying the EDAC checksum for PLL, SPW or 1553B clock configuration registers

6: 0 Register debug register 0 (REGE0) - Debug register displaying the EDAC checksum for PD, ECTRL, TCTRL, CFG or system clock configuration registers

Table 88. 0x24 - TCTRL - Test Clock Enable

31	3 2 1	0
RESERVED		EN
0x0		0
r		rw

31: 1 RESERVED

0 Enable of output test clock

Writing to this register will:

1. force the internal MIL-1553 clock to be available at GPIO 61.
2. force the internal SpaceWire clock to be available at GPIO 62
3. force the internal system clock to be available at GPIO 63
4. force the internal PWM0 clock to be available at GPIO 60
5. force the internal PWM1 clock to be available at GPIO 59

Table 89. 0x28 - PWM0REF - Select reference for PWM0 clock

31 24	23 16	15 10	9 8	7 3	0
RESERVED	D2	DUTY	RESERVED	SEL	DIV
0x0		0x0	0x0	0	0

Table 89. 0x28 - PWM0REF - Select reference for PWM0 clock

r		rw	r	rw	rw

31: 25 RESERVED

24 Divide reference clock by 2. To generate a 200 MHz clock the PWM0REF.SEL must be set to 0x3 i.e. the source of the PWM clock must be the output of the PLL.

23: 16 DUTY cycle for generated clock frequency - The duty cycle bitfield specifies how many of the total clock cycles specified in the DIV bitfield the generated clock shall be high. IF this register is set to 0x0 the duty cycle will be set to clock cycles defined in DIV and the clock period to 2xDIV.

15: 10 RESERVED

9: 8 PWM Reference Clock (SEL) - Select 1553B reference clock and source

0x0 - Clock source from external signal SYS_CLK

0x1 - Clock source from external signal SPW_CLK

0x2 - External PWM0 clock pin GPIO[17]

0x3 - Clock generated from PLL

7: 0 PWM reference Clock Divisor (DIV) - Set the divisor for input reference clock. Zero (default) bypass the divisor.

When bitfield DUTY period is set to 0x0. The input clock frequency will be divided by 2xDIV clock cycles with the duty cycle set to 50%
When bitfield DUTY period is larger then 0x1.The DIV bifield will divide the input frequency by DIV clock cycles and with the duty cycle defined in the DUTY bitfield

Table 90. 0x2C - PWM1REF - Select reference for PWM1 clock

31 24	23 16	15 10	9 8	7 0
RESERVED	DUTY	RESERVED	SEL	DIV
0x0	0x0	0x0	0	0
r	rw	r	rw	rw

31: 25 RESERVED

24 Divide reference clock by 2. To generate a 200 MHz clock the PWM1REF.SEL must be set to 0x3 i.e. the source of the PWM clock must be the output of the PLL.

23: 16 DUTY cycle for generated clock frequency - The duty cycle bitfield specifies how many of the total clock cycles specified in the DIV bitfield the generated clock shall be high. IF this register is set to 0x0 the duty cycle will be set to clock cycles defined in DIV and the clock period to 2xDIV.

15: 10 RESERVED

9: 8 PWM Reference Clock (SEL) - Select 1553B reference clock and source

0x0 - Clock source from external signal SYS_CLK

0x1 - Clock source from external signal SPW_CLK

0x2 - External PWM0 clock pin GPIO[18]

0x3 - Clock generated from PLL

7: 0 PWM reference Clock Divisor (DIV) - Set the divisor for input reference clock. Zero (default) bypass the divisor.

When bitfield DUTY period is set to 0x0. The input clock frequency will be divided by 2xDIV clock cycles with the duty cycle set to 50%
When bitfield DUTY period is larger then 0x1.The DIV bifield will divide the input frequency by DIV clock cycles and with the duty cycle defined in the DUTY bitfield

11 Voltage and Current References

11.1 Overview

The internal voltage and current reference block provides accurate reference voltage and currents in the system.

11.2 Operation

11.2.1 System overview

The internal voltage and current references consist of a bandgap reference providing a high-impedance unbuffered voltage of nominal 1V and a bias block generating accurate bias currents. The bias block includes a temperature sensor compatible with the ADC IP to enable digital temperature read out.

11.2.2 Detailed description

The reference blocks, internal voltage reference and current reference generator, are supplied by VDDA_REF and VSSA_REF. It is essential that there is good PCB decoupling on this supply, especially at high frequencies, since the on-chip disturbance suppression commonly is poor at high frequencies, which would result in high-frequency disturbance transferred directly onto the references used by analog blocks such as ADC and DACs.

Another decoupling capacitor, which is the most critical (sensitive) one for the whole Microcontroller, is on the internal voltage reference output pin, VREF. This decoupling capacitance should be 4.7nF located very close to the VREF pin, and grounded (very close) to the VSSA_REF pin. There should be no other components on PCB connected to the VREF pin, and its PCB layout connection should not extend beyond the decoupling capacitor, to avoid disturbance on this pin. Preferably, a VSSA_REF local ground plane and guard ring around this pin should be implemented in the PCB layout.

The reference buffer providing VREFBUF is a buffer amplifier with gain 2.4 of VREF. The maximum load current on VREFBUF, with full voltage performance maintained, is 2mA. It can be used, for example, to perform accurate bridge measurements with the ADC, such as thermistor measurements, or wherever a reference voltage (referred to VSSA_REF) is needed in application circuits on PCB. It is, however, critical that no fast current load steps are present on the VREFBUF output, since that can cause erroneous voltage transients.

The reference resistor, RREF, sets all the reference currents for internal bias currents and the fullscale current for the four DACs. Therefore, it is critical that RREF always is within 4.9-5.3 kohm over worst-case conditions. The DAC fullscale current is proportional to the current through RREF, where 5.11 Kohm gives a nominal fullscale current of 4.0mA.

12 Internal ADC, Pre-Amplifier and Analog MUX

12.1 Overview

The GR716 has 2 separate 11 bit Analog-to-Digital Converters (ADC) converters and 8 separate ADC control units. Each 11 bit resolution Analog-to-Digital Converters (ADC) converts analog single-ended or differential input signals to 11 bit digital outputs. An integrated analog multiplexer and pre-amplifier allow measuring both on- and off-chip analog signals. ADC control and status registers are accessible via 8 ADC control units from the processor. The 8 ADC control units supports CPU off-loading, autonomously ADC measurements and level detection to off-load the processor.

The ADC control units are located on APB bus in the address range from 0x80400000 to 0x80407FFF. See ADC converters and ADC control units connections in the next drawing. The figure shows memory locations and functions used for ADC configuration and control.

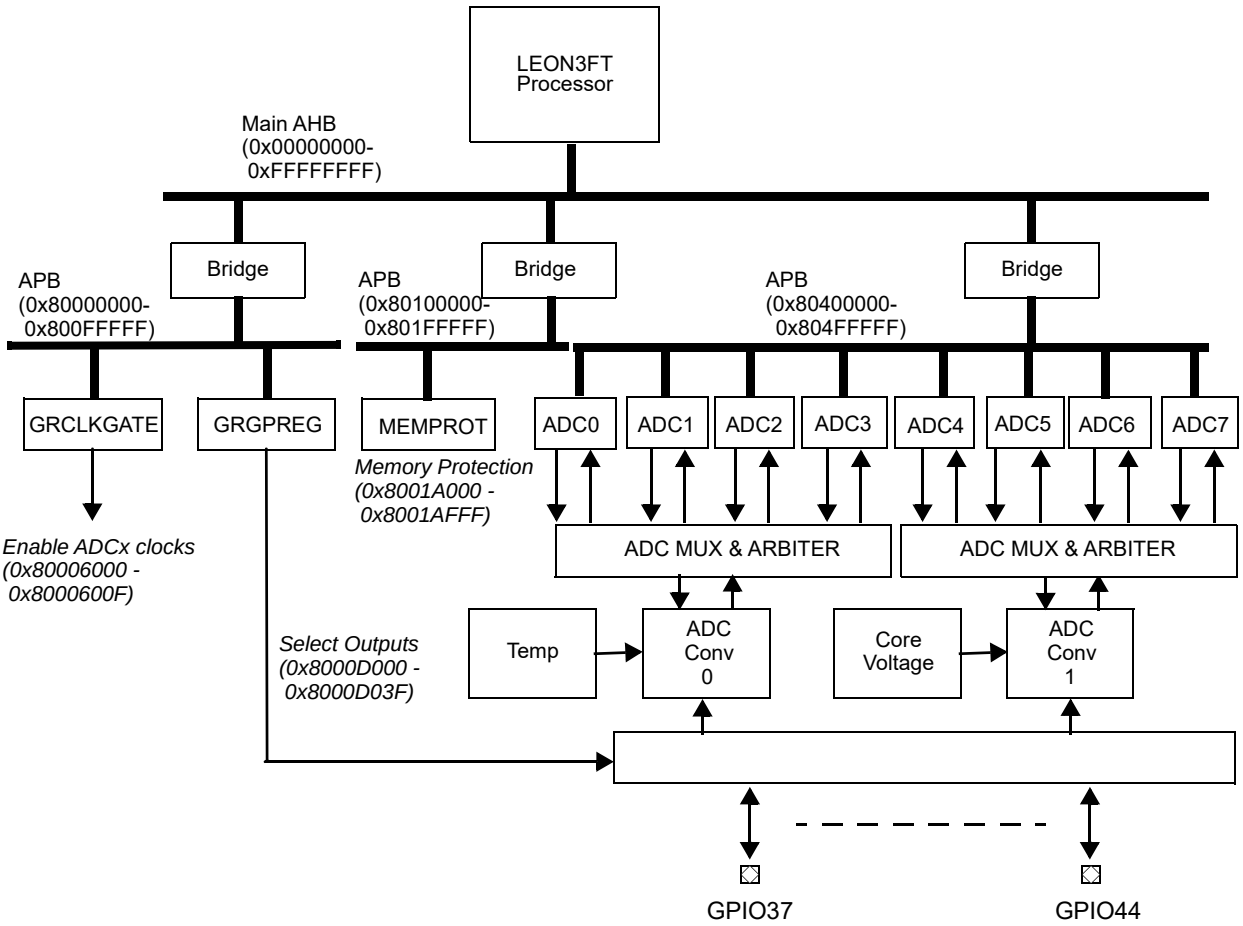


Figure 16. GR716 ADC bus and pin connection

The primary clock gating unit **GRCLKGATE** described in section 26 is used to enable/disable individual ADC converters and ADC control units. The unit **GRCLKGATE** can also be used to perform reset of individual ADC control units. Software must enable clock and release reset described in section 26 before ADC configuration and sampling can start.

External IO selection per ADC input pin is made in the system IO configuration register (**GRGPREG**) in the address range from 0x8000D000 to 0x8000D03F. See section 7.1 for further information.

Each **ADCx** control unit has access to external ADC pins via ADC converters and has a unique AMBA address described in chapter 2.11. ADC control unit 0, 1, 2, 3, 4, 5, 6 and 7 have identical configuration and status registers. Configuration and status registers are described in section 12.3.

The system can be configured to protect and restrict access to individual ADC units in the **MEMPROT** unit. See section 47 for more information.

12.2 Operation

12.2.1 System overview

Each ADC converter is a 11bit/200kSps SAR converter, and has an analog MUX in-front of it, which means that one MUX channel at a time can be measured. The ADC can be programmed to single-ended 11-bit range (0 V - 2.5 V) using one input pin per channel, or to differential-input 11-bit range (-2.0V- 2.0V) using two input pins per channel. In-between the ADC and MUX, there is a fully differential pre-amplifier, which has three programmable gain-settings (x1, x2, x4). It is to be used together with the fully-differential ADC setting. The amplifier input impedance is in the order of 5 to 20 kohm (TBC). The amplifier can be by-passed by programming; then, the DC input impedance is high (dominated by MUX leakage currents). These three blocks are supplied by VDDA_ADC and VSSA_ADC. This supply is not the analog reference for the ADC measurements. However, it must still be really well decoupled/filtered at high frequencies (>~1MHz) to not degrade the ADC performance.

The ADC supply ground, VSSA_ADC, should be hardwired to the same PCB ground point as VSSA_REF, directly outside the Microcontroller package.

12.2.2 Detailed description

The on-chip ADC and pre-amplifier has a digital control and status interface accessible via register on the APB bus. To support CPU offloading, autonomously ADC measurements and level detection a digital interface has been implemented in the digital core of the microcontroller to support different complex sampling modes over multiple ADC channels. The digital interface also supports sampling modes to suppress noise and to increase the resolution and ENOB. Increasing the resolution is supported via oversampling and increasing the ENOB by using higher gain-settings in the pre-amplifier. In order to make the oversampling effective the measured signal needs to be of AC signal type or a DC signal with dithering i.e. introduce random noise in the analog input signal to the ADC. AC signal is defined as a signal where the quantization error of 2 consequence samples are independent.

Single-ended or differential mode is selected per ADC channel but will only be valid for ADC channel 0,2,4 and 6, since multiple channel inputs will be used when differential mode is enabled. Differential mode have the capability to measure more accurately and the input gain can be adjusted using the on-chip amplifier. The on-chip amplifier gain can be configured individually for the differential channels to x1, x2 or x4. To use just a pin when single-ended mode is selected, bypass mode should be selected too. If bypass is not selected, the negative pin shall be grounded.

The digital control logic supports following **Sampling modes and configuration**:

- Read **current value** i.e. via the ADC status register see section12.3for register description.
- **Oversampling and averaging** to extend the number of effective bits. The sampling rate and number of samples accumulated is controlled via registers. The number of samples can be configured in the range of 1 to 65535 samples. No other manipulation of the results is performed in hardware. The accumulated samples can be consecutive or taken with a configurable distance in-between. For each additional bit resolution, the signal must be oversampled by a factor of four.

  For simplicity the hardware do not perform any truncation or division of the accumulated samples. To get a correct average sampled value the accumulated sample value shall be rounded and divided by the number of samples used. For application where the truncation error is less import-

ant the user should choose to oversample by a factor of 2^N. When a factor or 2^N is chosen and truncation error is less important the user can shift the accumulated result by N steps.

- **Sequence sampling** for autonomously collecting of data from single or multiple ADC input channels. The Digital ADC logic interface supports up to 4 contiguous samples. The Sequence sampler can be combined with the oversampler i.e. samples can be optionally accumulated or sampled with configurable distance between samples.

Triggers can set and used for sampling. When a trigger is selected and a trigger event occur the channels value will be recorded and stored and presented in the status register. Multiple event can be selected per channel.

Autonomously **Level detection** of internal and external voltage levels can enabled. The digital ADC will generate an interrupt to the processor if interrupts are enabled and measured voltage level is above or below configured thresholds. The level detection needs to be enabled in order to generate an event. In order to get the level detection working the ADC interface needs to be configured to sample the input. For autonomously level detection the ADC interface should be configured to sample the input periodically.

Amplifier Control can amplify the ADC input channel x1, x2 or x4. Amplifier control does only take affect if the ADC input channel is configured as differential input.

On-chip **Temperature and Core Supply Voltage** can be sampled and presented to the system.

Interrupts generation when ADC channel voltage level is outside specified voltage range or programmed sampling sequence is finished is supported.

For **low noise measurements** of external sources and DMA transfers to **offload the processor** interrupts needs to be setup and used by the system. To perform a low noise measurement on a ADC channel most of the internal clock network needs to be disabled and the IOs next to the ADC inputs pins needs to be silent. The system software needs to program the ADC to trigger and sample an input using an external or internal trigger while system is in sleep mode. The same trigger or timer can be used to wake the processor if needed. DMA transfers can be triggered by the interrupt generated by the ADC interface. Simple or multiple transfers of ADC samples to internal or external RAM can be setup and made by the DMA controller in the LEON3FT microcontroller.

Arbitration: The ADC control units can access the ADC channels through a multiplexing structure. When an ADC controller unit tries to start a conversion, it waits until the multiplexing structure grants access to the ADC. ADC control units with lower IDs have higher priority, although higher priority requests don’t stop the ongoing conversion.

12.2.3 Increasing the resolution of an ADC measurement

Applications measuring a large dynamic range, yet require fine resolution to measure small changes in a parameter. E.g. the on-chip ADC measure a large temperature range where the system requires the microcontroller to respond to small temperature change. Such a system could require an ADC measurement resolution of 12-15 bits. Via oversampling and averaging, a 12-15 bit resolution measurement can be supported with the on-chip 11 bit ADC.

To increase the effective number of bits (ENOB) by 1, the signal must be oversampled by a factor of four. To support an ADC resolution of 12-15 bits the on-chip ADC needs to be configured to oversample the signal by 4, 16, 64 or 256, respectively.

Assume a system is using the on-chip 11-bit ADC to output a temperature value once every second (1 Hz). To increase the resolution of the measurement to 14-bits, we calculate the oversampling frequency as follows: Sample Frequency = 4^(14-11)x1 Hz = 64Hz.

Thus, if we oversample the temperature sensor at 64 Hz, we will collect enough samples within the required sampling period to average them and can now use 14-bits of the output data for a 14-bit measurement. To do so, we accumulate i.e. add 64 consecutive samples together. Once the results have

been calculated we store the data in the status register of the ADC and begin to collect data for the next temperature measurement.

To further enhance the ENOB the system can make use of the pre-amplifier or/and use dithering i.e. introduce random noise to the external signal.

Example of setting up the ADC for oversampling of a temperature sensor:

This examples assume the system requires to sample a temperature sensor once every second with the accuracy of 14 bits and a system clock of 20Mhz.

Configuration and setup steps:

- Setup a timer to generate a tick/sync event with the frequency of 512Hz to oversample by a factor of 8. For this example we assume Timer unit 1 and counter 2 is used. See documentation for timer section.
- Register bit fields configuration for using ADC channel #0 (Single ended measurement is assumed i.e. pre-amplifier must be bypassed)

```
ACFG.AC = 8          // ADC clock should be set to maximum of 3Mhz. Here we use 2.5Mhz i.e. 20Mhz/8
ACFG.AE = 1          // Enable ADC
ACFG.AI = 0x0        // Channel #0
ACFG.AM = 0x1        // Single ended mode
ASAMPC.AO = 0x3F     // Oversample by 63+1 i.e. add 3 extra ENOB
ASEQC.SQ = 0x1       // Enable synchronization to synchronization source
ASEQC.SE = 0x1       // Enable sequencer
ASEQC.SC = 0x1       // Enable continuously sampling i.e. Software needs to disable sampling manually
ASYNC.S10 = 0x1      // Synchronize i.e. sample value when counter 2 in timer unit 1 generates a 'tick
ACFG.AS = 0x1        // Start sampling i.e. listen for sync defined in sync register
```

This will generate a new interrupt and temperature reading from e.g. an external temperature sensor once every second with 14 bit resolution.

The correct sequence should be as the following address and data table:

TABLE 91. Example of using on-board ADC to oversample an external analog source

Address	Data	Description
---	---	
0x80400018	0x00000009	ADC0 - Mask register (Enable events from ADC0)
0x8040000C	0x00000800	ADC0 - Select trigger (counter 2 in timer unit 1)
0x80400008	0xB0000000	ADC0 - Sequencer control (Enable synchronization to ext trigger, continuously enabled)
0x80400004	0x0000003F	ADC0 - Sampling configuration (Oversampling, no consecutive)
0x80400000	0x0008C001	ADC0 - Configuration (Speed, Channel, Enable)
---	---	

12.2.4 Using the DMA to sample long sequences

The build-in DMA controller can be used in order to support long autonomous sampling (or low noise sampling) with out processor intervention.

For this example we extend the previous example in chapter 12.2.3 by using the DMA to transfer 8 samples from the ADC to the local memory before interrupting the processor. The DMA can be programmed to transfer a pre-defined or infinite number samples. (The software needs to disable the DMA if infinite transfer mode is enabled and no interrupt). The DMA controller can be programmed to generate an interrupt after each transfer or at the end of the transfer. In this example we only generate an interrupt when all samples has been transfered in order to minimize the interrupt load.

In order to accomplish this we need to:

- Setup timer and ADC according to chapter 12.2.3

- Setup the DMA controller channel to respond to interrupt from ADC controller
- Program the DMA controller to read sample from fixed address when interrupt occur
- Program the DMA controller to write sample using incremental address

The correct sequence should be as the following address and data table:

TABLE 92. Example of transferring data from ADC to local processor memory using DMA

Address	Data	Description
...	...	
0x30000080	0x30001000	Channel Vector - Channel 0 M2B descriptor chain pointer
0x30000084	0x30001040	Channel Vector - Channel 0 B2M descriptor chain pointer
...	...	
0x30001000	0x30001023	M2B conditional descriptor 0 - next descriptor pointer (lsb set to 1 for cond. desc.)
0x30001004	0x80400018	M2B conditional descriptor 0 - address (ADC0 Interrupt register address)
0x30001008	0x00040013	M2B conditional descriptor 0 - control (conditional trigger enable, get 4 Byte)
0x3000100C	0x00000009	M2B conditional descriptor 0 - mask (check “End of Conversion” and "End of sequence")
0x30001010	0x00000009	M2B conditional descriptor 0 - data (check “End of Conversion” and "End of sequence")
0x30001014	0x0000001C	M2B conditional descriptor 0 - ADC0 event to trigger GRDMAC0
0x30001018	0x00080008	M2B conditional descriptor 0 - Transfer 8 samples and configure re-try to 8
0x3000101C	0x80005A5A	M2B conditional descriptor 0 - Protection bits for checking DMA descriptor
0x30001020	0x00000002	M2B data descriptor 0 - next descriptor pointer (NULL, end of chain)
0x30001024	0x80400010	M2B data descriptor 0 - address (DMA status register address)
0x30001028	0x00040015	M2B data descriptor 0 - control (4 Bytes from fixed address)
0x3000102C	0x00000000	M2B data descriptor 0 - status (Clear area)
...	...	
0x30001040	0x00000000	B2M data descriptor 0 - next descriptor pointer (NULL, end of chain)
0x30001044	0x30002000	B2M data descriptor 0 - address (DMA write address for ADC data)
0x30001048	0x00040001	B2M data descriptor 0 - control (4 Bytes, Increment address)
0x3000104C	0x00000000	B2M data descriptor 0 - status (Clear area)
...	...	
0x30002000	0x00000000	ADC data written by the DMA controller (Clear area)
0x30002004	0x00000000	..
0x30002008	0x00000000	..
0x3000200C	0x00000000	..
...	...	
0x80106000	0x00000002	GRDMAC Control register (Reset i.e. re-start core)
0x80100008	0x0000FFFF	GRDMAC interrupt mask register
0x80100010	0x31000080	GRDMAC channel vector pointer
0x80100000	0x0001004D	GRDMAC Control register (Enable channel in extended mode)
---	---	
0x80400018	0x00000009	ADC0 - Mask register (Enable events from ADC0)
0x8040000C	0x00000800	ADC0 - Select trigger (counter 2 in timer unit 1)
0x80400008	0xB0000000	ADC0 - Sequencer control (Enable synchronization to ext trigger, continuously enabled)
0x80400004	0x000000FF	ADC0 - Sampling configuration (Oversampling, no consecutive)
0x80400000	0x0008C001	ADC0 - Configuration (Speed, Channel, Enable)
...	...	

After completion 4 oversampled values should be located in the local processor data ram at 0x30002000.

12.2.5 Low noise sampling

The LEON3FT microcontroller supports low noise sampling i.e. the LEON3FT microcontroller can disable the LEON3FT processor and peripherals not needed by the system to minimize jitter introduced into the ADC by the LEON3FT microcontroller itself.

To be able to operate or be able to sample and wake-up the application shall:

- Set the PSR.PIL register low enough for processor to wake-up from expected interrupt
- Keep clocks enabled for peripherals generating the expected interrupt

Failure to keep expected interrupt source enabled will most likely result in the watch-dog wake-up the processor.

For low noise sampling the user application shall:

- Enable ADC clock for channel to use
- Disable all other interfaces or peripherals not needed in the clock gating unit
- Enable interrupt generation in ADC or if the DMA is used the DMA controller can be set to generate the interrupt to wake-up the processor
- Start sampling and set the LEON3FT microcontroller in power down mode. See 16.1.6

12.2.6 Level Detection

The ADC interface can be configured to monitor the input level. The application can get an event if the ADC input level is above specified value in register AHT or below the value specified in register AHL. See table 102 and 103 for register AHT and AHL for the ADC interface.

To enable the level detection and interrupt generation the corresponding bit in the interrupt mask register needs to be set. See table 100.

12.2.7 Access control

ADC, Pre-Amplifier and Analog MUX status and configuration can be accessed via registers

12.3 Registers

The set of configuration and status registers available for each ADC controller is reported in table 59. The GR716 has 8 input pins for the ADC. They can be grouped as single ended (up to 8 single ended channels) or differential ADC channels (up to 4), or in a mixed way. Another differential channel is internally available, connected to the temperature sensor described in chapter 14.

Table 93. ADC, Pre-Amplifier and Analog MUX status and control registers

APB address offset	Register
0x00	ADC control register
0x04	Sampling control Status register
0x08	Sequence control register
0x0C	Sequence synchronization register
0x10	Status register
0x14	Interrupt register
0x18	Interrupt mask register
0x1C	Amplifier control register
0x20	High range detection register
0x24	Low range detection register
0x2C - 0x38	Sequence Sampling memory register(s).

* Add offset n*0x100 to APB address offset in table for accessing ADC controller n.

Table 94. 0x00 - ACFG - ADC, Pre-Amplifier and Analog MUX Control register

31 16	15	14	13 9	8	7	6	5 2	1	0
AC	AE	AS	Reserved	AH	AL	R	AI	R	AM
0x1F4	0	0	0	0	0	0	0000	0	0
rw	rw	rw	r	rw	rw	r	rw	r	rw

31: 16 ADC Scaler (AC) - Scaler reload bits for setting the ADC data rate. The ADC scaler is clocked by the system clock and decrement on each clock cycle. When the ADC scaler underflows it is reloaded with the value of its reload register and a tick is generated. The ADC sample rate is equal to System Frequency / (ACFG.AC + 1). The ADC sample rate shall not violate the ADC maximum sampling frequency specified in section 52.

15 ADC Enable (AE) - Enable On-chip ADC.

14 ADC conversion start (AS) - Start conversion. This signal will stay high until ADC end of conversion gets high.

13: 9 Reserved

8 ADC high range check enable (AH)

7 ADC Low Range check enable (AL)

6 Reserved

Table 94. 0x00 - ACFG - ADC, Pre-Amplifier and Analog MUX Control register

5: 2 ADC channel select Input (AI)

b0000 - ADC0 if AM=1 and AB= 1; ADC0-ADC1 if AM=0
b0001 - ADC1 if AM=1 and AB= 1; ADC1-ADC0 if AM=0

b0010 - ADC2 if AM=1 and AB= 1; ADC2-ADC3 if AM=0

b0011 - ADC3 if AM=1 and AB= 1; ADC3-ADC2 if AM=0

b0100 - ADC4 if AM=1 and AB= 1; ADC4-ADC5 if AM=0
b0101 - ADC5 if AM=1 and AB= 1; ADC5-ADC4 if AM=0

b0110 - ADC6 if AM=1 and AB= 1; ADC6-ADC7 if AM=0

b0111 - ADC7 if AM=1 and AB= 1; ADC7-ADC6 if AM=0

b1000 - + TEMPERATURE / Core Voltage (valid only for AM= 0)

b1001 - -TEMPERATURE / Core Voltage (valid only for AM= 0)

1 Reserved

0 ADC single ended mode (AM) - Select single ended mode by setting bit to 1, differential mode if 0

Table 95. 0x04 - ASAMPC - ADC Sampling Control register

31 18	17 16	15 0
Reserved	AE	AO
0x0	0x0	0x0
r	rw	rw

31: 18 Reserved

17: 16 ADC Events (AE) - Number of consecutive events to sample and store. The maximum number of samples possible to store for each ADC channel is 4. When 4 events i.e. when 4 samples has been stored an interrupt.

b00 - Sample and store 1 sample
b01 - Sample and store 2 samples
b10 - Sample and store 3 samples
b11 - Sample and store 4 samples

15: 0 ADC Oversampling (AO) - Set the number of consecutive samples to be taken for ADC input channel. Number of samples taken and accumulated is AO + 1.

Note 1: The ASAMPC.AE and ASAMPC.AO control bits can be combined in order to sample the ADC channel. E.g. setting the bit field ASAMPC.AE=4 and ASAMPC.AO=255 will store 4 samples with the oversampling ratio of 256 for the selected ADC channel.

Table 96. 0x08 - ASEQC - ADC Sequence Control register

31	30	29	28	27	26 16	15 0
SQ	R	SE	SC	AC	R	SD
0	0	0	0	0	0x0	0
rw	r	rw	rw	rw	r	rw

31 SQ: Sequence synchronization enable. The sampling sequence for ADC will be synchronized to synchronization source selected in register ASYNC

30 Reserved.

29 SE: Sequence enable. This bit will self-clear when sequence is complete. In case of bit SC is set to continuously sequence the software needs to disable the sequence, setting AS and the this field to 0. When manual termination of the current sequence will always finish. The ADC sequence will start immediately when no synchronization source is selected.

28 SC: Sequence continuously enabled. Continuously sample from ADC input. When sequence interrupt is enabled by bit SI an interrupt will be generated every-time the ADC sampling memory is full.

27 AC: Auto clear interrupt. This feature can be used to clear automatic clear pending interrupt.

Table 96. 0x08 - ASEQC - ADC Sequence Control register

26: 16	Reserved
15: 0	SD: Sequence divisor determines the sequence-rate for the ADC.The sample rate is determined by the value (SD+1) / (System Frequency / (ACFG.AC + 1)) if no external synchronizer i selected.

Table 97. 0x0C - ASYNC - ADC Sequence Synchronization register

31 8	7	6	5 0
CSYNC	r	r	SYNC
0x0	0	0	0
r/w	r	r	r/w

31: 8	Synchronization delay counter (ASYNC) - Number of system clock cycles to delay sampling from trigger.
7: 6	Reserved
5: 0	Synchronization trigger (SYNC) - Select the trigger

63: 48		Not used
47: 40		Synchronize to PWM1 tick 7 downto 0
39: 32		Synchronize to PWM0 tick 7 downto 0
31: 16	-	Synchronize ADC to trigger on GPIO 63 to 56, 7 downto 0
15	-	Synchronize ADC to Timer unit 1 counter 6
14	-	Synchronize ADC to Timer unit 1 counter 5
13	-	Synchronize ADC to Timer unit 1 counter 4
13	-	Synchronize ADC to Timer unit 1 counter 3
11	-	Synchronize ADC to Timer unit 1 counter 2
10	-	Synchronize ADC to Timer unit 1 counter 1
9	-	Synchronize ADC to Timer unit 1 counter 0
8	-	Synchronize ADC to Timer unit 1 scaler tick
7	-	Synchronize ADC to Timer unit 0 counter 6
6	-	Synchronize ADC to Timer unit 0 counter 5
5	-	Synchronize ADC to Timer unit 0 counter 4
4	-	Synchronize ADC to Timer unit 0 counter 3
3	-	Synchronize ADC to Timer unit 0 counter 2
2	-	Synchronize ADC to Timer unit 0 counter 1
1	-	Synchronize ADC to Timer unit 0 counter 0
0	-	Synchronize ADC to Timer unit 0 scaler tick

Note 1: When selecting external GPIO trigger special care must be taken to ensure external signal used as trigger change state within 1 system clock frequency.

Table 98. 0x10 - ASTS - ADC, Pre-Amplifier and Analog MUX status register

31	30 19	18 0
AE	Reserved	AD
0	0	-
r	r	r

31 ADC End of conversion (AE) - Digital conversion and sampled data is valid in the bit field ASTS.AO. The ASTS.AE bit is set to valid when the number of samples has been taken specified in the bit field ASAMPC.AO. I.e. if the value in the bitfield ASAMPC.AO is set to 2 the ADC End of conversion bit AE will be set to valid when 2 consecutive samples has been accumulated and the result has been stored in the register bitfield ASTS.AD.

Table 98. 0x10 - ASTS - ADC, Pre-Amplifier and Analog MUX status register

30: 19 RESERVED

18: 0 ADC digital output (AD) - Digital sampled value. The number of samples accumulated is determined by the number of samples defined in the ASAMPC register. If the field is filled with ones, overflow during oversample occurred.

Table 99. 0x14 - AINT - ADC, Pre-Amplifier and Analog MUX Interrupt Register

31	4	3	2	1	0
RESERVED		IS	IH	IL	IE
0x00000000		0	0	0	0
r		wc	wc	wc	wc

31: 4 RESERVED

3 Interrupt for ADC End of Sequence (IS)

2 Interrupt for ADC High level detection (IH)

1 Interrupt for ADC Low level detection (IL)

0 Interrupt for ADC End of conversion channel n (IE)

Table 100. 0x18 - AMASK - ADC, Pre-Amplifier and Analog MUX Interrupt Mask Register

31	4	3	2	1	0
RESERVED		MS	MH	ML	ME
0x00000000		0	0	0	0
r		wc	rw	rw	rw

31: 4 RESERVED

3 Interrupt Mask for ADC End of sequence (MS)

2 Interrupt Mask for ADC High level detection (MH)

1 Interrupt Mask for ADC Low level detection (ML)

0 Interrupt Mask for ADC End of conversion channel n (ME)

Table 101. 0x1C - PACFG - Pre-Amplifier Control register

31	5	4	3	2	1	0
Reserved		R	R	AB	AG	
0		0	0	0	0x0	
r		r	r	rw	rw	

31: 5 Reserved

4 Reserved

3 Reserved

2 Amplifier Bypass (AB) - Bypass amplifier for no gain or single mode

1:0 Amplifier Gain (AG) - Select pre-amplifier gain (effective when AB = 0)

- b00 - 0 dB
- b01 - 6 dB
- b10 - 12 dB
- b11 - 12 dB

Table 102. 0x20 - AHT -ADC High Level detection register

31 19	18 0
Reserved	AHT
0	-
r	rw

31:19 RESERVED

18:0 ADC High Level detection threshold (AHT) - An interrupt shall be generated if the sampled value is above the specified value in this register

Table 103. 0x24 - ALT -ADC Low Level detection register

31 19	18 0
Reserved	ALT
0	-
r	rw

31:19 RESERVED

18:0 ADC Low Level detection threshold (ALT) - An interrupt shall be generated if the sampled value is below the specified value in this register

Note: To make use of this function the AD C must be enable the ACFG.AH bit must set

Table 104. 0x2C - 0x38 - ASQ - ADC Sequence status register 0,1,2 and 3

31 19	18 0
Reserved	AD
0	-
r	rw

31:19 RESERVED

18:0 ADC digital output (AD) - Digital sampled value. The number of samples accumulated is determined by the number of samples defined in the ASAMPC register. Reading a register with a higher index can cause the reading of an old value from previous sequences of events.

Note: To make use of this function the AD C must be enable the ACFG.AL bit must set

Note2: There are 4 individual status registers

13 LDO

13.1 Overview

The on-chip LDO supports single 3.3V supply for the LEON3FT microcontroller. This LDO is intended to be used in applications with medium and low system clock frequencies, since the additional power dissipation can become high when the core-supply current becomes high at high clock frequencies.

13.2 Operation

13.2.1 System overview

The internal LDO provides the digital core with a regulated VDD_CORE of 1.8V, and needs a 3.3V input supply. The LDO can be by-passed by feeding 1.8V regulated supply voltage from PCB directly into the VDD_CORE supply pins. When enabled, the LDO is always capable of supplying the full maximum current consumption needed by VDD_CORE, but the LDO increases the on-chip power dissipation so the maximum junction temperature should be carefully checked in applications where the core current can be high.

13.2.2 Detailed description

When the internal LDO is in use, the core-supply current is drawn from a 3.3V supply on PCB, flowing through the LDO, and then internally to VDD_CORE. There must still be decoupling capacitors connected to the VDD_CORE supply pins on PCB, which typically are ceramic capacitors in the order of 10nF placed as close to each VDD_CORE / GND pin pair as possible. Also, one larger capacitor is needed for damping and decoupling of lower frequencies, which typically is a tantalum capacitor in the order of 100uF and ESR in the order of 0.1ohm.

The LDO will cause additional on-chip power dissipation, equal to the core average current times the LDO voltage drop, which will further increase the Microcontroller junction temperature. Therefore, when running the core logic such that the core current is high, it is critical to carefully check that the maximum allowed junction temperature is never exceeded in the thermal situation at hand. This should of course be checked in all application implementations with the Microcontroller, but it is especially important when the LDO is in use at the same time as core current can be high.

The LDO can be by-passed. Then, the VDD_CORE pins are directly fed with 1.8V regulated supply voltage from PCB. In this case, the 3.3V LDO input pins must *not* be connected to any low-impedance node other than VDD_CORE. Another possibility is to leave the LDO input pins open (non-connected), but the recommendation is to connect them directly to VDD_CORE.

In regard to decoupling on VDD_CORE, it should be done in the same way, see above, whether the LDO is in use or by-passed. When the LDO is in use, decoupling on the LDO input supply pins should be done in the same way as for VDD_CORE pins, i.e. in the order of 10nF per pin pair, and one larger capacitor (which can be common to other ICs on PCB, to be decided at convenience of the PCB designer).

14 Temperature Sensor

14.1 Overview

There is an integrated temperature sensor on the GR716 microcontroller, which can be used to supervise the die temperature.

14.2 Operation

14.2.1 System overview

The on-chip temperature sensor can be sampled via the internal ADC. It is not accessible externally.

14.2.2 Detailed description

The temperature-sensor output signal is a monotonic voltage signal versus temperature. It is measured by the ADC in the same way as any other analog MUX channel. Its output is not threshold-detected or used in any other on-chip block, so if e.g. a chip over-temperature protection is desired the user needs to measure the sensor and take adequate actions in the system application at hand.

14.2.3 Access control

The temperature sensor is always enabled and the output can be sampled with the ADC interface.

15 Internal DAC

15.1 Overview

The GR716 has 4 separate 12 bit Digital-to-Analog Converter (DAC) converters and 4 separate DAC control units. Each Digital-to-Analog Converter (DAC) is a 12 bit resolution DAC. The digital core logic provides a register control and status interface via registers for each DAC. The digital interface also provides more complex control logic in order to synchronize the DAC output to e.g. timers in the LEON3FT microcontroller.

The DAC control units are located on APB bus in the address range from 0x80408000 to 0x8040BFFF. See DAC converters and DAC control units connections in the next drawing. The figure shows the memory locations and functions used for DAC configuration and control.

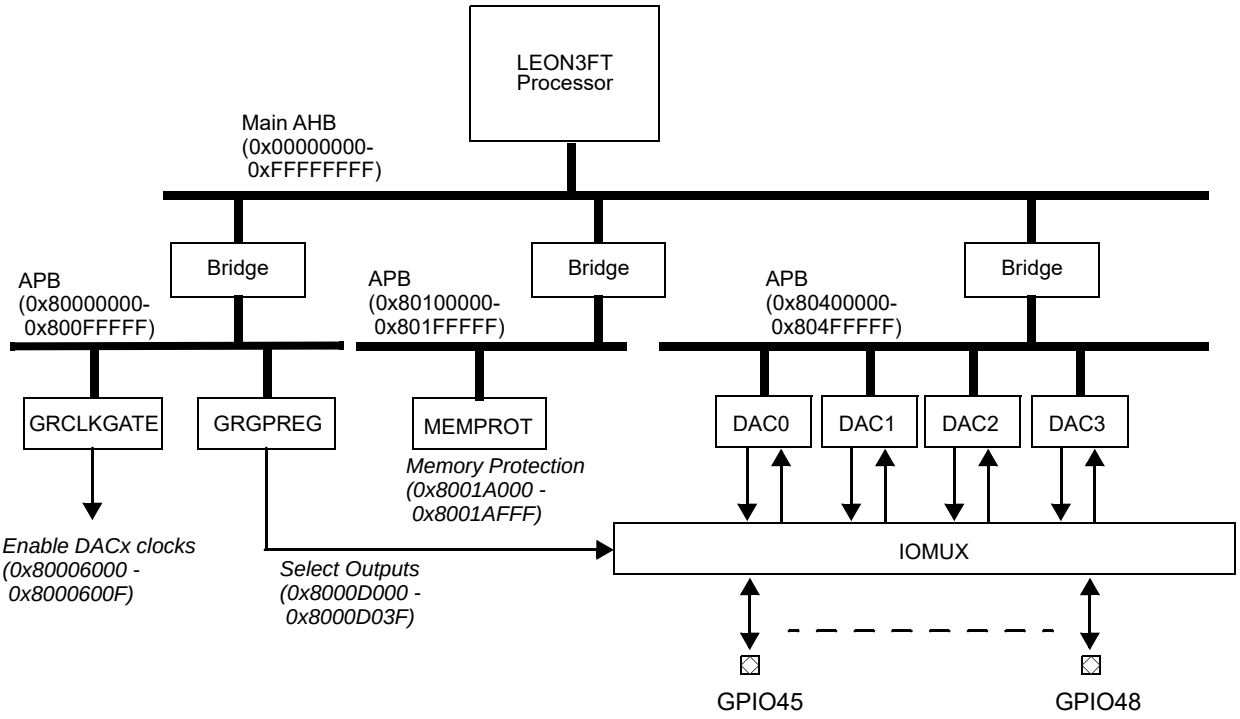


Figure 17. GR716 DAC bus and pin connection

The primary clock gating unit **GRCLKGATE** described in section 26 is used to enable/disable individual DAC units. The unit **GRCLKGATE** can also be used to perform reset of individual DAC units. Software must enable clock and release reset described in section 26 before DAC configuration and transmission can start.

External IO selection per DAC unit is made in the system IO configuration register (**GRGPREG**) in the address range from 0x8000D000 to 0x8000D03F. See section 7.1 for further information.

Each **DACx** unit controls its own external pins and has a unique AMBA address described in chapter 2.11. DAC units 0, 1, 2 and 3 have identical configuration and status registers. Configuration and status registers are described in section 15.3.

The system can be configured to protect and restrict access to individual DAC units in the **MEMPROT** unit. See section 47 for more information.

15.2 Operation

15.2.1 System overview

There are four independent 12bit/3MSps DAC blocks. They have sourcing-current single-ended outputs, typically to be loaded by virtual grounds generated by op-amps on PCB, or by passive impedances connected to PCB ground providing the output voltages directly across these impedances. These four blocks are supplied by VDDA_DAC and VSSA_DAC. In the same way as for the ADC, it is enough to provide really good decoupling at high frequencies (>~1MHz).

Note that the DAC fullscale current is proportional to the current through the external RREF, and 5.11kohm gives a fullscale current of 4.0mA nominally.

15.2.2 Detailed description

Each DAC will convert a 12 bit register to an analog output. The register is accessible via the APB register interface the digital DAC interface provides. The conversion from the 12 bit register can take affect immediately or when a selected trigger event occurs. The DSEQ.SQ bit determines the DAC mode. When DSEQ.SQ is set to ’0’ the conversion will take affect immediately and when DSEQ.SQ is set to ’1’ the conversion will take affect on the next trigger event selected in the DSYNC register.

Triggers can be set to synchronize outputs from the DAC. When triggers are used the DAC output level or value will not be updated or changed until an event has occurred on the selected trigger. The trigger event can be programmed to also generate an interrupt when a new value from the processor can be accepted. When the trigger event has occurred the status register is updated regardless of the interrupt generation.

In trigger mode the output value in register DOUT.DI can be updated at anytime without affecting the DAC output. The value in the 12 bit register is directly forwarded to the analog DAC when an trigger event occur.

The speed of the conversion can be in the range from 1Ksps to 3Msps. The conversion rate is set by the internal DAC scaler register field DCFG.DS. The register field is calculated by dividing the system clock frequency with sample rate.

Slew rate control can be enabled for system with sampling conversion rate up to 50Ksps. Enabling slew rate control will limit the DAC output current change and improve noise on the output. Slew rate control is enabled with register field DCFG.DD.

15.2.3 DAC output example

To enable DAC and direction conversation of the register use the following steps:

```
DCFG.DE = 8          // Enable DAC
DCFG.DS = 0x1F4      // Set DAC scaler
DOUT.DI = 1          // DAC digital input value
```

TABLE 105. Example of direction conversion of value 0xFF using DAC0

Address	Data	Description
---	---	
0x80408004	0x000000FF	DAC0 - Output Value
0x80408000	0x01FCC001	DAC0 - Configuration (Scaler, Mode, Enable)
---	---	

15.2.4 Access control

The integrated DAC is controlled via APB registers

15.3 Registers

Table 106. DAC control registers

APB address offset	Register
0x00	Control register
0x04	Output register
0x08	Sequence control register
0x0C	Sequence synchronization register
0x10	Status register
0x14	Interrupt register
0x18	Interrupt mask register

Table 107. 0x00 - DCFG - DAC Control register

31 16	15 8	7 4	3	2	1	0
DS	Reserved	DC	R	R	DD	DE
0x01F4	0	0xE	0	0	0	0
rw	r	rw	r	r	rw	rw

31: 16 DAC Scaler Divider (DS) - The DAC Scaler divider bits are sued for setting the DAC conversion rate. The system clock is used to create the DAC clock using the DAC scaler divider value. The scaler value shall be set to the system frequency divided by the conversion rate. E.g. if the system frequency is 50MHz and samples rate 1Msps the scaler should be set to 50.

15: 7 Reserved

7: 4 DAC Conversion interrupt delay (DC) - Number of DAC clock cycle for digital to analog conversion.

The register is used to delay the interrupt from the DAC to the system in-order to make sure the DAC output has been set before changing the DAC output register.

3 Reserved

2 Reserved

1 DAC DEM enable (DD) - The DAC support two operation modes:

- without DEM: data rate can change at maximum of 3Mhz data rate. An external filter at 1Mhz should be employed
- with DEM: data rate can change at division of 50Khz data rate. Other data rates will show drop in performance. A first order or filtering at 58.6khz must be employed to suppress switching artifacts of the DEM.

0 DAC Enable (DE) - Enable DAC. To power down the DAC set this bit to ’0’

Table 108. 0x04 - DOUT - DAC output register

31 12	11 0
R	DI
0x00	0x000
r	rw

31: 12 Reserved

11: 0 DAC Digital input (DI) - DAC Digital unsigned input. Conversion will start when a new value is written to this register.

Table 109. 0x08 - DSEQC - DAC Sequence Control register

31	30	0
SQ	Reserved	
0	0	
rw	r	

31 SQ: Sequence synchronization enable. The output sequence for the DAC will be synchronized to synchronization source selected in register DSYNC

30: 0 Reserved

Table 110. 0x0C - DSYNC - DAC Sequence Synchronization register

31	5	4	0
Reserved		SYNC	
0x0		0	
r		r/w	

31: 5 Reserved

4: 0 Synchronization trigger (SYNC) - Select the trigger

31: 24	-	Synchronize GPIO n to trigger on GPIO 56 to 63
23: 16	-	Synchronize GPIO n to trigger on GPIO 0 to 7
15	-	Synchronize GPIO n to Timer unit 1 counter 6
14	-	Synchronize GPIO n to Timer unit 1 counter 5
13	-	Synchronize GPIO n to Timer unit 1 counter 4
12	-	Synchronize GPIO n to Timer unit 1 counter 3
11	-	Synchronize GPIO n to Timer unit 1 counter 2
10	-	Synchronize GPIO n to Timer unit 1 counter 1
9	-	Synchronize GPIO n to Timer unit 1 counter 0
8	-	Synchronize GPIO n to Timer unit 1 scaler tick
7	-	Synchronize GPIO n to Timer unit 0 counter 6
6	-	Synchronize GPIO n to Timer unit 0 counter 5
5	-	Synchronize GPIO n to Timer unit 0 counter 4
4	-	Synchronize GPIO n to Timer unit 0 counter 3
3	-	Synchronize GPIO n to Timer unit 0 counter 2
2	-	Synchronize GPIO n to Timer unit 0 counter 1
1	-	Synchronize GPIO n to Timer unit 0 counter 0
0	-	Synchronize GPIO n to Timer unit 0 scaler tick

Table 111. 0x10 - DSTAT - DAC status register

31	1	0
Reserved		WT
0		0
r		r

31:1 Reserved

0 DAC Waiting for Trigger (WT) - DAC is set to wait for trigger to start conversion. When ’0’ the DAC conversion has been completed.

Table 112. 0x14 - DINT - DAC Interrupt Register

31	1	0
Reserved		EI
0x00000000		0
r		wc

31: 1 Reserved

0 Interrupt for DAC End of conversion (EM)

Table 113. 0x18 - DMASK - DAC Interrupt Mask Register

31	1	0
Reserved		EM
0x00000000		0
r		rw

31: 1 Reserved

0 Interrupt Mask for DAC End of conversion (EM) -

16 LEON3/FT - High-performance SPARC V8 32-bit Processor

16.1 Overview

LEON3 is a 32-bit processor core conforming to the IEEE-1754 (SPARC V8) architecture. It is designed for embedded applications, combining high performance with low complexity and low power consumption.

The LEON3 core has the following main features: 7-stage pipeline with Harvard architecture, hardware multiplier and divider, on-chip debug support and multi-processor extensions.

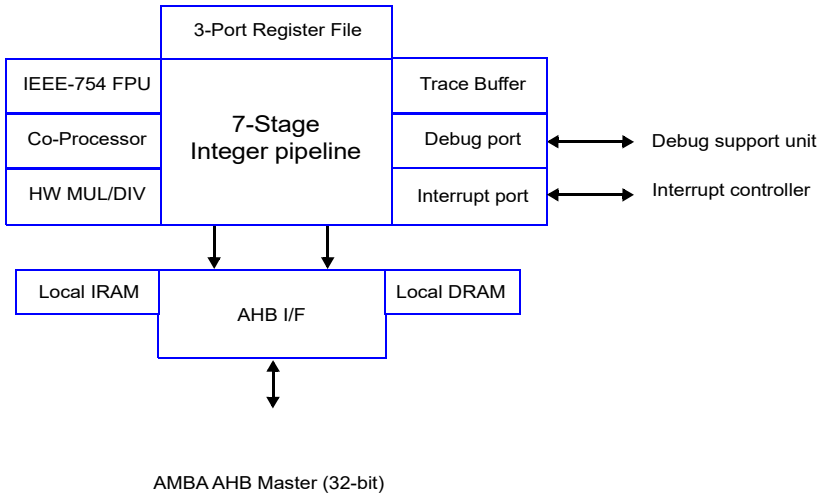


Figure 18. LEON3 processor core block diagram

16.1.1 Integer unit

The LEON3 integer unit implements the full SPARC V8 manual, including hardware multiply and divide instructions. The number of register windows is 31. The pipeline consists of 7 stages with a separate local instruction and data interface (Harvard architecture).

16.1.2 Floating-point unit and co-processor

The LEON3 integer unit provides interfaces for a floating-point unit (FPU). The floating-point processors execute in parallel with the integer unit, and does not block the operation unless a data or resource dependency exists.

16.1.3 On-chip debug support

The LEON3 pipeline includes functionality to allow non-intrusive debugging on target hardware. To aid software debugging, 4 watchpoint registers can be enabled. Each register can cause a breakpoint trap on an arbitrary instruction or data address range. When the debug support unit is attached, the watchpoints can be used to enter debug mode. Through a debug support interface, full access to all processor registers is provided. The debug interfaces also allows single stepping, instruction tracing and hardware breakpoint/watchpoint control. An internal trace buffer can monitor and store executed instructions, which can later be read out via the debug interface.

16.1.4 Interrupt interface

LEON3 supports the SPARC V8 interrupt model with a total of 15 asynchronous interrupts. The interrupt interface provides functionality to both generate and acknowledge interrupts.

16.1.5 AMBA interface

LEON3 implements an AMBA AHB master to load and store data. The interface is compliant with the AMBA-2.0 standard.

16.1.6 Power-down mode

The LEON3 processor core implements a power-down mode, which halts the pipeline until the next interrupt. The processor also supports clock gating during the power down period. A small part of the CPU is always awake and needs to run during power-down to check for wake-up conditions.

16.2 LEON3 integer unit

16.2.1 Overview

The LEON3 integer unit implements the integer part of the SPARC V8 instruction set. The implementation is focused on high performance and low complexity. The LEON3 integer unit has the following main features:

- 7-stage instruction pipeline
- 31 register windows
- Hardware multiplier
- Radix-2 divider (non-restoring)
- Static branch prediction
- Single-vector trapping for reduced code size

Figure 19 shows a block diagram of the integer unit.

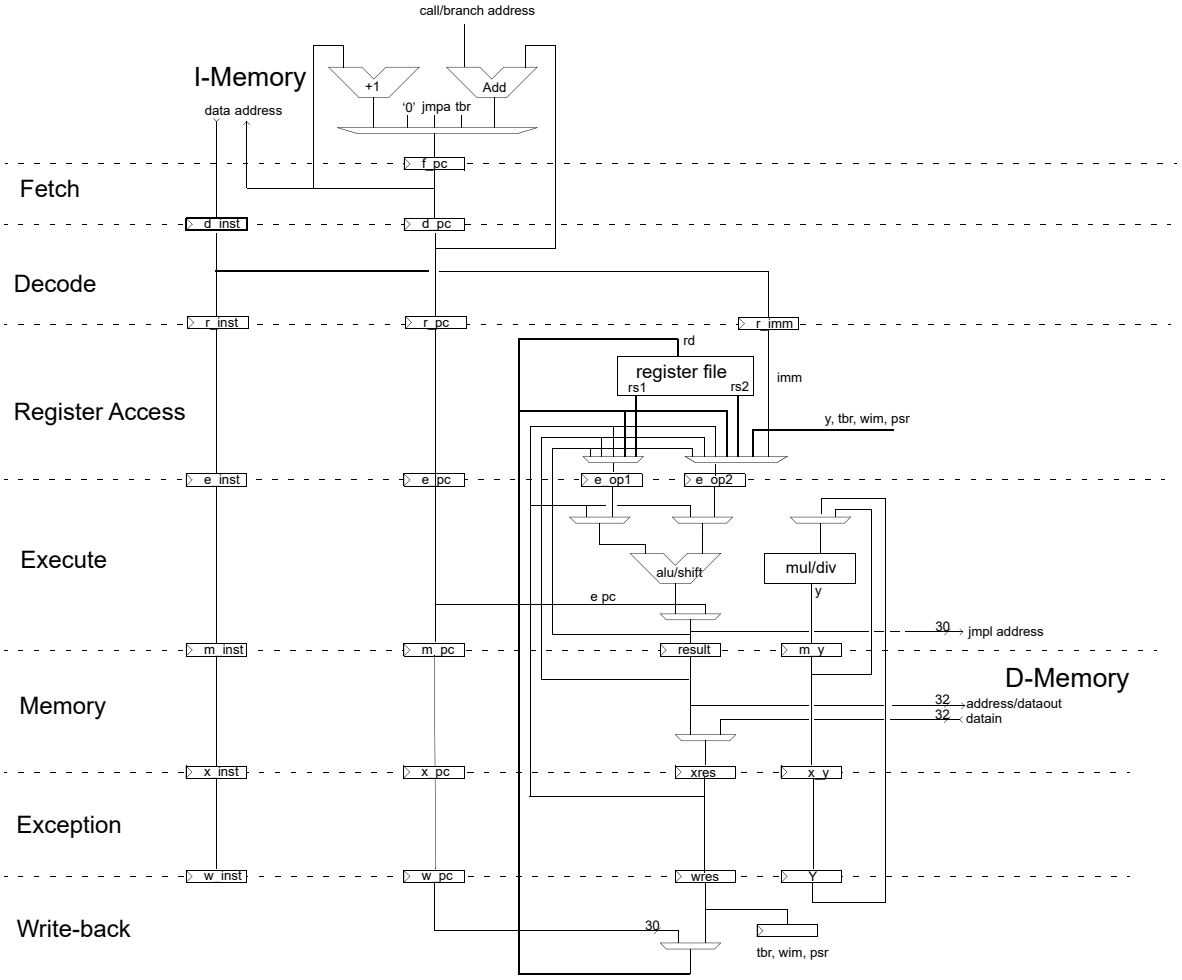


Figure 19. LEON3 integer unit datapath diagram

16.2.2 Instruction pipeline

The LEON3 integer unit uses a single instruction issue pipeline with 7 stages:

1. FE (Instruction Fetch): The instruction is fetched from the local instruction memory or external memory located on the AMBA bus. The instruction is valid at the end of this stage and is latched inside the IU.
2. DE (Decode): The instruction is decoded and the CALL and Branch target addresses are generated.
3. RA (Register access): Operands are read from the register file or from internal data bypasses.
4. EX (Execute): ALU, logical, and shift operations are performed. For memory operations (e.g., LD) and for JMPL/RETT, the address is generated.
5. ME (Memory): Data memory is read or written at this time.
6. XC (Exception) Traps and interrupts are resolved. For internal memory reads, the data is aligned as appropriate.
7. WR (Write): The result of any ALU, logical, shift, or internal memory operations are written back to the register file.

Table 114 lists the cycles per instruction (assuming local instruction and data memory are used):

*Table 114.*Instruction timing

Instruction	Cycles
JMPL	3[1]
JMPL,RETT pair	4
Double load	2
Single store	2
Double store	3
SMUL/UMUL	4
SDIV/UDIV	35
Taken Trap	5
Atomic load/store	3
All other instructions	**1**

[1] Assuming instruction in JMPL delay slot takes one cycle. Additional cycles spent in the delay slot will reduce the effective time of the JMPL to 2 or 1.

A number of conditions can extend an instruction's duration in the pipeline:

Branch interlock: When a conditional branch or trap is performed 1-2 cycles after an instruction which modifies the condition codes, 1-2 cycles of delay is added to allow the condition to be computed. If static branch prediction is enabled, this extra delay is incurred only if the branch is not taken.

Load delay: When using data resulting on a load shortly after the load, the instruction will be delayed to satisfy the pipeline's load delay. The processor pipeline is configured for one cycles load delay.

Hold cycles: When blocking on the store buffer, the pipeline will be held still until the data is ready, effectively extending the execution time of the instruction causing the miss by the corresponding number of cycles. Note that since the whole pipeline is held still, hold cycles will not mask load delay or interlock delays.

FPU/Coprocessor: The floating-point unit or coprocessor may need to hold the pipeline or extend a specific instruction. When this is done is specific to the FP/CP unit.

16.2.3 SPARC Implementor's ID

Cobham Gaisler is assigned number 15 (0xF) as SPARC implementor's identification. This value is hard-coded into bits 31:28 in the %psr register. The version number for LEON3 is 3, which is hard-coded in to bits 27:24 of the %psr.

16.2.4 Divide instructions

Full support for SPARC V8 divide instructions is provided (SDIV, UDIV, SDIVCC & UDIVCC). The divide instructions perform a 64-by-32 bit divide and produce a 32-bit result. Rounding and overflow detection is performed as defined in the SPARC V8 manual.

16.2.5 Multiply instructions

The LEON processor supports the SPARC integer multiply instructions UMUL, SMUL UMULCC and SMULCC. These instructions perform a 32x32-bit integer multiply, producing a 64-bit result. SMUL and SMULCC performs signed multiply while UMUL and UMULCC performs unsigned multiply. UMULCC and SMULCC also set the condition codes to reflect the result. The multiply instructions are performed using a 16x16 hardware multiplier which is iterated four times.

16.2.6 Compare and Swap instruction (CASA)

LEON3 implements the SPARC V9 Compare and Swap Alternative (CASA) instruction. The CASA operates as described in the SPARC V9 manual. The instruction is privileged but setting ASI = 0xA (user data) will allow it to be used in user mode.

16.2.7 Hardware breakpoints

The integer unit is configured to include 4 hardware breakpoints. Each breakpoint consists of a pair of ancillary state registers (see section 16.6.5). Any binary aligned address range can be watched for instruction or data access, and on a breakpoint hit, trap 0x0B is generated.

16.2.8 Instruction trace buffer

The instruction trace buffer consists of a circular buffer that stores executed instructions. This is enabled and accessed only through the processor's debug port via the Debug Support Unit. When enabled, the following information is stored in real time, without affecting performance:

- Instruction address and opcode
- Instruction result
- Load/store data and address
- Trap information
- 30-bit time tag

16.2.9 Processor configuration register

The ancillary state register 17 (%asr17) provides information on how various configuration options. This can be used to enhance the performance of software. See section 16.6.2 for layout.

16.2.10 Exceptions

LEON3 adheres to the general SPARC trap model. The table below shows the implemented traps and their individual priority. When PSR (processor status register) bit ET=0, an exception trap causes the processor to halt execution and enter error mode, and the external error signal will then be asserted.

*Table 115.*Trap allocation and priority

Trap	TT	Pri	Description	Class
reset	0x00	1	Power-on reset	Interrupting
data_store_error	0x2b	2	write buffer error during data store	Interrupting
instruction_access_exception	0x01	3	Error or MMU page fault during instruction fetch	Precise
privileged_instruction	0x03	4	Execution of privileged instruction in user mode	Precise
illegal_instruction	0x02	5	UNIMP or other un-implemented instruction	Precise
fp_disabled	0x04	6	FP instruction while FPU disabled	Precise
cp_disabled	0x24	6	CP instruction while Co-processor disabled	Precise
watchpoint_detected	0x0B	7	Hardware breakpoint match	Precise
window_overflow	0x05	8	SAVE into invalid window	Precise
window_underflow	0x06	8	RESTORE into invalid window	Precise
r_register_access_error	0x20	9	register file EDAC error (LEON3FT only)	Interrupting
mem_address_not_aligned	0x07	10	Memory access to un-aligned address	Precise
fp_exception	0x08	11	FPU exception	Deferred
cp_exception	0x28	11	Co-processor exception	Deferred
data_access_exception	0x09	13	Access error during data load, MMU page fault	Precise
tag_overflow	0x0A	14	Tagged arithmetic overflow	Precise
division_by_zero	0x2A	15	Divide by zero	Precise
trap_instruction	0x80 - 0xFF	16	Software trap instruction (TA)	Precise
interrupt_level_15	0x1F	17	Asynchronous interrupt 15	Interrupting
interrupt_level_14	0x1E	18	Asynchronous interrupt 14	Interrupting
interrupt_level_13	0x1D	19	Asynchronous interrupt 13	Interrupting
interrupt_level_12	0x1C	20	Asynchronous interrupt 12	Interrupting
interrupt_level_11	0x1B	21	Asynchronous interrupt 11	Interrupting
interrupt_level_10	0x1A	22	Asynchronous interrupt 10	Interrupting
interrupt_level_9	0x19	23	Asynchronous interrupt 9	Interrupting
interrupt_level_8	0x18	24	Asynchronous interrupt 8	Interrupting
interrupt_level_7	0x17	25	Asynchronous interrupt 7	Interrupting
interrupt_level_6	0x16	26	Asynchronous interrupt 6	Interrupting
interrupt_level_5	0x15	27	Asynchronous interrupt 5	Interrupting
interrupt_level_4	0x14	28	Asynchronous interrupt 4	Interrupting
interrupt_level_3	0x13	29	Asynchronous interrupt 3	Interrupting
interrupt_level_2	0x12	30	Asynchronous interrupt 2	Interrupting
interrupt_level_1	0x11	31	Asynchronous interrupt 1	Interrupting

The prioritization follows the SPARC V8 manual except for a minor difference for r_register_access_error, which has lower priority than window_over/underflow because the window condition is detected before the register file is accessed.

The data_store_error is delivered as a deferred exception but is non-resumable and therefore classed as interrupting. Likewise, r_register_access_error is delivered as a precise trap but since it is non-resumable it is classed as an interrupting trap.

16.2.11 Single vector trapping (SVT)

Single-vector trapping (SVT) is an SPARC V8e option to reduce code size for embedded applications. When enabled, any taken trap will always jump to the reset trap handler (%tbr.tba + 0). The trap type will be indicated in %tbr.tt, and must be decoded by the shared trap handler. SVT is enabled by setting bit 13 in %asr17.

16.2.12 Address space identifiers (ASI)

In addition to the address, a SPARC processor also generates an 8-bit address space identifier (ASI), providing up to 256 separate, 32-bit address spaces. During normal operation, the LEON3 processor accesses instructions and data using ASI 0x8 - 0xB as defined in the SPARC manual. Using the LDA/STA instructions, alternative address spaces can be accessed. The different available ASIs are described in section 16.6.

16.2.13 Partial WRPSR

The processor has support for partial WRPSR. Partial write %PSR (WRPSR) is a SPARC V8e option that allows WRPSR instructions to only affect the %PSR.ET field.

16.2.14 Alternative window pointer

Alternative window pointer (AWP) is a SPARC V8e option intended to reduce interrupt latency by allowing code that manipulates the current window pointer, mainly window over and underflow handlers and context switching code, to run with traps enabled.

Two bits are added to the PSR register, AW (alternative window) and PAW (previous alternative window). Also an AWP (alternative window pointer) field is added in an ASR register.

When the AW bit is set, the current register window used for reading/writing non-global registers is taken from the AWP register field instead of the normal CWP register field, and SAVE and RESTORE operations modify the AWP field instead of the CWP. SAVE and RESTORE can do not trigger the window over/underflow traps while AW is set.

When both AW and PAW are zero, the AWP field is kept equal to the CWP field.

When a trap occurs, the value of AW is copied into the PAW field, and AW is cleared. When returning from a trap using the RETT instruction, the PAW field is copied back into AW. The RETT will not trigger the window underflow trap if PAW is set regardless of if CWP or AWP point to an invalid window.

16.2.15 Register file partitioning

Register file partitioning is an optional extension to allow a subrange of the register windows to be used as if it was the whole register file. The selected subset is connected in a ring so that the outs of the lowest register window is aliased to the ins of the highest register window in the range. Other register windows outside this range are not accessible and will be kept at their old values while the partitioning is enabled.

The partitioning is activated by setting the STWIN and CWPMAX fields of the %asr20 register. This selects the subset of windows between STWIN and STWIN+CWPMAX so that they map to CWP values 0 to CWPMAX. STWIN and CWPMAX must be set so they map to a valid range, CWPMAX+STWIN must not exceed the highest possible CWP value supported in the normal case. Also, for correct operation, CWP must be set to a value between 0 and CWPMAX before accessing any non-global register.

Writing CWPMAX to (otherwise illegal value) 0 in %asr20 will result in writing only AWP and keeping the values of STWIN and CWPMAX.

A special write-only bit in the %asr20 register can be used to write CWP in the PSR at the same time as writing the STWIN,CWPMAX,AWP fields, this is intended to allow switching between two register file partitions without disabling interrupts.

The WIM register is not managed by the partitioning logic, therefore the lowest bits of the WIM will map to the partitioned windows. The highest bits of the WIM will be masked to 0 on read to simulate a smaller register file, however these bits are still writable.

16.2.16 Power-down

The processor can enter a power-down mode to minimize power consumption during idle periods. The power-down mode is entered by performing a WRASR instruction to %asr19:

```
wr %g0, %asr19
```

During power-down, the pipeline is halted until the next interrupt occurs. Signals inside the processor pipeline are then static, reducing power consumption from dynamic switching.

Note: %asr19 must always be written with the data value zero to ensure compatibility with future extensions.

Note: This instruction must be performed in supervisor mode with interrupts enabled.

When resuming from power-down, the pipeline will be re-filled from the point of power-down and the first instruction following the WRASR instruction will be executed prior to taking the interrupt trap. Up to six instructions after the WRASR instruction will be fetched prior to fetching the trap handler.

16.2.17 Processor reset operation

The processor is reset by asserting the RESET input for at least 4 clock cycles. The following table indicates the reset values of a subset of the registers which are affected by the reset..

*Table 116.*Processor reset values

Register	Reset value
Trap Base Register	Trap Base Address field reset (value 0)
PC (program counter)	0x0
nPC (next program counter)	0x4
PSR (processor status register)	ET=0, S=1

By default, the execution will start from address 0 and is taken from the register processor boot address register in the interrupt controller. This allows processor to be dynamically restarted and the reset address to be changed dynamically and can e.g. when new software has been remotely uploaded and processor should restart.

16.2.18 LEON-REX extension

The processor supports the LEON-REX addition to the SPARC instruction set, allowing a more compact code representation than the regular SPARC machine code, see reference document [LEON-REX]

Detection whether support is present can be done by checking the REXV field in the asr17 register (see section 16.6.2). The REX support can be set to enabled, illegal or transparent mode via the REXEN/REXILL bits in the asr17 register, after reset the default setting is illegal so any LEON-REX code will cause an illegal instruction trap.

16.2.19 Constant interrupt delay

The LEON3FT is enhanced with an interrupt zero jitter feature. When the interrupt zero jitter feature is enabled all sources of interrupt jitter introduced by the hardware can be eliminated. The latency is

controlled via a 12 bit counter register which also determines the interrupt latency. If the 12 bit counter is set in the range 0 to 4, the LEON3FT will start the to process the interrupt request as soon as possible. If the counter is set to a specific value depending on the timing of the memory system, then it can enable the zero jitter behavior to force the interrupt latency to higher number of cycles, but it is guaranteed to have zero jitter.

The processor interrupt delay bit fields are found and in the ASI2 register. Example of setting the interrupt delay to 10 clock cycles:

```
asm volatile (" sta %0, [%1] 2" : : "r"(10), "r"(4) : "memory");
```

16.3 Local instruction and data RAM

Local instruction and data ram is attached to the processor. The local instruction ram is 128KiB and the local data ram is 64KiB. Accesses performed to the local RAMs will not appear on the AHB bus. The address for the instruction ram is 0x31000000, and for the data ram 0x30000000.

The local instruction RAM is intended for executing instructions and will serve instructions without any wait states. Initializing the instruction local RAM is done from software via stores or remote via the local instruction memory AHB interface on the DMA bus.

The local data RAM will serve data accesses of any size without adding wait states. The local data ram can be accessed via AHB from any AMBA master with access to the DMA bus.

16.4 Floating-point unit

Cobham Gaisler's GRFPU-Lite is connected with the LEON3 pipeline. The characteristics of the FPU's are described in the next sections.

16.4.1 GRFPU-Lite

GRFPU-Lite is a smaller version of GRFPU, suitable for implementations with limited logic resources. The GRFPU-Lite is not pipelined and executes thus only one instruction at a time. To improve performance, the FPU controller (GRLFPC) allows GRFPU-Lite to execute in parallel with the processor pipeline as long as no new FPU instructions are pending. Below is a table of worst-case throughput of the GRFPU-Lite:

Table 117.GRFPU-Lite worst-case instruction timing with GRLFPC

Instruction	Throughput	Latency
FADDS, FADDD, FSUBS, FSUBD,FMULS, FMULD, FSMULD, FITOS, FITOD, FSTOI, FDTOI, FSTOD, FDTOS, FCMPS, FCMPD, FCMPES. FCMPED	8	8
FDIVS	31	31
FDIVD	57	57
FSQRTS	46	46
FSQRTD	65	65

The GRLFPC controller implements the SPARC deferred trap model, but the FPU trap queue (FQ) can contain only one queued instructions when an FPU exception is taken.When the GRFPU-Lite is enabled in the model, the version field in %fsr has the value of 3.

16.5 AMBA interface

16.5.1 Overview

The LEON3 processor uses one AHB master interface for all data and instruction accesses. Instructions and data are fetched with single READ cycles. Store data is performed using single accesses or a two-beat incremental burst in case of 64-bit store.

The HPROT signals of the AHB bus are driven to indicate if the accesses is instruction or data, and if it is a user or supervisor access.

*Table 118.*HPROT values

Type of access	User/Super	HPROT
Instruction	User	1100
Instruction	Super	1110
Data	User	1101
Data	Super	1111

In case of atomic accesses, a locked access will be made on the AMBA bus to guarantee atomicity as seen from other masters on the bus.

16.5.2 Error handling

An AHB ERROR response received while fetching instructions will normally cause an instruction access exception (tt=0x1).

An AHB ERROR response while fetching data will normally trigger a data_access_exception trap (tt=0x9).

16.6 Configuration registers

16.6.1 PSR, WIM, TBR registers

The %psr, %wim, %tbr registers are implemented as required by the SPARC V8 manual.

*Table 119.*LEON3 Processor state register (%psr)

31 28	27 24	23 20	19 16
IMPL	VER	ICC	RESERVED
0xF	0x3	0	0
r	r	r	r

15 14	13	12	11 8	7	6	5	4 0
RESERVED	EC	EF	PIL	S	PS	ET	CWP
0	0	0	0	1	1	0	0
r	r	rw	rw	rw	rw	rw	rw

31:28	Implementation ID (IMPL), read-only hardwired to “1111” (15)
27:24	Implementation version (VER), read-only hardwired to “0011” (3) for LEON3.
23:20	Integer condition codes (ICC), see sparcv8 for details
19:14	Reserved
13	Enable coprocessor (EC), always set to ’0’ to indicate no coprocessor available in microcontroller
12	Enable floating-point (EF)
11:8	Processor interrupt level (PIL) - controls the lowest IRQ number that can generate a trap
7	Supervisor (S)
6	Previous supervisor (PS), see sparcv8 for details
5	Enable traps (ET)
4:0	Current window pointer

*Table 120.*LEON3 Window invalid mask (%wim)

31	30 0
R	WIM
0	NR
r	rw

*Table 121.*LEON3 Trap base address register (%tbr)

31 12	11 4	3 0
TBA	TT	R
*	0	0
rw	r	r

31:12	Trap base address (TBA) - Top 20 bits used for trap table address
11:4	Trap type (TT) - Last taken trap type. Read only.
3:0	Always zero, read only

16.6.2 ASR17, LEON3 configuration register

The ancillary state register 17 (%asr17) provides information on current LEON3FT configuration. This can be used to enhance the performance of software. There are also a few bits that are writable to configure certain aspects of the processor.

*Table 122.*LEON3 configuration register (%asr17)

31 28	27	26	25	24 23	22 21	20 18	17	16
INDEX	R	NOTAG	R	REXV	REXM	RESERVED	R	R
0	0	1	1	01b	00b	0	0	0
r	r	r	r	r	rw	r	r	r

15	14	13	12	11 10	9	8	7 5	4 0
R	DW	SV	LD	FPU	M	V8	NWP	NWIN
0	0	0	0	3	0	1	4	30
r	rw	rw	r	r	r	r	r	r

31:28	Processor index (INDEX) -Processor index is set to zero.
27	Reserved and not used
26	Tagged arithmetic (NOTAG) - Then the processor supports tagged arithmetic.and compare-and-swap (CASA) instruction.
27	Reserved and not used
24:23	REX version (REXV) - REX version
22:21	REX mode (REXM) - set to ‘00’ for REX enabled, ‘01’ for REX illegal and ‘10’ for REX transparent mode. Writable with reset value ‘01’ when REX support has been enabled
20:18	Reserved for future implementations
17	Reserved for future implementations
16:15	Reserved for future implementations
14	Disable write error trap (DWT). When set, a write error trap (tt = 0x2b) will be ignored. Set to zero after reset.
13	Single-vector trapping (SVT) enable. If set, will enable single-vector trapping. Set to zero after reset.
12	Load delay (LDDEL) - Indicates 1-cycle load delay is used.
11:10	FPU Option (FPU) - Indicates system has a GRFPU-Lite
9	MAC instruction (M) - Set to zero to indicate multiply-accumulate (MAC) instruction is NOT available
8	MUL/DIV instructions available (V8) - Indicates SPARC V8 multiply and divide instructions are available
7:5	Hardward watchpoints (NWP) - Number of watchpoints available is 4
4:0	Register windows (NWIM) - Number of implemented registers windows corresponds to NWIN+1 i.e. 31 for GR716.

16.6.3 ASR20, Alternative window register

This register allows access to the alternative window pointer.

*Table 123.*LEON3 alternative window register (%asr20)

31 26	25 21	20 16
RESERVED	STWIN	CWPMAX
0	0	30
r	rw	rw

15 5	4 0	
RESERVED	WCWP	AWP
0	-	*
r	w	rw

31:26	Reserved for future implementations
25:21	Starting window (STWIN) - Starting window of partition.
20:16	Maximum value of current window pointer (CWPMAX) - Partition size minus 1. Reset value is number of windows minus 1, which with STWIN=0 maps whole register file into partition. If this field is written with value 0, STWIN and CWPMAX fields are unmodified.
15:5	Reserved for future implementations
5	Write CWP - If written with 1, then the CWP field in PSR will simultaneously be written with the value written to AWP.
4:0	Alternative Window Pointer (AWP). Continuously updated with the value of CWP when the alternative window feature is disabled.

16.6.4 ASR22-23 - Up-counter

The ancillary state registers 22 and 23 (%asr22-23) contain an internal up-counter that can be read by software without causing any access on the on-chip AMBA bus. The number of available bits in the counter is 32 bits and is the same as the number of counter bits in the DSU time tag counter. %ASR23 contains the least significant part of the counter value and %ASR22 contains the most significant part.

The time tag value accessible in these registers is the same time tag value used for the system's trace buffers and for all processors connected to the same debug support unit. The time tag counter will increment when any of the trace buffers is enabled, or when the time tag counter is forced to be enabled via the DSU register interface, or when any processor has its %ASR22 Disable Up-counter (DUCNT) field set to zero.

The up-counter value will increment even if all processors have entered power-down mode.

*Table 124.*LEON3 up-counter MSbs (%ASR22)

31	30 … 0
DUCNT	Not Used

31	Disable Up-counter (DUCNT) - Disable upcounter. When set to '1' the up-counter may be disabled. When cleared, the counter will increment each processor clock cycle. Default (reset) value is '1'.
30:0	Reserved and not used

*Table 125.*LEON3 up-counter LSbs (%ASR23)

31 … 0
UPCNT(31:0)

31:0	Counter value (UPCNT(31:0)) - Least significant bits of internal up-counter. Read-only.

16.6.5 ASR24-31, Hardware watchpoint/breakpoint registers

Each breakpoint consists of a pair of ancillary state registers (%asr24/25, %asr26/27, %asr28/29 and %asr30/31) registers; one with the break address and one with a mask:

%asr24, %asr26
%asr28, %asr30

31	2	1	0
WADDR[31:2]			IF
NR		0	0
rw		r	rw

%asr25, %asr27
%asr29, %asr31

31	2		0
WMASK[31:2]		DL	DS
NR		0	0
rw		r	rw

Figure 20. Watch-point registers

WADDR - Address to compare against

WMASK - Bit mask controlling which bits to check (1) or ignore (0) for match

IF - break on instruction fetch from the specified address/mask combination

DL - break on data load from the specified address/mask combination

DS - break on data store to the specified address/mask comination

Note: Setting IF=DL=DS=0 disables the breakpoint

When there is a hardware watchpoint match and DL or DS is set then trap 0x0B will be generated. Hardware watchpoints can be used with or without the LEON3 debug support unit (DSU) enabled.

16.6.6 Register protection control register

ASR register 16 (%asr16) is used to control the IU/FPU register file SEU protection. It is possible to disable the SEU protection by setting the IDI/FDI bits, and to inject errors using the ITE/FTE bits. Corrected errors in the register file are counted, and available in ICNT and FCNT fields. The counters saturate at their maximum value (7), and should be reset by software after read-out.

*Table 126.*LEON3FT Register protection control register (%asr16)

31 30	29 27	26 20	19 18	17	16
RESERVED	FCNT	RESERVED	EIUFT	FTE	FDI
0	0	0	1	0	0
r	rw	r	r	rw	r

15 14	13 11	10 3	2	1	0
IUFT	ICNT	RFTB[7:0]	DP	ITE	IDI
1	0	0	0	0	0
r	rw	rw	rw	rw	rw

31:30	Reserved for future implementations
29:27	FP RF error counter - Number of detected parity errors in the FP register file.
26: 20	Reserved for future implementations
19: 18	Extended IU FT ID - Top bits of IUFT field to indicate FT values higher than 3
17	FPU RF Test Enable - Enables FPU register file test mode. Parity bits are xored with TB before written to the FPU register file.
16	FP RF protection disable (FDI) - Disables FP RF parity protection when set.
15:14	IU FT ID - SEU protection is available for IU
13:11	IU RF error counter - Number of detected parity errors in the IU register file.
10:3	RF Test bits (RFTB) - In test mode, these bits are xored with correct parity bits before written to the register file.
2	DP ram select (DP) - Only applicable if the IU or FPU register files consists of two dual-port rams. See table 127 below.
1	IU RF Test Enable - Enables register file test mode. Parity bits are xored with TB before written to the register file.
0	IU RF protection disable (IDI) - Disables IU RF parity protection when set.

*Table 127.*DP ram select usage

ITE/FTE	DP	Function
1	0	Write to IU register (%i, %l, %o, %g) will only write location of %rs2 Write to FPU register (%f) will only write location of %rs2
1	1	Write to IU register (%i, %l, %o, %g) will only write location of %rs1 Write to FPU register (%f) will only write location of %rs1
0	X	IU and FPU registers written nominally

16.7 Software considerations

16.7.1 Register file initialization on power up for LEON3FT

This section is only valid if internal boot ROM is bypassed.

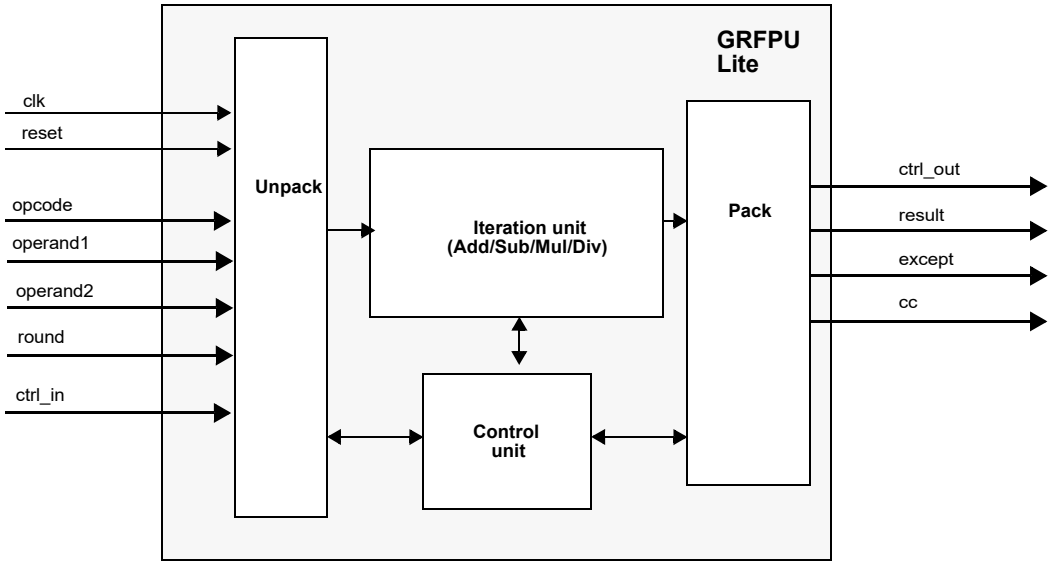
After power-on and internal boot ROM is bypassed, the check bits in the IU and FPU register files are not initialized. This means that access to an un-initialized (un-written) general-purpose register could cause a register access trap (tt = 0x20). Such behavior is considered as a software error, as the software should not read a register before it has been written. It is recommended that the boot code for the processor writes all registers in the IU and FPU register files before launching the main application. Initialization of IU and FPU register files is performed by the internal boot ROM before handover to application software.

17 IEEE-754 Floating-Point Unit

17.1 Overview

The floating-point unit implements floating-point operations as defined in IEEE Standard for Binary Floating-Point Arithmetic (IEEE-754) and SPARC V8 standard (IEEE-1754).

Supported formats are single and double precision floating-point numbers. The floating-point unit is not pipelined and executes one floating-point operation at a time.



17.2 Functional Description

17.2.1 Floating-point number formats

The floating-point unit handles floating-point numbers in single or double precision format as defined in IEEE-754 standard.

17.2.2 FP operations

The floating-point unit supports four types of floating-point operations: arithmetic, compare, convert and move. The operations, summarized in the table below, implement all FP instructions specified by the SPARC V8 instruction set except FSMULD and instructions with quadruple precision.

Table 128.:Floating-point operations

Operation	Op1	Op2	Result	Exceptions	Description
Arithmetic operations					
FADDS FADDD	SP DP	SP DP	SP DP	NV, OF, UF, NX	Addition
FSUBS FSUBD	SP DP	SP DP	SP DP	NV, OF, UF, NX	Subtraction
FMULS FMULD	SP DP	SP DP	SP DP	NV, OF, UF, NX NV, OF, UF, NX	Multiplication
FDIVS FDIVD	SP DP	SP DP	SP DP	NV, OF, UF, NX, DZ	Division
FSQRTS FSQRTD	- -	SP DP	SP DP	NV, NX	Square-root
Conversion operations					
FITOS FITOD	-	INT	SP DP	NX -	Integer to floating-point conversion
FSTOI FDTOI	-	SP DP	INT	NV, NX	Floating-point to integer conversion. The result is rounded in round-to-zero mode.
FSTOD FDTOS	-	SP DP	DP SP	NV NV, OF, UF, NX	Conversion between floating-point formats
Comparison operations					
FCMPS FCMPD	SP DP	SP DP	CC	NV	Floating-point compare. Invalid exception is generated if either operand is a signaling NaN.
FCMPES FCMPED	SP DP	SP DP	CC	NV	Floating point compare. Invalid exception is generated if either operand is a NaN (quiet or signaling).
Negate, Absolute value and Move					
FABSS	-	SP	SP	-	Absolute value.
FNEGS	-	SP	SP	-	Negate.
FMOVS		SP	SP	-	Move. Copies operand to result output.

SP - single precision floating-point number

DP - double precision floating-point number

INT - 32 bit integer

CC - condition codes

NV, OF, UF, NX - floating-point exceptions, see section 17.2.3

Below is a table of worst-case throughput of the floating point unit.

*Table 129.*Worst-case instruction timing

Instruction	Throughput	Latency
FADDS, FADDD, FSUBS, FSUBD,FMULS, FMULD, FITOS, FITOD, FSTOI, FDTOI, FSTOD, FDTOS, FCMPS, FCMPD, FCMPES. FCMPED	8	8
FDIVS	31	31
FDIVD	57	57
FSQRTS	46	46
FSQRTD	65	65

17.2.3 Exceptions

The floating-point unit detects all exceptions defined by the IEEE-754 standard. This includes detection of Invalid Operation (NV), Overflow (OF), Underflow (UF), Division-by-Zero (DZ) and Inexact (NX) exception conditions. Generation of special results such as NaNs and infinity is also supported.

17.2.4 Rounding

All four rounding modes defined in the IEEE-754 standard are supported: round-to-nearest, round-to-+inf, round-to--inf and round-to-zero.

18 UART Serial Interface

The GR716 comprises 6 separate UART units and 2 debug and remote access UART units. The 2 debug and remote access UART units also called AHBUART units are described in section 48. This chapter only describes the UART units also called APBUART. The main difference between the UART units described in this section and the debug UART units are the debug and remote access UART units capability to respond to external UART singling without software support. The two debug and remote access UART units can also act as a master on the internal bus without software support. The UART units described in this section requires software support for all operations.

The APB UART units are located on APB bus in the address range from 0x80300000 to 0x80305FFF. See UART units connections in the next drawing. The figure shows memory locations and functions used for UART configuration and control.

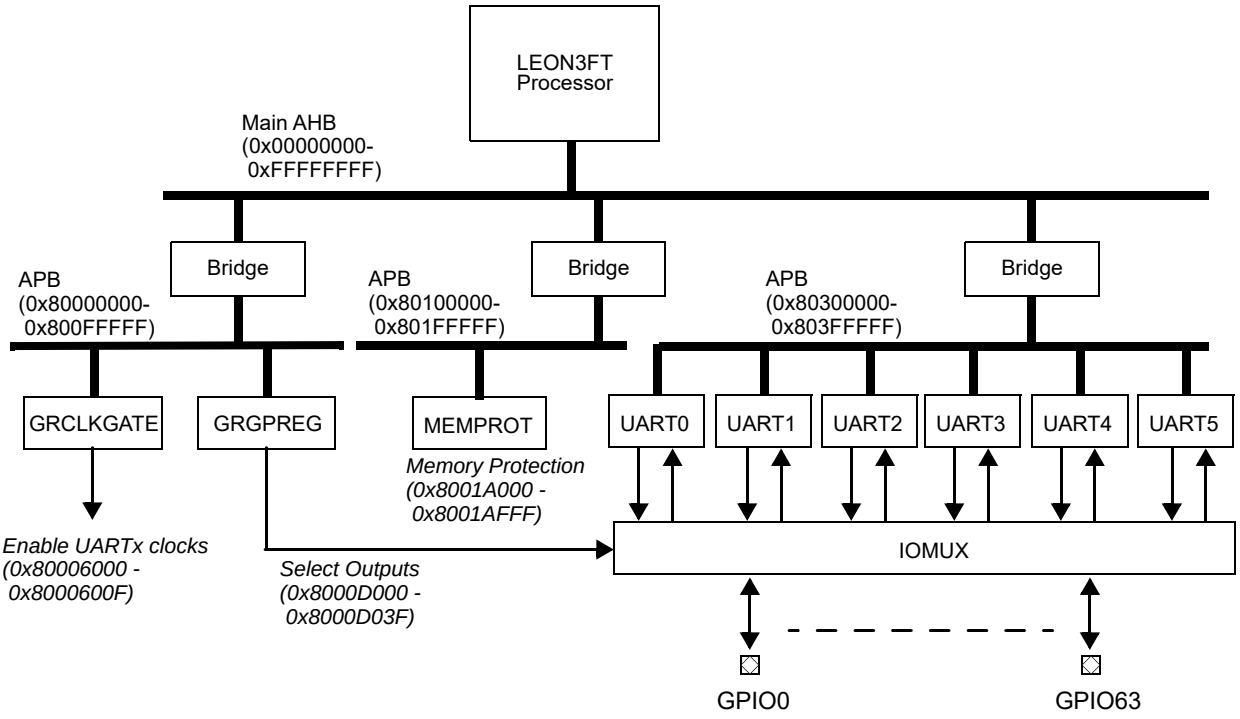


Figure 21. GR716 UART bus and pin connection

The primary clock gating unit **GRCLKGATE** described in section 26 is used to enable/disable individual UART units. The unit **GRCLKGATE** can also be used to perform reset of individual UART units. Software must enable clock and release reset described in section 26 before UART configuration and transmission can start.

External IO selection per UART unit is made in the system IO configuration register (**GRGPREG**) in the address range from 0x8000D000 to 0x8000D03F. See section 7.1 for further information.

Each **UARTx** unit controls its own external pins and has a unique AMBA address described in chapter 2.11. UART unit 0, 1, 2, 3, 4 and 5 have identical configuration and status registers. Configuration and status registers are described in section 18.7.

The system can be configured to protect and restrict access to individual UART unit in the **MEMPROT** unit. See section 47 for more information.

18.1 Overview

The universal asynchronous receiver-transmitter (UART) interface takes bytes and transmits the individual bit sequentially. The UART supports data frames with 8 data bits, one optional parity bit and one or two stop bits. To generate the bit-rate, each UART has a programmable 12-bit clock divider. To minimize the interrupts two 16-byte FIFOs are used for data transfer between the APB bus and UART, one FIFO for reception and one for transmission. Hardware flow-control is supported through the RTSN/CTSN hand-shake signals. Parity checking can be enabled per UART interface.

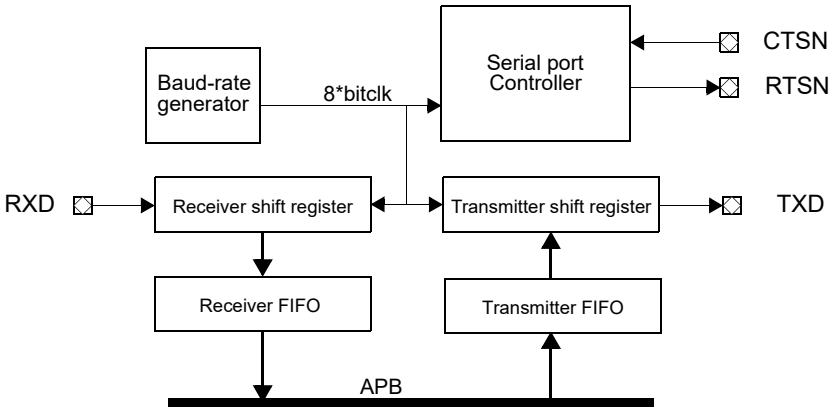


Figure 22. UART unit block diagram

18.2 Operation

18.2.1 Transmitter operation

The transmitter is enabled through the TE bit in the UART control register. Data that is to be transferred is stored in the 16-byte FIFO by writing to the data register. When ready to transmit, data is transferred from the transmitter FIFO to the transmitter shift register and converted to a serial stream on the transmitter serial output pin (TXD). It automatically sends a start bit followed by eight data bits, an optional parity bit, and one stop bit (figure 23). The least significant bit of the data is sent first. It is also possible to use two stop bits, this is configured via the control register.

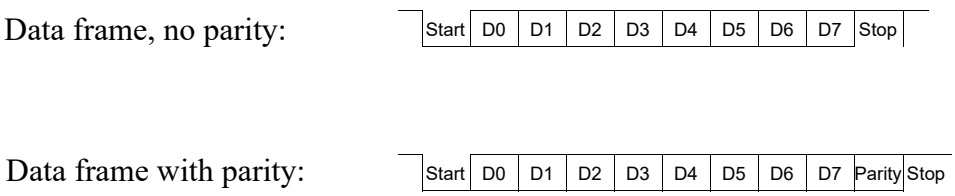


Figure 23. UART data frames

Following the transmission of the stop bit, if a new character is not available in the transmitter FIFO, the transmitter serial data output remains high and the transmitter shift register empty bit (TS) will be set in the UART status register. Transmission resumes and the TS is cleared when a new character is

loaded into the transmitter FIFO. When the FIFO is empty the TE bit is set in the status register. If the transmitter is disabled, it will immediately stop any active transmissions including the character currently being shifted out from the transmitter shift register. The transmitter FIFO may not be loaded when the transmitter is disabled or when the FIFO is full. If this is done, data might be overwritten and one or more frames are lost.

The TF status bit (not to be confused with the TF control bit) is set if the transmitter FIFO is currently full and the TH bit is set as long as the FIFO is *less* than half-full (less than half of entries in the FIFO contain data). The TF control bit enables FIFO interrupts when set. The status register also contains a counter (TCNT) showing the current number of data entries in the FIFO.

When flow control is enabled, the CTSN input must be low in order for the character to be transmitted. If it is deasserted in the middle of a transmission, the character in the shift register is transmitted and the transmitter serial output then remains inactive until CTSN is asserted again. If the CTSN is connected to a receivers RTSN, overrun can effectively be prevented.

18.2.2 Receiver operation

The receiver is enabled for data reception through the receiver enable (RE) bit in the UART control register. The receiver looks for a high to low transition of a start bit on the receiver serial data input pin. If a transition is detected, the state of the serial input is sampled a half bit clocks later. If the serial input is sampled high the start bit is invalid and the search for a valid start bit continues. If the serial input is still low, a valid start bit is assumed and the receiver continues to sample the serial input at one bit time intervals (at the theoretical centre of the bit) until the proper number of data bits and the parity bit have been assembled and one stop bit has been detected.

The receiver also has a 16-byte FIFO which is identical to the one in the transmitter.

During reception, the least significant bit is received first. The data is then transferred to the receiver FIFO and the data ready (DR) bit is set in the UART status register as soon as the FIFO contains at least one data frame. The parity, framing and overrun error bits are set at the received byte boundary, at the same time as the receiver ready bit is set. The data frame is not stored in the FIFO if an error is detected. Also, the new error status bits are or:ed with the old values before they are stored into the status register. Thus, they are not cleared until written to with zeros from the AMBA APB bus. If both the receiver FIFO and shift registers are full when a new start bit is detected, then the character held in the receiver shift register will be lost and the overrun bit will be set in the UART status register. A break received (BR) is indicated when a BREAK has been received, which is a framing error with all data received being zero.

RTSN will be negated (high) when a valid start bit is detected and the receiver FIFO is full. When the FIFO is read, the RTSN will automatically be reasserted again. This behavior applies regardless of the value of the FL bit in the UART control register.

The RF status bit (not to be confused with the RF control bit) is set when the receiver FIFO is full. The RH status bit is set when the receiver FIFO is half-full (at least half of the entries in the FIFO contain data frames). The RF control bit enables receiver FIFO interrupts when set. A RCNT field is also available showing the current number of data frames in the FIFO.

18.3 Baud-rate generation

Each UART contains a 12-bit down-counting scaler to generate the desired baud-rate. The scaler is clocked by the system clock and generates a UART tick each time it underflows. It is reloaded with the value of the UART scaler reload register after each underflow. The resulting UART tick frequency should be 8 times the desired baud-rate. One appropriate formula to calculate the scaler value for a desired baud rate, using integer division where the remainder is discarded, is:

*scaler value = (system_clock_frequency) / (baud_rate * 8 + 7).*

To calculate the exact required scaler value use:

*scaler value = (system_clock_frequency) / (baud_rate * 8) - 1*

18.4 Loop back mode

If the LB bit in the UART control register is set, the UART will be in loop back mode. In this mode, the transmitter output is internally connected to the receiver input and the RTSN is connected to the CTSN. It is then possible to perform loop back tests to verify operation of receiver, transmitter and associated software routines. In this mode, the outputs remain in the inactive state, in order to avoid sending out data.

18.5 FIFO debug mode

FIFO debug mode is entered by setting the debug mode bit in the control register. In this mode it is possible to read the transmitter FIFO and write the receiver FIFO through the FIFO debug register. The transmitter output is held inactive when in debug mode. A write to the receiver FIFO generates an interrupt if receiver interrupts are enabled.

18.6 Interrupt generation

Two different kinds of interrupts are available: normal interrupts and FIFO interrupts.

Normal interrupts from the transmitter are generated when transmitter interrupts are enabled (TI), the transmitter is enabled and the transmitter FIFO goes from containing data to being empty. For the receiver normal interrupts are generated when receiver interrupts are enabled (RI), the receiver is enabled and a character is received. The interrupt is generated if the character is correct and stored in the receive FIFO or if an error, such as parity; framing or overrun occurred.

Transmitter FIFO interrupts are generated when the transmitter FIFO interrupts are enabled (TF), transmissions are enabled (TE) and the UART is less than half-full (that is, whenever the TH status bit is set). This is a level interrupt and the interrupt signal is continuously driven high as long as the condition prevails. Receiver FIFO interrupts are generated when receiver FIFO interrupts are enabled (RF), the receiver is enabled and the FIFO is half-full. The interrupt signal is continuously driven high as long as the receiver FIFO is half-full (at least half of the entries contain data frames).

Note that the processor acknowledges and clears the corresponding interrupt pending register but for FIFO interrupts the interrupt signal from the UART is continuously driven high, resulting in a new pending interrupt immediately being set in the interrupt controller. If FIFO interrupts are used for controlling FIFO handling, an interrupt handler need to check that there is room in the transmit FIFO before writing and that characters are available in the receive FIFO before reading.

To reduce interrupt occurrence a delayed receiver interrupt is available. It is enabled using the delayed interrupt enable (DI) bit. When enabled a timer is started each time a character is received and an interrupt is only generated if another character has not been received within 4 character + 4 bit times. If receiver FIFO interrupts are enabled a pending character interrupt will be cleared when the FIFO interrupt is active since the character causing the pending irq state is already in the FIFO and is noticed by the driver through the FIFO interrupt. In order to not take one additional interrupt, software should clear the corresponding pending bit after the FIFO has been emptied.

There is also a separate interrupt for break characters. When enabled an interrupt will always be generated immediately when a break character is received even when delayed receiver interrupts are enabled. When break interrupts are disabled no interrupt will be generated for break characters when delayed interrupts are enabled.

When delayed interrupts are disabled the behavior is the same for the break interrupt bit except that an interrupt will be generated for break characters if receiver interrupt enable is set even if break interrupt is disabled.

An interrupt can also be enabled for the transmitter shift register. When enabled the core will generate an interrupt each time the shift register goes from a non-empty to an empty state.

18.7 Registers

The core is controlled through registers mapped into APB address space.

*Table 130.*UART registers

APB address offset	Register
0x80300000	UART0 Data register (UART0.DATA)
0x80300004	UART0 Status register (UART0.STATUS)
0x80300008	UART0 Control register (UART0.CTRL)
0x8030000C	UART0 Scaler register (UART0.SCALER)
0x80300010	UART0 FIFO debug register (UART0.FIFO)
0x80301000	UART1 Data register (UART1.DATA)
0x80301004	UART1 Status register (UART1.STATUS)
0x80301008	UART1 Control register (UART1.CTRL)
0x8030100C	UART1 Scaler register (UART1.SCALER)
0x80301010	UART1 FIFO debug register (UART1.FIFO)
0x80302000	UART2 Data register (UART2.DATA)
0x80302004	UART2 Status register (UART2.STATUS)
0x80302008	UART2 Control register (UART2.CTRL)
0x8030200C	UART2 Scaler register (UART2.SCALER)
0x80302010	UART2 FIFO debug register (UART2.FIFO)
0x80303000	UART3 Data register (UART3.DATA)
0x80303004	UART3 Status register (UART3.STATUS)
0x80303008	UART3 Control register (UART3.CTRL)
0x8030300C	UART3 Scaler register (UART3.SCALER)
0x80303010	UART3 FIFO debug register (UART3.FIFO)
0x80304000	UART4 Data register (UART4.DATA)
0x80304004	UART4 Status register (UART4.STATUS)
0x80304008	UART4 Control register (UART4.CTRL)
0x8030400C	UART4 Scaler register (UART4.SCALER)
0x80304010	UART4 FIFO debug register (UART4.FIFO)
0x80305000	UART5 Data register (UART5.DATA)
0x80305004	UART5 Status register (UART5.STATUS)
0x80305008	UART5 Control register (UART5.CTRL)
0x8030500C	UART5 Scaler register (UART5.SCALER)
0x80305010	UART5 FIFO debug register (UART5.FIFO)

18.7.1 UART Data Register

Table 131. 0x00 - DATA - UART data register

31 … 8	7 … 0
RESERVED	DATA
	NR
	rw

7: 0 Receiver FIFO (read access)

7: 0 Transmitter FIFO (write access)

18.7.2 UART Status Register

Table 132. 0x04 - STAT - UART status register

31 … 26	25 … 20	19 … 11	10	9	8	7	6	5	4	3	2	1	0
RCNT	TCNT	RESERVED	RF	TF	RH	TH	FE	PE	OV	BR	TE	TS	DR
0	0	0	0	0	0	0	0	0	0	0	1	1	0
r	r	r	r	r	r	r	rw	rw	rw	rw	r	r	r

31: 26 Receiver FIFO count (RCNT) - shows the number of data frames in the receiver FIFO. Reset: 0

25: 20 Transmitter FIFO count (TCNT) - shows the number of data frames in the transmitter FIFO. Reset: 0

10 Receiver FIFO full (RF) - indicates that the Receiver FIFO is full. Reset: 0

9 Transmitter FIFO full (TF) - indicates that the Transmitter FIFO is full. Reset: 0

8 Receiver FIFO half-full (RH) -indicates that at least half of the FIFO is holding data. Reset: 0

7 Transmitter FIFO half-full (TH) - indicates that the FIFO is less than half-full. Reset: 0

6 Framing error (FE) - indicates that a framing error was detected. Reset: 0

5 Parity error (PE) - indicates that a parity error was detected. Reset: 0

4 Overrun (OV) - indicates that one or more character have been lost due to overrun. Reset: 0

3 Break received (BR) - indicates that a BREAK has been received. Reset: 0

2 Transmitter FIFO empty (TE) - indicates that the transmitter FIFO is empty. Reset: 1

1 Transmitter shift register empty (TS) - indicates that the transmitter shift register is empty. Reset: 1

0 Data ready (DR) - indicates that new data is available in the receiver FIFO. Reset: 0

18.7.3 UART Control Register

Table 133. UART control register

31	30 ... 16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
FA	RESERVED	NS	SI	DI	BI	DB	RF	TF	R	LB	FL	PE	PS	TI	RI	TE	RE
1	0	NR	NR	NR	NR	NR	NR	NR	0	NR	0	NR	NR	NR	NR	0	0
r	r	rw	rw	rw	rw	rw	rw	rw	r	rw	rw	rw	rw	rw	rw	rw	rw

31 FIFOs available (FA) - Set to 1 when receiver and transmitter FIFOs are available.

30: 16 RESERVED

15 Number of stop bits (NS) - When set to ‘1’ then two stop bits will be used, otherwise one stop bit will be used.

14 Transmitter shift register empty interrupt enable (SI) - When set, an interrupt will be generated when the transmitter shift register becomes empty. See section 18.6 for more details.

13 Delayed interrupt enable (DI) - When set, delayed receiver interrupts will be enabled and an interrupt will only be generated for received characters after a delay of 4 character times + 4 bits if no new character has been received during that interval. This is only applicable if receiver interrupt enable is set. See section 18.6 for more details.

12 Break interrupt enable (BI) - When set, an interrupt will be generated each time a break character is received. See section 18.6 for more details.

11 FIFO debug mode enable (DB) - when set, it is possible to read and write the FIFO debug register.

10 Receiver FIFO interrupt enable (RF) - when set, Receiver FIFO level interrupts are enabled.

9 Transmitter FIFO interrupt enable (TF) - when set, Transmitter FIFO level interrupts are enabled.

8 RESERVED and should always be set to ’0’ for the GR716 device

7 Loop back (LB) - if set, loop back mode will be enabled.

6 Flow control (FL) - if set, enables flow control using CTS/RTS

5 Parity enable (PE) - if set, enables parity generation and checking

4 Parity select (PS) - selects parity polarity (0 = even parity, 1 = odd parity)

3 Transmitter interrupt enable (TI) - if set, interrupts are generated when characters are transmitted (see section 18.6 for details).

2 Receiver interrupt enable (RI) - if set, interrupts are generated when characters are received (see section 18.6 for details).

1 Transmitter enable (TE) - if set, enables the transmitter.

0 Receiver enable (RE) - if set, enables the receiver.

18.7.4 UART Scaler Register

*Table 134.*0x0C - SCALER - UART scaler reload register

31 ... 20	19 ... 0
RESERVED	SCALER RELOAD VALUE
0	NR
r	rw

19:0 Scaler reload value

18.7.5 UART FIFO Debug Register

Table 135. 0x10 - DEBUG - UART FIFO debug register

31 ... 8	7 ... 0
RESERVED	DATA
0	NR
r	rw

7: 0 Transmitter FIFO (read access)

7: 0 Receiver FIFO (write access)

19 Hardware Debug Support Unit

19.1 Overview

To simplify debugging on target hardware, the LEON3 processor implements a debug mode during which the pipeline is idle and the processor is controlled through a special debug interface. The LEON3 Debug Support Unit (DSU) is used to control the processor during debug mode. The DSU acts as an AHB slave and can be accessed by any AHB master. An external debug host can therefore access the DSU through several different interfaces.

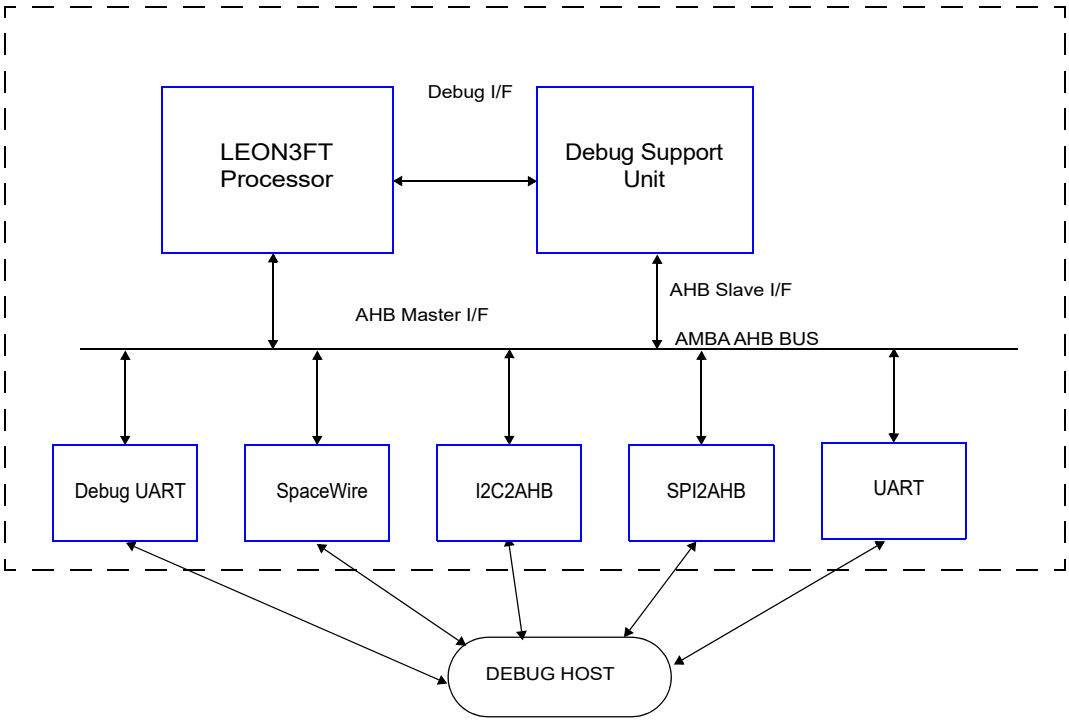


Figure 24. LEON3FT/DSU Connection

19.2 Operation

Through the DSU AHB slave interface, any AHB master can access the processor registers and the contents of the instruction trace buffer. The DSU control registers can be accessed at any time, while the processor registers and trace buffer can only be accessed when the processor has entered debug mode. In debug mode, the processor pipeline is held and the processor state can be accessed by the DSU. Entering the debug mode can occur on the following events:

- executing a breakpoint instruction (ta 1)
- integer unit hardware breakpoint/watchpoint hit (trap 0xb)
- rising edge of the external break signal (DSUBRE)
- setting the break-now (BN) bit in the DSU control register
- a trap that would cause the processor to enter error mode
- occurrence of any, or a selection of traps as defined in the DSU control register
- after a single-step operation
- the processor has entered the debug mode
- DSU AHB breakpoint or watchpoint hit

The debug mode can only be entered when the debug support unit is enabled through an external signal (DSUEN). For DSU break (DSUBRE), and the break-now BN bit, to have effect the Break-on-IU-watchpoint (BW) bit must be set in the DSU control register. This bit is set when DSUBRE is active after reset and should also be set by debug monitor software (like Cobham Gaisler's GRMON) when initializing the DSU. When the debug mode is entered, the following actions are taken:

- PC and nPC are saved in temporary registers (accessible by the debug unit)
- an output signal (DSUACT) is asserted to indicate the debug state
- the timer unit is (optionally) stopped to freeze the LEON timers and watchdog

The instruction that caused the processor to enter debug mode is not executed, and the processor state is kept unmodified. Execution is resumed by clearing the BN bit in the DSU control register or by de-asserting DSUEN. The timer unit will be re-enabled and execution will continue from the saved PC and nPC. Debug mode can also be entered after the processor has entered error mode, for instance when an application has terminated and halted the processor. The error mode can be reset and the processor restarted at any address.

When a processor is in the debug mode, an access to ASI diagnostic area is forwarded to the IU which performs access with ASI equal to value in the DSU ASI register and address consisting of 20 LSB bits of the original address.

19.3 AHB trace buffer

The AHB trace buffer consists of a circular buffer that stores AHB data transfers, the monitored AHB bus is either the same bus as the DSU AHB slave interface is connected to, or a completely separate bus. The address, data and various control signals of the AHB bus are stored and can be read out for later analysis. The trace buffer is 128 wide. The way information stored is indicated in the table below:

*Table 136.*AHB Trace buffer data allocation

Bits	Name	Definition
127	AHB breakpoint hit	Set to '1' if a DSU AHB breakpoint hit occurred.
126	-	Not used
125:96	Time tag	DSU time tag counter
95:80	-	Not used
79	Hwrite	AHB HWRITE
78:77	Htrans	AHB HTRANS
76:74	Hsize	AHB HSIZE
73:71	Hburst	AHB HBURST
70:67	Hmaster	AHB HMASTER
66	Hmastlock	AHB HMASTLOCK
65:64	Hresp	AHB HRESP
63:32	Load/Store data	AHB HRDATA/HWDATA(31:0)
31:0	Load/Store address	AHB HADDR

In addition to the AHB signals, the DSU time tag counter is also stored in the trace.

The trace buffer is enabled by setting the enable bit (EN) in the trace control register. Each AHB transfer is then stored in the buffer in a circular manner. The address to which the next transfer is written is held in the trace buffer index register, and is automatically incremented after each transfer. Tracing is stopped when the EN bit is reset, or when a AHB breakpoint is hit. Tracing is temporarily suspended when the processor enters debug mode, unless the trace force bit (TF) in the trace control register is set. If the trace force bit is set, the trace buffer is activated as long as the enable bit is set.

The force bit is reset if an AHB breakpoint is hit and can also be cleared by software. Note that neither the trace buffer memory nor the breakpoint registers (see below) can be read/written by software when the trace buffer is enabled.

The DSU has an internal time tag counter and this counter is frozen when the processor enters debug mode. When AHB tracing is performed in debug mode (using the trace force bit) it may be desirable to also enable the time tag counter. This can be done using the timer enable bit (TE). Note that the time tag is also used for the instruction trace buffer and the timer enable bit should only be set when using the DSU as an AHB trace buffer only, and not when performing profiling or software debugging. The timer enable bit is reset on the same events as the trace force bit.

19.3.1 AHB trace buffer filters

The DSU is implemented with filters that can be applied to the AHB trace buffer, breakpoints and watchpoints. These filters are controlled via the AHB trace buffer filter control and AHB trace buffer filter mask registers. The fields in these registers allows masking access characteristics such as master, slave, read, write and address range so that accesses that correspond to the specified mask are not written into the trace buffer. Address range masking is done using the second AHB breakpoint register set. The values of the LD and ST fields of this register has no effect on filtering.

19.3.2 AHB statistics

The DSU generates statistics from the traced AHB bus. Statistics is collected and output to LEON statistics unit (L3STAT). The statistical outputs can be filtered by the AHB trace buffer filters, this is controlled by the Performance counter Filter bit (PF) in the AHB trace buffer filter control register. The DSU can collect data for the events listed in table 137 below.

*Table 137.*AHB events

Event	Description	Note
idle	HTRANS=IDLE	Active when HTRANS IDLE is driven on the AHB slave inputs and slave has asserted HREADY.
busy	HTRANS=BUSY	Active when HTRANS BUSY is driven on the AHB slave inputs and slave has asserted HREADY.
nseq	HTRANS=NONSEQ	Active when HTRANS NONSEQ is driven on the AHB slave inputs and slave has asserted HREADY.
seq	HTRANS=SEQ	Active when HTRANS SEQUENTIAL is driven on the AHB slave inputs and slave has asserted HREADY.
read	Read access	Active when HTRANS is SEQUENTIAL or NON-SEQUENTIAL, slave has asserted HREADY and the HWRITE input is low.
write	Write access	Active when HTRANS is SEQUENTIAL or NON-SEQUENTIAL, slave has asserted HREADY and the HWRITE input is high.
hsize[5:0]	Transfer size	Active when HTRANS is SEQUENTIAL or NON-SEQUENTIAL, slave has asserted HREADY and HSIZE is BYTE (hsize[0]), HWORD (HSIZE[1]), WORD (hsize[2]), DWORD (hsize[3]), 4WORD hsize[4], or 8WORD (hsize[5]).
ws	Wait state	Active when HREADY input to AHB slaves is low and AMBA response is OKAY.
retry	RETRY response	Active when master receives RETRY response
split	SPLIT response	Active when master receives SPLIT response

*Table 137.*AHB events

Event	Description	Note
spdel	SPLIT delay	Active during the time a master waits to be granted access to the bus after reception of a SPLIT response. The core will only keep track of one master at a time. This means that when a SPLIT response is detected, the core will save the master index. This event will then be active until the same master is re-allowed into bus arbitration and is granted access to the bus. This also means that the delay measured will include the time for re-arbitration, delays from other ongoing transfers and delays resulting from other masters being granted access to the bus before the SPLIT:ed master is granted again after receiving SPLIT complete. If another master receives a SPLIT response while this event is active, the SPLIT delay for the second master will not be measured.
locked	Locked access	Active while the HMASTLOCK signal is asserted on the AHB slave inputs.

19.4 Instruction trace buffer

The instruction trace buffer consists of a circular buffer that stores executed instructions. The instruction trace buffer is located in the processor, and read out via the DSU. The trace buffer is 128 bits wide, the information stored is indicated in the table below:

*Table 138.*Instruction trace buffer data allocation

Bits	Name	Definition
127	-	Unused
126	Multi-cycle instruction	Set to ‘1’ on the second and third instance of a multi-cycle instruction (LDD, ST or FPOP)
125:96	Time tag	The value of the DSU time tag counter
95:64	Load/Store parameters	Instruction result, Store address or Store data
63:34	Program counter	Program counter (2 lsb bits removed since they are always zero)
33	Instruction trap	Set to ‘1’ if traced instruction trapped
32	Processor error mode	Set to ‘1’ if the traced instruction caused processor error mode
31:0	Opcode	Instruction opcode

During tracing, one instruction is stored per line in the trace buffer with the exception of multi-cycle instructions. Multi-cycle instructions are entered two or three times in the trace buffer. For store instructions, bits [95:64] correspond to the store address on the first entry and to the stored data on the second entry (and third in case of STD). Bit 126 is set on the second and third entry to indicate this. A double load (LDD) is entered twice in the trace buffer, with bits [95:64] containing the loaded data. Bit 126 is set for the second entry.

When the processor enters debug mode, tracing is suspended. The trace buffer and the trace buffer control register can be read and written while the processor is in the debug mode. During the instruction tracing (processor in normal mode) the trace buffer and trace buffer control register 0 can not be written. The traced instructions can optionally be filtered on instruction types. Which instructions are traced is defined in the instruction trace register [31:28], as defined in the table below:

*Table 139.*Trace filter operation

Trace filter	Instructions traced
0x0	All instructions
0x1	SPARC Fomat 2 instructions
0x2	Control-flow changes. All Call, branch and trap instructions including branch targets
0x4	SPARC Format 1 instructions (CALL)
0x8	SPARC Format 3 instructions except LOAD or STORE
0xC	SPARC Format 3 LOAD or STORE instructions
0xD	SPARC Format 3 LOAD or STORE instructions to alternate space
0xE	SPARC Format 3 LOAD or STORE instructions to alternate space 0x80 - 0xFF

19.5 Using the DSU trace buffer

The debug monitor GRMON3 has build-in support for using trace buffer in the DSU. For more information see chapter for using the trace buffer in the GRMON3 User's Manual [GRMON3].

19.6 DSU memory map

The DSU memory map can be seen in table 140 below.

Note: The DSU memory interface is intended to be accessed by a debug monitor. Software running on the LEON processors should not access the DSU interface. Registers, such as ASR registers, may not have all fields available via the DSU interface

*Table 140.*DSU memory map

Address offset	Register
0x000000	DSU control register
0x000008	Time tag counter
0x000020	Break and Single Step register
0x000024	Debug Mode Mask register
0x000040	AHB trace buffer control register
0x000044	AHB trace buffer index register
0x000048	AHB trace buffer filter control register
0x00004c	AHB trace buffer filter mask register
0x000050	AHB breakpoint address 1
0x000054	AHB mask register 1
0x000058	AHB breakpoint address 2
0x00005c	AHB mask register 2
0x100000 - 0x10FFFF	Instruction trace buffer (..0: Trace bits 127 - 96, ..4: Trace bits 95 - 64, ..8: Trace bits 63 - 32, ..C : Trace bits 31 - 0)
0x110000	Instruction Trace buffer control register 0
0x110004	Instruction Trace buffer control register 1
0x200000 - 0x210000	AHB trace buffer (..0: Trace bits 127 - 96, ..4: Trace bits 95 - 64, ..8: Trace bits 63 - 32, ..C : Trace bits 31 - 0)
0x300000 - 0x3007FC	IU register file, port1 (%asr16.dpsel = 0) IU register file, port 2 (%asr16.dpsel = 1)
0x300800 - 0x300FFC	IU register file information for correctable and uncorrectable errors
0x301000 - 0x30107C	FPU register file
0x400000 - 0x4FFFFC	IU special purpose registers

*Table 140.*DSU memory map

Address offset	Register
0x400000	Y register
0x400004	PSR register
0x400008	WIM register
0x40000C	TBR register
0x400010	PC register
0x400014	NPC register
0x400018	FSR register
0x40001C	CPSR register
0x400020	DSU trap register
0x400024	DSU ASI register
0x400040 - 0x40007C	ASR16 - ASR31
0x700000 - 0x7FFFFC	ASI diagnostic access (ASI = value in DSU ASI register, address = address[19:0]) ASI = 0x9 : Local instruction RAM, ASI = 0xB : Local data RAM

19.7 DSU registers

19.7.1 DSU control register

The DSU is controlled by the DSU control register:

*Table 141.*0x000000 - CTRL - DSU control register

31	12	11	10	9	8	7	6	5	4	3	2	1	0
RESERVED		PW	HL	PE	EB	EE	DM	BZ	BX	BS	BW	BE	TE
0		0	0	0	*	*		*	*	*	*	*	*
r		r	rw	rw	r	r	r	rw	rw	rw	rw	rw	rw

31: 12 Reserved

11 Power down (PW) - Returns ‘1’ when processor is in power-down mode.

10 Processor halt (HL) - Returns ‘1’ on read when processor is halted. If the processor is in debug mode, setting this bit will put the processor in halt mode.

9 Processor error mode (PE) - returns ‘1’ on read when processor is in error mode, else ‘0’. If written with ‘1’, it will clear the error and halt mode.

8 External Break (EB) - Value of the external DSUBRE signal (read-only)

7 External Enable (EE) - Value of the external DSUEN signal (read-only)

6 Debug mode (DM) - Indicates when the processor has entered debug mode (read-only).

5 Break on error traps (BZ) - if set, will force the processor into debug mode on all *except* the following traps: priviledged_instruction, fpu_disabled, window_overflow, window_underflow, asynchronous_interrupt, ticc_trap.

4 Break on trap (BX) - if set, will force the processor into debug mode when any trap occurs.

3 Break on S/W breakpoint (BS) - if set, debug mode will be forced when an breakpoint instruction (ta 1) is executed.

2 Break on IU watchpoint (BW) - if set, debug mode will be forced on a IU watchpoint (trap 0xb).

1 Break on error (BE) - if set, will force the processor to debug mode when the processor would have entered error condition (trap in trap).

0 Trace enable (TE) - Enables instruction tracing. If set the instructions will be stored in the trace buffer. Remains set when then processor enters debug or error mode

19.7.2 DSU Break and Single Step register

This register is used to break or single step the processor(s).

*Table 142.*0x000020 - BRSS - BRSS - DSU Break and Single Step register

31 16	15 0
SS[15:0]	BN[15:0]

31: 16 Single step (SSx) - if set, the processor x will execute one instruction and return to debug mode. The bit remains set after the processor goes into the debug mode. As an exception, if the instruction is a branch with the annul bit set, and if the delay instruction is effectively annulled, the processor will execute the branch, the annulled delay instruction and the instruction thereafter before returning to debug mode.

15: 0 Break now (BNx) -Force processor x into debug mode if the Break on watchpoint (BW) bit in the processors DSU control register is set. If cleared, the processor x will resume execution.

19.7.3 DSU Debug Mode Mask Register

When the processors enters the debug mode the value of the DSU Debug Mode Mask register determines if the other processor is forced in the debug mode.

*Table 143.*0x000024 - DBGM - DSU Debug Mode Mask register

31 17	16	15 1	0
Reserved	DM	Reserved	ED

31: 16 Debug mode mask (DMx) - If set, the processor will not be able to force running processor into debug mode even if it enters debug mode.

15: 0 Enter debug mode (ED) - Force processor into debug mode If 0, the processor will not enter the debug mode.

19.7.4 DSU trap register

The DSU trap register is a read-only register that indicates which SPARC trap type that caused the processor to enter debug mode. When debug mode is force by setting the BN bit in the DSU control register, the trap type will be 0xb (hardware watchpoint trap).

*Table 144.*0x400020 - DTR - DSU Trap register

31 13	12	11 4	3 0
RESERVED	EM	TRAPTYPE	R

31: 13 RESERVED

12 Error mode (EM) - Set if the trap would have cause the processor to enter error mode.

11: 4 Trap type (TRAPTYPE) - 8-bit SPARC trap type

3: 0 Read as 0x0

19.7.5 DSU time tag counter

The trace buffer time tag counter is incremented each clock as long as the processor is running. The counter is stopped when the processor enters debug mode and when the DSU is disabled (unless the

timer enable bit in the AHB trace buffer control register is set), and restarted when execution is resumed.

*Table 145.*0x000008 - DTTC - DSU time tag counter

31	0
TIMETAG	
0	
rw	

31: 0 DSU Time Tag Value (TIMETAG)

The value is used as time tag in the instruction and AHB trace buffer.

19.7.6 DSU ASI register

The DSU can perform diagnostic accesses to different ASI areas. The value in the ASI diagnostic access register is used as ASI while the address is supplied from the DSU.

*Table 146.*0x400024 - DASI - ASI diagnostic access register

31	8	7	0
RESERVED		ASI	
0		NR	
r		rw	

31: 8 RESERVED

7: 0 ASI (ASI) - ASI to be used on diagnostic ASI access

19.7.7 AHB Trace buffer control register

The AHB trace buffer is controlled by the AHB trace buffer control register:

*Table 147.*0x000040 - ATBC - AHB trace buffer control register

31	16	15	8	7	6	5	4	3	2	1	0
DCNT		RESERVED	DF	SF	TE	TF	BW		BR	DM	EN
0		0	0	0	0	0	0		0	0	0
rw		r	rw	rw	rw	rw	r		rw	rw	rw

31: 16 Trace buffer delay counter (DCNT)

15: 8 RESERVED

7 Sample Force (SF) - If this bit is written to ‘1’ it will have the same effect on the AHB trace buffer as if HREADY was asserted on the bus at the same time as a sequential or non-sequential transfer is made. This means that setting this bit to ‘1’ will cause the values in the trace buffer’s sample registers to be written into the trace buffer, and new values will be sampled into the registers. This bit will automatically be cleared after one clock cycle.

Writing to the trace buffer still requires that the trace buffer is enabled (EN bit set to ‘1’) and that the CPU is not in debug mode or that tracing is forced (TF bit set to ‘1’). This functionality is primarily of interest when the trace buffer is tracing a separate bus and the traced bus appears to have frozen.

6 Timer enable (TE) - Activates time tag counter also in debug mode.

5 Trace force (TF) - Activates trace buffer also in debug mode. Note that the trace buffer must be disabled when reading out trace buffer data via the core’s register interface.

4: 3 Bus width (BW) - This value corresponds to log2(Supported bus width / 32)

2 Break (BR) - If set, the processor will be put in debug mode when AHB trace buffer stops due to AHB breakpoint hit.

1 Delay counter mode (DM) - Indicates that the trace buffer is in delay counter mode.

0 Trace enable (EN) - Enables the trace buffer.

19.7.8 AHB trace buffer index register

The AHB trace buffer index register contains the address of the next trace line to be written.

*Table 148.*0x000044 - ATBI - AHB trace buffer index register

31	4	3	0
INDEX		R	
NR		0	
rw		r	

31: 4 Trace buffer index counter (INDEX)

3: 0 Read as 0x0

19.7.9 AHB trace buffer filter control register

*Table 149.*0x000048 - ATBFC - AHB trace buffer filter control register

31 14	13 12	11 10	9 8	7 4	3	2	1	0
RESERVED	WPF	R	BPF	RESERVED	PF	AF	FR	FW
0	0	0	0	0	0	0	0	0
r	rw	r	rw	r	rw	rw	rw	rw

31: 14 RESERVED

13: 12 AHB watchpoint filtering (WPF) - Bit 13 of this field applies to AHB watchpoint 2 and bit 12 applies to AHB watchpoint 1. If the WPF bit for a watchpoint is set to '1' then the watchpoint will not trigger unless the access also passes through the filter. This functionality can be used to, for instance, set a AHB watchpoint that only triggers if a specified master performs an access to a specified slave.

11: 10 RESERVED

9: 8 AHB breakpoint filtering (BPF) - Bit 9 of this field applies to AHB breakpoint 2 and bit 8 applies to AHB breakpoint 1. If the BPF bit for a breakpoint is set to '1' then the breakpoint will not trigger unless the access also passes through the filter. This functionality can be used to, for instance, set a AHB breakpoint that only triggers if a specified master performs an access to a specified slave. Note that if a AHB breakpoint is coupled with an AHB watchpoint then the setting of the corresponding bit in this field has no effect.

7: 4 RESERVED

3 Performance counter Filter (PF) - If this bit is set to '1', the cores performance counter (statistical) outputs will be filtered using the same filter settings as used for the trace buffer. If a filter inhibits a write to the trace buffer, setting this bit to '1' will cause the same filter setting to inhibit the pulse on the statistical output.

2 Address Filter (AF) - If this bit is set to '1', only the address range defined by AHB trace buffer breakpoint 2's address and mask will be included in the trace buffer.

1 Filter Reads (FR) - If this bit is set to '1', read accesses will not be included in the trace buffer.

0 Filter Writes (FW) - If this bit is set to '1', write accesses will not be included in the trace buffer.

19.7.10 AHB trace buffer filter mask registeri

*Table 150.*0x00004C - ATBFM - AHB trace buffer filter mask register

31 16	15 0
SMASK[15:0]	MMASK[15:0]
0	0
rw	rw

31: 16 Slave Mask (SMASK) - If SMASK[n] is set to '1', the trace buffer will not save accesses performed to slave n.

15: 0 Master Mask (MMASK) - If MMASK[n] is set to '1', the trace buffer will not save accesses performed by master n.

19.7.11 AHB trace buffer breakpoint registers

The DSU contains two breakpoint registers for matching AHB addresses. A breakpoint hit is used to freeze the trace buffer by automatically clearing the enable bit. Freezing can be delayed by programming the DCNT field in the trace buffer control register to a non-zero value. In this case, the DCNT value will be decremented for each additional trace until it reaches zero, after which the trace buffer is frozen. A mask register is associated with each breakpoint, allowing breaking on a block of addresses. Only address bits with the corresponding mask bit set to '1' are compared during breakpoint detection. To break on AHB load or store accesses, the LD and/or ST bits should be set.

*Table 151.*0x000050, 0x000058 - ATBBA - AHB trace buffer break address register

31 2	1 0
BADDR[31:2]	R

*Table 151.*0x000050, 0x000058 - ATBBA - AHB trace buffer break address register

NR	0
rw	r

31: 2 Break point address (BADDR) - Bits 31:2 of breakpoint address

1: 0 Read as 0b00

*Table 152.*0x000054, 0x00005C - ATBBM - AHB trace buffer break mask register

31 2	1	0
BMASK[31:2]	LD	ST
NR	0	0
rw	rw	rw

31: 2 Breakpoint mask (BMASK) - (see text)

1 Load (LD) - Break on data load address

0 Store (ST) - Break on data store address

19.7.12 Instruction trace control register 0

The instruction trace control register 0 contains a pointer that indicates the next line of the instruction trace buffer to be written.

*Table 153.*0x110000 - ITBCO - Instruction trace control register 0

31 29	28 16	15 0
	RESERVED	ITPOINTER
	0	NR
	r	rw

31: 28 Trace filter configuration

27: 16 RESERVED

15: 0 Instruction trace pointer (ITPOINTER)

19.7.13 Instruction trace control register 1

The instruction trace control register 1 contains settings used for trace buffer overflow detection. This register can be written while the processor is running.

*Table 154.*0x110004 - ITBCI - Instruction trace control register 1

31 28	27	26 24	23	22 0
RESERVED	WO	TLIM	OV	RESERVED
0	0	0	0	0
r	rw	rw	rw	r

31: 28 RESERVED

27 Watchpoint on overflow (WO) - If this bit is set, and Break on iu watchpoint (BW) is enabled in the DSU control register, then a watchpoint will be inserted when a trace overflow is detected (TOV field in this register gets set).

26: 24 Trace Limit (TLIM) - TLIM is compared with the top bits of ITPOINTER in Instruction trace control register 0 to generate the value in the TOV field below.

23 Trace Overflow (TOV) - Gets set to ‘1’ when the DSU detects that TLIM equals the top three bits of ITPOINTER.

22: 0 RESERVED

20 On-chip Dual-port Memory with EDAC Protection

The LEON3FT microcontroller have 2 separate Local on-chip SRAM with EDAC (LRAM) units.

Each Local on-chip SRAM with EDAC (LRAM) have a unique control register interface a unique memory address range. AMBA address are described in chapter 2.11.

The Local on-chip SRAM with EDAC (LRAM) control and status register are located on APB bus in the address range from 0x80001000 to 0x80001FFF and from 0x8000B000 to 0x8000BFFF. See Local on-chip SRAM with EDAC (LRAM) units connections in the next drawing.

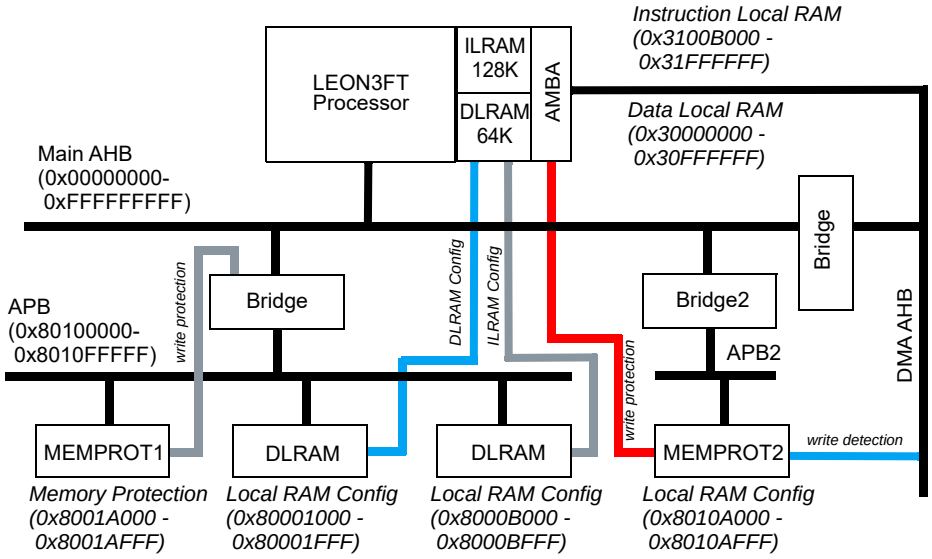


Figure 25. GR716 LRAM bus connection

System can be configured to protect and restrict access to the Local on-chip SRAM with EDAC (LRAM) units configuration and memory area in the **MEMPROT** units. For more information See section 47 for more information.

20.1 Overview

The LEON3FT microcontroller includes a 128KiB Dual port SRAM with EDAC for local instruction (ILRAM) execution and 64KiB Dual port SRAM with EDAC for local data storage (DLRAM). This chapter describes the functionality of the instruction and data memory in the LEON3FT microcontroller.

The local instruction and data memory provides the functionality to access the memory directly from the processor and from the DMA AMBA bus. Accesses from the processor have always precedence over accesses made via the DMA AMBA interface. The processor interface and priority scheme guarantees single cycle instruction and data execution in the LEON3FT processor.

The instruction and data memory implements a control interface accessible via the AMBA APB interface. See section 20.2 and 2.11 for register description and base addresses.The instruction and data on-chip memory implements volatile memory that is protected by means of Error Detection And Correction (EDAC). One error can be corrected and two errors can be detected, which is performed by using a (39, 32, 7) BCH code. Some of the optional features available are single error counter, diagnostic reads and writes, scrubbing, automatic correction of single errors during reads. All features are configurable via a configuration register, support for the AMBA protection unit.

Memory areas can be defined and protected from erroneous write accesses. To protect memory segments in the instruction or data memory, protection should be enabled and defined in the AMBA pro-

tection unit, see chapter 47. A write to a protected area without write permission to will result in a AMBA error and the write request to the memory will be ignored.

Figure 26 shows a block diagram of the internals of the controller.

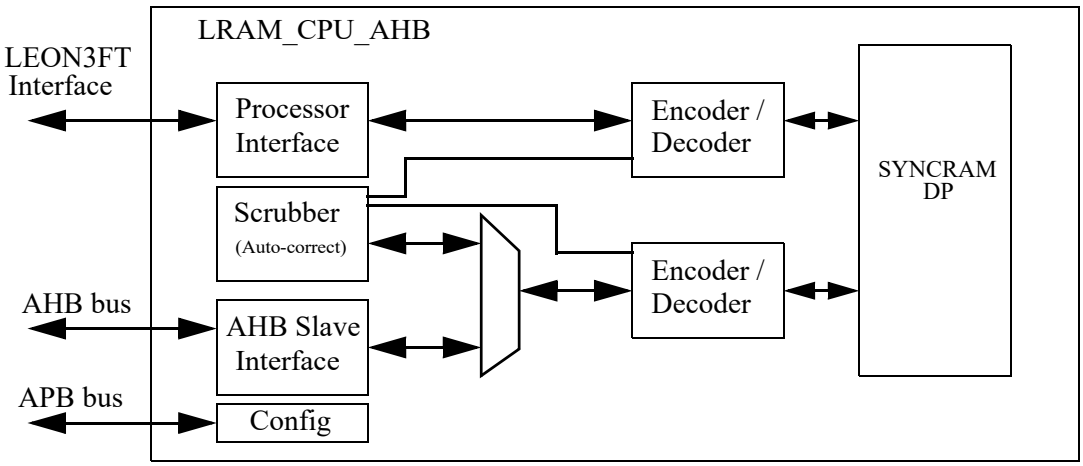


Figure 26. Block diagram

Operation

The EDAC checksum is always updated for write operations, but only checked during reads when enabled by the LRAMCFG.EN configuration field. When correctable error is detected a counter LRAMCFG.ECNT is incremented and can be used to monitor the error rate.

When a uncorrectable error is detected the read operation will complete with an error response.

20.1.1 AHB interface

For single read or the first beat in a read burst the access is performed with 2 wait-states. For the continuing read burst no wait-states are added to the access. Sub-word writes has the same bus timing as single read and the access is performed with 2 wait-states. Sub-word writes are performed as an read-modify-write operation by the memory controller to be able to correctly update the checksum. For word write no wait-states are added. The access on the AHB port could be stalled due to scrub operations or when a write conflict is detected between the AHB port and the CPU port. When the CPU port performs a read to a specific address, a write on the AHB port to the same address is stalled until the CPU read has completed. This feature is enabled by the LRAMCFG.PC configuration field.

Correctable errors are automatically corrected and not visible on the AHB bus (the auto-correction feature can be disabled by the LRAMCFG.ACOR configuration field). When an uncorrectable error is detected the access will terminate with an AMBA ERROR response.

When a write-protected area (defined by the AMBA protection unit) is written the access will be terminated with a AMBA ERROR response.

20.1.2 Processor interface

The CPU port is designed to allow word reads and writes with no stalling. Sub-word writes is assumed to be performed as a read-modify-write by the CPU. This port is not affected by the scrubbing operations.

The atomic operations OR, AND, XOR, Set&Clear is mapped at an offset described in the Atomic operation section and is only supported for the data memory.

Correctable errors are automatically corrected and not visible for the CPU (the auto-correction feature can be disabled by the LRAMCFG.ACOR configuration field). When an uncorrectable error is detected the access will terminate with a data_access/store_exception.

20.1.3 Atomic operation

The atomic operations (OR, AND, XOR, Set&Clear) are performed by adding an offset or the address. The offset is equal to the size of the memory. For the operations: OR, AND, XOR the size of the area is the same as the memory size. Accessing offset 0x10 and OR_OFFSET+0x10 would affect the same word in memory. The operation is performed by applying or, and, xor with the write data and the value of the memory location. For the Set&Clear operations the area is two times the memory size because each memory location is mapped to two consecutive addresses. Accessing Set&Clear_OFFSET 0x0 and 0x4 would affect memory offset 0x0 (Set&Clear_OFFSET 0x8 and 0xc would affect memory offset 0x4). To perform the Set&Clear operation a store-double should be performed to this area. The store operation should write the Set pattern followed by the Clear pattern.

20.1.4 Scrubber

The scrubber is designed to loop through all memory locations and check for errors. The scrubbing is performed as a dummy read access which in case of a detected correctable error will trigger the auto-correction feature (which would perform a read-modify-write to update the data and checksum). When a uncorrectable error is detected, the scrubber will not alter the memory location. Instead an interrupt can be generated (by setting the LRAMCFG.IE field to '1'). The scrubber can also be configured to be disabled once a uncorrectable error is detected (by setting the SCRUBCFG.DISE field to '1'). In this case the offset of the failing memory location can be read out from the SCRUBCTRL.ADDR field (this field would in this case point to the memory location directly after the failing location). The scrubbing rate can be configured with the SCRUBCFG.DELAY field. The value of this field sets the number of clock cycles between each scrubbing access.

Wash

The scrubber can be configured to wash the memory (writing to all memory location) and generate valid checksums. This is done by setting then SCRUBCFG.WASH field to '1'. To trig the wash function the address, pending, and enable fields need to be set in the scrub control register. The address field should be set to zero to wash the entire memory. When the wash function completes, the scrubber will be automatically enabled to check the memory for errors. To disable the scrubber after the wash has completed, the SCRUBCFG.DISW field needs to be set to '1'.

Diagnostic read/write

To perform diagnostic accesses the scrubber is configured to read or write checksum directly using the SCRUBCFG.CB field.

To read out the checksum of a memory location the SCRUBCFG.RCB field needs to be configured to '1'. To perform the read out access, the address and pending bit need to be set in the scrub control register (SCRUBCTRL.ADDR and SCRUBCTRL.PEN). When the access has completed (SCRUBCTRL.PEN = '0') the checksum can be read from the SCRUBCFG.CB field and the corresponding data can be read for the scrub data register.

To write the checksum of a memory location the SCRUBCFG.WCB field needs to be configured to '1' and the SCRUBCFG.CB needs to be set to the checksum. To perform the write access, the address and pending bit need to be set in the scrub control register (SCRUBCTRL.ADDR and SCRUBCTRL.PEN). This would trigger a read-modify-write access to the memory location but instead of using the calculated checksum the value of SCRUBCFG.CB field is used instead.

Error injection

To inject error on a memory location the scrubber is configured to xor the checksum with the SCRUBCFG.CB field. This is done by setting the SCRUBCFG.XCB field to '1' and configure the xor pattern in the SCRUBCFG.CB field. To perform the error injection, the address and pending bit need to be set in the scrub control register (SCRUBCTRL.ADDR and SCRUBCTRL.PEN). This would trigger a read-modify-write access to the memory location and xor:ed checksum is written to memory.

20.2 Local Memory memory map and register

The local memory control registers is programmed via registers mapped into APB address space and the memory area is accessible via processor local interface or via AHB address space.

*Table 155.*Local Data and Instruction memory map and configuration registers

Address offset and range	Register
0x30000000 - 0x3000FFFF 1) 2)	Local Data memory area
0x30001000 - 0x3001FFFF 1) 2)	Local Data memory atomic OR access area
0x30002000 - 0x3002FFFF 1) 2)	Local Data memory atomic AND access area
0x30003000 - 0x3003FFFF 1) 2)	Local Data memory atomic XOR access area
0x30004000 - 0x3004FFFF 1) 2)	Local Data memory atomic Set&Clear access area
0x31000000 - 0x3101FFFF 3) 4)	Local Data memory instruction area
0x80001000	Data memory configuration Register (AHBRAM0.LRAMCFG)
0x80001004	Data memory Scrubber data (AHBRAM0.SCRUBDATA)
0x80001008	Data memory Scrubber control (AHBRAM0.SCRUBCTRL)
0x8000100C	Data memory Scrubber configuration (AHBRAM0.SCRUBCFG)
0x8000B000	Instruction memory configuration Register (AHBRAM1.LRAMCFG)
0x8000B004	Instruction memory Scrubber data AHBRAM1.SCRUBDATA)
0x8000B008	Instruction memory Scrubber control (AHBRAM1.SCRUBCTRL)
0x8000B00C	Instruction memory Scrubber configuration (AHBRAM1.SCRUBCFG)

1) LEON3FT processor access address range for data fetch or store via local processor interface. Access is always single cycle access

2) LEON3FT processor access address range for Instruction fetch via system and DMA bus interface.

3) LEON3FT processor access address range for instruction and data fetch via local processor interface. Access is always single cycle access and data store is restricted.

20.2.1 Local Data RAM registers

The core is programmed via registers mapped into APB address space

Table 156. 0x80001000 - AHBRAM0.LRAMCFG - Configuration Register

31	30 29	28	27 24	23 16	15 14	13	12	11 10	9 8	7 4	3 1	0
FT	AOP	SC	RES	MEMSIZE	RES	PC	IE	ACOR	SERR	ECNT	RES	EN
1	3	1	0	6	0	0	0	0	0	0	0	0
r	r	r	r	r	r	rw	rw	rw	wc	wc	r	rw

31 FT - EDAC support implemented.

30: 29 AOP - Atomic operation implemented for local data RAM.

28 SC - Scrubber implemented.

27: 24 Reserved.

23: 16 MEMSIZE - Memory size is 96 Kbytes. (2^6 Kbytes)

15: 14 Reserved.

13 PC - Port write conflict detection. When enabled, a write on the AHB port to the same address as the access on the CPU port is stalled.

12 IE - Interrupt enable. Enable the assertion of an interrupt when the scrubber detects a un-correctable error.

11: 10 ACOR - Auto-correction disable. Disable auto-correction for detected errors. Bit[11]: AHB port, bit[10]: CPU port.

Table 156. 0x80001000 - AHBRAM0.LRAMCFG - Configuration Register

9:	8	SERR - Scrub error status. Bit[9] indicates a correctable error is detected by the scrubber. Bit[8] indicates a uncorrectable error is detected by the scrubber. Write '1' to clear.
7:	4	ECNT - Correctable error counter. Write '1' to clear.
3:	1	Reserved.
	0	EN - EDAC enable.

Table 157. 0x80001004 - AHBRAM0.SCRUBDATA - Scrubber Data Register

31	0
DATA	
n/r	
rw	

31: 0 DATA - Data used by the scrubber in wash mode.

Table 158. 0x80001008 - AHBRAM0.SCRUBCTRL - Scrubber Control Register

31	2	1	0
ADDR		PEN	SEN
0		0	0
rw		rw	rw

31: 2 ADDR - Scrubber address offset.
1 PEN - Scrub access pending.
0 SEN - Scrubber enable.

Table 159. 0x8000100C - AHBRAM0.SCRUBCFG - Scrubber Configuration Register

31	16	15	14	13	12	11	10	4	3	2	1	0
DELAY		RES		DISW	DISE	RES	CB		WCB	RCB	XCB	WASH
0		0		0	0	0	0		0	0	0	0
rw		r		rw	rw	rw	rw		rw	rw	rw	rw

31: 16 DELAY - Scrubber delay. Delay in clock cycles between each scrub access.
15: 14 Reserved.
13 DISW - Disable the scrubber after the wash operation is complete.
12 DISE - Disable the scrubber when a uncorrectable error is detected.
11 Reserved.
10: 4 CB - Checksum.
3 WCB - Write checksum.
2 RCB - Read checksum.
1 XCB - XOR checksum with the value of field CB.
0 WASH - Enable wash mode.

20.2.2 Local Instruction RAM registers

The core is programmed via registers mapped into APB address space

Table 160. 0x8000B000 - AHBRAM1.LRAMCFG - Configuration Register

31	30 29	28	27 24	23 16	15 14	13	12	11 10	9 8	7 4	3 1	0
FT	AOP	SC	RES	MEMSIZE	RES	PC	IE	ACOR	SERR	ECNT	RES	EN
1	0	1	0	6	0	0	0	0	0	0	0	0
r	r	r	r	r	r	rw	rw	rw	wc	wc	r	rw

31 FT - EDAC support implemented.

30: 29 AOP - No Atomic operation implemented for local instruction RAM.

28 SC - Scrubber implemented.

27: 24 Reserved.

23: 16 MEMSIZE - Memory size is 128 Kbytes. (2^7 Kbytes)

15: 14 Reserved.

13 PC - Port write conflict detection. When enabled, a write on the AHB port to the same address as the access on the CPU port is stalled.

12 IE - Interrupt enable. Enable the assertion of an interrupt when the scrubber detects a un-correctable error.

11: 10 ACOR - Auto-correction disable. Disable auto-correction for detected errors. Bit[11]: AHB port, bit[10]: CPU port.

9: 8 SERR - Scrub error status. Bit[9] indicates a correctable error is detected by the scrubber. Bit[8] indicates a uncorrectable error is detected by the scrubber. Write '1' to clear.

7: 4 ECNT - Correctable error counter. Write '1' to clear.

3: 1 Reserved.

0 EN - EDAC enable.

Table 161. 0x8000B004 - AHBRAM1.SCRUBDATA - Scrubber Data Register

31 0
DATA
n/r
rw

31: 0 DATA - Data used by the scrubber in wash mode.

Table 162. 0x8000B008 - AHBRAM1.SCRUBCTRL - Scrubber Control Register

31 2	1	0
ADDR	PEN	SEN
0	0	0
rw	rw	rw

31: 2 ADDR - Scrubber address offset.

1 PEN - Scrub access pending.

0 SEN - Scrubber enable.

Table 163. 0x8000B00C - AHBRAM1.SCRUBCFG - Scrubber Configuration Register

31 16	15 14	13	12	11	10 4	3	2	1	0
DELAY	RES	DISW	DISE	RES	CB	WCB	RCB	XCB	WASH
0	0	0	0	0	0	0	0	0	0
rw	r	rw	rw	rw	rw	rw	rw	rw	rw

31: 16 DELAY - Scrubber delay. Delay in clock cycles between each scrub access.

15: 14 Reserved.

13 DISW - Disable the scrubber after the wash operation is complete.

12 DISE - Disable the scrubber when a uncorrectable error is detected.

11 Reserved.

10: 4 CB - Checksum.

3 WCB - Write checksum.

2 RCB - Read checksum.

1 XCB - XOR checksum with the value of field CB.

0 WASH - Enable wash mode.

21 Fault Tolerant PROM/SRAM Memory Interface

21.1 Overview

The fault tolerant 8-bit memory controller (FTMCTRL) provides a bridge between external memory and the AHB bus. The memory controller can handle two types of devices: PROM, asynchronous static ram (SRAM) The PROM and SRAM areas can be EDAC-protected using a (39,7) BCH code. The BCH code provides single-error correction and double-error detection for each 32-bit memory word.

The memory controller is configured through three configuration registers accessible via an APB bus interface. The PROM and SRAM external data bus is configured in 8-bit mode, for the application requirements.

External chip-selects are provided for up to two PROM bank and four SRAM banks. External PROM are mapped in the address range from 0x01000000 to 0x01FFFFFF and external SRAM in the address range 0x40000000 to 0x4FFFFFFF.

The fault tolerant 8-bit memory controller configuration registers are located on APB bus in the address range from 0x80000000 to 0x80000FFF. See fault tolerant 8-bit memory controller unit connections in the next drawing. The drawing picture memory locations and functions used for fault tolerant 8-bit memory controller configuration and control.

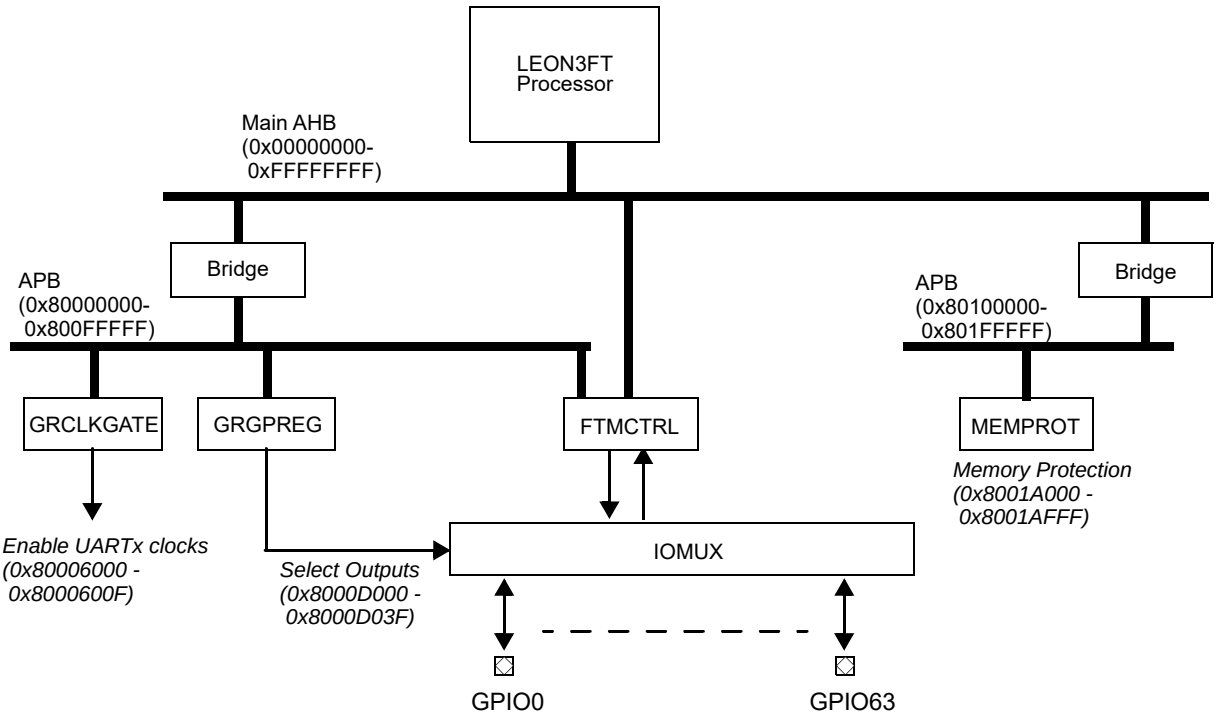


Figure 27. GR716 FTMCTRL bus and pin

The primary clock gating unit **GRCLKGATE** described in section 26 is used to enable/disable the fault tolerant 8-bit memory controller (FTMCTRL). The unit **GRCLKGATE** can also be used to perform reset of the fault tolerant 8-bit memory controller (FTMCTRL). Software must enable clock and release reset described in section 26 before memory configuration and operations can start.

External IO selection is made in the system IO configuration register (**GRGPREG**) in the address range from 0x8000D000 to 0x8000D03F. See section 7.1 for further information.

The system can be configured to protect and restrict access to the fault tolerant 8-bit memory controller (FTMCTRL) units in the **MEMPROT** unit. See section 47 for more information.

21.2 PROM access

Two external PROM chip-select signals are provided for the PROM area. The size of the banks can be set in binary steps from 16KiB to 256MiB. If the AHB memory area assigned to the memory controller for PROM accesses is larger than the combined size of the memory banks then the PROM memory area will wrap.

A read access to PROM consists of two data cycles and between 0 and 30 waitstates. The read data (and optional EDAC check-bits) are latched on the rising edge of the clock on the last data cycle. On non-consecutive accesses, a idle cycle is placed between the read cycles to prevent bus contention due to slow turn-off time of PROM devices. Figure 28 shows the basic read cycle waveform (zero waitstate) for non-consecutive PROM reads. Note that the address is undefined in the idle cycle. Figure 29 shows the timing for consecutive cycles (zero waitstate). Waitstates are added by extending the data2 phase. This is shown in figure 30 and applies to both consecutive and non-consecutive cycles. Only an even number of waitstates can be assigned to the PROM area.

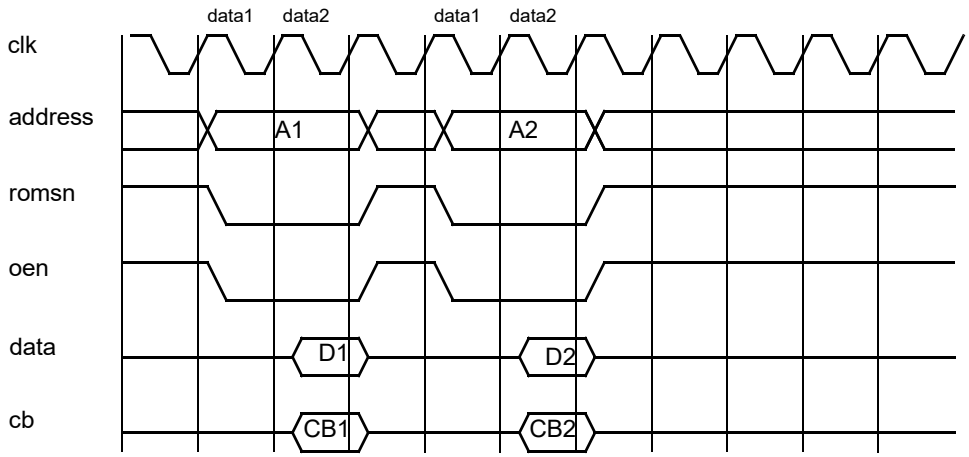


Figure 28. Prom non-consecutive read cycles.

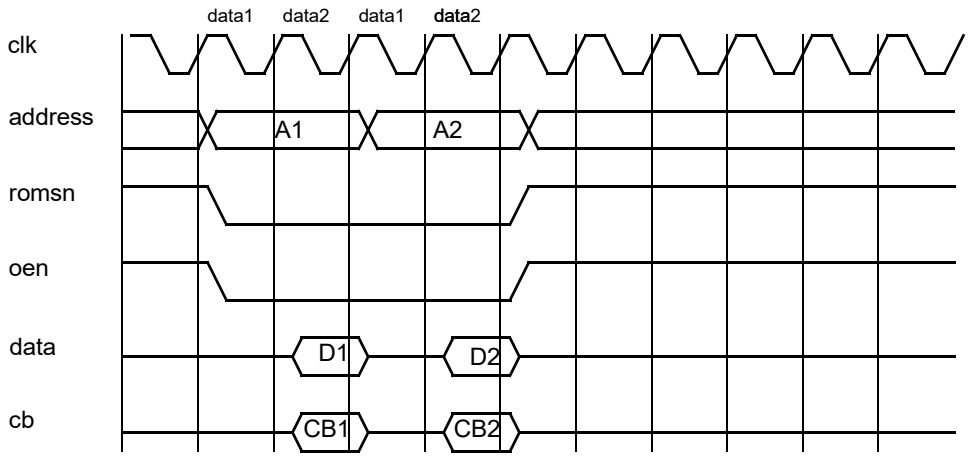


Figure 29. Prom consecutive read cycles.

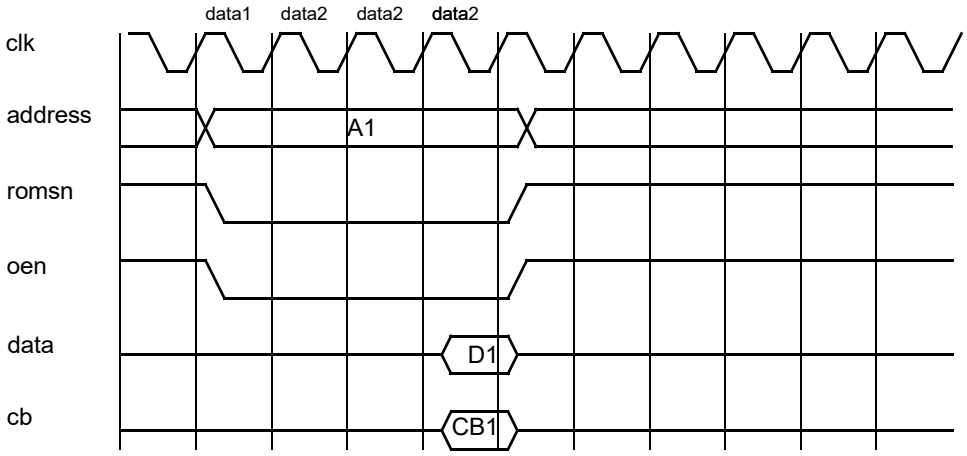


Figure 30. Prom read access with two waitstates.

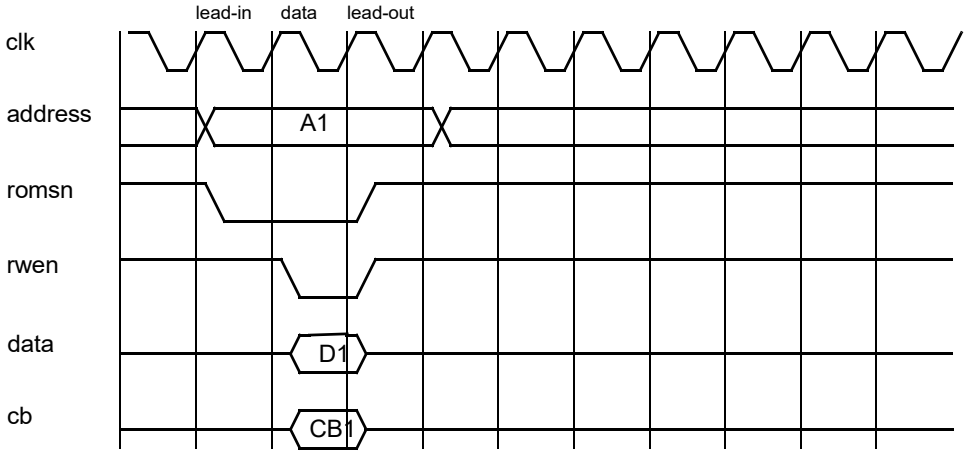


Figure 31. Prom write cycle (0-waitstates)

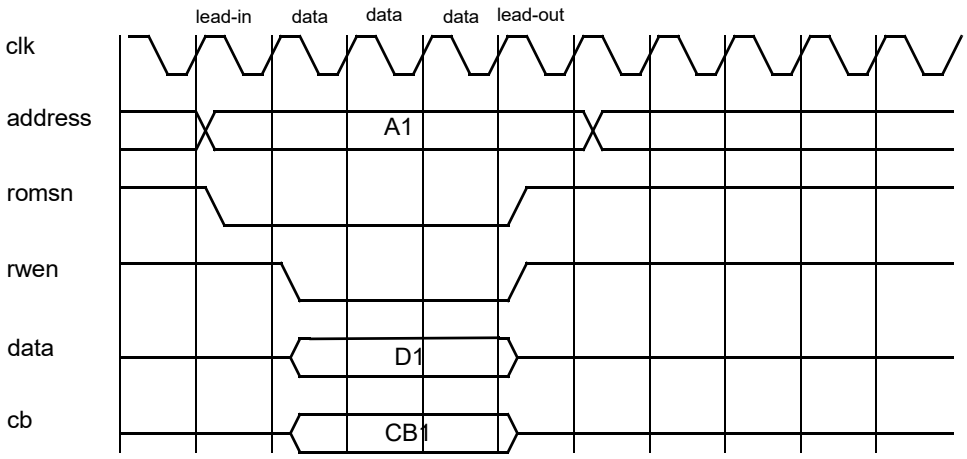


Figure 32. Prom write cycle (2-waitstates)

21.3 SRAM access

The SRAM area is divided on up to four RAM banks. The size of banks is programmed in the RAM bank-size field (MCFG2[12:9]) and can be set in binary steps from 8KiB to 256MiB. A read access to SRAM consists of two data cycles and between zero and three waitstates. The read data (and optional EDAC check-bits) are latched on the rising edge of the clock on the last data cycle. Accesses to RAM bank four can further be stretched by de-asserting BRDYN until the data is available. On non-consecutive accesses, a idle cycle is added after a read cycle to prevent bus contention due to slow turn-off time of memories. Figure 33 shows the basic read cycle waveform (zero waitstate). Waitstates are added in the same way as for PROM in figure 30.

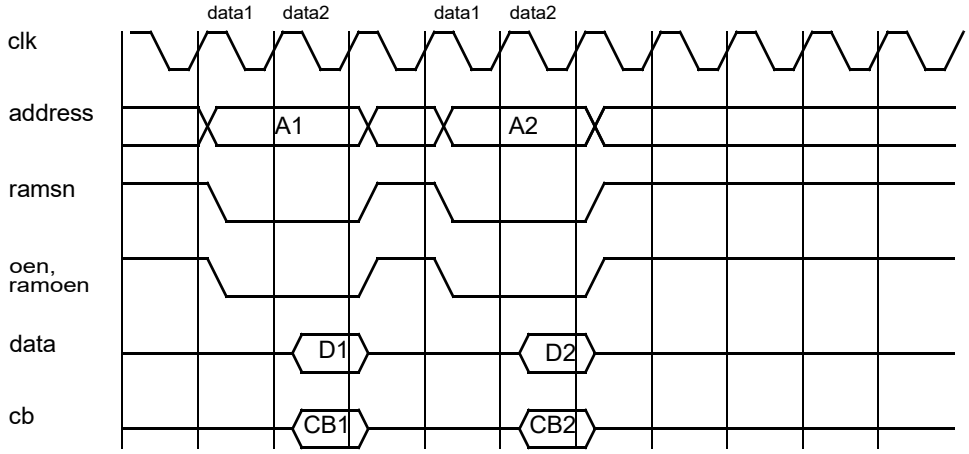


Figure 33. SRAM non-consecutive read cycles.

The SRAM and PROM areas is configured for 8-bit operations. Since reads to memory are always done on 32-bit word basis, read access to 8-bit memory will be transformed in a burst of four read cycles. During writes, only the necessary bytes will be written.

All possible combinations of width, EDAC, and RMW are not supported. The supported combinations are given in table 164, and the behavior of setting an unsupported combination is undefined.

*Table 164.*FTMCTRL supported SRAM and PROM configurations

PROM/SRAM bus width	RWEN resolution (SRAM)	EDAC	RMW bit (SRAM)	Core configuration
8	Bus width	None	0	8-bit support
8	Bus width	BCH	1	8-bit support, EDAC

21.4 Memory EDAC

21.4.1 BCH EDAC

The FTMCTRL is provided with an BCH EDAC that can correct one error and detect two errors in a 32-bit word. For each word, a 7-bit checksum is generated according to the equations below. A correctable error will be handled transparently by the memory controller, but adding one waitstate to the access. If an un-correctable error (double-error) is detected, the current AHB cycle will end with an error response. The EDAC can be used during access to PROM and SRAM areas by setting the corresponding EDAC enable bits in the MCFG3 register. The equations below show how the EDAC check-bits are generated:

```
CB0 = D0 ^ D4 ^ D6 ^ D7 ^ D8 ^ D9 ^ D11 ^ D14 ^ D17 ^ D18 ^ D19 ^ D21 ^ D26 ^ D28 ^ D29 ^ D31
```

```
CB1 = D0 ^ D1 ^ D2 ^ D4 ^ D6 ^ D8 ^ D10 ^ D12 ^ D16 ^ D17 ^ D18 ^ D20 ^ D22 ^ D24 ^ D26 ^ D28
CB2 = D0 ^ D3 ^ D4 ^ D7 ^ D9 ^ D10 ^ D13 ^ D15 ^ D16 ^ D19 ^ D20 ^ D23 ^ D25 ^ D26 ^ D29 ^ D31
CB3 = D0 ^ D1 ^ D5 ^ D6 ^ D7 ^ D11 ^ D12 ^ D13 ^ D16 ^ D17 ^ D21 ^ D22 ^ D23 ^ D27 ^ D28 ^ D29
CB4 = D2 ^ D3 ^ D4 ^ D5 ^ D6 ^ D7 ^ D14 ^ D15 ^ D18 ^ D19 ^ D20 ^ D21 ^ D22 ^ D23 ^ D30 ^ D31
CB5 = D8 ^ D9 ^ D10 ^ D11 ^ D12 ^ D13 ^ D14 ^ D15 ^ D24 ^ D25 ^ D26 ^ D27 ^ D28 ^ D29 ^ D30 ^ D31
CB6 = D0 ^ D1 ^ D2 ^ D3 ^ D4 ^ D5 ^ D6 ^ D7 ^ D24 ^ D25 ^ D26 ^ D27 ^ D28 ^ D29 ^ D30 ^ D31
```

Data is always accessed as words (4 bytes at a time) and the corresponding checkbits are located at the address acquired by inverting the word address (bits 2 to 27) and using it as a byte address. The same chip-select is kept active. A word written as four bytes to addresses 0, 1, 2, 3 will have its checkbits at address 0xFFFFFFF, addresses 4, 5, 6, 7 at 0xFFFFFFE and so on. All the bits up to the maximum bank size will be inverted while the same chip-select is always asserted. This way all the bank sizes can be supported and no memory will be unused (except for a maximum of 4 byte in the gap between the data and checkbit area). A read access will automatically read the four data bytes individually from the nominal addresses and the EDAC checkbit byte from the top part of the bank. A write cycle is performed the same way. Byte or half-word write accesses will result in an automatic read-modify-write access where 4 data bytes and the checkbit byte are firstly read, and then 4 data bytes and the newly calculated checkbit byte are writen back to the memory.

For the ROM the EDAC protection is provided in a similar way as for the SRAM memory described above. The difference is that write accesses are not being handled automatically. Instead, write accesses must only be performed as individual byte accesses by the software, writing one byte at a time, and the corresponding checkbit byte must be calculated and be written to the correct location by the software.

The operation of the EDAC can be tested trough the MCFG3 register. If the WB (write bypass) bit is set, the value in the TCB field will replace the normal checkbits during memory write cycles. If the RB (read bypass) is set, the memory checkbits of the loaded data will be stored in the TCB field during memory read cycles. NOTE: when the EDAC is enabled, the RMW bit in memory configuration register 2 must be set.

21.5 Bus Ready signalling

The BRDYN signal can be used to stretch all types of access cycles to the PROM and the SRAM area. This covers read and write accesses in general, and additionally read-modify-write accesses to the SRAM area. The accesses will always have at least the pre-programmed number of waitstates as defined in memory configuration registers 1 & 2, but will be further stretched until BRDYN is asserted. BRDYN should be asserted in the cycle preceding the last one. If bit 29 in MCFG1 is set, BRDYN can be asserted asynchronously with the system clock. In this case, the read data must be kept stable until the de-assertion of OEN/RAMOEN and BRDYN must be asserted for at least 1.5 clock cycle. It is recommended that BRDYN is asserted until the corresponding chip select signal is de-asserted, to ensure that the access has been properly completed and avoiding the system to stall.

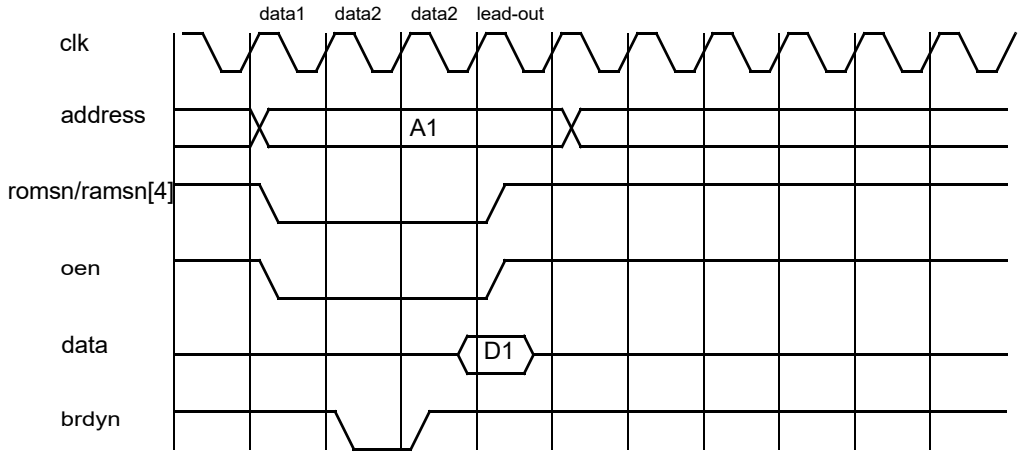


Figure 34. READ cycle with one extra data2 cycle added with BRDYN (synchronous sampling).

Figure 35 shows the use of BRDYN with asynchronous sampling. BRDYN is kept asserted for more than 1.5 clock-cycle. Two synchronization registers are used so it will take at least one additional cycle from when BRDYN is first asserted until it is visible internally. In figure 35 one cycle is added to the data2 phase.

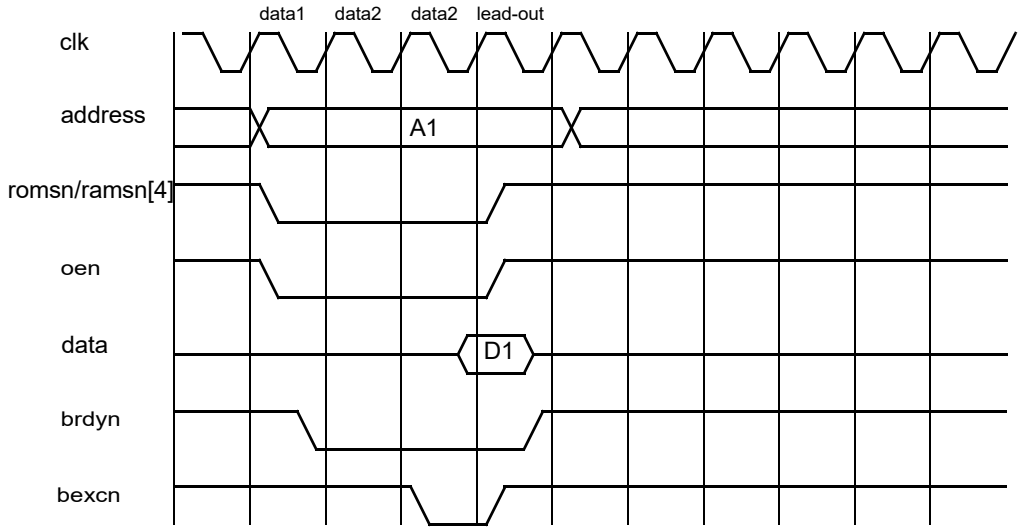


Figure 35. BRDYN (asynchronous) sampling and BEXCN timing.

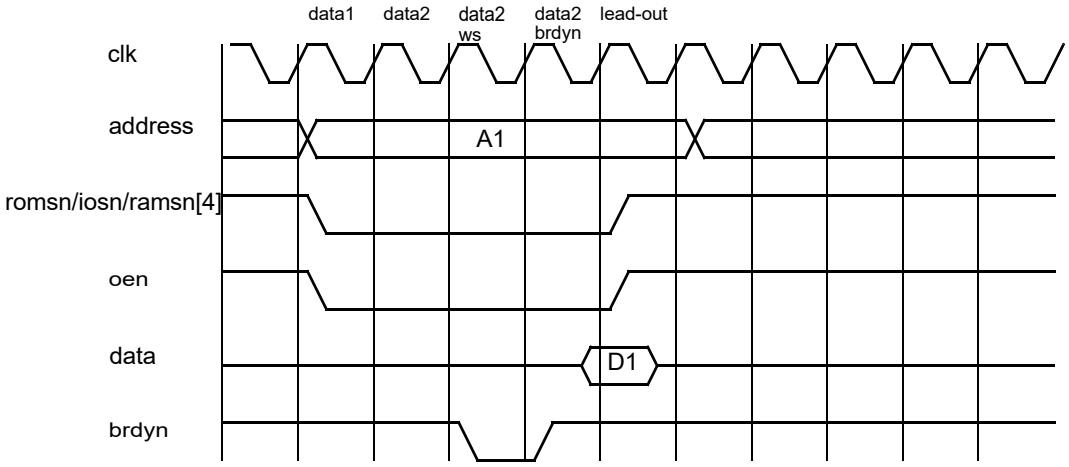


Figure 36. Read cycle with one waitstate (configured) and one BRDYN generated waitstate (synchronous sampling).

If burst accesses and BRDYN signalling are to be used together, special care needs to be taken to make sure BRDYN is raised between the separate accesses of the burst. The controller does not raise the select and OEN signal (in the read case) between accesses during the burst so if BRDYN is kept asserted until the select signal is raised, all remaining accesses in the burst will finish with the configured fixed number of wait states.

21.6 Access errors

An access error can be signalled by asserting the BEXCN signal for read and write accesses. For reads it is sampled together with the read data. For writes it is sampled on the last rising edge before chip select is de-asserted, which is controlled by means of waitstates or bus ready signalling. If the usage of BEXCN is enabled in memory configuration register 1, an error response will be generated on the internal AHB bus. BEXCN can be enabled or disabled through memory configuration register 1, and is active for all areas (PROM and RAM).

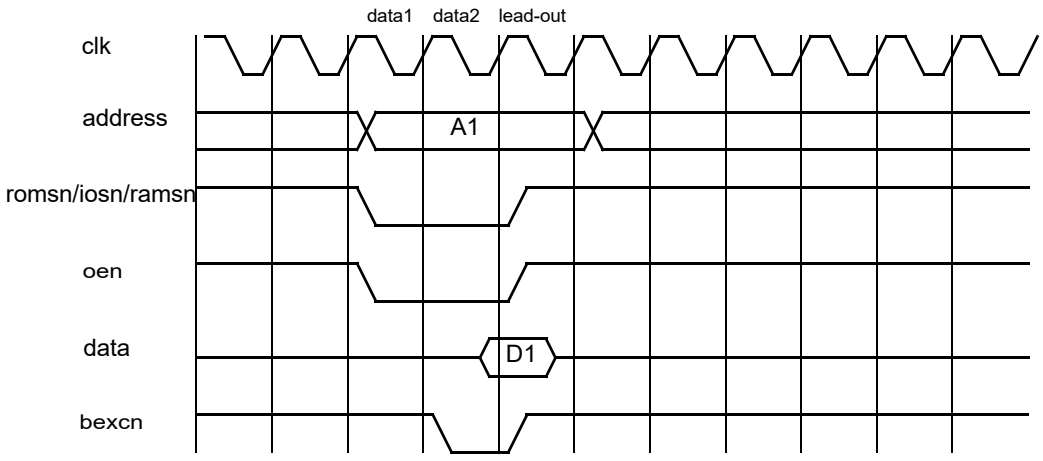


Figure 37. Read cycle with BEXCN.

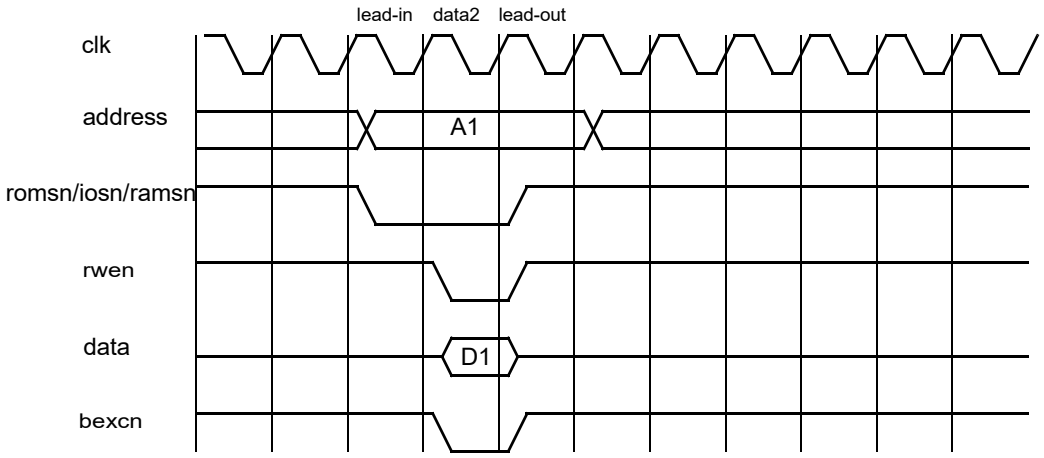


Figure 38. Write cycle with BEXCN. Chip-select (iosn) is not asserted in lead-in cycle for io-accesses.

21.7 Registers

The core is programmed through registers mapped into APB address space.

*Table 165.*FTMCTRL memory controller registers

APB Address offset	Register
0x0	Memory configuration register 1 (MCFG1)
0x4	Memory configuration register 2 (MCFG2)
0x8	Memory configuration register 3 (MCFG3)
0xC	Memory configuration register 4 (MCFG4)
0x10	Memory configuration register 5 (MCFG5)
0x14	Memory configuration register 6 (MCFG6)

21.7.1 Memory configuration register 1 (MCFG1)

Memory configuration register 1 is used to program the timing of rom and IO accesses.

*Table 166.*0x00 - MCFG1 - Memory configuration register 1

31	30	29	28	27	26	25	24	23 20	19	18	17
R	PBRDY	ABRDY	RESERVED		R	BEXCN	R	RESERVED	IOEN	R	ROMBANKSZ
0	0	0	NR		0	0	0	0XF	0	0	0x0
r	rw	rw	rw		rw	rw	r	rw	rw	rw	rw

14	13 12	11	10	9 8	7 4	3 0
ROMANKS7	RESERVED	PWEN	RES	PROM WIDTH	PROM WRITE WS	PROM READ WS
	0	0	0	0	0xF	0xF
rw	r	rw	r	rw	rw	rw

31	RESERVED
30	PROM area bus ready enable (PBRDY) - Enables bus ready (BRDYN) signalling for the PROM area. Reset to ‘0’.
29	Asynchronous bus ready (ABRDY) - Enables asynchronous bus ready.
28 : 27	RESERVED
26	RESERVED
25	Bus error enable (BEXCN) - Enables bus error signalling for all areas. Reset to ‘0’.
24	RESERVED
23 : 20	RESERVED

*Table 166.*0x00 - MCFG1 - Memory configuration register 1

19	I/O enable (IOEN) - Enables accesses to the memory bus I/O area. GR716 doesn't provide any I/O area, i.e. for GR716 this bit field shall always be set to '0'.
18	RESERVED
17: 14	PROM bank size (ROMBANKSZ) - Returns current PROM bank size when read. "0000" is a special case and corresponds to a bank size of 256MiB. All other values give the bank size in binary steps: "0001"=16KiB, "0010"=32KiB, "0011"=64KiB,... , "1111"=256MiB (i.e. 8KIB * 2 ^(ROMBANKSZ)). For value "0000" or "1111" only two chip selects are available. For other values, two chip select signals are available for fixed bank sizes. For other values, four chip select signals are available for programmable bank sizes. Programmable bank sizes can be changed by writing to this register field. The written values correspond to the bank sizes and number of chip-selects as above. Reset to "0000" when programmable.
13:12	RESERVED
11	PROM write enable (PWEN) - Enables write cycles to the PROM area.
10	RESERVED
9 : 8	PROM width (PROM WIDTH) - Sets the data width of the PROM area ("00"=8, "01"=16, "10"=32). For GR716 the data width is locked to 8 bits i.e. for GR716 this bit field shall always be set to "00".
7 : 4	PROM write waitstates (PROM WRITE WS) - Sets the number of wait states for PROM write cycles ("0000"=0, "0001"=2, "0010"=4,..., "1111"=30).
3 : 0	PROM read waitstates (PROM READ WS) - Sets the number of wait states for PROM read cycles ("0000"=0, "0001"=2, "0010"=4,...,"1111"=30). Reset to "1111".

21.7.2 Memory configuration register 2 (MCFG2)

Memory configuration register 2 is used to control the timing of the SRAM.

*Table 167.*0x04 - MLFG2 - Memory configuration register 2

31													16
RESERVED													
15	14	13	12	9	8	7	6	5	4	3	2	1	0
R	R	SI	RAM BANK SIZE		R	RBRDY	RMW	RAM WIDTH		RAM WRITE WS		RAM READ WS	
0	0	0	0x3			0	0	0		3		3	
r	r	rw	rw			rw	rw	rw		rw		rw	

31 : 14	RESERVED
13	SRAM disable (SI) - Disables accesses to SRAM bank if bit 14 (SE) is set to '1'.
12 : 9	RAM bank size (RAM BANK SIZE) - Sets the size of each RAM bank ("0000"=8KiB, "0001"=16KiB, "0010"=32KiB, "0011"= 64KiB,.., "1111"=256MiB)(i.e. (i.e. 8KIB * 2 ^(RAMBANKSZ)).
8	RESERVED
7	RAM bus ready enable (RBRDY) - Enables bus ready signalling for the RAM area.
6	Read-modify-write enable (RMW) - Enables read-modify-write cycles for sub-word writes to 16- bit 32-bit areas with common write strobe (no byte write strobe). Set at reset from external pin.
5 : 4	RAM width (RAM WIDTH) - Sets the data width of the RAM area ("00"=8, "01"=16, "1X"=32). For GR716 the data width is locked to 8 bits i.e. for GR716 this bit field shall always be set to "00".
3 : 2	RAM write waitstates (RAM WRITE WS) - Sets the number of wait states for RAM write cycles ("00"=0, "01"=1, "10"=2, "11"=3).
1 : 0	RAM read waitstates (RAM READ WS) - Sets the number of wait states for RAM read cycles ("00"=0, "01"=1, "10"=2, "11"=3).

21.7.3 Memory configuration register 3 (MCFG3)

MCFG3 contains the control and monitor the memory EDAC.

*Table 168.*0x08 - MCFG3 - Memory configuration register 3

31 28	27	26
RESERVED	ME	RESERVED
0	1	
r	r	

12	11	10	9	8	7 0
RESERVED	WB	RB	RE	PE	TCB
	0	0	*	*	NR
	rw	rw	rw	rw	rw

31 : 28 RESERVED

27 Memory EDAC (ME) - Indicates if memory EDAC is present. (read-only)

26 : 12 RESERVED

11 EDAC diagnostic write bypass (WB) - Enables EDAC write bypass.

10 EDAC diagnostic read bypass (RB) - Enables EDAC read bypass.

9 RAM EDAC enable (RE) - Enable EDAC checking of the RAM area. Set at reset from external pin

8 PROM EDAC enable (PE) - Enable EDAC checking of the PROM area. Set at reset from external pin

7 : 0 Test checkbits (TCB) - This field replaces the normal checkbits during write cycles when WB is set. It is also loaded with the memory checkbits during read cycles when RB is set.

21.7.4 Memory configuration register 4 (MCFG4)

*Table 169.*0x0C - MCFG4 - Memory configuration register 4

31 16
RESERVED

15 0
RESERVED

31 : 16 RESERVED

15 : 0 RESERVED

21.7.5 Memory configuration register 5 (MCFG5)

MCFG5 contains fields to control lead out cycles for the ROM areas.

*Table 170.*0x10 - MCFG5 - Memory configuration register 5

31 30	29 23	22 16
RESERVED	RESERVED	RESERVED

15 14	13 7	6 0
RESERVED	ROMHWS	RESERVED
	0x00	
	rw	

31 : 30 RESERVED

29:23 RESERVED

*Table 170.*0x10 - MCFG5 - Memory configuration register 5

22 : 14	RESERVED
13:7	ROM lead out (ROMHWS) - Lead out cycles added to ROM accesses are ROMHWS(3:0)*$2^{ROMHWS(6:4)}$
6 : 0	RESERVED

21.7.6 Memory configuration register 6 (MCFG6)

MCFG6 contains fields to control lead out cycles for the (S)RAM area.

*Table 171.*0x14 - MCFG6 - Memory configuration register 6

31	16
RESERVED	
0	
r	

15	14	13	7	6	0
RESERVED		RAMHWS		RESERVED	
r		0x00		r	
0		rw		0	

31 : 14	RESERVED
13:7	RAM lead out (RAMHWS) - Lead out cycles added to RAM accesses are RAMHWS(3:0)*$2^{RAMHWS(6:4)}$
6 : 0	RESERVED

22 Fault Tolerant NVRAM Memory Interface

This section is reserved to describe the NVRAM controller available to access in-package embedded memory. The LEON3FT microcontroller support up to four chip selects using this type of memory. The memory controller interface is not available on external pins on currently available GR716 models and the documentation for the memory controller is not included in this document. For more information please contact Cobham Gaisler.

23 MIL-STD-1553B / AS15531 Interface

The GR716 microcontroller comprises a MIL-STD-1553B / AS15531 Interface (GR1553B) unit. The MIL-STD-1553B / AS15531 Interface (GR1553B) unit controls its own external pins and has a unique AMBA address described in chapter 2.11.

The MIL-STD-1553B / AS15531 Interface (GR1553B) unit is located on APB bus in the address range from 0x80101000 to 0x80101FFF. See GR1553B unit connections in the next drawing. The drawing picture memory locations and functions used for GR1553B configuration and control.

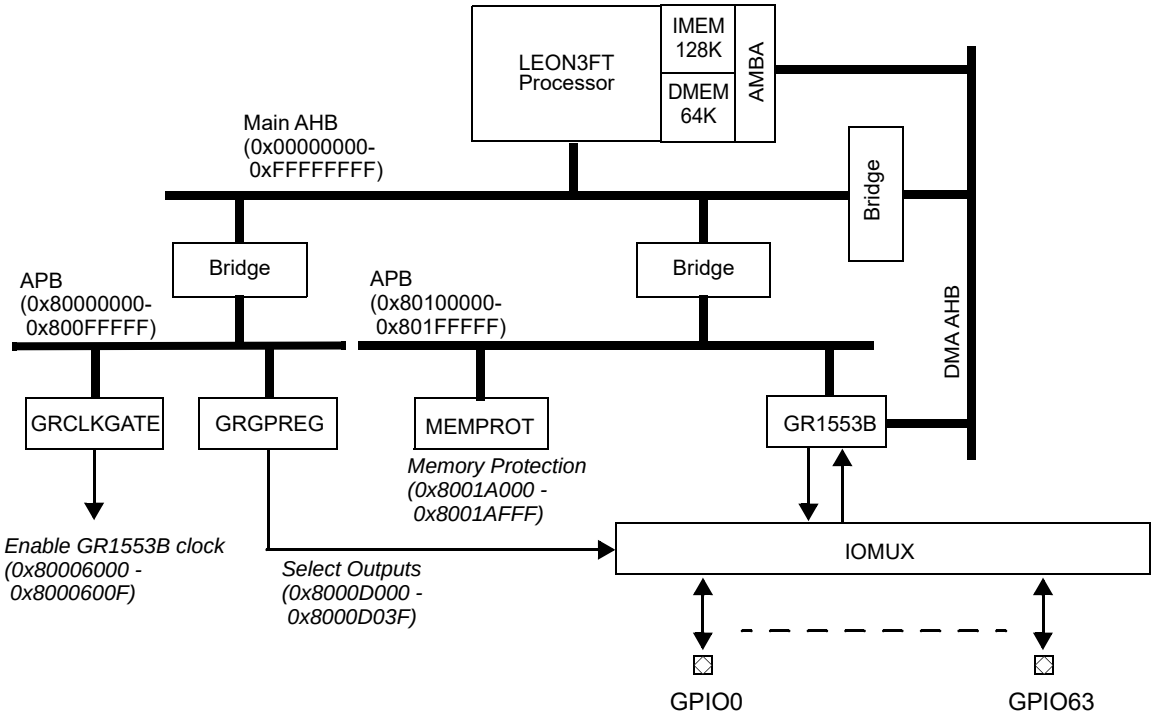


Figure 39. GR716 GR1553B bus and pin connection

The primary clock gating unit **GRCLKGATE** described in section 26 is used to enable/disable the GR1553B unit. The unit **GRCLKGATE** can also be used to perform reset of the GR1553B unit. Software must enable clock and release reset described in section 26 before GR1553B configuration and transmission can start.

External IO selection per GR1553B unit is made in the system IO configuration register (**GRGPREG**) in the address range from 0x8000D000 to 0x8000D03F. See section 7.1 for further information.

The **GR1553B** unit controls its own external pins and has a unique AMBA address described in chapter 2.11. Configuration and status registers are described in section 23.7.

The system can be configured to protect and restrict access to GR1553B in the **MEMPROT** unit. See section 47 for more information.

23.1 Overview

This interface core connects the AMBA AHB/APB bus to a single- or dual redundant MIL-STD-1553B bus, and can act as either Bus Controller, Remote Terminal or Bus Monitor.

MIL-STD-1553B (and derived standard SAE AS15531) is a bus standard for transferring data between up to 32 devices over a shared (typically dual-redundant) differential wire. The bus is designed for predictable real-time behavior and fault-tolerance. The raw bus data rate is fixed at 1 Mbit/s, giving a maximum of around 770 kbit/s payload data rate.

One of the terminals on the bus is the Bus Controller (BC), which controls all traffic on the bus. The other terminals are Remote Terminals (RTs), which act on commands issued by the bus controller. Each RT is assigned a unique address between 0-30. In addition, the bus may have passive Bus Monitors (BM:s) connected.

There are 5 possible data transfer types on the MIL-STD-1553 bus:

- BC-to-RT transfer (“receive”)
- RT-to-BC transfer (“transmit”)
- RT-to-RT transfer
- Broadcast BC-to-RTs
- Broadcast RT-to-RTs

Each transfer can contain 1-32 data words of 16 bits each.

The bus controller can also send “mode codes” to the RTs to perform administrative tasks such as time synchronization, and reading out terminal status.

23.2 Electrical interface

The core is connected to the MIL-STD-1553B bus wire through single or dual transceivers, isolation transformers and transformer or stub couplers as shown in figure 40. If single-redundancy is used, the unused bus receive P/N signals should be tied both-high or both-low. The transmitter enables are typically inverted and therefore called transmitter inibit (txinh).

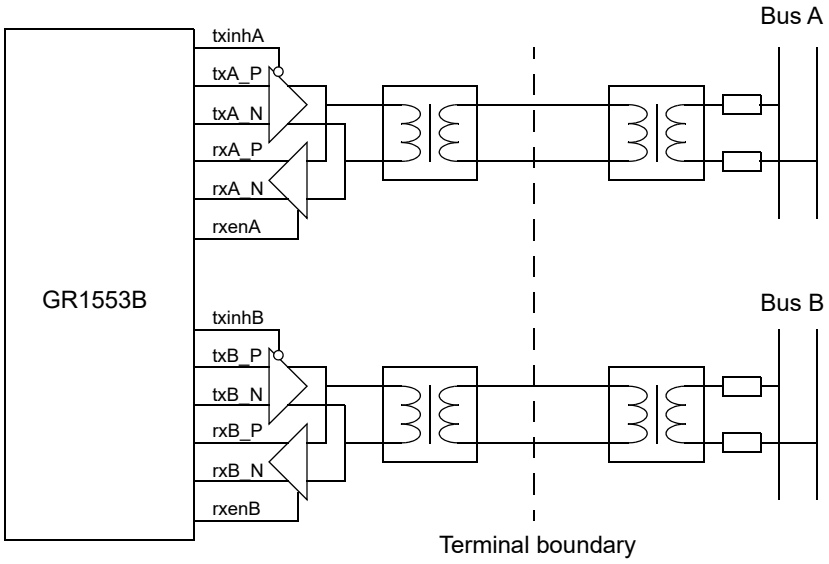


Figure 40. Interface between core and MIL-STD-1553B bus (dual-redundant, transformer coupled)

23.3 Operation

23.3.1 Operating modes

The core contains three separate control units for the Bus Controller, Remote Terminal and Bus Monitor handling, with a shared 1553 codec.

The operating mode of the core is controlled by starting and stopping of the BC/RT/BM units via register writes. At start-up, none of the parts are enabled, and the core is completely passive on both the 1553 and AMBA bus.

The BC and RT parts of the core can not be active on the 1553 bus at the same time. While the BC is running or suspended, only the BC (and possibly BM) has access to the 1553 bus, and the RT can only receive and respond to commands when both the BC schedules are completely stopped (not running or even suspended).

The Bus Monitor, however, is only listening on the codec receivers and can therefore operate regardless of the enabled/disabled state of the other two parts.

23.3.2 Register interface

The core is configured and controlled through control registers accessed over the APB bus. Each of the BC,RT,BM parts has a separate set of registers, plus there is a small set of shared registers.

Some of the control register fields for the BC and RT are protected using a 'key', a field in the same register that has to be written with a certain value for the write to take effect. The purpose of the keys are to give RT/BM designers a way to ensure that the software can not interfere with the bus traffic by enabling the BC or changing the RT address. If the software is built without knowledge of the key to a certain register, it is very unlikely that it will accidentally perform a write with the correct key to that control register.

23.3.3 Interrupting

The core has one interrupt output, which can be generated from several different source events. Which events should cause an interrupt can be controlled through the IRQ Enable Mask register.

23.3.4 MIL-STD-1553 Codec

The core's internal codec receives and transmits data words on the 1553 bus, and generates and checks sync patterns and parity.

Loop-back checking logic checks that each transmitted word is also seen on the receive inputs. If the transmitted word is not echoed back, the transmitter stops and signals an error condition, which is then reported back to the user.

23.4 Bus Controller Operation

23.4.1 Overview

When operating as Bus Controller, the core acts as master on the MIL-STD-1553 bus, initiates and performs transfers.

This mode works based on a scheduled transfer list concept. The software sets up in memory a sequence of transfer descriptors and branches, data buffers for sent and received data, and an IRQ pointer ring buffer. When the schedule is started (through a BC action register write), the core processes the list, performs the transfers one after another and writes resulting status into the transfer list and incoming data into the corresponding buffers.

23.4.2 Timing control

In each transfer descriptor in the schedule is a “slot time” field. If the scheduled transfer finishes sooner than its slot time, the core will pause the remaining time before scheduling the next command. This allows the user to accurately control the message timing during a communication frame.

If the transfer uses more than its slot time, the overshooting time will be subtracted from the following command’s time slot. The following command may in turn borrow time from the following command and so on. The core can keep track of up to one second of borrowed time, and will not insert pauses again until the balance is positive, except for intermessage gaps and pauses that the standard requires.

If you wish to execute the schedule as fast as possible you can set all slot times in the schedule to zero. If you want to group a number of transfers you can move all the slot time to the last transfer.

The schedule can be stopped or suspended by writing into the BC action register. When suspended, the schedule’s time will still be accounted, so that the schedule timing will still be correct when the schedule is resumed. When stopped, on the other hand, the schedule’s timers will be reset.

When the extsync bit is set in the schedule’s next transfer descriptor, the core will wait for a positive edge on the external sync input before starting the command. The schedule timer and the time slot balance will then be reset and the command is started. If the sync pulse arrives before the transfer is reached, it is stored so the command will begin immediately. The trigger memory is cleared when stopping (but not when suspending) the schedule. Also, the trigger can be set/cleared by software through the BC action register.

23.4.3 Bus selection

Each transfer descriptor has a bus selection bit that allows you to control on which one of the two redundant buses (‘0’ for bus A, ‘1’ for bus B) the transfer will occur.

Another way to control the bus usage is through the per-RT bus swap register, which has one register bit for each RT address. The bus swap register is an optional feature, software can check the BCFEAT read-only register field to see if it is available.

Writing a ‘1’ to a bit in the per-RT Bus Swap register inverts the meaning of the bus selection bit for all transfers to the corresponding RT, so ‘0’ now means bus ‘B’ and ‘1’ means bus ‘A’. This allows you to switch all transfers to one or a set of RT:s over to the other bus with a single register write and without having to modify any descriptors.

The hardware determines which bus to use by taking the exclusive-or of the bus swap register bit and the bus selection bit. Normally it only makes sense to use one of these two methods for each RT, either the bus selection bit is always zero and the swap register is used, or the swap register bit is always zero and the bus selection bit is used.

If the bus swap register is used for bus selection, the store-bus descriptor bit can be enabled to automatically update the register depending on transfer outcome. If the transfer succeeded on bus A, the bus swap register bit is set to ‘0’, if it succeeds on bus B, the swap register bit is set to ‘1’. If the transfer fails, the bus swap register is set to the opposite value.

23.4.4 Secondary transfer list

The core can be set up with a secondary “asynchronous” transfer list with the same format as the ordinary schedule. This transfer list can be commanded to start at any time during the ordinary schedule. While the core is waiting for a scheduled command’s slot time to finish, it will check if the next asynchronous transfer’s slot time is lower than the remaining sleep time. In that case, the asynchronous command will be scheduled.

If the asynchronous command doesn’t finish in time, time will be borrowed from the next command in the ordinary schedule. In order to not disturb the ordinary schedule, the slot time for the asynchronous messages must therefore be set to pessimistic values.

The exclusive bit in the transfer descriptor can be set if one does not want an asynchronous command scheduled during the sleep time following the transfer.

Asynchronous messages will not be scheduled while the schedule is waiting for a sync pulse or the schedule is suspended and the current slot time has expired, since it is then not known when the next scheduled command will start.

23.4.5 Interrupt generation

Each command in the transfer schedule can be set to generate an interrupt after certain transfers have completed, with or without error. Invalid command descriptors always generate interrupts and stop the schedule. Before a transfer-triggered interrupt is generated, the address to the corresponding descriptor is written into the BC transfer-triggered IRQ ring buffer and the BC Transfer-triggered IRQ Ring Position Register is incremented.

A separate error interrupt signals DMA errors. If a DMA error occurs when reading/writing descriptors, the executing schedule will be suspended. DMA errors in data buffers will cause the corresponding transfer to fail with an error code (see table 175).

Whether any of these interrupt events actually cause an interrupt request on the AMBA bus is controlled by the IRQ Mask Register setting.

23.4.6 Transfer list format

The BC:s transfer list is an array of transfer descriptors mixed with branches as shown in table 172. Each entry has to be aligned to start on a 128-bit (16-byte) boundary. The two unused words in the branch case are free to be used by software to store arbitrary data.

*Table 172.*GR1553B transfer descriptor format

Offset	Value for transfer descriptor	DMA R/W	Value for branch	DMA R/W
0x00	Transfer descriptor word 0 (see table 173)	R	Condition word (see table 177)	R
0x04	Transfer descriptor word 1 (see table 174)	R	Jump address, 128-bit aligned	R
0x08	Data buffer pointer, 16-bit aligned. For write buffers, if bit 0 is set the received data is discarded and the pointer is ignored. This can be used for RT-to-RT transfers where the BC is not interested in the data transferred.	R	Unused	-
0x0C	Result word, written by core (see table 175)	W	Unused	-

The transfer descriptor words are structured as shown in tables 173-175 below.

*Table 173.*GR1553B BC transfer descriptor word 0 (offset 0x00)

31	30	29	28	27	26	25	24 23	22 20	19	18	17 16	15 0
0	WTRIG	EXCL	IRQE	IRQN	SUSE	SUSN	RETMD	NRET	STBUS	GAP	RESERVED	STIME

31	Must be 0 to identify as descriptor
30	Wait for external trigger (WTRIG)
29	Exclusive time slot (EXCL) - Do not schedule asynchronous messages
28	IRQ after transfer on Error (IRQE)
27	IRQ normally (IRQN) - Always interrupts after transfer
26	Suspend on Error (SUSE) - Suspends the schedule (or stops the async transfer list) on error
25	Suspend normally (SUSN) - Always suspends after transfer
24 : 23	Retry mode (RETMD). 00 - Retry on same bus only. 01 - Retry alternating on both buses 10: Retry first on same bus, then on alternating bus. 11 - Reserved, do not use
22 : 20	Number of retries (NRET) - Number of automatic retries per bus The total number of tries (including the first attempt) is NRET+1 for RETMD=00, 2 x (NRET+1) for RETMD=01/10
19	Store bus (STBUS) - If the transfer succeeds and this bit is set, store the bus on which the transfer succeeded (0 for bus A, 1 for bus B) into the per-RT bus swap register. If the transfer fails and this bit is set, store the opposite bus instead. (only if the per-RT bus mask is supported in the core) See section 23.4.3 for more information.
18	Extended intermessage gap (GAP) - If set, adds an additional amount of gap time, corresponding to the RTTO field, after the transfer
17 : 16	Reserved - Set to 0 for forward compatibility
15 : 0	Slot time (STIME) - Allocated time in 4 microsecond units, remaining time after transfer will insert delay

*Table 174.*GR1553B BC transfer descriptor word 1 (offset 0x04)

31	30	29 26	25 21	20 16	15 11	10	9 5	4 0
DUM	BUS	RTTO	RTAD2	RTSA2	RTAD1	TR	RTSA1	WCMC

31	Dummy transfer (DUM) - If set to ‘1’ no bus traffic is generated and transfer “succeeds” immediately For dummy transfers, the EXCL,IRQN,SUSN,STBUS,GAP,STIME settings are still in effect, other bits and the data buffer pointer are ignored.	
30	Bus selection (BUS) - Bus to use for transfer, 0 - Bus A, 1 - Bus B	
29:26	RT Timeout (RTTO) - Extra RT status word timeout above nominal in units of 4 us (0000 -14 us, 1111 -74 us). Note: This extra time is also used as extra intermessage gap time if the GAP bit is set.	
25:21	Second RT Address for RT-to-RT transfer (RTAD2)	See table 176 for details on how to setup RTAD1,RTSA1,RTAD2,RTSA2,WCMC,TR for different transfer types. Note that bits 15:0 correspond to the (first) command word on the 1553 bus
20:16	Second RT Subaddress for RT-to-RT transfer (RTSA2)	
15:11	RT Address (RTAD1)	
10	Transmit/receive (TR)	
9:5	RT Subaddress (RTSA1)	
4:0	Word count/Mode code (WCMC)	

*Table 175.*GR1553B transfer descriptor result word (offset 0x0C)

31	30 24	23 16	15 8	7 4	3	2 0
0	Reserved	RT2ST	RTST	RETCNT	RES	TFRST

31	Always written as 0
30:24	Reserved - Mask away on read for forward compatibility
23:16	RT 2 Status Bits (RT2ST) - Status bits from receiving RT in RT-to-RT transfer, otherwise 0 Same bit pattern as for RTST below
15:8	RT Status Bits (RTST) - Status bits from RT (transmitting RT in RT-to-RT transfer) 15 - Message error, 14 - Instrumentation bit or reserved bit set, 13 - Service request, 12 - Broadcast command received, 11 - Busy bit, 10 - Subsystem flag, 9 - Dynamic bus control acceptance, 8 - Terminal flag
7:4	Retry count (RETCNT) - Number of retries performed
3	Reserved - Mask away on read for forward compatibility
2:0	Transfer status (TFRST) - Outcome of last try 000 - Success (or dummy bit was set) 001 - RT did not respond (transmitting RT in RT-to-RT transfer) 010 - Receiving RT of RT-to-RT transfer did not respond 011 - A responding RT:s status word had message error, busy, instrumentation or reserved bit set (*) 100 - Protocol error (improperly timed data words, decoder error, wrong number of data words) 101 - The transfer descriptor was invalid 110 - Data buffer DMA timeout or error response 111 - Transfer aborted due to loop back check failure

* Error code 011 is issued only when the number of data words match the success case, otherwise code 100 is used. Error code 011 can be issued for a correctly executed “transmit last command” or “transmit last status word” mode code since these commands do not reset the status word.

*Table 176.*GR1553B BC Transfer configuration bits for different transfer types

Transfer type	**RTAD1 (15:11)**	**RTSA1 (9:5)**	**RTAD2 (25:21)**	**RTSA2 (20:16)**	**WCMC (4:0)**	**TR (10)**	**Data buffer direction**
Data, BC-to-RT	RT address (0-30)	RT subaddr (1-30)	Don’t care	0	Word count (0 for 32)	0	Read (2-64 bytes)
Data, RT-to-BC	RT address (0-30)	RT subaddr (1-30)	Don’t care	0	Word count (0 for 32)	1	Write (2-64 bytes)
Data, RT-to-RT	Recv-RT addr (0-30)	Recv-RT subad. (1-30)	Xmit-RT addr (0-30)	Xmit-RT subad. (1-30)	Word count (0 for 32)	0	Write (2-64 bytes)
Mode, no data	RT address (0-30)	0 or 31 (*)	Don’t care	Don’t care	Mode code (0-8)	1	Unused
Mode, RT-to-BC	RT address (0-30)	0 or 31 (*)	Don’t care	Don’t care	Mode code (16/18/19)	1	Write (2 bytes)
Mode, BC-to-RT	RT address (0-30)	0 or 31 (*)	Don’t care	Don’t care	Mode code (17/20/21)	0	Read (2 bytes)
Broadcast Data, BC-to-RTs	31	RTs subaddr (1-30)	Don’t care	0	Word count (0 for 32)	0	Read (2-64 bytes)
Broadcast Data, RT-to-RTs	31	Recv-RTs subad. (1-30)	Xmit-RT addr (0-30)	Xmit-RT subad. (1-30)	Word count (0 for 32)	0	Write (2-64 bytes)
Broadcast Mode, no data	31	0 or 31 (*)	Don’t care	Don’t care	Mode code (1, 3-8)	1	Unused
Broadcast Mode, BC-to-RT	31	0 or 31 (*)	Don’t care	Don’t care	Mode code (17/20/21)	0	Read (2 bytes)

(*) The standard allows using either of subaddress 0 or 31 for mode commands.

The branch condition word is formed as shown in table 177.

*Table 177.*GR1553B branch condition word (offset 0x00)

31	30 27	26	25	24	23 16	15 8	7 0
1	Reserved (0)	IRQC	ACT	MODE	RT2CC	RTCC	STCC

31	Must be 1 to identify as branch
30 : 27	Reserved - Set to 0
26	Interrupt if condition met (IRQC)
25	Action (ACT) - What to do if condition is met, 0 - Suspend schedule, 1 - Jump
24	Logic mode (MODE): 0 = Or mode (any bit set in RT2CC, RTCC is set in RT2ST,RTST, or result is in STCC mask) 1 - And mode (all bits set in RT2CC,RTCC are set in RT2ST,RTST and result is in STCC mask)
23:16	RT 2 Condition Code (RT2CC) - Mask with bits corresponding to RT2ST in result word of last transfer
15:8	RT Condition Code (RTCC) - Mask with bits corresponding to RTST in result word of last transfer
7:0	Status Condition Code (STCC) - Mask with bits corresponding to status value of last transfer

Note that you can get a constant true condition by setting MODE=0 and STCC=0xFF, and a constant false condition by setting STCC=0x00. 0x800000FF can thus be used as an end-of-list marker.

23.5 Remote Terminal Operation

23.5.1 Overview

When operating as Remote Terminal, the core acts as a slave on the MIL-STD-1553B bus. It listens for requests to its own RT address (or broadcast transfers), checks whether they are configured as legal and, if legal, performs the corresponding transfer or, if illegal, sets the message error flag in the status word. Legality is controlled by the subaddress control word for data transfers and by the mode code control register for mode codes.

To start the RT, set up the subaddress table and log ring buffer, and then write the address and RT enable bit is into the RT Config Register.

23.5.2 Data transfer handling

The Remote Terminal mode uses a three-level structure to handle data transfer DMA. The top level is a subaddress table, where each subaddress has a subaddress control word, and pointers to a transmit descriptor and a receive descriptor. Each descriptor in turn contains a descriptor control/status word, pointer to a data buffer, and a pointer to a next descriptor, forming a linked list or ring of descriptors. Data buffers can reside anywhere in memory with 16-bit alignment.

When the RT receives a data transfer request, it checks in the subaddress table that the request is legal. If it is legal, the transfer is then performed with DMA to or from the corresponding data buffer. After a data transfer, the descriptor's control/status word is updated with success or failure status and the subaddress table pointer is changed to point to the next descriptor.

If logging is enabled, a log entry will be written into a log ring buffer area. A transfer-triggered IRQ may also be enabled. To identify which transfer caused the interrupt, the RT Event Log IRQ Position points to the corresponding log entry. For that reason, logging must be enabled in order to enable interrupts.

If a request is legal but can not be fulfilled, either because there is no valid descriptor ready or because the data can not be accessed within the required response time, the core will signal a RT table access error interrupt and not respond to the request. Optionally, the terminal flag status bit can be automatically set on these error conditions.

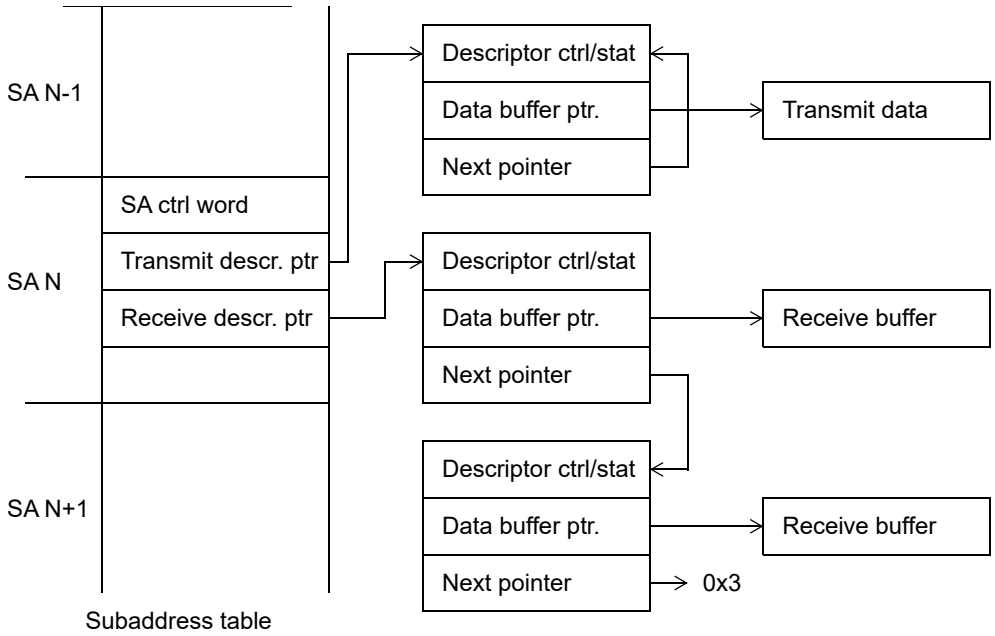


Figure 41. RT subaddress data structure example diagram

23.5.3 Mode Codes

Which of the MIL-STD-1553B mode codes that are legal and should be logged and interrupted are controlled by the RT Mode Code Control register. As for data transfers, to enable interrupts you must also enable logging. Inhibit mode codes are controlled by the same fields as their non-inhibit counterpart and mode codes that can be broadcast have two separate fields to control the broadcast and non-broadcast variants.

The different mode codes and the corresponding action taken by the RT are tabulated below. Some mode codes do not have a built-in action, so they will need to be implemented in software if desired. The relation between each mode code to the fields in the RT Mode Code control register is also shown.

*Table 178.*RT Mode Codes

Mode code		Description	Built-in action, if mode code is enabled	Can log/ IRQ	Enabled after reset	Ctrl. reg bits
0	00000	Dynamic bus control	If the DBCA bit is set in the RT Bus Status register, a Dynamic Bus Control Acceptance response is sent.	Yes	No	17:16
1	00001	Synchronize	The time field in the RT sync register is updated. The output rtsync is pulsed high one AMBA cycle.	Yes	Yes	3:0
2	00010	Transmit status word	Transmits the RT:s status word Enabled always, can not be logged or disabled.	No	Yes	-
3	00011	Initiate self test	No built-in action	Yes	No	21:18
4	00100	Transmitter shutdown	The RT will stop responding to commands on the other bus (not the bus on which this command was given).	Yes	Yes	11:8
5	00101	Override transmitter shutdown	Removes the effect of an earlier transmitter shutdown mode code received on the same bus	Yes	Yes	11:8
6	00110	Inhibit terminal flag	Masks the terminal flag of the sent RT status words	Yes	No	25:22
7	00111	Override inhibit terminal flag	Removes the effect of an earlier inhibit terminal flag mode code.	Yes	No	25:22
8	01000	Reset remote terminal	The fail-safe timers, transmitter shutdown and inhibit terminal flag inhibit status are reset. The Terminal Flag and Service Request bits in the RT Bus Status register are cleared. The extreset output is pulsed high one AMBA cycle.	Yes	No	29:26
16	10000	Transmit vector word	Responds with vector word from RT Status Words Register	Yes	No	13:12
17	10001	Synchronize with data word	The time and data fields in the RT sync register are updated. The rtsync output is pulsed high one AMBA cycle	Yes	Yes	7:4
18	10010	Transmit last command	Transmits the last command sent to the RT. Enabled always, can not be logged or disabled.	No	Yes	-
19	10011	Transmit BIT word	Responds with BIT word from RT Status Words Register	Yes	No	15:14
20	10100	Selected transmitter shutdown	No built-in action	No	No	-
21	10101	Override selected transmitter shutdown	No built-in action	No	No	-

23.5.4 Event Log

The event log is a ring of 32-bit entries, each entry having the format given in table 179. Note that for data transfers, bits 23-0 in the event log are identical to bits 23-0 in the descriptor status word.

*Table 179.*GR1553B RT Event Log entry format

31	30 29	28 24	23 10	9	8 3	2 0
IRQSR	TYPE	SAMC	TIMEL	BC	SZ	TRES

31	IRQ Source (IRQSRC) - Set to '1' if this transfer caused an interrupt
30 : 29	Transfer type (TYPE) - 00 - Transmit data, 01 - Receive data, 10 - Mode code
28 : 24	Subaddress / Mode code (SAMC) - If TYPE=00/01 this is the transfer subaddress, If TYPE=10, this is the mode code
23 : 10	TIMEL - Low 14 bits of time tag counter.
9	Broadcast (BC) - Set to 1 if request was to the broadcast address
8 : 3	Transfer size (SZ) - Count in 16-bit words (0-32)
2 : 0	Transfer result (TRES) 000 = Success 001 = Superseded (canceled because a new command was given on the other bus) 010 = DMA error or memory timeout occurred 011 = Protocol error (improperly timed data words or decoder error) 100 = The busy bit or message error bit was set in the transmitted status word and no data was sent 101 = Transfer aborted due to loop back checker error

23.5.5 Subaddress table format

*Table 180.*GR1553B RT Subaddress table entry for subaddress number N, 0<N<31

Offset	Value	DMA R/W
0x10*N + 0x00	Subaddress N control word (table 181)	R
0x10*N + 0x04	Transmit descriptor pointer, 16-byte aligned (0x3 to indicate invalid pointer)	R/W
0x10*N + 0x08	Receive descriptor pointer, 16-byte aligned (0x3 to indicate invalid pointer)	R/W
0x10*N + 0x0C	Unused	-

Note: The table entries for mode code subaddresses 0 and 31 are never accessed by the core.

*Table 181.*GR1553B RT Subaddress table control word (offset 0x00)

31 19	18	17	16	15	14	13	12 8	7	6	5	4 0
0 (reserved)	WRAP	IGNDV	BCRXE	RXEN	RXLOG	RXIRQ	RXSZ	TXEN	TXLOG	TXIRQ	TXSZ

31 : 19	Reserved - set to 0 for forward compatibility
18	Auto-wraparound enable (WRAP) - Enables a test mode for this subaddress, where transmit transfers send back the last received data. This is done by copying the finished transfer's descriptor pointer to the transmit descriptor pointer address after each successful transfer. Note: If WRAP=1, you should not set TXSZ > RXSZ as this might cause reading beyond buffer end
17	Ignore data valid bit (IGNDV) - If this is '1' then receive transfers will proceed (and overwrite the buffer) if the receive descriptor has the data valid bit set, instead of not responding to the request. This can be used for descriptor rings where you don't care if the oldest data is overwritten.
16	Broadcast receive enable (BCRXEN) - Allow broadcast receive transfers to this subaddress
15	Receive enable (RXEN) - Allow receive transfers to this subaddress
14	Log receive transfers (RXLOG) - Log all receive transfers in event log ring (only used if RXEN=1)
13	Interrupt on receive transfers (RXIRQ) - Each receive transfer will cause an interrupt (only if also RXEN,RXLOG=1)
12 : 8	Maximum legal receive size (RXSZ) to this subaddress - in16-bit words, 0 means 32
7	Transmit enable (TXEN) - Allow transmit transfers from this subaddress
6	Log transmit transfers (TXLOG) - Log all transmit transfers in event log ring (only if also TXEN=1)
5	Interrupt on transmit transfers (TXIRQ) - Each transmit transfer will cause an interrupt (only if TXEN,TXLOG=1)
4 : 0	Maximum legal transmit size (TXSZ) from this subaddress - in 16-bit words, 0 means 32

*Table 182.*GR1553B RT Descriptor format

Offset	Value	DMA R/W
0x00	Control and status word, see table 183	R/W
0x04	Data buffer pointer, 16-bit aligned	R
0x08	Pointer to next descriptor, 16-byte aligned or 0x0000003 to indicate end of list	R

*Table 183.*GR1553B RT Descriptor control/status word (offset 0x00)

31	30	29 26	25 10	9	8 3	2 0
DV	IRQEN	Reserved (0)	TIME	BC	SZ	TRES

31	Data valid (DV) - Should be set to 0 by software before and set to 1 by hardware after transfer. If DV=1 in the current receive descriptor before the receive transfer begins then a descriptor table error will be triggered. You can override this by setting the IGNDV bit in the subaddress table.
30	IRQ Enable override (IRQEN) - Log and IRQ after transfer regardless of SA control word settings Can be used for getting an interrupt when nearing the end of a descriptor list.
29 : 26	Reserved - Write 0 and mask out on read for forward compatibility
25 : 10	Transmission time tag (TTIME) - Set by the core to the value of the RT timer when the transfer finished.
9	Broadcast (BC) - Set by the core if the transfer was a broadcast transfer
8 : 3	Transfer size (SZ) - Count in 16-bit words (0-32)
2 : 0	Transfer result (TRES) 000 = Success 001 = Superseded (canceled because a new command was given on the other bus) 010 = DMA error or memory timeout occurred 011 = Protocol error (improperly timed data words or decoder error) 100 = The busy bit or message error bit was set in the transmitted status word and no data was sent 101 = Transfer aborted due to loop back checker error

23.6 Bus Monitor Operation

23.6.1 Overview

The Bus Monitor (BM) can be enabled by itself, or in parallel to the BC or RT. The BM acts as a passive logging device, writing received data with time stamps to a ring buffer.

23.6.2 Filtering

The Bus Monitor can also support filtering. This is an optional feature, software can check for this by testing whether the BM filter registers are writable.

Transfers can be filtered per RT address and per subaddress or mode code, and the filter conditions are logically AND:ed. If all bits of the three filter registers and bits 2-3 of the control register are set to '1', the BM core will log all words that are received on the bus.

In order to filter on subaddress/mode code, the BM has logic to track 1553 words belonging to the same message. All 10 message types are supported. If an unexpected word appears, the filter logic will restart. Data words not appearing to belong to any message can be logged by setting a bit in the control register.

The filter logic can be manually restarted by setting the BM enable bit low and then back to high. This feature is mainly to improve testability of the BM itself.

23.6.3 No-response handling

In the MIL-STD-1553B protocol, a command word for a mode code using indicator 0 or a regular transfer to subaddress 8 has the same structure as a legal status word. Therefore ambiguity can arise when the subaddress or mode code filters are used, an RT is not responding on a subaddress, and the BC then commands the same RT again on subaddress 8 or mode code indicator 0 on the same bus. This can lead to the second command word being interpreted as a status word and filtered out.

The BM can use the instrumentation bit and reserved bits to disambiguate, which means that this case will never occur when subaddresses 1-7, 9-30 and mode code indicator 31 are used. Also, this case does not occur when the subaddress/mode code filters are unused and only the RT address filter is used.

23.6.4 Log entry format

Each log entry is two 32-bit words.

*Table 184.*GR1553B BM Log entry word 0 (offset 0x00)

31	30 24	23 0
1	Reserved	TIME

31	Always written as 1
30 : 24	Reserved - Mask out on read for forward compatibility
23 : 0	Time tag (TIME)

*Table 185.*GR1553B BM Log entry word 1 (offset 0x04)

31	30 20	19	18 17	16	15 0
0	Reserved	BUS	WST	WTP	WD

31	Always written as 0
30 : 20	Reserved - Mask out on read for forward compatibility
19	Receive data bus (BUS) - 0:A, 1:B
18 : 17	Word status (WST) - 00=word OK, 01=Manchester error, 10=Parity error
16	Word type (WTP) - 0:Data, 1:Command/status
15 : 0	Word data (WD)

23.7 Registers

The core is programmed through registers mapped into APB address space. Reserved register fields should be written as zeroes and masked out on read.

*Table 186.*MIL-STD-1553B interface registers

APB address offset	Register	R/W	Reset value
0x00	IRQ Register	RW (write '1' to clear)	0x00000000
0x04	IRQ Enable	RW	0x00000000
0x08...0x0F	(Reserved)		
0x10	Hardware config register	R (constant)	0x00000000*
0x14...0x3F	(Reserved)		
0x40...0x7F	BC Register area (see table 187)		
0x80...0xBF	RT Register area (see table 188)		
0xC0...0xFF	BM Register area (see table 189)		

(*) May differ depending on core configuration

*Table 187.*MIL-STD-1553B interface BC-specific registers

APB address offset	Register	R/W	Reset value
0x40	BC Status and Config register	RW	0xf0000000*
0x44	BC Action register	W	
0x48	BC Transfer list next pointer	RW	0x00000000
0x4C	BC Asynchronous list next pointer	RW	0x00000000
0x50	BC Timer register	R	0x00000000
0x54	BC Timer wake-up register	RW	0x00000000
0x58	BC Transfer-triggered IRQ ring position	RW	0x00000000
0x5C	BC Per-RT bus swap register	RW	0x00000000
0x60...0x67	(Reserved)		
0x68	BC Transfer list current slot pointer	R	0x00000000
0x6C	BC Asynchronous list current slot pointer	R	0x00000000
0x70...0x7F	(Reserved)		

(*) May differ depending on core configuration

*Table 188.*MIL-STD-1553B interface RT-specific registers

APB address offset	Register	R/W	Reset value
0x80	RT Status register	R	0x80000000
0x84	RT Config register	RW	0x0000e03e***
0x88	RT Bus status bits register	RW	0x00000000
0x8C	RT Status words register	RW	0x00000000
0x90	RT Sync register	R	0x00000000
0x94	RT Subaddress table base address	RW	0x00000000
0x98	RT Mode code control register	RW	0x00000555
0x9C...0xA3	(Reserved)		
0xA4	RT Time tag control register	RW	0x00000000
0xA8	(Reserved)		
0xAC	RT Event log size mask	RW	0xfffffffc
0xB0	RT Event log position	RW	0x00000000
0xB4	RT Event log interrupt position	R	0x00000000
0xB8.. 0xBF	(Reserved)		

(***) Reset value is affected by the external RTADDR/RTPAR input signals

*Table 189.*MIL-STD-1553B interface BM-specific registers

APB address offset	Register	R/W	Reset value
0xC0	BM Status register	R	0x80000000
0xC4	BM Control register	RW	0x00000000
0xC8	BM RT Address filter register	RW	0xffffffff
0xCC	BM RT Subaddress filter register	RW	0xffffffff
0xD0	BM RT Mode code filter register	RW	0xffffffff
0xD4	BM Log buffer start	RW	0x00000000
0xD8	BM Log buffer end	RW	0x00000007
0xDC	BM Log buffer position	RW	0x00000000
0xE0	BM Time tag control register	RW	0x00000000
0xE4...0xFF	(Reserved)		

23.7.1 IRQ Register

*Table 190.*0x00 - IRQ - GR1553B IRQ Register

31 18	17	16	15 11	10	9	8	7 3	2	1	0
RESERVED	BMTOF	BMD	RESERVED	RTTE	RTD	RTEV	RESERVED	BCWK	BCD	BCEV
0	0	0	0	0	0	0	0	0	0	0
r	wc	wc	r	wc	wc	wc	r	wc	wc	wc

Bits read '1' if interrupt occurred, write back '1' to acknowledge

- 17 BM Timer overflow (BMTOF)
- 16 BM DMA Error (BMD)
- 10 RT Table access error (RTTE)
- 9 RT DMA Error (RTD)
- 8 RT transfer-triggered event interrupt (RTEV)
- 2 BC Wake-up timer interrupt (BCWK)
- 1 BC DMA Error (BCD)
- 0 BC Transfer-triggered event interrupt (BCEV)

23.7.2 IRQ Enable Register

*Table 191.*0x04 - IRQE - GR1553B IRQ Enable Register

31 18	17	16	15 11	10	9	8	7 3	2	1	0
RESERVED	BMTOE	BMDE	RESERVED	RTTEE	RTDE	RTEVE	RESERVED	BCWKE	BCDE	BCEVE
0	0	0	0	0	0	0	0	0	0	0
r	rw	rw	r	rw	rw	rw	r	rw	rw	rw

- 17 BM Timer overflow interrupt enable (BMTOE)
- 16 BM DMA error interrupt enable (BMDE)
- 10 RT Table access error interrupt enable (RTTEE)
- 9 RT DMA error interrupt enable (RTDE)
- 8 RT Transfer-triggered event interrupt enable (RTEVE)
- 2 BC Wake up timer interrupt (BCWKE)
- 1 BC DMA Error Enable (BCDE)
- 0 BC Transfer-triggered event interrupt (BCEVE)

23.7.3 Hardware Configuration Register

*Table 192.*GR1553B Hardware Configuration Register

31	30 12	11	10 9	8	7 0
MOD	RESERVED	XKEYS	ENDIAN	SCLK	CCFREQ
0	0	0	0	0	0
r	r	r	r	r	r

Note: This register reads 0x0000 for the standard configuration of the core

- 31 Modified (MOD) - Reserved to indicate that the core has been modified / customized in an unspecified manner
- 11 Set if safety keys are enabled for the BM Control Register and for all RT Control Register fields.
- 10 : 9 AHB Endianness - 00=Big-endian, 01=Little-endian, 10/11=Reserved
- 8 Same clock (SCLK) - Reserved for future versions to indicate that the core has been modified to run with a single clock
- 7 : 0 Codec clock frequency (CCFREQ) - Reserved for future versions of the core to indicate that the core runs at a different codec clock frequency. Frequency value in MHz, a value of 0 means 20 MHz.

23.7.4 BC Status and Config Register

*Table 193.*0x40 - BCSL - GR1553B BC Status and Config Register

31	30 28	27 17	16	15 11	10	9 8	7 3	2 0
BCSUP	BCFEAT	RESERVED	BCCHK	ASADL	R	ASST	SCADL	SCST
*	*	0	0	0	0	0	0	0
r	r	r	rw	r	r	r	r	r

31 BC Supported (BCSUP) - Reads '1' if core supports BC mode

30 : 28 BC Features (BCFEAT) - Bit field describing supported optional features ('1'=supported):

- 30 BC Schedule timer supported
- 29 BC Schedule time wake-up interrupt supported
- 28 BC per-RT bus swap register and STBUS descriptor bit supported

16 Check broadcasts (BCCHK) - Writable bit, if set to '1' enables waiting and checking for (unexpected) responses to all broadcasts.

15 : 11 Asynchronous list address low bits (ASADL) - Bit 8-4 of currently executing (if ASST=01) or next asynchronous command descriptor address

9 : 8 Asynchronous list state (ASST) - 00=Stopped, 01=Executing command, 10=Waiting for time slot

7 : 3 Schedule address low bits (SCADL) - Bit 8-4 of currently executing (if SCST=001) or next schedule descriptor address

2 : 0 Schedule state (SCST) - 000=Stopped, 001=Executing command, 010=Waiting for time slot, 011=Suspended, 100=Waiting for external trigger

23.7.5 BC Action Register

*Table 194.*0x44 - BCA - GR1553B BC Action Register

31 16	15 10	9	8	7 5	4	3	2	1	0
BCKEY	RESERVED	ASSTP	ASSRT	RESERVED	CLRT	SETT	SCSTP	SCSUS	SCSRT
-	-	-	-	-	-	-	-	-	-
w	-	w	w	-	w	w	w	w	w

31 : 16 Safety code (BCKEY) - Must be 0x1552 when writing, otherwise register write is ignored

9 Asynchronous list stop (ASSTP) - Write '1' to stop asynchronous list (after current transfer, if executing)

8 Asynchronous list start (ASSRT) - Write '1' to start asynchronous list

4 Clear external trigger (CLRT) - Write '1' to clear trigger memory

3 Set external trigger (SETT) - Write '1' to force the trigger memory to set

2 Schedule stop (SCSTP) - Write '1' to stop schedule (after current transfer, if executing)

1 Schedule suspend (SCSUS) - Write '1' to suspend schedule (after current transfer, if executing)

0 Schedule start (SCSRT) - Write '1' to start schedule

23.7.6 BC Transfer List Next Pointer Register

*Table 195.*0x48 - BCTNP - GR1553B BC Transfer list next pointer register

31 0
SCHEDULE TRANSFER LIST POINTER
0
rw

31 : 0 Read: Currently executing (if SCST=001) or next transfer to be executed in regular schedule.
Write: Change address. If running, this will cause a jump after the current transfer has finished.

23.7.7 BC Asynchronous List Next Pointer Register

*Table 196.*0x4C - BCANP - GR1553B BC Asynchronous list next pointer register

31	0
ASYNCHRONOUS LIST POINTER	
0	
rw	

31 :0 Read: Currently executing (if ASST=01) or next transfer to be executed in asynchronous schedule.
Write: Change address. If running, this will cause a jump after the current transfer has finished.

23.7.8 BC Timer Register

*Table 197.*0x50 - BCT - GR1553B BC Timer register

31 24	23 0
RESERVED	SCHEDULE TIME (SCTM)
0	0
r	r

23 : 0 Elapsed “transfer list” time in microseconds (read-only)
Set to zero when schedule is stopped or on external sync.

Note: This register is an optional feature, see BC Status and Config Register, bit 30

23.7.9 BC Timer Wake-up Register

*Table 198.*0x54 - BCTW - GR1553B BC Timer Wake-up register

31	30 24	23 0
WKEN	RESERVED	WAKE-UP TIME (WKTM)
0	0	0
rw	r	rw

31 Wake-up timer enable (WKEN) - If set, an interrupt will be triggered when WKTM=SCTM

23 : 0 Wake-up time (WKTM).

Note: This register is an optional feature, see BC Status and Config Register, bit 29

23.7.10 BC Transfer-triggered IRQ Ring Position Register

*Table 199.*0x58 - BCRD - GR1553B BC Transfer-triggered IRQ ring position register

31	0
BC IRQ SOURCE POINTER RING POSITION	
0	
rw	

31 : 0 The current write pointer into the transfer-tirggered IRQ descriptor pointer ring.
Bits 1:0 are constant zero (4-byte aligned)
The ring wraps at the 64-byte boundary, so bits 31:6 are only changed by user

23.7.11 BC per-RT Bus Swap Register

*Table 200.*0x5C - BCBS - GR1553B BC per-RT Bus swap register

31	0
BC PER-RT BUS SWAP	
0	
rw	

31 : 0 The bus selection value will be logically exclusive-or:ed with the bit in this mask corresponding to the addressed RT (the receiving RT for RT-to-RT transfers). This register gets updated by the core if the STBUS descriptor bit is used.

For more information on how to use this feature, see section 23.4.3.

Note: This register is an optional feature, see BC Status and Config Register, bit 28

23.7.12 BC Transfer List Current Slot Pointer

*Table 201.*0x68 - BCTCP - GR1553B BC Transfer list current slot pointer

31	0
BC TRANSFER SLOT POINTER	
0	
r	

31 : 0 Points to the transfer descriptor corresponding to the current time slot (read-only, only valid while transfer list is running).

Bits 3:0 are constant zero (128-bit/16-byte aligned)

23.7.13 BC Asynchronous List Current Slot Pointer

*Table 202.*0x6C - BCACP - GR1553B BC Asynchronous list current slot pointer

31	0
BC TRANSFER SLOT POINTER	
0	
r	

31 : 0 Points to the transfer descriptor corresponding to the current asynchronous schedule time slot (read-only, only valid while asynchronous list is running).

Bits 3:0 are constant zero (128-bit/16-byte aligned)

23.7.14 RT Status Register

*Table 203.*0x80 - RTS - GR1553B RT Status register (read-only)

31	30	4	3	2	1	0
RTSUP	RESERVED		ACT	SHDA	SHDB	RUN

31 RT Supported (RTSUP) - Reads ‘1’ if core supports RT mode

3 RT Active (ACT) - ‘1’ if RT is currently processing a transfer

2 Bus A shutdown (SHDA) - Reads ‘1’ if bus A has been shut down by the BC (using the transmitter shutdown mode command on bus B)

1 Bus B shutdown (SHDB) - Reads ‘1’ if bus B has been shut down by the BC (using the transmitter shutdown mode command on bus A)

0 RT Running (RUN) - ‘1’ if the RT is listening to commands.

23.7.15 RT Config Register

*Table 204.*0x84 - RTC - GR1553B RT Config register

31 16	15	14	13	12 7	6	5 1	0
RTKEY	SYS	SYDS	BRS	RESERVED	RTEIS	RTADDR	RTEN
0	1	1	1	0	*	*	0
w	rw	rw	rw	r	r	rw	rw

31 : 16	Safety code (RTKEY) - Must be written as 0x1553 when changing the RT address, otherwise the address field is unaffected by the write. When reading the register, this field reads 0x0000. If extra safety keys are enabled (see Hardware Config Register), the lower half of the key is used to also protect the other fields in this register.
15	Sync signal enable (SYS) - Set to '1' to pulse the rtsync output when a synchronize mode code (without data) has been received
14	Sync with data signal enable (SYDS) - Set to '1' to pulse the rtsync output when a synchronize with data word mode code has been received
13	Bus reset signal enable (BRS) - Set to '1' to pulse the busreset output when a reset remote terminal mode code has been received.
6	Reads '1' if current address was set through external inputs. After setting the address from software this field is set to '0'
5 : 1	RT Address (RTADDR) - This RT:s address (0-30)
0	RT Enable (RTEN) - Set to '1' to enable listening for requests

23.7.16 RT Bus Status Register

*Table 205.*0x88 - RTBS - GR1553B RT Bus status register

31 9	8	7 5	4	3	2	1	0
RESERVED	TFDE	RESERVED	SREQ	BUSY	SSF	DBCA	TFLG
0	0	0	0	0	0	0	0
r	rw	rw	rw	rw	rw	rw	rw

8	Set Terminal flag automatically on DMA and descriptor table errors (TFDE)
4 : 0	These bits will be sent in the RT:s status responses over the 1553 bus.
4	Service request (SREQ)
3	Busy bit (BUSY) Note: If the busy bit is set, the RT will respond with only the status word and the transfer "fails"
2	Subsystem Flag (SSF)
1	Dynamic Bus Control Acceptance (DBCA) Note: This bit is only sent in response to the Dynamic Bus Control mode code
0	Terminal Flag (TFLG) The BC can mask this flag using the "inhibit terminal flag" mode command, if legal

23.7.17 RT Status Words Register

*Table 206.*0x8C - RTSW - GR1553B RT Status words register

31 16	15 0
BIT WORD (BITW)	VECTOR WORD (VECW)
0	0
rw	rw

31 : 16	BIT Word - Transmitted in response to the "Transmit BIT Word" mode command, if legal
15 : 0	Vector word - Transmitted in response to the "Transmit vector word" mode command, if legal.

23.7.18 RT Sync Register

*Table 207.*0x90 - RTSY - GR1553B RT Sync register

31 16	15 0
SYNC TIME (SYTM)	SYNC DATA (SYD)
0	0
r	r

31 : 16	The value of the RT timer at the last sync or sync with data word mode command, if legal.
15 : 0	The data received with the last synchronize with data word mode command, if legal

23.7.19 Sub Address Table Base Address Register

*Table 208.*0x94 - RTSTBA - GR1553B RT Sub address table base address register

31 9	8 0
SUBADDRESS TABLE BASE (SATB)	RESERVED
0	0
rw	r

31 : 9	Base address, bits 31-9 for subaddress table
8 : 0	Always read ‘0’, writing has no effect

23.7.20 RT Mode Code Control Register

*Table 209.*0x98 - RTMCC - GR1553B RT Mode code control register

31 30	29 28	27 26	25 24	23 22	21 20	19 18	17 16
RESERVED	RRTB	RRT	ITFB	ITF	ISTB	IST	DBC
0	0	0	0	0	0	0	0
r	rw	rw	rw	rw	rw	rw	rw

15 14	13 12	11 10	9 8	7 6	5 4	3 2	1 0
TBW	TVW	TSB	TS	SDB	SD	SB	S
0	0	1	1	1	1	1	1
rw	rw	rw	rw	rw	rw	rw	rw

For each mode code: “00” - Illegal, “01” - Legal, “10” - Legal, log enabled, “11” - Legal, log and interrupt

29 : 28	Reset remote terminal broadcast (RRTB)
27 : 26	Reset remote terminal (RRT)
25 : 24	Inhibit & override inhibit terminal flag bit broadcast (ITFB)
23 : 22	Inhibit & override inhibit terminal flag (ITF)
21 : 20	Initiate self test broadcast (ISTB)
19 : 18	Initiate self test (IST)
17 : 16	Dynamic bus control (DBC)
15 : 14	Transmit BIT word (TBW)
13 : 12	Transmit vector word (TVW)
11 : 10	Transmitter shutdown & override transmitter shutdown broadcast (TSB)
9 : 8	Transmitter shutdown & override transmitter shutdown (TS)
7 : 6	Synchronize with data word broadcast (SDB)
5 : 4	Synchronize with data word (SD)
3 : 2	Synchronize broadcast (SB)
1 : 0	Synchronize (S)

23.7.21 RT Time Tag Control Register

*Table 210.*0xA4 - RTTTC - GR1553B RT Time tag control register

31 16	15 0
TIME RESOLUTION (TRES)	TIME TAG VALUE (TVAL)
0	0
rw	rw

31 : 16 Time tag resolution (TRES) - Time unit of RT:s time tag counter in microseconds, minus 1

15 : 0 Time tag value (TVAL) - Current value of running time tag counter

23.7.22 RT Event Log Mask Register

*Table 211.*0xAC - RTELM - GR1553B RT Event Log mask register

31 21	20 2	1 0
RESERVED	EVENT LOG SIZE MASK	RES
	0xFFFFFFC	
r	rw	r

31 : 0 Mask determining size and alignment of the RT event log ring buffer. All bits “above” the size should be set to ‘1’, all bits below should be set to ‘0’

23.7.23 RT Event Log Position Register

*Table 212.*0xB0 - RTELP - GR1553B RT Event Log position register

31 0
EVENT LOG WRITE POINTER
0
rw

31 : 0 Address to first unused/oldest entry of event log buffer, 32-bit aligned

23.7.24 RT Event Log Interrupt Position Register

*Table 213.*0xB4 - RTELIP - GR1553B RT Event Log interrupt position register

31 0
EVENT LOG IRQ POINTER
0
r

31 : 0 Address to event log entry corresponding to interrupt, 32-bit aligned
The register is set for the first interrupt and not set again until the interrupt has been acknowledged.

23.7.25 BM Status Register

*Table 214.*0xC0 - BMS - GR1553B BM Status register

31	30	29 0
BMSUP	KEYEN	RESERVED
*	*	0
r	r	r

31 BM Supported (BMSUP) - Reads ‘1’ if BM support is in the core.

30 Key Enabled (KEYEN) - Reads ‘1’ if the BM validates the BMKEY field when the control register is written.

23.7.26 BM Control Register

*Table 215.*0xC4 - BMC - GR1553B BM Control register

31 16	15 6	5	4	3	2	1	0
BMKEY	RESERVED	WRSTP	EXST	IMCL	UDWL	MANL	BMEN
0	0	0	0	0	0	0	0
rw	r	rw	rw	rw	rw	rw	rw

31 : 16	Safety key - If extra safety keys are enabled (see KEYEN), this field must be 0x1543 for a write to be accepted. Is 0x0000 when read.
5	Wrap stop (WRSTP) - If set to ‘1’, BMEN will be set to ‘0’ and stop the BM when the BM log position wraps around from buffer end to buffer start
4	External sync start (EXST) - If set to ‘1’,BMEN will be set to ‘1’ and the BM is started when an external BC sync pulse is received
3	Invalid mode code log (IMCL) - Set to ‘1’ to log invalid or reserved mode codes.
2	Unexpected data word logging (UDWL) - Set to ‘1’ to log data words not seeming to be part of any command
1	Manchester/parity error logging (MANL) - Set to ‘1’ to log bit decoding errors
0	BM Enable (BMEN) - Must be set to ‘1’ to enable any BM logging

23.7.27 BMRT Address Filter Register

*Table 216.*0xC8 - BMRTAF - GR1553B BM RT Address filter register

31 0
ADDRESS FILTER MASK
0xFFFFFFFF
rw

31	Enables logging of broadcast transfers
30 : 0	Each bit position set to ‘1’ enables logging of transfers with the corresponding RT address

23.7.28 BMRT Sub address Filter Register

*Table 217.*0xCC - BMRTSF - GR1553B BM RT Sub address filter register

31 0
SUBADDRESS FILTER MASK
0xFFFFFFFF
rw

31	Enables logging of mode commands on sub address 31
30 : 1	Each bit position set to ‘1’ enables logging of transfers with the corresponding RT sub address
0	Enables logging of mode commands on sub address 0

23.7.29 BMRT Mode Code Filter Register

*Table 218.*0xCC - BMRTMC - GR1553B BM RT Mode code filter register

31	19	18	17	16
RESERVED		STSB	STS	TLC
0x1ttt		1	1	1
r		rw	rw	rw

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
TSW	RRTB	RRT	ITFB	ITF	ISTB	IST	DBC	TBW	TVW	TSB	TS	SDB	SD	SB	S
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Each bit set to '1' enables logging of a mode code:

- 18 Selected transmitter shutdown broadcast & override selected transmitter shutdown broadcast (STSB)
- 17 Selected transmitter shutdown & override selected transmitter shutdown (STS)
- 16 Transmit last command (TLC)
- 15 Transmit status word (TSW)
- 14 Reset remote terminal broadcast (RRTB)
- 13 Reset remote terminal (RRT)
- 12 Inhibit & override inhibit terminal flag bit broadcast (ITFB)
- 11 Inhibit & override inhibit terminal flag (ITF)
- 10 Initiate self test broadcast (ISTB)
- 9 Initiate self test (IST)
- 8 Dynamic bus control (DBC)
- 7 Transmit BIT word (TBW)
- 6 Transmit vector word (TVW)
- 5 Transmitter shutdown & override transmitter shutdown broadcast (TSB)
- 4 Transmitter shutdown & override transmitter shutdown (TS)
- 3 Synchronize with data word broadcast (SDB)
- 2 Synchronize with data word (SD)
- 1 Synchronize broadcast (SB)
- 0 Synchronize (S)

23.7.30 BMLog Buffer Start

*Table 219.*0xD4 - BMLBS - GR1553B BM Log buffer start

31	0
BM LOG BUFFER START	
0	
rw	

31 : 0 Pointer to the lowest address of the BM log buffer (8-byte aligned)
Due to alignment, bits 2:0 are always 0.

23.7.31 BMLog Buffer End

*Table 220.*0xD8 - BMLBE - GR1553B BM Log buffer end

31 22	21 3	2 0
-	BM LOG BUFFER END	-
	0x0000007	
r	rw	r

31 : 0 Pointer to the highest address of the BM log buffer
Only bits 21:3 are settable, i.e. the buffer can not cross a 4 MB boundary Bits 31:22 read the same as the buffer start address.Due to alignment, bits 2:0 are always equal to 1

23.7.32 BMLog Buffer Position

*Table 221.*0xDC - BMLBP - GR1553B BM Log buffer position

31 22	21 3	2 0
-	BM LOG BUFFER POSITION	-
	0x00000000	
r	rw	r

31 : 0 Pointer to the next position that will be written to in the BM log buffer

Only bits 21:3 are settable, i.e. the buffer can not cross a 4 MB boundary Bits 31:22 read the same as the buffer start address.Due to alignment, bits 2:0 are always equal to 0

23.7.33 BM Time Tag Control Register

*Table 222.*0xE0 - BMTTC - GR1553B BM Time tag control register

31 24	23 0
TIME TAG RESOLUTION	TIME TAG VALUE
0	0
rw	rw

31 : 24 Time tag resolution (TRES) - Time unit of BM:s time tag counter in microseconds, minus 1

23 : 0 Time tag value (TVAL) - Current value of running time tag counter

24 ADC / DAC Interface

24.1 Overview

The combined ADC and DAC Interface (GRDACADC) is used to interface external DACs and ADCs. The block diagram in figure 42 shows a possible partitioning of the combined analogue-to-digital converter (ADC) and digital-to-analogue converter (DAC) interface.

The combined analogue-to-digital converter (ADC) and digital-to-analogue converter (DAC) interface is assumed to operate in an AMBA bus system where an APB bus is present. The AMBA APB bus is used for data access, control and status handling.

The ADC/DAC interface provides a combined signal interface to parallel ADC and DAC devices. The two interfaces are merged both at the pin/pad level as well as at the interface towards the AMBA bus. The interface supports simultaneously one ADC device and one DAC device in parallel.

Address and data signals unused by the ADC and the DAC can be used for general purpose input output, providing 0, 8, 16 or 24 channels.

The ADC interface supports 8 and 16 bit data widths. It provides chip select, read/convert and ready signals. The timing is programmable. It also provides an 8-bit address output. The ADC conversion can be initiated either via the AMBA interface or by internal or external triggers. An interrupt is generated when a conversion is completed.

The DAC interface supports 8 and 16 bit data widths. It provides a write strobe signal. The timing is programmable. It also provides an 8-bit address output. The DAC conversion is initiated via the AMBA interface. An interrupt is generated when a conversion is completed.

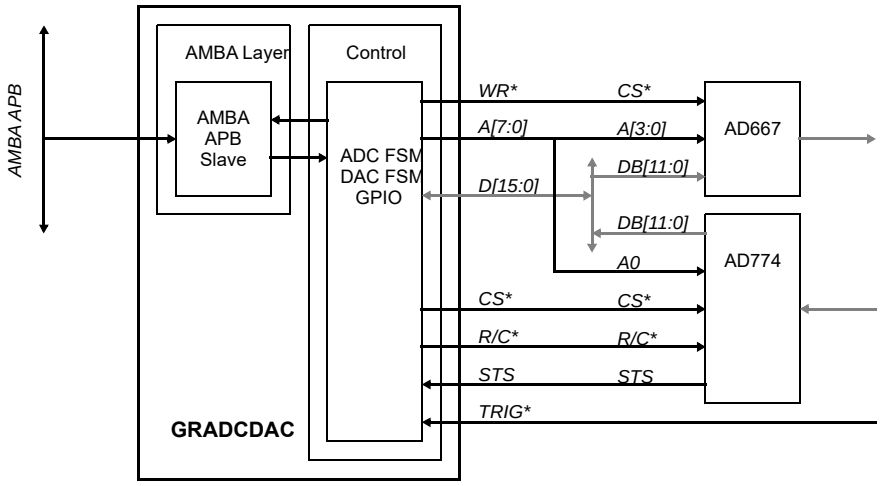


Figure 42. Block diagram and usage example

24.1.1 Function

The core implements the following functions:

- ADC interface conversion:
- ready feed-back, or
- timed open-loop
- DAC interface conversion:
- timed open-loop
- General purpose input output:

- unused data bus, and
- unused address bus
- Status and monitoring:
- on-going conversion
- completed conversion
- timed-out conversion

Note that it is not possible to perform ADC and DAC conversions simultaneously. On only one conversion can be performed at a time.

24.1.2 Interfaces

The core provides the following external and internal interfaces:

- Combined ADC/DAC interface
- programmable timing
- programmable signal polarity
- programmable conversion modes
- AMBA APB slave interface

The ADC interface is intended for amongst others the following devices:

Name:Width:Type:

AD574 12-bit R/C*, CE, CS*, RDY*, tri-state

AD674 12-bit R/C*, CE, CS*, RDY*, tri-state

AD774 12-bit R/C*, CE, CS*, RDY*, tri-state

AD670 8-bit R/W*, CE*, CS*, RDY, tri-state

AD571 10-bit Blank/Convert*, RDY*, tri-state

AD1671 12-bit Encode, RDY*, non-tri-state

LTC141414-bitConvert*, RDY, non-tri-state

STM1401 14-bit continuously sampling

The DAC interface is intended for amongst others the following devices:

Name:Width:Type:

AD56110-bitParallel-Data-in-Analogue-out

AD56512-bitParallel-Data-in-Analogue-out

AD66712-bitParallel-Data-in-Analogue-out, CS*

AD76712-bitParallel-Data-in-Analogue-out, CS*

DAC08 8-bit Parallel-Data-in-Analogue-out

24.2 Operation

24.2.1 Interfaces

The internal interface on the on-chip bus towards the core is a common AMBA APB slave for data access, configuration and status monitoring, used by both the ADC interface and the DAC interface.

The ADC address output and the DAC address output signals are shared on the external interface. The address signals are possible to use as general purpose input output channels. This is only realized when the address signals are not used by either ADC or DAC.

The ADC data input and the DAC data output signals are shared on the external interface. The data input and output signals are possible to use as general purpose input output channels. This is only realized when the data signals are not used by either ADC or DAC.

Each general purpose input output channel shall be individually programmed as input or output. This applies to both the address bus and the data bus. The default reset configuration for each general purpose input output channel is as input. The default reset value each general purpose input output channel is logical zero.

Note that protection toward spurious pulse commands during power up shall be mitigated as far as possible by means of I/O cell selection from the target technology.

24.2.2 Analogue to digital conversion

The ADC interface supports 8 and 16 bit wide input data.

The ADC interface provides an 8-bit address output, shared with the DAC interface. Note that the address timing is independent of the acquisition timing.

The ADC interface shall provide the following control signals:

- Chip Select
- Read/Convert
- Ready

The timing of the control signals is made up of two phases:

- Start Conversion
- Read Result

The Start Conversion phase is initiated by one of the following sources, provided that no other conversion is ongoing:

- Event on one of three separate trigger inputs
- Write access to the AMBA APB slave interface

Note that the trigger inputs can be connected to internal or external sources to the ASIC incorporating the core. Note that any of the trigger inputs can be connected to a timer to facilitate cyclic acquisition. The selection of the trigger source is programmable. The trigger inputs is programmable in terms of: Rising edge or Falling edge. Triggering events are ignored if ADC or DAC conversion is in progress.

The transition between the two phases is controlled by the Ready signal. The Ready input signal is programmable in terms of: Rising edge or Falling edge. The Ready input signaling is protected by means of a programmable time-out period, to assure that every conversion terminates. It is also possible to perform an ADC conversion without the use of the Ready signal, by means of a programmable conversion time duration. This can be seen as an open-loop conversion.

The Chip Select output signal is programmable in terms of:

- Polarity
- Number of assertions during a conversion, either

- Pulsed once during Start Conversion phase only,
- Pulsed once during Start Conversion phase and once during Read Result phase, or
- Asserted at the beginning of the Start Conversion phase and de-asserted at the end of the Read Result phase

The duration of the asserted period is programmable, in terms of system clock periods, for the Chip Select signal when pulsed in either of two phases.

The Read/Convert signal is de-asserted during the Start Conversion phase, and asserted during the Read Result phase. The Read/Convert output signal is programmable in terms of: Polarity. The setup timing from Read/Convert signal being asserted till the Chip Select signal is asserted is programmable, in terms of system clock periods. Note that the programming of Chip Select and Read/Convert timing is implemented as a common parameter.

At the end of the Read Result phase, an interrupt is generated, indicating that data is ready for readout via the AMBA APB slave interface. The status of an on-going conversion is possible to read out via the AMBA APB slave interface. The result of a conversion is read out via the AMBA APB slave interface. Note that this is independent of what trigger started the conversion.

An ADC conversion is non-interruptible. It is possible to perform at least 1000 conversions per second.

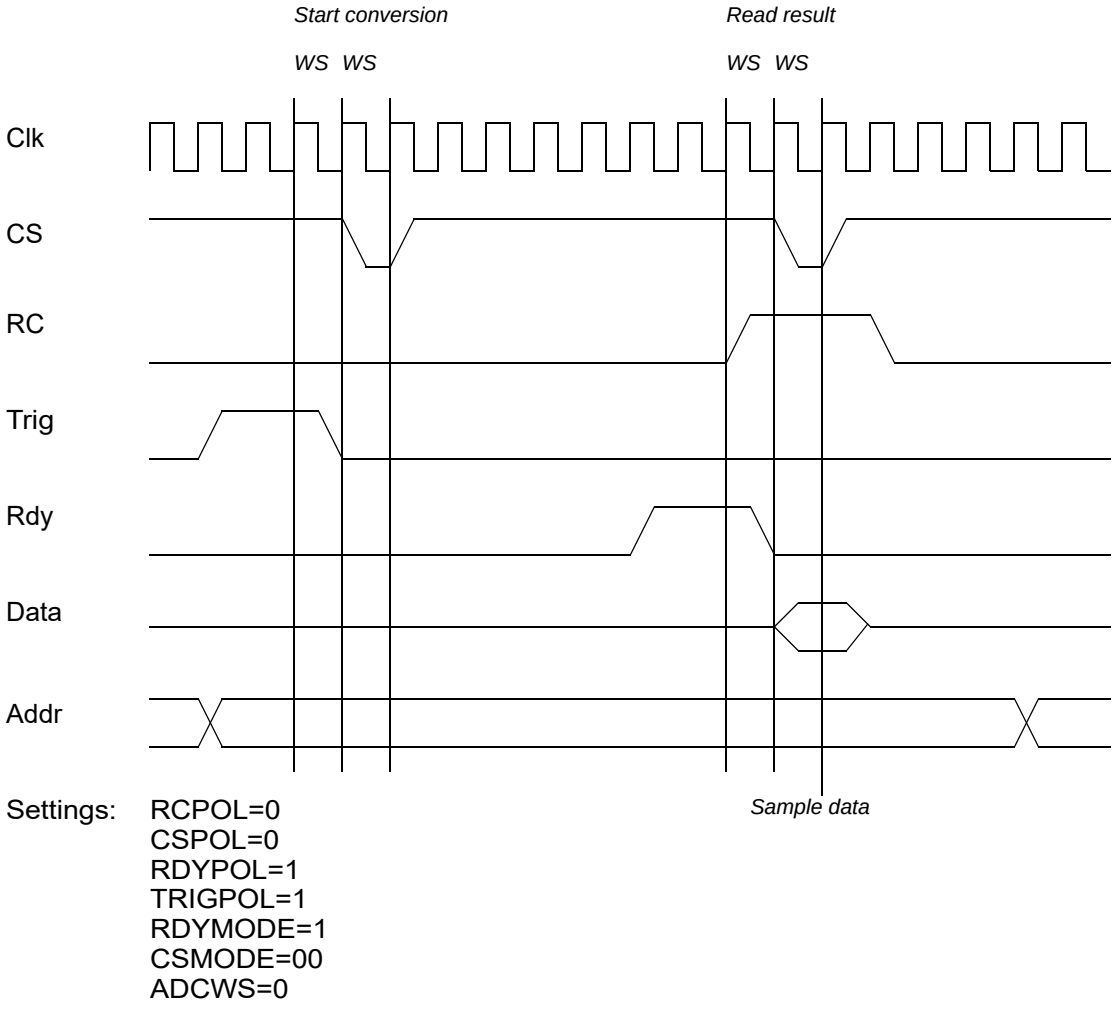


Figure 43. Analogue to digital conversion waveform, 0 wait states (WS)

24.2.3 Digital to analogue conversion

The DAC interface supports 8 and 16 bit wide output data. The data output signal is driven during the conversion and is placed in high impedance state after the conversion.

The DAC interface provides an 8-bit address output, shared with the ADC interface. Note that the address timing is independent of the acquisition timing.

The DAC interface provides the following control signal: Write Strobe. Note that the Write Strobe signal can also be used as a chip select signal. The Write Strobe output signal is programmable in terms of: Polarity. The Write Strobe signal is asserted during the conversion. The duration of the asserted period of the Write Strobe is programmable in terms of system clock periods.

At the end the conversion, an interrupt is generated. The status of an on-going conversion is possible to read out via the AMBA APB slave interface. A DAC conversion is non-interruptible.

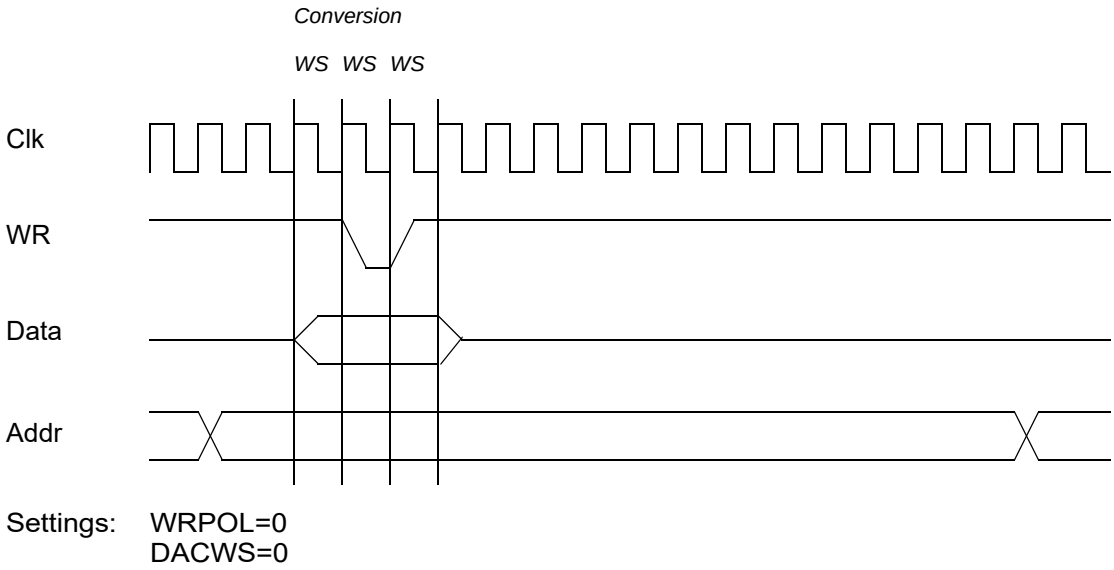


Figure 44. Digital to analogue conversion waveform, 0 wait states (WS)

24.3 Registers

The core is programmed through registers mapped into APB address space.

*Table 223.*GRADCDAC registers

APB address offset	Register
0x00§	Configuration Register
0x04§	Status Register
0x10§	ADC Data Input Register
0x14§	DAC Data Output Register
0x20§	Address Input Register
0x24§	Address Output Register
0x28§	Address Direction Register
0x30§	Data Input Register
0x34§	Data Output Register
0x38§	Data Direction Register

24.3.1 Configuration Register [ADCONF] R/W

*Table 224.*Configuration register

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
								DACWS					WR POL	DACDW	
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ADCWS					RCP OL	CSMODE		CSP OL	RD YM OD E	RD YP OL	TRI GP OL	TRIG-MODE		ADCDW	

23-19: DACWS Number of DAC wait states, 0 to 31 [5 bits]
18: WRPOL Polarity of DAC write strobe:
0b = active low
1b = active high
17-16: DACDW DAC data width
00b = none
01b = 8 bit ADO.Dout[7:0]
10b = 16 bit ADO.Dout[15:0]
11b = none/spare
15-11: ADCWS Number of ADC wait states, 0 to 31 [5 bits]
10: RCPOL Polarity of ADC read convert:
0b = active low read
1b = active high read
9-8: CSMODE Mode of ADC chip select:
00b = asserted during conversion and read phases
01b = asserted during conversion phase
10b = asserted during read phase
11b = asserted continuously during both phases
7: CSPOL Polarity of ADC chip select:0b = active low
1b = active high
6: RDYMODE:Mode of ADC ready:
0b = unused, i.e. open-loop
1b = used, with time-out
5: RDYPOL Polarity of ADC ready:
0b = falling edge
1b = rising edge
4: TRIGPOL Polarity of ADC triggers:
0b = falling edge
1b = rising edge
3-2: TRIGMODEADC trigger source:
00b = none
01b = ADI.TRIG[0]
10b = ADI.TRIG[1]
11b = ADI.TRIG[2]
1-0: ADCDW ADC data width:
00b = none
01b = 8 bit ADI.Din[7:0]
10b = 16 bit ADI.Din[15:0]
11b = none/spare

The ADCDW field defines what part of ADI.Din[15:0] is read by the ADC.

The DACDW field defines what part of ADO.Dout[15:0] is written by the DAC.

Parts of the data input/output signals used neither by ADC nor by DAC are available for the general purpose input output functionality.

Note that an ADC conversion can be initiated by means of a write access via the AMBA APB slave interface, thus not requiring an explicit ADC trigger source setting.

The ADCONF.ADCWS field defines the number of system clock periods, ranging from 1 to 32, for the following timing relationships between the ADC control signals:

- ADO.RC stable before ADO.CS period
- ADO.CS asserted period, when pulsed
- ADO.TRIG[2:0] event until ADO.CS asserted period
- Time-out period for ADO.RDY: 2048 * (1+ADCONF.ADCWS)
- Open-loop conversion timing: 512 * (1+ADCONF.ADCWS)

The ADCONF.DACWS field defines the number of system clock periods, ranging from 1 to 32, for the following timing relationships between the DAC control signals:

- ADO.Dout[15:0] stable before ADO.WR period
- ADO.WR asserted period
- ADO.Dout[15:0] stable after ADO.WR period

24.3.2 Status Register [ADSTAT] R

*Table 225.*Status register

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
15	**14**	**13**	**12**	**11**	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
									DACNO	DACRDY	DACON	ADCTO	ADCNO	ADCRDY	ADCON

6: DACNO DAC conversion request rejected (due to ongoing DAC or ADC conversion)
5: DACRDY DAC conversion completed
4: DACON DAC conversion ongoing
3: ADCTO ADC conversion timeout
2: ADCNO ADC conversion request rejected (due to ongoing ADC or DAC conversion)
1: ADCRDY ADC conversion completed
0: ADCON ADC conversion ongoing

When the register is read, the following sticky bit fields are cleared:

- DACNO, DACRDY,
- ADCTO, ADCNO, and ADCRDY.

Note that the status bits can be used for monitoring the progress of a conversion or to ascertain that the interface is free for usage.

24.3.3 ADC Data Input Register [ADIN] R/W

*Table 226.*ADC Data Input Register

31	16	15	0
		ADCIN	

15-0: ADCIN ADC input data *ADI.Din[15:0]*

A write access to the register initiates an analogue to digital conversion, provided that no other ADC or DAC conversion is ongoing (otherwise the request is rejected).

A read access that occurs before an ADC conversion has been completed returns the result from a previous conversion.

Note that any data can be written and that it cannot be read back, since not relevant to the initiation of the conversion.

Note that only the part of ADI.Din[15:0] that is specified by means of bit ADCONF.ADCDW is used by the ADC. The rest of the bits are read as zeros.

24.3.4 DAC Data Output Register [ADOUT] R/W

*Table 227.*DAC Data Output Register

31	16	15	0
		DACOUT	

15-0: DACOUT DAC output data *ADO.Dout[15:0]*

A write access to the register initiates a digital to analogue conversion, provided that no other DAC or ADC conversion is ongoing (otherwise the request is rejected).

Note that only the part of ADO.Dout[15:0] that is specified by means of ADCONF.DACDW is driven by the DAC. The rest of the bits are not driven by the DAC during a conversion.

Note that only the part of ADO.Dout[15:0] which is specified by means of ADCONF.DACDW can be read back, whilst the rest of the bits are read as zeros.

24.3.5 Address Input Register [ADAIN] R

*Table 228.*Address Input Register

31	8	7	0
		AIN	

7-0: AIN Input address *ADI.Ain[7:0]*

All bits are cleared to 0 at reset.

24.3.6 Address Output Register [ADAOUT] R/W

*Table 229.*Address Output Register

31	8	7	0
		AOUT	

7-0: AOUT Output address *ADO.Aout[7:0]*

All bits are cleared to 0 at reset.

24.3.7 Address Direction Register [ADADIR] R/W

*Table 230.*Address Direction Register

31	8	7	0
		ADIR	

7-0: ADIR Direction: *ADO.Aout[7:0]*

0b = input = high impedance,
1b = output = driven

All bits are cleared to 0 at reset.

24.3.8 Data Input Register [ADDIN] R

*Table 231.*Data Input Register

31	16	15	0
		DIN	

15-0: DIN Input data *ADI.Din[15:0]*

All bits are cleared to 0 at reset.

Note that only the part of ADI.Din[15:0] not used by the ADC can be used as general purpose input output, see ADCONF.ADCDW.

24.3.9 Data Output Register [ADDOUT] R/W

*Table 232.*Data Output Register

31	16	15	0
		DOUT	

15-0: DOUT Output data *ADO.Dout[15:0]*

All bits are cleared to 0 at reset.

Note that only the part of ADO.Dout[15:0] neither used by the DAC nor the ADC can be used as general purpose input output, see ADCONF.DACDW and ADCONF. ADCDW.

24.3.10 Data Register [ADDDIR] R/W

*Table 233.*Data Direction Register

31	16	15	0
		DDIR	

15-0: DDIR Direction: *ADO.Dout[15:0]*
0b = input = high impedance,
1b = output = driven

All bits are cleared to 0 at reset.

Note that only the part of ADO.Dout[15:0] not used by the DAC can be used as general purpose input output, see ADCONF.DACDW.

25 CAN 2.0 Controller

Note: The CAN 2.0 Controller is planned to be replaced by a CAN-FD controller in the next revision of the silicon. See section 56.

The GR716 microcontroller comprises two separate CAN 2.0 controller (GRCAN) units. Each CAN 2.0 controller unit controls its own external pins and has a unique AMBA address described in chapter 2.11.

The CAN 2.0 controller (GRCAN) units are located on APB bus in the address range from 0x80102000 to 0x80102FFF and 0x80103000 to 0x80103FFF. See GRCAN units connections in the next drawing. The drawing picture memory locations and functions used for GRCAN configuration and control.

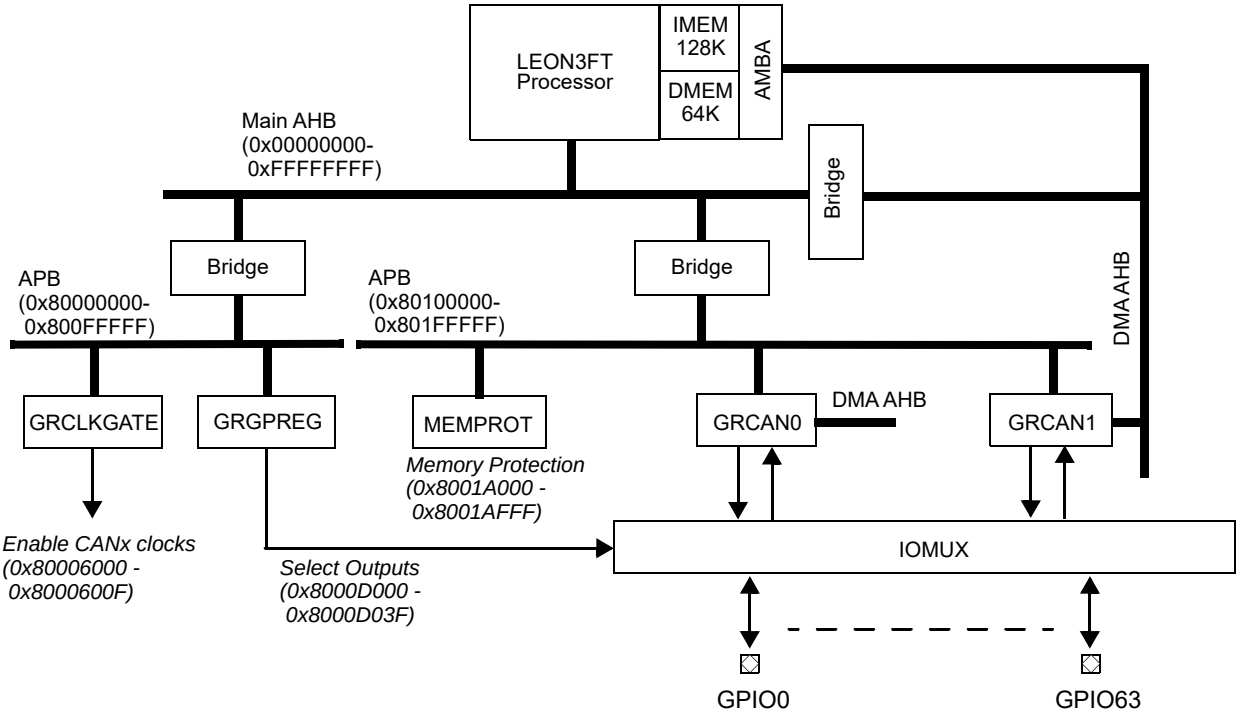


Figure 45. GR716 GRCAN bus and pin connection

The primary clock gating unit **GRCLKGATE** described in section 26 is used to enable/disable individual GRCAN units. The unit **GRCLKGATE** can also be used to perform reset of individual GRCAN units. Software must enable clock and release reset described in section 26 before GRCAN configuration and transmission can start.

External IO selection per GRCAN unit is made in the system IO configuration register (**GRGPREG**) in the address range from 0x8000D000 to 0x8000D03F. See section 7.1 for further information.

Each **GRACNx** unit controls its own external pins and has a unique AMBA address described in chapter 2.11. GRCAN unit 0 and 1 have identical configuration and status registers. Configuration and status registers are described in section 25.8.

System can be configured to protect and restrict access to individual GRCAN units in the **MEMPROT** unit. See section 47 for more information.

25.1 Overview

The CAN controller is assumed to operate in an AMBA bus system where both the AMBA AHB bus and the APB bus are present. The AMBA APB bus is used for configuration, control and status handling. The AMBA AHB bus is used for retrieving and storing CAN messages in memory external to the CAN controller. This memory can be located on-chip, as shown in the block diagram, or external to the chip.

The CAN controller supports transmission and reception of sets of messages by use of circular buffers located in memory external to the core. Separate transmit and receive buffers are assumed. Reception and transmission of sets of messages can be ongoing simultaneously.

After a set of message transfers has been set up via the AMBA APB interface the DMA controller initiates a burst of read accesses on the AMBA AHB bus to fetch messages from memory, which are performed by the AHB master. The messages are then transmitted by the CAN core. When a programmable number of messages have been transmitted, the DMA controller issues an interrupt.

After the reception has been set up via the AMBA APB interface, messages are received by the CAN core. To store messages to memory, the DMA controller initiates a burst of write accesses on the AMBA AHB bus, which are performed by the AHB master. When a programmable number of messages have been received, the DMA controller issues an interrupt.

The CAN controller can detect a SYNC message and generate an interrupt, which is also available as an output signal from the core. The SYNC message identifier is programmable via the AMBA APB interface. Separate synchronisation message interrupts are provided.

The CAN controller can transmit and receive messages on either of two CAN busses, but only on one at a time. The selection is programmable via the AMBA APB interface.

Note that it is not possible to receive a CAN message while transmitting one.

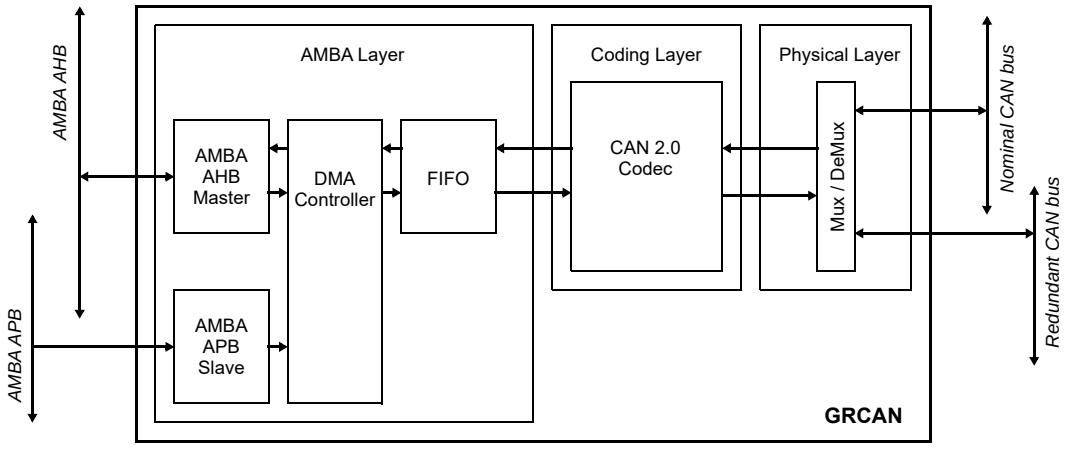


Figure 46. Block diagram

25.1.1 Function

The core implements the following functions:

- CAN protocol
- Message transmission
- Message filtering and reception
- SYNC message reception
- Status and monitoring

- Interrupt generation
- Redundancy selection

25.1.2 Interfaces

The core provides the following external and internal interfaces:

- CAN interface
- AMBA AHB master interface, with sideband signals as per [GRLIB] including:
- cacheability information
- interrupt bus
- configuration information
- diagnostic information
- AMBA APB slave interface, with sideband signals as per [GRLIB] including:
- interrupt bus
- configuration information
- diagnostic information

25.1.3 Hierarchy

The CAN controller core can be partitioned in the following hierarchical elements:

- CAN 2.0 Core
- Redundancy Multiplexer / De-multiplexer
- Direct Memory Access controller
- AMBA APB slave
- AMBA AHB master

25.2 Interface

The external interface towards the CAN bus features two redundant pairs of transmit output and receive input (i.e. 0 and 1).

The active pair (i.e. 0 or 1) is selectable by means of a configuration register bit. Note that all reception and transmission is made over the active pair.

For each pair, there is one enable output (i.e. 0 and 1), each being individually programmable. Note that the enable outputs can be used for enabling an external physical driver. Note that both pairs can be enabled simultaneously. Note that the polarity for the enable/inhibit inputs on physical interface drivers differs, thus the meaning of the enable output is undefined.

Redundancy is implemented by means of Selective Bus Access. Note that the active pair selection above provides means to meet this requirement.

25.3 Protocol

The CAN controller complies with CAN Specification Version 2.0 Part B, except for the overload frame generation.

Note that there are three different CAN types generally defined:

- 2.0A, which considers 29 bit ID messages as an error
- 2.0B Passive, which ignores 29 bit ID messages
- 2.0B Active, which handles 11 and 29 bit ID messages

Only 2.0B Active is implemented.

25.4 Status and monitoring

The CAN interface incorporates status and monitoring functionalities. This includes:

- Transmitter active indicator
- Bus-Off condition indicator
- Error-Passive condition indicator
- Over-run indicator
- 8-bit Transmission error counter
- 8-bit Reception error counter

The status is available via a register and is also stored in a circular buffer for each received message.

25.5 Transmission

The transmit channel is defined by the following parameters:

- base address
- buffer size
- write pointer
- read pointer

The transmit channel can be enabled or disabled.

25.5.1 Circular buffer

The transmit channel operates on a circular buffer located in memory external to the CAN controller. The circular buffer can also be used as a straight buffer. The buffer memory is accessed via the AMBA AHB master interface.

Each CAN message occupies 4 consecutive 32-bit words in memory. Each CAN message is aligned to 4 words address boundaries (i.e. the 4 least significant byte address bits are zero for the first word in a CAN message).

The size of the buffer is defined by the CanTxSIZE.SIZE field, specifying the number of CAN messages * 4 that fit in the buffer.

E.g. CanTxSIZE.SIZE =2 means 8 CAN messages fit in the buffer.

Note however that it is not possible to fill the buffer completely, leaving at least one message position in the buffer empty. This is to simplify wrap-around condition checking.

E.g. CanTxSIZE.SIZE =2 means that 7 CAN messages fit in the buffer at any given time.

25.5.2 Write and read pointers

The write pointer (CanTxWR.WRITE) indicates the position+1 of the last CAN message written to the buffer. The write pointer operates on number of CAN messages, not on absolute or relative addresses.

The read pointer (CanTxRD.READ) indicates the position+1 of the last CAN message read from the buffer. The read pointer operates on number of CAN messages, not on absolute or relative addresses.

The difference between the write and the read pointers is the number of CAN messages available in the buffer for transmission. The difference is calculated using the buffer size, specified by the CanTxSIZE.SIZE field, taking wrap around effects of the circular buffer into account.

Examples:

- There are 2 CAN messages available for transmit when CanTxSIZE.SIZE=2, CanTxWR.WRITE=2 and CanTxRD.READ=0.
- There are 2 CAN messages available for transmit when CanTxSIZE.SIZE=2, CanTxWR.WRITE =0 and CanTxRD.READ =6.
- There are 2 CAN messages available for transmit when CanTxSIZE.SIZE=2, CanTxWR.WRITE =1 and CanTxRD.READ =7.
- There are 2 CAN messages available for transmit when CanTxSIZE.SIZE=2, CanTxWR.WRITE =5 and CanTxRD.READ =3.

When a CAN message has been successfully transmitted, the read pointer (CanTxRD.READ) is automatically incremented, taking wrap around effects of the circular buffer into account. Whenever the write pointer CanTxWR.WRITE and read pointer CanTxRD.READ are equal, there are no CAN messages available for transmission.

25.5.3 Location

The location of the circular buffer is defined by a base address (CanTxADDR.ADDR), which is an absolute address. The location of a circular buffer is aligned on a 1kbyte address boundary.

25.5.4 Transmission procedure

When the channel is enabled (CanTxCTRL.ENABLE=1), as soon as there is a difference between the write and read pointer, a message transmission will be started. Note that the channel should not be enabled if a potential difference between the write and read pointers could be created, to avoid the message transmission to start prematurely.

A message transmission will begin with a fetch of the complete CAN message from the circular buffer to a local fetch-buffer in the CAN controller. After a successful data fetch, a transmission request will be forwarded to the CAN core. If there is at least an additional CAN message available in the circular buffer, a prefetch of this CAN message from the circular buffer to a local prefetch-buffer in the CAN controller will be performed. The CAN controller can thus hold two CAN messages for transmission: one in the fetch buffer, which is fed to the CAN core, and one in the prefetch buffer.

After a message has been successfully transmitted, the prefetch-buffer contents are moved to the fetch buffer (provided that there is message ready). The read pointer (CanTxRD.READ) is automatically incremented after a successful transmission, i.e. after the fetch-buffer contents have been transmitted, taking wrap around effects of the circular buffer into account. If there is at least an additional CAN message available in the circular buffer, a new prefetch will be performed.

If the write and read pointers are equal, no more prefetches and fetches will be performed, and transmission will stop.

If the single shot mode is enabled for the transmit channel (CanTxCTRL.SINGLE=1), any message for which the arbitration is lost, or failed for some other reason, will lead to the disabling of the channel (CanTxCTRL.ENABLE=0), and the message will not be put up for re-arbitration.

Interrupts are provided to aid the user during transmission, as described in detail later in this section. The main interrupts are the Tx, TxEmpty and TxIrq which are issued on the successful transmission of a message, when all messages have been transmitted successfully and when a predefined number of messages have been transmitted successfully. The TxLoss interrupt is issued whenever transmission arbitration has been lost, could also be caused by a communications error. The TxSync interrupt is issued when a message matching the SYNC Code Filter Register.SYNC and SYNC Mask Filter Register.MASK registers is successfully transmitted. Additional interrupts are provided to signal error conditions on the CAN bus and AMBA bus.

25.5.5 Straight buffer

It is possible to use the circular buffer as a straight buffer, with a higher granularity than the 1kbyte address boundary limited by the base address (CanTxADDR.ADDR) field.

While the channel is disabled, the read pointer (CanTxRD.READ) can be changed to an arbitrary value pointing to the first message to be transmitted, and the write pointer (CanTxWR.WRITE) can be changed to an arbitrary value.

When the channel is enabled, the transmission will start from the read pointer and continue to the write pointer.

25.5.6 AMBA AHB error

Definition:

- a message fetch occurs when no other messages is being transmitted
- a message prefetch occurs when a previously fetched message is being transmitted
- the local fetch buffer holds the message being fetched
- the local prefetch buffer holds the message being prefetched
- the local fetch buffer holds the message being transmitted by the CAN core
- a successfully prefetched message is copied from the local prefetch buffer to the local fetch buffer when that buffer is freed after a successful transmission.

An AHB error response occurring on the AMBA AHB bus while a CAN message is being fetched will result in a TxAHBErr interrupt.

If the CanCONF.ABORT bit is set to 0b, the channel causing the AHB error will skip the message being fetched from memory and will increment the read pointer. No message will be transmitted.

If the CanCONF.ABORT bit is set to 1b, the channel causing the AHB error will be disabled (CanTxCTRL.ENABLE is cleared automatically to 0 b). The read pointer can be used to determine which message caused the AHB error. Note that it could be any of the four word accesses required to read a message that caused the AHB error.

If the CanCONF.ABORT bit is set to 1b, all accesses to the AMBA AHB bus will be disabled after an AMBA AHB error occurs, as indicated by the CanSTAT.AHBErr bit being 1b. The accesses will be disabled until the CanSTAT register is read, and automatically clearing bit CanSTAT.AHBErr.

An AHB error response occurring on the AMBA AHB bus while a CAN message is being prefetched will not cause an interrupt, but will stop the ongoing prefetch and further prefetch will be prevented temporarily. The ongoing transmission of a CAN message from the fetch buffer will not be affected. When the fetch buffer is freed after a successful transmission, a new fetch will be initiated, and if this fetch results in an AHB error response occurring on the AMBA AHB bus, this will be handled as for the case above. If no AHB error occurs, prefetch will be allowed again.

25.5.7 Enable and disable

When an enabled transmit channel is disabled (CanTxCTRL.ENABLE=0b), any ongoing CAN message transfer request will not be aborted until a CAN bus arbitration is lost or the message has been sent successfully. If the message is sent successfully, the read pointer (CanTxRD.READ) is automatically incremented. Any associated interrupts will be generated.

The progress of the any ongoing access can be observed via the CanTxCTRL.ONGOING bit. The CanTxCTRL.ONGOING must be 0b before the channel can be re-configured safely (i.e. changing address, size or read pointer). It is also possible to wait for the Tx and TxLoss interrupts described hereafter.

The channel can be re-enabled again without the need to re-configure the address, size and pointers.

Priority inversion is handled by disabling the transmitting channel, i.e. setting CanTxCTRL.ENABLE=0b as described above, and observing the progress, i.e. reading via the CanTxCTRL.ONGOING bit as described above. When the transmit channel is disabled, it can be reconfigured and a higher priority message can be transmitted. Note that the single shot mode does not require the channel to be disabled, but the progress should still be observed as above.

No message transmission is started while the channel is not enabled.

25.5.8 Interrupts

During transmission several interrupts can be generated:

- TxLoss: Message arbitration lost for transmit (could be caused by communications error, as indicated by other interrupts as well)
- TxErrCntr: Error counter incremented for transmit
- TxSync: Synchronization message transmitted
- Tx: Successful transmission of one message
- TxEmpty: Successful transmission of all messages in buffer
- TxIrq: Successful transmission of a predefined number of messages
- TxAHBErr: AHB access error during transmission
- Off: Bus-off condition
- Pass: Error-passive condition

The Tx, TxEmpty and TxIrq interrupts are only generated as the result of a successful message transmission, after the CanTxRD.READ pointer has been incremented.

25.6 Reception

The receive channel is defined by the following parameters:

- base address
- buffer size
- write pointer
- read pointer

The receive channel can be enabled or disabled.

25.6.1 Circular buffer

The receive channel operates on a circular buffer located in memory external to the CAN controller. The circular buffer can also be used as a straight buffer. The buffer memory is accessed via the AMBA AHB master interface.

Each CAN message occupies 4 consecutive 32-bit words in memory. Each CAN message is aligned to 4 words address boundaries (i.e. the 4 least significant byte address bits are zero for the first word in a CAN message).

The size of the buffer is defined by the CanRxSIZE.SIZE field, specifying the number of CAN messages * 4 that fit in the buffer.

E.g. CanRxSIZE.SIZE=2 means 8 CAN messages fit in the buffer.

Note however that it is not possible to fill the buffer completely, leaving at least one message position in the buffer empty. This is to simplify wrap-around condition checking.

E.g. CanRxSIZE.SIZE=2 means that 7 CAN messages fit in the buffer at any given time.

25.6.2 Write and read pointers

The write pointer (CanRxWR.WRITE) indicates the position+1 of the last CAN message written to the buffer. The write pointer operates on number of CAN messages, not on absolute or relative addresses.

The read pointer (CanRxRD.READ) indicates the position+1 of the last CAN message read from the buffer. The read pointer operates on number of CAN messages, not on absolute or relative addresses.

The difference between the write and the read pointers is the number of CAN message positions available in the buffer for reception. The difference is calculated using the buffer size, specified by the CanRxSIZE.SIZE field, taking wrap around effects of the circular buffer into account.

Examples:

- There are 2 CAN messages available for read-out when CanRxSIZE.SIZE=2, CanRxWR.WRITE=2 and CanRxRD.READ=0.
- There are 2 CAN messages available for read-out when CanRxSIZE.SIZE=2, CanRxWR.WRITE =0 and CanRxRD.READ=6.
- There are 2 CAN messages available for read-out when CanRxSIZE.SIZE=2, CanRxWR.WRITE =1 and CanRxRD.READ=7.
- There are 2 CAN messages available for read-out when CanRxSIZE.SIZE=2, CanRxWR.WRITE =5 and CanRxRD.READ=3.

When a CAN message has been successfully received and stored, the write pointer (CanRxWR.WRITE) is automatically incremented, taking wrap around effects of the circular buffer into account. Whenever the read pointer CanRxRD.READ equals (CanRxWR.WRITE+1) modulo (CanRxSIZE.SIZE*4), there is no space available for receiving another CAN message.

The error behavior of the CAN core is according to the CAN standard, which applies to the error counter, buss-off condition and error-passive condition.

25.6.3 Location

The location of the circular buffer is defined by a base address (CanRxADDR.ADDR), which is an absolute address. The location of a circular buffer is aligned on a 1kbyte address boundary.

25.6.4 Reception procedure

When the channel is enabled (CanRxCTRL.ENABLE=1), and there is space available for a message in the circular buffer (as defined by the write and read pointer), as soon as a message is received by the CAN core, an AMBA AHB store access will be started. The received message will be temporarily stored in a local store-buffer in the CAN controller. Note that the channel should not be enabled until the write and read pointers are configured, to avoid the message reception to start prematurely

After a message has been successfully stored the CAN controller is ready to receive a new message. The write pointer (CanRxWR.WRITE) is automatically incremented, taking wrap around effects of the circular buffer into account.

Interrupts are provided to aid the user during reception, as described in detail later in this section. The main interrupts are the Rx, RxFull and RxIrq which are issued on the successful reception of a message, when the message buffer has been successfully filled and when a predefined number of messages have been received successfully. The RxMiss interrupt is issued whenever a message has been received but does not match a message filtering setting, i.e. neither for the receive channel nor for the SYNC message described hereafter.

The RxSync interrupt is issued when a message matching the SYNC Code Filter Register.SYNC and SYNC Mask Filter Register.MASK registers has been successfully received. Additional interrupts are provided to signal error conditions on the CAN bus and AMBA bus.

25.6.5 Straight buffer

It is possible to use the circular buffer as a straight buffer, with a higher granularity than the 1kbyte address boundary limited by the base address (CanRxADDR.ADDR) field.

While the channel is disabled, the write pointer (CanRxWR.WRITE) can be changed to an arbitrary value pointing to the first message to be received, and the read pointer (CanRxRD.READ) can be changed to an arbitrary value.

When the channel is enabled, the reception will start from the write pointer and continue to the read pointer.

25.6.6 AMBA AHB error

An AHB error response occurring on the AMBA AHB bus while a CAN message is being stored will result in an RxAHBErr interrupt.

If the CanCONF.ABORT bit is set to 0b, the channel causing the AHB error will skip the received message, not storing it to memory. The write pointer will be incremented.

If the CanCONF.ABORT bit is set to 1b, the channel causing the AHB error will be disabled (CanRxCTRL.ENABLE is cleared automatically to 0b). The write pointer can be used to determine which message caused the AHB error. Note that it could be any of the four word accesses required to writ a message that caused the AHB error.

If the CanCONF.ABORT bit is set to 1b, all accesses to the AMBA AHB bus will be disabled after an AMBA AHB error occurs, as indicated by the CanSTAT.AHBErr bit being 1b. The accesses will be disabled until the CanSTAT register is read, and automatically clearing bit CanSTAT.AHBErr.

25.6.7 Enable and disable

When an enabled receive channel is disabled (CanRxCTRL.ENABLE=0b), any ongoing CAN message storage on the AHB bus will not be aborted, and no new message storage will be started. Note that only complete messages can be received from the CAN core. If the message is stored successfully, the write pointer (CanRxWR.WRITE) is automatically incremented. Any associated interrupts will be generated.

The progress of the any ongoing access can be observed via the CanRxCTRL.ONGOING bit. The CanRxCTRL.ONGOING must be 0b before the channel can be re-configured safely (i.e. changing address, size or write pointer). It is also possible to wait for the Rx and RxMiss interrupts described hereafter.

The channel can be re-enabled again without the need to re-configure the address, size and pointers.

No message reception is performed while the channel is not enabled

25.6.8 Interrupts

During reception several interrupts can be generated:

- RxMiss: Message filtered away for receive
- RxErrCntr: Error counter incremented for receive
- RxSync: Synchronization message received
- Rx: Successful reception of one message
- RxFull: Successful reception of all messages possible to store in buffer
- RxIrq: Successful reception of a predefined number of messages
- RxAHBErr: AHB access error during reception
- OR: Over-run during reception

- OFF: Bus-off condition
- PASS: Error-passive condition

The Rx, RxFull and RxIrq interrupts are only generated as the result of a successful message reception, after the CanRxWR.WRITE pointer has been incremented.

The OR interrupt is generated when a message is received while a previously received message is still being stored. A full circular buffer will lead to OR interrupts for any subsequently received messages. Note that the last message stored which fills the circular buffer will not generate an OR interrupt. The overrun is also reported with the CanSTAT.OR bit, which is cleared when reading the register.

The error behavior of the CAN core is according to the CAN standard, which applies to the error counter, buss-off condition and error-passive condition.

25.7 Global reset and enable

When the CanCTRL.RESET bit is set to 1b, a reset of the core is performed. The reset clears all the register fields to their default values. Any ongoing CAN message transfer request will be aborted, potentially violating the CAN protocol.

When the CanCTRL.ENABLE bit is cleared to 0b, the CAN core is reset and the configuration bits CanCONF.SCALER, CanCONF.PS1, CanCONF.PS2, CanCONF.RSJ and CanCONF.BPR may be modified. When disabled, the CAN controller will be in sleep mode not affecting the CAN bus by only sending recessive bits. Note that the CAN core requires that 10 recessive bits are received before any reception or transmission can be initiated. This can be caused either by no unit sending on the CAN bus, or by random bits in message transfers.

25.8 Registers

The core is programmed through registers mapped into APB address space.

*Table 234.*GRCAN registers

APB address offset	Register
0x000	Configuration Register
0x004	Status Register
0x008	Control Register
0x018	SYNC Mask Filter Register
0x01C	SYNC Code Filter Register
0x100	Pending Interrupt Masked Status Register
0x104	Pending Interrupt Masked Register
0x108	Pending Interrupt Status Register
0x10C	Pending Interrupt Register
0x110	Interrupt Mask Register
0x114	Pending Interrupt Clear Register
0x200	Transmit Channel Control Register
0x204	Transmit Channel Address Register
0x208	Transmit Channel Size Register
0x20C	Transmit Channel Write Register
0x210	Transmit Channel Read Register
0x214	Transmit Channel Interrupt Register
0x300	Receive Channel Control Register
0x304	Receive Channel Address Register
0x308	Receive Channel Size Register
0x30C	Receive Channel Write Register
0x310	Receive Channel Read Register
0x314	Receive Channel Interrupt Register
0x318	Receive Channel Mask Register
0x31C	Receive Channel Code Register

25.8.1 Configuration Register [CanCONF] R/W

*Table 235.*Configuration Register

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
SCALER								PS1				PS2			
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
	RSJ					BPR				SAM	Silent	Select	Enable1	Enable0	Abort

31-24: SCALER Prescaler setting, 8-bit: system clock / (SCALER +1)
23-20: PS1 Phase Segment 1, 4-bit: (valid range 1 to 15)
19-16: PS2 Phase Segment 2, 4-bit: (valid range 2 to 8)
14-12: RSJ ReSynchronization Jumps, 3-bit: (valid range 1 to 4)
9:8: BPR Baud rate, 2-bit:
00b = system clock / (SCALER +1) / 1
01b = system clock / (SCALER +1) / 2
10b = system clock / (SCALER +1) / 4
11b = system clock / (SCALER +1) / 8

5: SAM Single sample when 0b. Triple sample when 1b.
4: SILENT Listen only to the CAN bus, send recessive bits.
3: SELECT Selection receiver input and transmitter output:
Select receive input 0 as active when 0b,
Select receive input 1 as active when 1b
Select transmit output 0 as active when 0b,
Select transmit output 1 as active when 1b
2: ENABLE1 Set value of output 1 enable
1: ENABLE0 Set value of output 0 enable
0: ABORT Abort transfer on AHB ERROR

All bits are cleared to 0 at reset.

Note that constraints on PS1, PS2 and RSJ are defined as:

- PS1 +1 >= PS2
- PS1 > PS2
- PS2 >= RSJ

Note that CAN standard TSEG1 is defined by PS1+1.

Note that CAN standard TSEG2 is defined by PS2.

Note that the SCALER setting defines the CAN time quantum, together with the BPR setting:

system clock / ((SCALER+1) * BPR)

where SCALER is in range 0 to 255, and the resulting division factor due to BPR is 1, 2, 4 or 8.

For a quantum equal to one system clock period, an additional quantum is added to the node delay. Note that for minimizing the node delay, then set either SCALER > 0 or BRP > 0.

Note that the resulting bit rate is:

system clock / ((SCALER+1) * BPR * (1+ PS1+1 + PS2))

where PS1 is in the range 1 to 15, and PS2 is in the range 2 to 8.

Note that RSJ defines the number of allowed re-synchronization jumps according to the CAN standard, being in the range 1 to 4.

For SAM = 0b (single), the bus is sampled once; recommended for high speed buses (SAE class C).

For SAM = 1b (triple), the bus is sampled three times; recommended for low/medium speed buses (SAE class A and B) where filtering spikes on the bus line is beneficial.

Note that the transmit or receive channel active during the AMBA AHB error is disabled if the ABORT bit is set to 1b. Note that all accesses to the AMBA AHB bus will be disabled after an AMBA AHB error occurs while the ABORT bit is set to 1b. The accesses will be disabled until the CanSTAT register is read.

25.8.2 Status Register [CanSTAT] R

*Table 236.*Status register

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
TxChannels				RxChannels				TxErrCntr							
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RxErrCntr											Active	AHB Err	OR	Off	Pass

31-28: TxChannelsNumber of TxChannels -1, 4-bit
27-24: RxChannelsNumber of RxChannels -1, 4-bit

23-16:	TxErrCntr	Transmission error counter, 8-bit
15-8:	RxErrCntr	Reception error counter, 8-bit
4:	ACTIVE	Transmission ongoing
3:	AHBErr	AMBA AHB master interface blocked due to previous AHB error
2:	OR	Overrun during reception
1:	OFF	Bus-off condition
0:	PASS	Error-passive condition

All bits are cleared to 0 at reset.

The OR bit is set if a message with a matching ID is received and cannot be stored via the AMBA AHB bus, this can be caused by bandwidth limitations or when the circular buffer for reception is already full.

The OR and AHBErr status bits are cleared when the register has been read.

Note that TxErrCntr and RxErrCntr are defined according to CAN protocol.

Note that the AHBErr bit is only set to 1b if an AMBA AHB error occurs while the CanCONF.ABORT bit is set to 1b.

25.8.3 Control Register [CanCTRL] R/W

*Table 237.*Control Register

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
														Reset	Enable

1:	RESET	Reset complete core when 1
0:	ENABLE	Enable CAN controller, when 1. Reset CAN controller, when 0

All bits are cleared to 0 at reset.

Note that RESET is read back as 0b.

Note that ENABLE should be cleared to 0b to while other settings are modified, ensuring that the CAN core is properly synchronized.

Note that when ENABLE is cleared to 0b, the CAN interface is in sleep mode, only outputting recessive bits.

Note that the CAN core requires that 10 recessive bits be received before receive and transmit operations can begin.

25.8.4 SYNC Code Filter Register [CanCODE] R/W

*Table 238.*SYNC Code Filter Register

31	30	29	28 ... 0
			SYNC

28-0:	SYNC	Message Identifier

All bits are cleared to 0 at reset.

Note that Base ID is bits 28 to 18 and Extended ID is bits 17 to 0.

25.8.5 SYNC Mask Filter Register [CanMASK] R/W

*Table 239.*SYNC Mask Filter Register

31	30	29	28 ... 0
			MASK

28-0: MASK Message Identifier

All bits are set to 1 at reset.

Note that Base ID is bits 28 to 18 and Extended ID is bits 17 to 0.

A RxSYNC message ID is matched when:

((Received-ID XOR CanCODE.SYNC) AND CanMASK.MASK) = 0

A TxSYNC message ID is matched when:

((Transmitted-ID XOR CanCODE.SYNC) AND CanMASK.MASK) = 0

25.8.6 Transmit Channel Control Register [CanTxCTRL] R/W

*Table 240.*Transmit Channel Control Register

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
15	**14**	**13**	**12**	**11**	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
													Sin-gle	Ong oing	Ena ble

2: SINGLE Single shot mode
1: ONGOING Transmission ongoing
0: ENABLE Enable channel

All bits are cleared to 0 at reset.

Note that if the SINGLE bit is 1b, the channel is disabled (i.e. the ENABLE bit is cleared to 0b) if the arbitration on the CAN bus is lost.

Note that in the case an AHB bus error occurs during an access while fetching transmit data, and the CanCONF.ABORT bit is 1b, then the ENABLE bit will be reset automatically.

At the time the ENABLE is cleared to 0b, any ongoing message transmission is not aborted, unless the CAN arbitration is lost or communication has failed.

Note that the ONGOING bit being 1b indicates that message transmission is ongoing and that configuration of the channel is not safe.

25.8.7 Transmit Channel Address Register [CanTxADDR] R/W

*Table 241.*Transmit Channel Address Register

31 ... 10	9 ... 0
ADDR	

31-10: ADDR Base address for circular buffer

All bits are cleared to 0 at reset.

25.8.8 Transmit Channel Size Register [CanTxSIZE] R/W

*Table 242.*Transmit Channel Size Register

31	21	20	6	5	0
		SIZE			

20-6: SIZE The size of the circular buffer is SIZE*4 messages

All bits are cleared to 0 at reset.

Valid SIZE values are between 0 and 16384.

Note that each message occupies four 32-bit words.

Note that the resulting behavior of invalid SIZE values is undefined.

Note that only (SIZE*4)-1 messages can be stored simultaneously in the buffer. This is to simplify wrap-around condition checking.

25.8.9 Transmit Channel Write Register [CanTxWR] R/W

*Table 243.*Transmit Channel Write Register

31	20	19	4	3	0
		WRITE			

19-4: WRITE Pointer to last written message +1

All bits are cleared to 0 at reset.

The WRITE field is written to in order to initiate a transfer, indicating the position +1 of the last message to transmit.

Note that it is not possible to fill the buffer. There is always one message position in buffer unused. Software is responsible for not over-writing the buffer on wrap around (i.e. setting WRITE=READ).

The field is implemented as relative to the buffer base address (scaled with the SIZE field).

25.8.10 Transmit Channel Read Register [CanTxRD] R/W

*Table 244.*Transmit Channel Read Register

31	20	19	4	3	0
		READ			

19-4: READ Pointer to last read message +1

All bits are cleared to 0 at reset.

The READ field is written to automatically when a transfer has been completed successfully, indicating the position +1 of the last message transmitted.

Note that the READ field can be use to read out the progress of a transfer.

Note that the READ field can be written to in order to set up the starting point of a transfer. This should only be done while the transmit channel is not enabled.

Note that the READ field can be automatically incremented even if the transmit channel has been disabled, since the last requested transfer is not aborted until CAN bus arbitration is lost.

When the Transmit Channel Read Pointer catches up with the Transmit Channel Write Register, an interrupt is generated (TxEmpty). Note that this indicates that all messages in the buffer have been transmitted.

The field is implemented as relative to the buffer base address (scaled with the SIZE field).

25.8.11 Transmit Channel Interrupt Register [CanTxIRQ] R/W

*Table 245.*Transmit Channel Interrupt Register

31	20	19	4	3	0
		IRQ			

19-4: IRQ Interrupt is generated when CanTxRD.READ=IRQ, as a consequence of a message transmission

All bits are cleared to 0 at reset.

Note that this indicates that a programmed number of messages have been transmitted.

The field is implemented as relative to the buffer base address (scaled with the SIZE field).

25.8.12 Receive Channel Control Register [CanRxCTRL] R/W

*Table 246.*Receive Channel Control Register

31	2	1	0
		OnGoing	Enable

1: ONGOING Reception ongoing (read-only)
0: ENABLE Enable channel

All bits are cleared to 0 at reset.

Note that in the case an AHB bus error occurs during an access while fetching transmit data, and the CanCONF.ABORT bit is 1b, then the ENALBE bit will be reset automatically.

At the time the ENABLE is cleared to 0b, any ongoing message reception is not aborted

Note that the ONGOING bit being 1b indicates that message reception is ongoing and that configuration of the channel is not safe.

25.8.13 Receive Channel Address Register [CanRxADDR] R/W

*Table 247.*Receive Channel Address Register

31	10	9	0
ADDR			

31-10: ADDR Base address for circular buffer

All bits are cleared to 0 at reset.

25.8.14 Receive Channel Size Register [CanRxSIZE] R/W

*Table 248.*Receive Channel Size Register

31	21	20	6	5	0
		SIZE			

20-6: SIZE The size of the circular buffer is SIZE*4 messages

All bits are cleared to 0 at reset.

Valid SIZE values are between 0 and 16384.

Note that each message occupies four 32-bit words.

Note that the resulting behavior of invalid SIZE values is undefined.

Note that only (SIZE*4)-1 messages can be stored simultaneously in the buffer. This is to simplify wrap-around condition checking.

25.8.15 Receive Channel Write Register [CanRxWR] R/W

*Table 249.*Receive Channel Write Register

31	20	19	4	3	0
		WRITE			

19-4: WRITE Pointer to last written message +1

All bits are cleared to 0 at reset.

The field is implemented as relative to the buffer base address (scaled with the SIZE field).

The WRITE field is written to automatically when a transfer has been completed successfully, indicating the position +1 of the last message received.

Note that the WRITE field can be use to read out the progress of a transfer.

Note that the WRITE field can be written to in order to set up the starting point of a transfer. This should only be done while the receive channel is not enabled.

25.8.16 Receive Channel Read Register [CanRxRD] R/W

*Table 250.*Receive Channel Read Register

31	20	19	4	3	0
		READ			

19-4: READ Pointer to last read message +1

All bits are cleared to 0 at reset.

The field is implemented as relative to the buffer base address (scaled with the SIZE field).

The READ field is written to in order to release the receive buffer, indicating the position +1 of the last message that has been read out.

Note that it is not possible to fill the buffer. There is always one message position in buffer unused. Software is responsible for not over-reading the buffer on wrap around (i.e. setting WRITE=READ).

25.8.17 Receive Channel Interrupt Register [CanRxIRQ] R/W

*Table 251.*Receive Channel Interrupt Register

31	20	19	4	3	0
		IRQ			

19-4: IRQ Interrupt is generated when CanRxWR.WRITE=IRQ, as a consequence of a message reception

All bits are cleared to 0 at reset.

Note that this indicates that a programmed number of messages have been received.

The field is implemented as relative to the buffer base address (scaled with the SIZE field).

25.8.18 Receive Channel Mask Register [CanRxMASK] R/W

*Table 252.*Receive Channel Mask Register

31	30	29	28 ... 0
			AM

28-0: AM Acceptance Mask, bits set to 1b are taken into account in the comparison between the received message ID and the CanRxCODE.AC field

All bits are set to 1 at reset.

Note that Base ID is bits 28 to 18 and Extended ID is bits 17 to 0.

25.8.19 Receive Channel Code Register [CanRxCODE] R/W

*Table 253.*Receive Channel Code Register

31	30	29	28 ... 0
			AC

28-0: AC Acceptance Code, used in comparison with the received message

All bits are cleared to 0at reset.

Note that Base ID is bits 28 to 18 and Extended ID is bits 17 to 0.

A message ID is matched when:

((Received-ID XOR CanRxCODE.AC) AND CanRxMASS.AM) = 0

25.8.20 Interrupt registers

The interrupt registers give complete freedom to the software, by providing means to mask interrupts, clear interrupts, force interrupts and read interrupt status.

When an interrupt occurs the corresponding bit in the Pending Interrupt Register is set. The normal sequence to initialize and handle a module interrupt is:

- Set up the software interrupt-handler to accept an interrupt from the module.
- Read the Pending Interrupt Register to clear any spurious interrupts.
- Initialize the Interrupt Mask Register, unmasking each bit that should generate the module interrupt.
- When an interrupt occurs, read the Pending Interrupt Status Register in the software interrupt-handler to determine the causes of the interrupt.
- Handle the interrupt, taking into account all causes of the interrupt.
- Clear the handled interrupt using Pending Interrupt Clear Register.

Masking interrupts: After reset, all interrupt bits are masked, since the Interrupt Mask Register is zero. To enable generation of a module interrupt for an interrupt bit, set the corresponding bit in the Interrupt Mask Register.

Clearing interrupts: All bits of the Pending Interrupt Register are cleared when it is read or when the Pending Interrupt Masked Register is read. Reading the Pending Interrupt Masked Register yields the contents of the Pending Interrupt Register masked with the contents of the Interrupt Mask Register.

Selected bits can be cleared by writing ones to the bits that shall be cleared to the Pending Interrupt Clear Register.

Forcing interrupts: When the Pending Interrupt Register is written, the resulting value is the original contents of the register logically OR-ed with the write data. This means that writing the register can force (set) an interrupt bit, but never clear it.

Reading interrupt status: Reading the Pending Interrupt Status Register yields the same data as a read of the Pending Interrupt Register, but without clearing the contents.

Reading interrupt status of unmasked bits: Reading the Pending Interrupt Masked Status Register yields the contents of the Pending Interrupt Register masked with the contents of the Interrupt Mask Register, but without clearing the contents.

The interrupt registers comprise the following:

- Pending Interrupt Masked Status Register[CanPIMSR]R
- Pending Interrupt Masked Register[CanPIMR]R
- Pending Interrupt Status Register[CanPISR]R
- Pending Interrupt Register[CanPIR]R/W
- Interrupt Mask Register[CanIMR]R/W
- Pending Interrupt Clear Register[CanPICR]W

*Table 254.*Interrupt registers

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
															Tx Loss
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Rx Miss	Tx Err Cntr	Rx Err Cntr	Tx Sync	Rx Sync	Tx	Rx	Tx Empty	Rx Full	Tx IRQ	Rx IRQ	Tx AHB Err	Rx AHB Err	OR	Off	Pass

16: TxLoss Message arbitration lost during transmission (could be caused by communications error, as indicated by other interrupts as well)
15: RxMiss Message filtered away during reception
14: TxErrCntr Transmission error counter incremented
13: RxErrCntr Reception error counter incremented
12: TxSync Synchronization message transmitted
11: RxSync Synchronization message received
10: Tx Successful transmission of message
9: Rx Successful reception of message
8: TxEmpty Successful transmission of all messages in buffer
7: RxFull Successful reception of all messages possible to store in buffer
6: TxIRQ Successful transmission of a predefined number of messages
5: RxIRQ Successful reception of a predefined number of messages
4: TxAHBErr AHB error during transmission
3: RxAHBErr AHB error during reception
2: OR Over-run during reception
1: OFF Bus-off condition
0: PASS Error-passive condition

All bits in all interrupt registers are reset to 0b after reset.

Note that the TxAHBErr interrupt is generated in such way that the corresponding read and write pointers are valid for failure analysis. The interrupt generation is independent of the CanCONF.ABORT field setting.

Note that the RxAHBErr interrupt is generated in such way that the corresponding read and write pointers are valid for failure analysis. The interrupt generation is independent of the CanCONF.ABORT field setting.

25.9 Memory mapping

The CAN message is represented in memory as shown in table 255.

*Table 255.*CAN message representation in memory.

AHB addr

0x0

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
IDE	RTR	-	bID											eID	
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
eID															

0x4

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
DLC				-	-	-	-	TxErrCntr							
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RxErrCntr								-	-	-	-	AhbErr	OR	Off	Pass

0x8

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Byte 0 (first transmitted)								Byte 1							
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Byte 2								Byte 3							

0xC

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Byte 4								Byte 5							
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Byte 6								Byte 7 (last transmitted)							

Values: Levels according to CAN standard: 1b is recessive, 0b is dominant

Legend: Naming and number in according to CAN standard

IDE Identifier Extension: 1b for Extended Format, 0b for Standard Format

RTR Remote Transmission Request: 1b for Remote Frame, 0b for Data Frame

bID Base Identifier

eID Extended Identifier

DLC Data Length Code, according to CAN standard:

0000b 0 bytes
0001b 1 byte
0010b 2 bytes
0011b 3 bytes
0100b 4 bytes
0101b 5 bytes
0110b 6 bytes
0111b 7 bytes

1000b 8 bytes
OTHERS illegal

TxErrCntr Transmission Error Counter
RxErrCntr Reception Error Counter
AHBErr AHB interface blocked due to AHB Error when 1b
OR Reception Over run when 1b
OFF Bus Off mode when 1b
PASS Error Passive mode when 1b
Byte 00 to 07 Transmit/Receive data, Byte 00 first Byte 07 last

26 Clock gating unit (Primary)

The GR716 microcontroller have 2 separate clock gating units. Each clock gating unit will control its own clock domains and has a unique AMBA address described in chapter 2.11.

26.1 Overview

The clock gating unit provides a mean to save power by disabling the clock to unused functional blocks. The core provides a mechanism to automatically disabling the clock to the LEON processor when it is in power-down mode, and also to disable the clock for the shared floating-point unit. The also core provides a mechanism to reset, enable clock and disable clock for following cores:

- FTMCTRL
- SPI4S
- GRSPWTDP
- GRMEMPROT
- L3STAT
- UART
- GRPWM
- I2C
- SPI
- GRPWRX
- GRPWTX
- SPI2AHB
- I2C2AHB
- NVRAM

The core provides a register interface via its APB slave bus interface.

26.2 Operation

The operation of the clock gating unit is controlled through four registers: the unlock, clock enable, core reset and CPU/FPU override registers. The clock enable register defines if a clock is enabled or disabled. A ‘1’ in a bit location will enable the corresponding clock, while a ‘0’ will disable the clock. The core reset register allows to generate a reset signal for each generated clock. A reset will be generated as long as the corresponding bit is set to ‘1’. The bits in clock enable and core reset registers can only be written when the corresponding bit in the unlock register is 1. If a bit in the unlock register is 0, the corresponding bits in the clock enable and core reset registers cannot be written.

To gate the clock for a core, the following procedure should be applied:

1. Disable the core through software to make sure it does not initialize any AHB accesses
2. Write a 1 to the corresponding bit in the unlock register
3. Write a 0 to the corresponding bit in the clock enable register
4. Write a 0 to the corresponding bit in the unlock register

To enable the clock for a core, the following procedure should be applied

1. Write a 1 to the corresponding bit in the unlock register
2. Write a 1 to the corresponding bit in the core reset register
3. Write a 1 to the corresponding bit in the clock enable register

4. Write a 0 to the corresponding bit in the clock enable register
5. Write a 0 to the corresponding bit in the core reset register
6. Write a 1 to the corresponding bit in the clock enable register
7. Write a 0 to the corresponding bit in the unlock register

The clock gating unit also provides gating for the processor core and floating-point unit. The processor core will be automatically gated off when it enters power-down mode.

The FPU will be gated off when the LEON3FT processor core connected to the FPU have floating-point disabled or when the LEON3FT processor core is in power-down mode.

Processor/FPU clock gating can be disabled by writing ‘1’ to bit 0 of the CPU/FPU override register.

26.3 Registers

The core’s registers are mapped into APB address space.

Table 256. Clock gate unit registers

APB address offset	Register
0x00	Unlock register 0
0x04	Clock enable register 0
0x08	Core reset register 0
0x0C	CPU/FPU override register 0
0x10 - 0xFF	Reserved

26.3.1 Unlock register 0

*Table 257.*0x00 - UNLOCK1 - Unlock register 1

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
R	R	SP	TD	AS	MP	AU	L3	R	R	H5	U4	U3	U2	U1	U0	P1	P0	DA	IS1	IS0	IM1	IM0	S1	S0	M1	M0	MC	PX	PR	IA	SA
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
r	r	rw	rw	rw	rw	rw	rw	rw	r	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

31: 30 RESERVED

29: 0 Unlock clock enable and reset registers (UNLOCK) - The bits in clock enable and core reset registers can only be written when the corresponding bit in this field is 1. See Table 258 for bit field description

26.3.2 Clock enable register 0

*Table 258.*0x04 - CLKEN1 - Clock enable register 1

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
R	NV	SP	TD	AS	MP	AU	L3	ID	R	H5	U4	U3	U2	U1	U0	P1	P0	DA	IS1	IS0	IM1	IM0	S1	S0	M1	M0	MC	PX	PR	IA	SA
0	0**	0**	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0**	0**	0	0	0**	0**	0**	0	0	0**	0**
r	rw	rw	rw	rw	rw	rw	rw	rw	r	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

31: 30 RESERVED

30 Clock Enable NVRAM (NV)

29 Clock enable SPI4S (SP)

28 Clock enable GRSPWTDP (TD)

27 Clock enable ASUP (AS)

26 Clock enable MEMPROT (MP)

25 Clock enable AHBUART (AU)

24 Clock enable L3STAT (L3)

23 IO Disable (ID) See section 8 for more information

22 RESERVED

21 Clock enable APBUART5 (U5)

20 Clock enable APBUART4 (U4)

19 Clock enable APBUART3 (U3)

18 Clock enable APBUART2 (U2)

17 Clock enable APBUART1 (U1)

16 Clock enable APBUART0 (U0)

15 Clock enable GRPWM2 (P2)

14 Clock enable GRPWM1 (P1)

13 Clock enable GRDACADC (DA)

12 Clock enable I2CLSV1 (IS1)

11 Clock enable I2CLSV0 (IS0)

10 Clock enable I2CMST1 (IM1)

9 Clock enable I2CMST0 (IM0)

8 Clock enable SPICTRL1 (S1)

7 Clock enable SPICTRL0 (S0)

6 Clock enable SPIMCTRL1 (M1)

5 Clock enable SPIMCTRL0 (M0)

4 Clock enable FTMCTRL (MC)

3 Clock enable GRPWTX (PX)

*Table 258.*0x04 - CLKEN1 - Clock enable register 1

2	Clock enable GRPWRX (PR)
1	Clock enable I2C2AHB (IA)
0	Clock enable SPI2AHB (SA)

* Cock enable - A ‘1’ in a bit location will enable the corresponding clock, while a ‘0’ will disable the clock.

** Clock enable might be set to ’1’ by bootstrap signals or boot SW during startup of the device

26.3.3 Core reset register 0

Table 259. 0x08 - RESET1 - Reset register 1

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
R	NV	SP	TD	AS	MP	AU	L3	ID	R	H5	U4	U3	U2	U1	U0	P1	P0	DA	IS1	IS0	IM1	IM0	S1	S0	M1	M0	MC	PX	PR	IA	SA
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
r	r	rw	rw	rw	rw	rw	rw	rw	r	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

31	RESERVED
30: 0	Reset (RESET) - A reset will be generated as long as the corresponding bit is set to ‘1’. See Table 258 for bit field description

26.3.4 CPU/FPU override register 0

Table 260. 0x0c - OVERRIDE1 - CPU/FPU override register 1

31 17	16	15 1	0
RESERVED	FOVERRIDE	RESERVED	OVERRIDE
0	0	0	0
r	rw	r	rw

31: 17	RESERVED
16	Override FPU clock gating (FOVERRIDE) - If bit n of this field is set to ’1’ then the clock for FPU n will be active regardless of the value of %PSR.EF.
15: 1	RESERVED
0	Override CPU clock gating (OVERRIDE) - If bit n of this field is set to ’1’ then the clock for the processor and FPU will always be active.

27 Clock gating unit (Secondary)

The GR716 microcontroller have 2 separate clock gating units. Each clock gating unit will control its own clock domains and has a unique AMBA address described in chapter 2.11.

27.1 Overview

The clock gating unit provides a mean to save power by disabling the clock to unused functional blocks. The core provides a mechanism to reset, enable clock and disable clock for following cores:

- GRDMA
- GR1553
- GRCAN
- GRSPW
- GRADC
- GRDAC
- GRSEQ

The core provides a register interface via its APB slave bus interface.

27.2 Operation

The operation of the secondary clock gating unit is controlled through three registers: the unlock, clock enable and core reset registers. The clock enable register defines if a clock is enabled or disabled. A ‘1’ in a bit location will enable the corresponding clock, while a ‘0’ will disable the clock. The core reset register allows to generate a reset signal for each generated clock. A reset will be generated as long as the corresponding bit is set to ‘1’. The bits in clock enable and core reset registers can only be written when the corresponding bit in the unlock register is 1. If a bit in the unlock register is 0, the corresponding bits in the clock enable and core reset registers cannot be written.

To gate the clock for a core, the following procedure should be applied:

1. Disable the core through software to make sure it does not initialize any AHB accesses
2. Write a 1 to the corresponding bit in the unlock register
3. Write a 0 to the corresponding bit in the clock enable register
4. Write a 0 to the corresponding bit in the unlock register

To enable the clock for a core, the following procedure should be applied

1. Write a 1 to the corresponding bit in the unlock register
2. Write a 1 to the corresponding bit in the core reset register
3. Write a 1 to the corresponding bit in the clock enable register
4. Write a 0 to the corresponding bit in the clock enable register
5. Write a 0 to the corresponding bit in the core reset register
6. Write a 1 to the corresponding bit in the clock enable register
7. Write a 0 to the corresponding bit in the unlock register

27.3 Registers

The core’s registers are mapped into APB address space.

Table 261. Clock gate unit registers

APB address offset	Register
0x00	Unlock register 1
0x04	Clock enable register 1
0x08	Core reset register 1
0x0C - 0xFF	Reserved

27.3.1 Unlock register 1

*Table 262.*0x00 - UNLOCK1 - Unlock register 1

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RESERVED										S1	S0	A7	A6	A5	A4	A3	A2	A1	A0	D3	D2	D1	D0	SP	C1	C0	ML	D3	D2	D1	D0
0										0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
r										rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

31: 22 RESERVED

21: 0 Unlock clock enable and reset registers (UNLOCK) - The bits in clock enable and core reset registers can only be written when the corresponding bit in this field is 1. See Table 263 for bit field description

27.3.2 Clock enable register 1

*Table 263.*0x04 - CLKEN1 - Clock enable register 1

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RESERVED										S1	S0	A7	A6	A5	A4	A3	A2	A1	A0	D3	D2	D1	D0	SP	C1	C0	ML	D3	D2	D1	D0
0										0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
r										rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

31: 22 RESERVED

21 Clock enable GPIO Sequencer (S1)

20 Clock enable GPIO Sequencer (S0)

19 Clock enable GRADC7 (A7)

18 Clock enable GRADC6 (A6)

17 Clock enable GRADC5 (A5)

16 Clock enable GRADC4 (A4)

15 Clock enable GRADC3 (A3)

14 Clock enable GRADC2 (A2)

13 Clock enable GRADC1 (A1)

12 Clock enable GRADC0 (A0)

11 Clock enable GRDAC3 (D3)

10 Clock enable GRDAC2 (D2)

9 Clock enable GRDAC1 (D1)

8 Clock enable GRDAC0 (D0)

7 Clock enable GRSPW (SP)

6 Clock enable GRCAN1 (C1)

5 Clock enable GRCAN0 (C0)

4 Clock enable GR1553B (ML)

3 Clock enable GRDMAC (D3)

2 Clock enable GRDMAC (D2)

1 Clock enable GRDMAC (D1)

0 Clock enable GRDMAC (D0)

* Cock enable - A ‘1’ in a bit location will enable the corresponding clock, while a ‘0’ will disable the clock.

** Clock enable might be set to ’1’ by bootstrap signals or boot software during startup of the device

27.3.3 Core reset register 1

Table 264. 0x08 - RESET1 - Reset register 1

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RESERVED										S1	S0	A7	A6	A5	A4	A3	A2	A1	A0	D3	D2	D1	D0	SP	C1	C0	ML	D3	D2	D1	D0
0										0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
r										rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

31: 22 RESERVED

21: 0 Reset (RESET) - A reset will be generated as long as the corresponding bit is set to ‘1’. See Table 263 for bit field description

28 DMA Controller with internal AHB/APB bridge

The GR716 microcontroller comprises 4 separate DMA controller with internal AHB/APB bridge units (GRDMAC). The GRDMAC units described in this section provides a flexible direct memory access controller. The core can perform burst transfers of data between AHB and APB peripherals at aligned or unaligned memory addresses.

The control and status register for the DMA controller units are located on APB bus in the address range from 0x80106000 to 0x80109FFF. See DMA controller units connections in the next drawing. The drawing picture memory locations and bus connections used for DMA controller units.

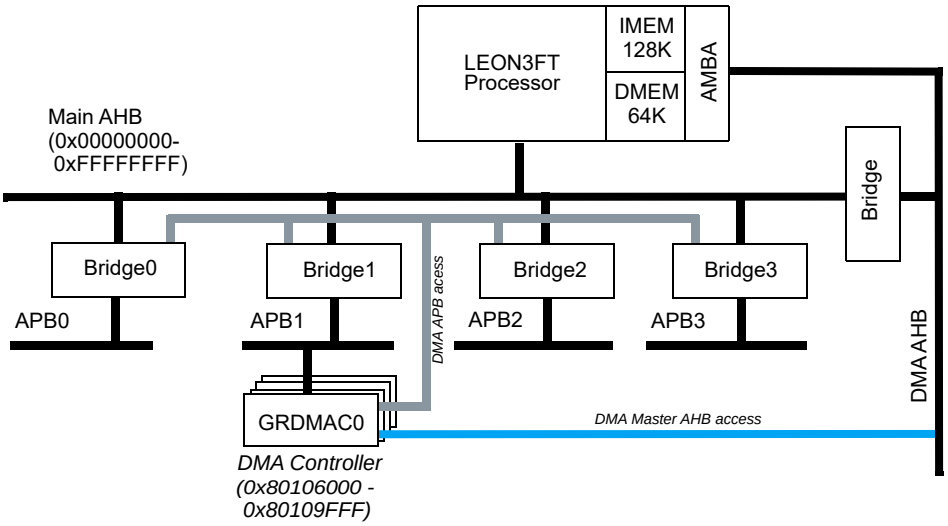


Figure 47. GR716 GRDMACx bus connection

The primary clock gating unit **GRCLKGATE** described in section 26 is used to enable/disable the individual DMA controller units. The unit **GRCLKGATE** can also be used to perform reset of individual DMA controller units. Software must enable clock and release reset described in section 26 before configuration.

The system can be configured to protect and restrict access to DMA controller units.

28.1 Overview

The GR716 provides 4 individual DMA cores. Each DMA core provides a flexible direct memory access controller. The core can perform burst transfers of data between AHB and APB peripherals at aligned or unaligned memory addresses.

One DMA channel per DMA controller is supported. The channel can be configured flexibly by means of two descriptor chains residing in main memory: a Memory to Buffer (M2B) chain and a Buffer to Memory (B2M) chain. Each chain is composed of a linked list of descriptors, where each descriptor specifies an AHB address and the size of the data to read/write, supporting a scatter/gather behavior.

Once enabled, the core will proceed in reading the descriptor chains, then reading memory mapped addresses specified by the M2B chain and filling its internal buffer. It will then write the content of the buffer back to memory mapped addresses by elaborating the B2M descriptor chain.

The core supports a simplified mode of operation, with only one channel. In this mode of operation only one descriptor is present for each of the M2B and B2M chains. These two descriptors are written directly in the core's register via APB.

28.2 Configuration

The GRDMAC core consists of four main components: the DMA control unit, the AHB Master interface, the internal buffer with realignment support and second AHB Master interface. The core will perform two types of DMA transfers through one of the AMBA AHB Master interfaces: from memory to the internal buffer (M2B) and from the internal buffer to memory (B2M). The core will read data from memory until its internal buffer is filled or until the M2B descriptor chain is completed. When one of these two events is detected, GRDMAC will start writing the buffer content into memory, by switching to the B2M chain.

28.2.1 Core setup

The GRDMAC core reads its configuration from any memory mapped address (typically the on-chip data memory). The M2B and B2M descriptor linked lists must be set up, and a pointer to the first descriptor in the two chains must be provided. These pointers are organized in a structure called Channel Vector. The Channel Vector is organized as in Table 265, below. For the GRDMAC channel there are two pointers: one pointer to the M2B descriptor linked list and one pointer to the B2M descriptor linked list. The Channel Vector array must be created at a 128-byte-aligned address.

*Table 265.*GRDMAC Channel Vector format

Address offset	Field
0x00	Channel 0: M2B descriptor pointer
0x04	Channel 0: B2M descriptor pointer

28.2.2 Descriptor specification

Fields that are named RESERVED, RES, or R are read-only fields. These fields can be written with zero or with the value read from the same register field

28.2.3 Descriptor type 0

Each descriptor consists of a four-field structure as provided in the tables below and must be created at a 16-byte-aligned address. There are three descriptor types: M2B descriptors, B2M descriptors and conditional descriptors.

The former two descriptors, categorized as data descriptors, are only allowed in the respective descriptor linked lists (M2B descriptor linked list and B2M descriptor linked list).

Conditional descriptors on the other hand, are required to be followed by a data descriptor, to which they bond to, and they can be specified in both the M2B and B2M descriptor linked lists. They are special descriptors that enable conditional behavior in a descriptor linked list and they are described in more detail in paragraph 28.3.2.

28.2.4 Descriptor type 1

Special descriptor type 1 consists of a eight field structure. Descriptor type 1 is a extension of the conditional descriptor type 0. The descriptor type 1, are required to be followed by a data descriptor, to which they bond to, and can only be specified in both the M2B and B2M descriptor linked list. They are special descriptors that enable conditional behavior in a descriptor linked list and they are described in more detail in paragraph 28.3.2

28.2.5 Data descriptors

For data descriptors, the first field, the next_descriptor field, is the address of the next descriptor in the chain. The chain ends with a descriptor whose next_descriptor field is all zeroes (NULL pointer).

The second field of an M2B descriptor, the address field, defines the address to read the data from. It can be any address in the system, and there are no alignment requirements. The number of bytes to transfer from memory to the internal buffer is specified in the third field, the control field, as seen in the table below.

Fields that are named RESERVED, RES, or R are read-only fields. These fields can be written with zero or with the value read from the same register field.

*Table 266.*GRDMAC M2B descriptor format

Address offset	Field
0x0	M2B next_descriptor
0x4	M2B address
0x8	M2B control
0xC	M2B status

Table 267. GRDMAC M2B descriptor next_descriptor field (address offset 0x00)

31	4	3	1	0
NEXT_PTR		VER		DT

31: 4	M2B Next descriptor pointer address (NEXT_PTR) - MSb of 16 Byte aligned address of the next descriptor in the M2B descriptor chain or NULL.
3: 1	M2B descriptor version. This bitfield should be set to ’0’ in normal mode and set to ’1’ for extended mode
0	M2B descriptor type (DT) - Descriptor type field, ‘0’ for data descriptors, ‘1’ for conditional descriptors. Must be set to ‘0’ for this type of descriptor.

Table 268. GRDMAC M2B descriptor address field (address offset 0x04)

31	0
ADDR	

31: 0	M2B Address (ADDR) - Starting address the core will read data from.

Table 269. GRDMAC M2B descriptor control field (address offset 0x08)

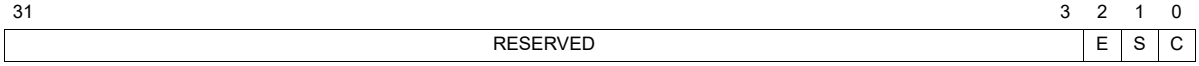
31	16	15	6	5	4	3	2	1	0
SIZE		RESERVED		FS	FA	AN	IE	WB	EN

31: 16	M2B descriptor size (SIZE) - Size in Bytes of the data that will be fetched from the address specified in the M2B address register.
5	M2B descriptor Fixed Start address (FS) - If set to ’1’ in extended mode the start address for each new descriptor transfer is reset to default set in the descriptor address field. If this bit is ’0’ the next descriptor start address will be incremented with the size of the current transfer.
4	M2B descriptor Fixed Address (FA) - If set to ‘1’, the data will be fetched from the same address for the entire size of the descriptor transfer. This is useful when reading from IO peripheral registers in combination with a conditional descriptor. If set to ‘0’, normal operation mode is attained.

Table 269. GRDMAC M2B descriptor control field (address offset 0x08)

3	M2B descriptor AHB Master Interface Number (AN) - If set to ‘0’, the descriptor’s transfer will be performed by the main AHB Master Interface (AHBM0). If set to ‘1’, the descriptor’s transfer will be performed by the second AHB Master Interface (AHBM1).
2	M2B descriptor Interrupt Enable (IE) - If set to one, an interrupt will be generated when the M2B descriptor is completed. Descriptor interrupt generation also depends on interrupt mask for channel 0 and global interrupt enable.
1	M2B descriptor write-back (WB) - If set to one, the descriptor’s status field will be written back in main memory after completion.
0	M2B descriptor Enable (EN) - If set to one, the descriptor will be enabled, otherwise it will be skipped and the next descriptor fetched from memory.

Table 270. GRDMAC M2B descriptor status field (address offset 0x0C)



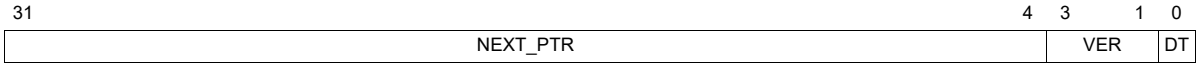
2	M2B descriptor error (E) - If set to one, an error was generated during execution of the M2B descriptor. See error register for more information.
1	M2B descriptor status (S) - If set to one, the descriptor is being executed and running. Otherwise set to zero.
0	M2B descriptor completion (C) - If set to one, the descriptor was completed successfully.

For the B2M chain, the same holds true, with the exception of the address field, which specifies the address in main memory to write to.

*Table 271.*GRDMAC B2M descriptor format

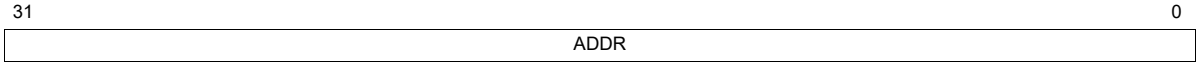
Address offset	Field
0x0	B2M next_descriptor
0x4	B2M address
0x8	B2M control
0xC	B2M status

Table 272. GRDMAC B2M descriptor next_descriptor field (address offset 0x00)



31: 4	B2M Next descriptor pointer address (NEXT_PTR) - Address of the next descriptor in the B2M descriptor chain or NULL.
3: 1	B2M descriptor version. This bit field should be set to ’0’ in normal mode and set to ’1’ for extended mode
0	B2M descriptor type (DT) - Descriptor type field, ‘0’ for data descriptors, ‘1’ for conditional descriptors. Must be set to ‘0’ for this type of descriptor.

Table 273. GRDMAC B2M descriptor address field (address offset 0x04)



31: 0	B2M Address (ADDR) - Starting address the core will write data to.

Table 274. GRDMAC B2M descriptor control field (address offset 0x08)

31	16	15	7	5	4	3	2	1	0
SIZE		RESERVED		FS	FA	AN	IE	WB	EN

31: 16	B2M descriptor size (SIZE) - Size in Bytes of the data that will be written to the address specified in the B2M address register.
5	B2M descriptor Fixed Start address (FS) - If set to ’1’ in extended mode the start address for each new descriptor transfer is reset to default set in the descriptor address field. If this bit is ’0’ the next descriptor start address will be incremented with the size of the current transfer.
4	B2M descriptor Fixed Address (FA) - If set to ‘1’, the data will be fetched from the same address for the entire size of the descriptor transfer. This is useful when writing to IO peripheral registers in combination with a conditional descriptor. If set to ‘0’, normal operation mode is attained.
3	B2M descriptor AHB Master Interface Number (AN) - If set to ‘0’, the descriptor’s transfer will be performed by the main AHB Master Interface (AHBM0). If set to ‘1’, the descriptor’s transfer will be performed by the second AHB Master Interface (AHBM1).
2	B2M descriptor Interrupt Enable (IE) - If set to one, an interrupt will be generated when the B2M descriptor is completed. Descriptor interrupt generation also depends on interrupt mask for channel 0 and global interrupt enable.
1	B2M descriptor write-back (WB) - If set to one, the descriptor’s status field will be written back in main memory after completion.
0	B2M descriptor Enable (EN) - If set to one, the descriptor will be enabled, otherwise it will be skipped and the next descriptor fetched from memory.

Table 275. GRDMAC B2M descriptor status field (address offset 0x0C)

31	3	2	1	0
RESERVED		E	S	C

2	B2M descriptor error (E) - If set to one, an error was generated during execution of the B2M descriptor. See error register for more information.
1	B2M descriptor status (S) - If set to one, the descriptor is being executed and running. Otherwise set to zero.
0	B2M descriptor completion (C) - If set to one, the descriptor was completed successfully.

If a descriptor’s write-back bit in its control field is set to one, the descriptor’s status field will be written back to memory after completion. The transfer uses the AMBA AHB Master interface of the core.

28.2.6 Conditional descriptors

A conditional descriptor is a special kind of descriptor which bonds to a data descriptor and provides additional conditional behavior to it. A conditional descriptor can be used to create a DMA channel that retrieves data from IO cores, therefore off loading the CPU from the task. Usually IO cores provide a status register or an interrupt line to notify the CPU of the availability of new data. A conditional descriptor can be set up to poll this status register or to be triggered by an interrupt, signaling for instance, the availability of new data. Once data is available, the bond data descriptor is executed, accumulating the data in the internal buffer of the DMA core, before bursting it to memory for the software to handle it.

There are, hence, two kinds of conditional descriptors: polling conditional descriptors or triggering conditional descriptors. The former kind will continuously poll an address for data, and once a termination condition on the retrieved data is met, will yield to the data descriptor. The latter kind will instead have the core entering a state where it waits for a monitored input signal line to trigger. When the monitored input line is sampled to a value of ‘1’, the data descriptor will be executed.

To set up a triggering conditional descriptor, the IT bit field in the descriptor's control field needs to be set to '1'. Bits 5:0 of the conditional address/triggering line field will specify which of the 64 input lines of the IRQ_TRIG signal will be monitored. During the execution of the triggering conditional descriptor, the triggering line is monitored every clock cycle, and when the value of the line is '1', the conditional execution will terminate and the data descriptor will be yield, fetching COND_SIZE bytes before going back to executing the conditional triggering. The data descriptor will be considered completed when all the bytes from the data descriptor, specified in the SIZE field, have been transfered, in amounts of COND_SIZE at each triggering. An optional timeout counter can be enabled during the triggering conditional descriptor execution. By setting the TE bit field in the core's control register to '1' and by setting the Timer Reset Value Register to the required number of clock cycles, the descriptor execution is halted with a Timeout Error if an interrupt is not received before the timer expires. The error halts the channel execution after eventual descriptor write-back is performed.

To set up a polling conditional descriptor, the DT bit field in the descriptor's control field needs to be set to '0'. Bits 31:0 of the conditional address/triggering line field will point to the address that the DMA core will poll for data until the termination condition is TRUE. The condition is specified as the bitwise AND between the 32-bit word pointed by COND_ADDR and the COND_MASK. This value is compared to 0 according to the following formulas, according to the termination condition type selected in the conditional control field (CT).

Table 276. GRDMAC Conditional descriptor Termination condition type 0

$$(*\text{COND_ADDR} \wedge \text{COND_MASK}) = 0$$

Table 277. GRDMAC Conditional descriptor Termination condition type 1

$$*\text{COND_ADDR} \wedge \text{COND_MASK} \neq 0$$

When the condition is TRUE, the conditional descriptor will stop polling and will proceed with fetching COND_SIZE bytes from the data descriptor pointed by NEXT_PTR. The behavior of conditional descriptors is explained in depth in paragraph 28.3.2.

Also in paragraph 28.3.2 is an example configuration of a conditional DMA channel for UART reading.

Fields that are named RESERVED, RES, or R are read-only fields. These fields can be written with zero or with the value read from the same register field.

*Table 278.*GRDMAC Conditional descriptor format

Address offset	Field
0x0	Conditional next_descriptor
0x4	Conditional address/triggering line
0x8	Conditional control
0xC	Conditional mask

Table 279. GRDMAC Conditional descriptor next_descriptor field (address offset 0x00)

31	4	3	1	0
NEXT_PTR		VER		DT

Table 279. GRDMAC Conditional descriptor next_descriptor field (address offset 0x00)

31: 4	Conditional Next descriptor pointer address (NEXT_PTR) - Address of the data descriptor in the descriptor chain which the conditional descriptor is bond to. Cannot be NULL.
3: 1	Conditional descriptor version. This bit field should be set to ’0’ in normal mode and set to ’1’ for extended mode
0	Conditional descriptor type (DT) - Descriptor type field, ‘0’ for data descriptors, ‘1’ for conditional descriptors. Must be set to ‘1’ for this type of descriptor.

Table 280. GRDMAC Conditional descriptor address field (address offset 0x04)

31	6	5	0
COND_ADDR[31:6]		COND_ADDR[5:0] / IRQN	

31: 0	Conditional Address (COND_ADDR) - Address of the 32-bit word the core will read for the conditional termination expression matching.
5: 0	IRQ Trigger Line Number (IRQN) - Index of the IRQ_TRIG signal input vector which is used as the triggering line for triggered conditional descriptors, 0 to 63.

Note: The register has dual purpose. When DMA is configured for polling all 32 bits are used for address and when DMA is configured for trigger events only 6 bits are used. Bits 6 to 31 are ignored for trigger events and should be regarded as a reserved bit field.

Table 281. GRDMAC Conditional descriptor control field (address offset 0x08)

31	16	15	4	3	2	1	0
COND_SIZE		COUNTER_RST		AN	CT	IT	EN

31: 16	Conditional descriptor total size (COND_SIZE) - Total size in Bytes of the data that will be fetched from the bond data descriptor each time the conditional termination expression matches to true.
15: 4	Conditional descriptor counter reset value (COUNTER_RST) - Reset value of the conditional counter timer that is executed before every polling or triggering. The unit is number of clock cycles and the purpose is to provide a timer between polling requests onto the AMBA AHB bus with enough clock cycles in order not to clog the bus.
3	Conditional descriptor AHB Master Interface Number (AN) - If set to ‘0’, the descriptor’s transfer will be performed by the main AHB Master Interface (AHBM0). If set to ‘1’, the descriptor’s transfer will be performed by the second AHB Master Interface (AHBM1).
2	Conditional descriptor Termination Condition type (CT) - If the conditional descriptor is of type “polling”, this bits specifies which type of termination condition is used. If ‘0’, the termination condition is of type 0 as specified in this paragraph. If ‘1’, the termination condition is of type 1.
1	Conditional Descriptor Irq Trigger (IT) - If set to ‘1’, the conditional descriptor will wait for the input interrupt line to go high before executing the bond data descriptor. The selected interrupt line is the one indexed by IRQN in the IRQ_TRIG signal input vector. This bit enables triggering behavior of conditional descriptors. If this bit is set to ‘0’, normal polling behavior with termination condition is enabled.
0	Conditional descriptor Enable (EN) - If set to one, the descriptor will be enabled, otherwise it will be skipped and the next descriptor fetched from memory.

Table 282. GRDMAC Conditional descriptor mask field (address offset 0x0C)

31	0
COND_MASK	

Table 282. GRDMAC Conditional descriptor mask field (address offset 0x0C)

31: 0	Conditional Mask (COND_MASK) - Bit mask used in the conditional descriptor termination condition matching.

28.2.7 Conditional descriptors type 1

The conditional descriptor type 1 is an extension of the descriptor type described in the chapter 28.2.4. The extension enables features to loop existing dma descriptor without software and automatic check and compare for 0's and 1's in a specific register before next descriptor is executed. Extra features are enabled by setting the bit Extended Mode (ME) in the GRDMAC control register and specifying descriptor version 0x1 in descriptors used.

The extended descriptor is designed to be used with external trigger. If polling functionality is needed it is recommended to setup a timer to trigger polling event to trigger poll an address for data. The conditional descriptor type 1 will entering a state where it waits for a monitored input signal line to trigger. When the monitored input line is sampled to a value of '1', the data descriptor will be executed.

To set up a triggering conditional descriptor, the IT bit field in the descriptor's control field needs to be set to '1'. Bits 5:0 of the conditional address/triggering line field will specify which of the 64 input lines of the IRQ_TRIG signal will be monitored. During the execution of the triggering conditional descriptor, the triggering line is monitored every clock cycle, and when the value of the line is '1', the status of the specified conditional register is checked for match. The status of the specified register needs match specified data and mask before conditional execution will terminate and the data descriptor will be yield, fetching COND_SIZE bytes before going back to executing the conditional triggering. An optional retry counter, COND_RETRIES, can be enabled to set the maximum number of retries that are allowed before conditional condition is considered to never be meet. Exceeding the number of retries will stop the DMA and an error event will be issued.

Direct and simple matching can be achieved by the following formula, according to the termination condition type selected in the conditional control field (CT)

Table 283. GRDMAC Conditional descriptor version 1 Termination condition type 0

$$((\text{COND_ADDR} \otimes \text{COND_DATA}) \wedge \text{COND_MASK}) = 0$$

The termination conditional be changed to check data in read register is not equal to by changing the conditional control field (CT)

Table 284. GRDMAC Conditional descriptor version 1 Termination condition type 1

$$((\text{COND_ADDR} \otimes \text{COND_DATA}) \wedge \text{COND_MASK}) \neq 0$$

The data descriptor will be considered completed when all the bytes from the data descriptor, specified in the SIZE field, have been transfered, in amounts of COND_SIZE at each triggering. An optional timeout counter can be enabled during the triggering conditional descriptor execution. By setting the TE bit field in the core's control register to '1' and by setting the Timer Reset Value Register to the required number of clock cycles, the descriptor execution is halted with a Timeout Error if an interrupt is not received before the timer expires. The error halts the channel execution after eventual descriptor write-back is performed.

The conditional descriptor will considered to be complete when the data descriptors has been executed the number of times specified in the conditional loop counter field, COND_CNT. When the

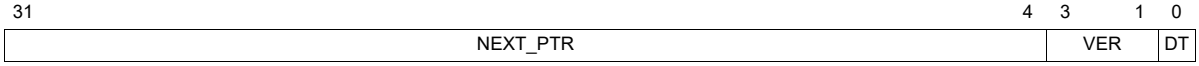
conditional descriptor is complete the status bit Conditional type 1 counter End (TE) in the error register will be set and an interrupt is issued if the interrupt enable bit is set in the control register.

Fields that are named RESERVED, RES, or R are read-only fields. These fields can be written with zero or with the value read from the same register field

*Table 285.*GRDMAC Conditional descriptor format version 1

Address offset	Field
0x0	Conditional next_descriptor
0x4	Conditional address
0x8	Conditional control
0xC	Conditional mask
0x10	Conditional data
0x14	Conditional trigger
0x18	Conditional extra
0x1C	Conditional protection

Table 286. GRDMAC Conditional descriptor next_descriptor field for version 1 (address offset 0x00)



31: 4 Conditional Next descriptor pointer address (NEXT_PTR) - Address of the data descriptor in the descriptor chain which the conditional descriptor is bond to. Cannot be NULL.

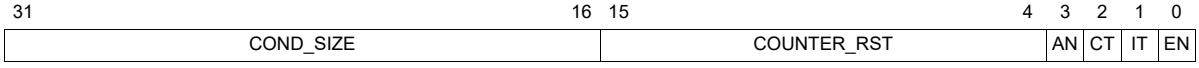
3: 1 Conditional descriptor version. This bit field should be set to ’0’ in normal mode and set to ’1’ for extended mode

0 Conditional descriptor type (DT) - Descriptor type field, ‘0’ for data descriptors, ‘1’ for conditional descriptors. Must be set to ‘1’ for this type of descriptor.

Table 287. GRDMAC Conditional descriptor address field for version 1 (address offset 0x04)

31: 0 Conditional Address (COND_ADDR) - Address of the 32-bit word the core will read for the conditional termination expression matching.

Table 288. GRDMAC Conditional descriptor control field for version 1 (address offset 0x08)



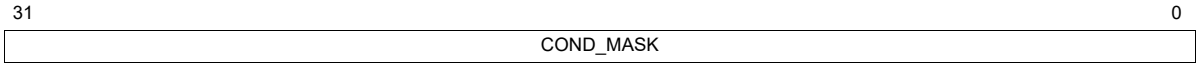
31: 16 Conditional descriptor total size (COND_SIZE) - Total size in Bytes of the data that will be fetched from the bond data descriptor each time the conditional termination expression matches to true.

15: 4 Conditional descriptor counter reset value (COUNTER_RST) - Reset value of the conditional counter timer that is executed before every polling or triggering. The unit is number of clock cycles and the purpose is to provide a timer between polling requests onto the AMBA AHB bus with enough clock cycles in order not to clog the bus.

Table 288. GRDMAC Conditional descriptor control field for version 1 (address offset 0x08)

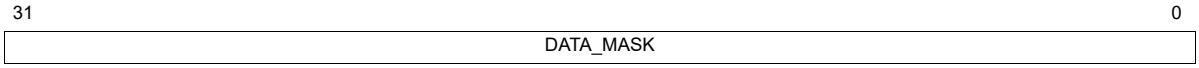
3	Conditional descriptor AHB Master Interface Number (AN) - If set to ‘0’, the descriptor’s transfer will be performed by the main AHB Master Interface (AHBM0). If set to ‘1’, the descriptor’s transfer will be performed by the second AHB Master Interface (AHBM1).
2	Conditional descriptor Termination Condition type (CT) - If the conditional descriptor is of type “polling”, this bits specifies which type of termination condition is used. If ‘0’, the termination condition is of type 0 as specified in this paragraph. If ‘1’, the termination condition is of type 1. For conditional type 1 this bit should be set to ’0’ for simple or direct match of data and mask.
1	Conditional Descriptor Irq Trigger (IT) - If set to ‘1’, the conditional descriptor will wait for the input interrupt line to go high before executing the bond data descriptor. The selected interrupt line is the one indexed by IRQN in the IRQ_TRIG signal input vector. This bit enables triggering behavior of conditional descriptors. If this bit is set to ‘0’, normal polling behavior with termination condition is enabled.
0	Conditional descriptor Enable (EN) - If set to one, the descriptor will be enabled, otherwise it will be skipped and the next descriptor fetched from memory.

Table 289. GRDMAC Conditional descriptor mask field for version 1 (address offset 0x0C)



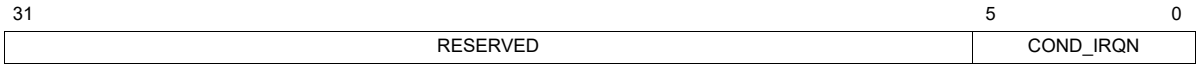
31: 0	Conditional Mask (COND_MASK) - Bit mask used in the conditional descriptor termination condition matching.

Table 290. GRDMAC Conditional descriptor data field for version 1 (address offset 0x10)



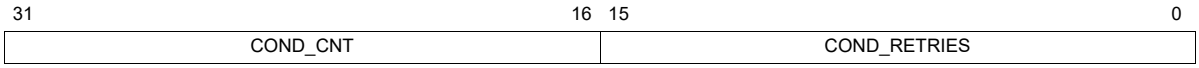
31: 0	Conditional DATA (DATA_MASK) - Bit data used in the conditional descriptor termination condition matching.

Table 291. GRDMAC Conditional IRQ trigger field for version 1 (address offset 0x14)



5: 0	IRQ Trigger Line Number (COND_IRQN) - Index of the IRQ_TRIG signal input vector which is used as the triggering line for triggered conditional descriptors, 0 to 63.

Table 292. GRDMAC Conditional descriptor extra field for version 1 (address offset 0x18)



31: 16	Conditional descriptor loop counter (COND_CNT) - number of times the descriptors should be executed. The counter counts the number of times all conditions are met in the conditional descriptor. If register is set to ’0’ the descriptors will be executed once. If register is set to ’0xFFFF’ descriptors will be executed until DMA controller is disabled manually by software or until an error will occur
15: 0	Conditional descriptor data register retry counter (COND_RETRIES) - The number of retries of the data and mask condition will be tried before an error is given. If register is set to ’0’ the data and mask will be tested once. If register is set to ’0xFFFF’ data and mask will be tested at every event until the DMA controller is disabled manually by software or until an error will occur.

Table 293. GRDMAC Conditional descriptor protection field for version 1 (address offset 0x1C)

31	30 ... 0
PE	COND_CRC

31	Conditional Protection Enable (PE) - Enable descriptor validation check of descriptor. If '1' an extra check will be performed to make sure the descriptors are read correctly into the memory
30: 0	Conditional descriptor data CRC (COND_CRC) - Data checksum for conditional type 1 descriptors

28.2.8 Register setup

Once the channel vector and the relative descriptor chain are setup in main memory, the GRDMAC register must be also setup. The 128-byte-aligned address, where the Channel Vector resides, must be written in the Channel Vector Pointer register. The control register must also be setup. Once the enable bit of the control register is set to one, the core will start running and will execute all the channels which are enabled.

28.3 Operation

28.3.1 Normal mode of operation

In normal mode of execution, GRDMAC will start executing all the enabled channels until they are complete or an error is generated.

When executing a DMA channel, the core will initially fetch the two descriptor pointers from the address provided in the CVP register which are relative to the channel. It will then fetch the first M2B and B2M descriptors from main memory. The M2B descriptor chain is then executed until either the internal buffer is full, or the M2B chain is completed. If one of this events happen, the core will switch to the B2M descriptor chain. The B2M chain will switch back to the M2B chain when the buffer is empty. The DMA channel is marked complete when the last descriptor in the B2M chain is executed, finally emptying the buffer.

During the execution of a chain, the core will fetch a new descriptor after the successful completion of the previous one, following the pointers in the linked list. When the core reaches a NULL pointer in the M2B chain, it will switch to the B2M chain. When it reaches a NULL pointer in the B2M chain, the core will update the DMA channel status and switch to the next enabled DMA channel, until all the channels are completed.

28.3.2 Operation with conditional descriptors

Conditional descriptors bond to the following data descriptor in the linked list and provide conditional behavior to the execution of the data descriptor. During the execution of a DMA channel, when the core fetches a conditional descriptor from memory, it will proceed and fetch the following descriptor in the chain as well, which must be a data descriptor.

After the descriptors' pair has been fetched, the conditional execution will follow these steps:

a) the core will execute the conditional counter, down counting for COUNTER_RST clock cycles

b) if the conditional descriptor is a polling descriptor, go to step **c1**, if it's a triggering descriptor, go to step **c2**.

c1) the core will fetch a 32-bit word at the COND_ADDR address.

d1) if the conditional termination condition of Table 277 is *false* then the core will go back to step **a,** if the conditional termination condition of Table 277 is *true*, the core will fetch a portion of the data from the data descriptor which is COND_SIZE bytes, then go back to step **a**.

c2) the core will monitor line IRQN of the IRQ_TRIG input signal.

d2) when the monitored line has a value of '1', the core will fetch a portion of the data from the data descriptor which is COND_SIZE bytes, then go back to step **a**.

The total SIZE of the bond data descriptor will be decremented by COND_SIZE bytes every time the bond data descriptor is executed, and the ADDRESS will be incremented by the same amount (unless the FA flag is set).

The FA (Fixed Address) bit field in the data descriptor control field is useful when accessing data to/from a peripheral data register, i.e. UART data register, when you need to read/write always from/to the same address.

The execution of the descriptor pair (conditional and bond data descriptors) ends when the SIZE field of the data descriptor reaches 0. In other words, the execution ends when SIZE bytes have been fetched in total from the data descriptor, by fetching COND_SIZE byte amounts every time the conditional condition (polling or triggering) is true.

28.3.3 Operation with conditional descriptors type 1

Conditional descriptors version 1 only associates with 1 pair of data descriptors which will be executed COND_CNT number of times.

Conditional descriptor and data descriptor will only be fetched once and kept in memory until completion or an error occur. Note that the conditional descriptor can be programed to loop in infinity and will only end at an error or when manually disabled by user or software.

After the descriptors' pair has been fetched, the conditional execution will follow these steps:

a) the core will execute the conditional counter, down counting for COUNTER_RST clock cycles

b) the core will monitor line COND_IRQN of the IRQ_TRIG input signal.

c) if trigger is detected read data at address COND_ADDR.

d) Match read data bits specified in bit fields COND_DATA and COND_MASK according to table 283 and 284. If *false* then the core will go back to step **b**.

The total SIZE of the bond data descriptor will be decremented by COND_SIZE bytes every time the bond data descriptor is executed, and the ADDRESS will be incremented by the same amount (unless the FA flag is set).

The FA (Fixed Address) bit field in the data descriptor control field is useful when accessing data to/from a peripheral data register, i.e. UART data register, when read/write always is executed from/to the same address.

The FS (Fixed Start address) bit field in the data descriptor control field is useful when accessing data to/from a peripheral with multiple data registers, i.e. multiple samples from the internal ADC interface, when read/write always is executed from/to the same addresses.

The conditional descriptor will considered to be complete when the data descriptors has been executed the number of times specified in the conditional loop counter field, COND_CNT. When the conditional descriptor is complete the status bit Conditional type 1 counter End (TE) in the error register will be set and an interrupt is issued if the interrupt enable bit is set in the control register.

28.3.4 Simplified mode of operation

In Simplified Mode of Operation, the GRDMAC core configuration resides entirely in its configuration registers and the Channel Vector structure is not used. The core will not perform any memory access to fetch configuration data. This mode of operation makes use of only two data descriptors,

respectively one descriptor for M2B transfers and one for B2M transfers. Conditional descriptors are not supported in this mode. The descriptors are written directly onto GRDMAC via APB at offsets 0x20 and 0x30. Their next_descriptor field is hardwired to zeroes. Their status is always written-back to their relative descriptor status register.

When the core is configured in Simplified mode of operation, the relative bit (SM) must be set to one in the control register. The core will execute the two internal descriptors on channel zero. Channel zero must therefore be enabled, and the core status can be read on channel zero's status bits in the status register.

28.4 AHB transfers

For every descriptor executed, GRDMAC will perform an AHB data transfer at the address and of the size specified. The AHB accesses can be at aligned or unaligned memory addresses.

The core will perform unaligned memory access if defined by the descriptors. It will perform byte (8 bit) accesses at byte-aligned addresses, half-word (16 bit) accesses at half-word aligned addresses

In some cases, the total transfer size might require GRDMAC to perform additional half-word and/or byte accesses at the end of the transfer. The burst accesses performed by GRDMAC are of type incrementing burst of unspecified length. These bursts will never cross a 1KB memory boundary. At the 1KB memory boundary the burst will be interrupted, an idle cycle will be inserted and the incrementing burst of unspecified length will restart from the next address.

28.5 Interrupts

GRDMAC provides fine-grained control of interrupt generation. At the highest level, the global Interrupt Enable bit (IE) in the control register can be set to zero to mask every other interrupt setting in the system. If set to one, interrupt generation depends on the following settings.

The Interrupt on Error Enable bit (IEE) in the control register provides a way to generate interrupts in the event of errors. Error generation is discussed further in the next paragraph.

An interrupt can be also generated by the successful completion of a descriptor, if the Interrupt Enable (IE) bit is set to one in the descriptor's control field. The Interrupt Mask bit (Ix) in the Interrupt Mask register can be set to zero to mask all the descriptor completion interrupts. If descriptor write-back is enabled, the interrupt will be generated after writing back the descriptor's status in main memory.

For both interrupts on error and interrupts on descriptor completion events, a flag will be raised in the interrupt flag register at the bit corresponding to the channel where the interrupt event happened (IFx).

As an example of interrupt generation setup, one can enable interrupt on channel completion by performing the following steps. The Interrupt Enable (IE) bit in GRDMAC control register must be set to one, as must be the relevant channel's interrupt mask bit in the Interrupt mask register. Finally the Interrupt Enable (IE) bit in the control field of the last descriptor in the B2M chain of the channel must be set to one, while the same field must be set to zero in every other descriptor in the channel. This way, when the last descriptor in the buffer to memory chain is completed successfully, an interrupt will be generated.

28.6 Errors

Six types of errors can be generated by GRDMAC. Transfer errors, descriptor errors, Channel Vector Pointer errors, conditional errors, conditional type 1 retry error, conditional type 1 counter error and timeout errors, as defined in the Error Register.

Transfer errors are generated when the core is accessing DMA data from and to memory and it encounters an AMBA AHB ERROR response. When a transfer error occurs on a descriptor which has the write-back flag enabled, the descriptor status will be written back to main memory with the error field set to one. An eventual interrupt will be generated only after the write back.

Descriptor errors are generated when an ERROR response is received while reading or writing back a descriptor in main memory.

Channel Vector Pointer errors are generated when the core receives an ERROR response when accessing the Channel Vector data structure in main memory.

Conditional errors are generated when a conditional polling descriptor encounters a problem during an AHB polling operation such as an ERROR response.

Conditional type 1 retry error are generated when the retry counter exceed the maximum number of allowed retries

Conditional type 1 counter error are generated when the conditional counter exceed the maximum number of allowed retries.

Finally timeout errors are caused by the timeout counter expiring before receiving an interrupt during triggered conditional descriptor execution. This requires the TE bit field in the control register to be configured to '1' during execution.

The core will enable the corresponding error type bit in the error register in addition to the error flag bit (E). The channel number where the error happened can be also read directly from the channel error field (CHERR) of the error register. Additionally an interrupt will be generated if the Interrupt on Error Enable bit (IEE) and the global Interrupt Enable (IE) bit in GRDMAC control register are set to one, and a flag will be raised in the interrupt flag register bit corresponding to the channel where the error event occurred (IFx).

28.7 Internal Buffer Readout Interface

In case of an error, the execution of the DMA channels will halt and the error will be reported as described in the previous session. It can happen that data that has been accumulated in the internal buffer during the M2B chain transactions, is not written out as part of the B2M chain, due to the channel halting. This internal data can still be read via the APB interface of the GRDMAC core, through the Internal Buffer Readout Interface memory area. The memory area is located at offset 0x800 of the GRDMAC core memory address, as seen in Table 294. This area can only be read when the core is in an idle state and bit flag EN of the Control Register is set to '0'. The amount of valid data in the internal buffer can be inferred by reading the read pointer and write pointers to the buffer from the Internal Buffer Pointers Register (offset 0x40).

28.8 Registers

The core is programmed through registers mapped into APB address space.

Fields that are named RESERVED, RES, or R are read-only fields. These fields can be written with zero or with the value read from the same register field.

*Table 294.*GRDMAC controller and status registers

APB address offset	Register
0x00	Control register
0x04	Status register
0x08	Interrupt mask register
0x0C	Error register
0x10	Channel Vector Pointer
0x14	Timer Reset Value Error Register
0x18	Capability register
0x1C	Interrupt flag register
0x20	Reserved
0x24	M2B Descriptor Address register*
0x28	M2B Descriptor Control register*
0x2C	M2B Descriptor Status register*
0x30	Reserved
0x34	B2M Descriptor Address register*
0x38	B2M Descriptor Control register*
0x3C	B2M Descriptor Status register*
0x800-0x81F	Internal Buffer Readout Area

*Only used in Simplified Mode of Operation

28.8.1 Control Register

*Table 295.*GRDMAC control register

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15 12	11 8	7	6	5	4	3	2	1	0
EF	EE	ED	EC	EB	EA	E9	E8	E7	E6	E5	E4	E3	E2	E1	E0	TSL	RESERVED	NS	EM	TE	SM	IEE	IE	RS	EN
NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	0	0	0	0	NR	NR	NR	0	0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	r	rw	rw	rw	rw	rw	rw	rw	rw

31: 16 Enable channel x (Ex) - Set to one to enable DMA channel x, from 0 to 15.

15 12 Transfer Size limit (TSL) - If set to 1, the GRDMAC core will limit its maximum transfer size to 32b accesses. If set to 2, it will limit the transfer size to 64 bits. If set to 3, it will limit the maximum transfer size to 128 bit. If set to 0 no limit is imposed.

7 No Starve Mode (NS) - Set to '1' forces the DMA controller to always switch queue after descriptor completion. This mode can be used to make sure fetched data in the m2b queue always gets handled by the b2m queue. When mode is used data transfers length of m2b queue shall match the b2m queue.

6 Extended Mode (ME) - Set to '1' to enable the use of extended conditional descriptor type 1.

5 Timer Enable (TE) - Set to '1' to enable the timeout timer during triggered conditional descriptor execution.

4 Simplified mode (SM) - Set to one to use the core in simplified mode of operation

3 Interrupt enable for Errors (IEE) - Set to one to enable interrupt generation on error. Interrupt generation on error depends on the global Interrupt Enable (IE).

2 Interrupt Enable (IE) - Global Interrupt Enable. If set to zero, no interrupt will be generated. If set to one, interrupts from errors, descriptor completion, won't be masked.

1 Reset (RS) - Resets the core register if set to one. Writing a '1' to this bit field will reset internal states and registers to default value.

0 Enable/Run (EN) - When set to one, the core will be enabled and start running.

28.8.2 Status Register

*Table 296.*GRDMAC status register

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
SF	SE	SD	SC	SB	SA	S9	S8	S7	S6	S5	S4	S3	S2	S1	S0	CF	CE	CD	CC	CB	CA	C9	C8	C7	C6	C5	C4	C3	C2	C1	C0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r	r

31: 16 Status of channel - Set to one if DMA channel is running, set to zero otherwise.

15: 0 Completion of channel - Set to one if DMA channel has completed successfully, zero otherwise.

28.8.3 Interrupt Mask

*Table 297.*GRDMAC Interrupt Mask

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RESERVED																IF	IE	ID	IC	IB	IA	I9	I8	I7	I6	I5	I4	I3	I2	I1	I0
0																NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
r																rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

15: 0 Interrupt Mask for channel - Set to 0 to mask descriptor interrupt generation from channel. Interrupt generation depends on the global Interrupt Enable in the control register.

28.8.4 Error Register

*Table 298.*GRDMAC error register

31 20	19 16	15 7	6	5	4	3	2	1	0
RESERVED	CHERR	RESERVED	TE	RE	ME	OE	TE	DE	CE	E
			0	0	0	0	0	0	0	0
	r		wc	wc	wc	wc	wc	wc	wc	wc

19: 16 Channel error (CHERR) - Channel number where last error was generated.

7 Conditional type 1 counter End (EE) - Conditional type 1 descriptor has finished

6 Conditional type 1 retry timeout Error (RE) - Conditional type 1 descriptor has ended due to retry counter has exceed the limit

5 Timeout Error (ME) - One if the last generated error was of type timeout error. This field is cleared by writing a one to it.

4 Conditional Error (OE) - One if the last generated error was of type conditional execution error. This field is cleared by writing a one to it.

3 Transfer Error (TE) - One if the last generated error was of type transfer error. This field is cleared by writing a one to it.

2 Descriptor Error (DE) - One if the last generated error was of type descriptor error. This field is cleared by writing a one to it.

1 CVP Error (CE) - One if the last generated error was of type CVP error. This field is cleared by writing a one to it.

0 Error (E) - If set to one, an error was generated by the entity. This field is cleared by writing a one to it.

28.8.5 Channel Vector Pointer

*Table 299.*GRDMAC Channel Vector Pointer

31 7	6 0
CVP	RESERVED
NR	
rw	

31: 7 Channel Vector Pointer (CVP) - 128 Byte aligned memory address pointing to the vector of up to 16 couples of descriptor chain pointers.

28.8.6 Timer Reset Value Register

*Table 300.*GRDMAC Timer reset value register

31 0
TIMER_RST
0x00
rw

31: 0 Timer Reset VAlue (TIMER_RST) - Reset value for the triggered conditional descriptor timeout

28.8.7 Capability Register

*Table 301.*GRDMAC capability register

31 16	15 12	11	10 9	8	7 4	3 0
BUFSZ	RESERVED	TT	R	H1	NCH	VER
4	0	1	0	1	15	3
r	r	r	r	r	r	r

31: 16 Buffer size (BUFSZ) - Internal DMA buffer is 4 words.

11 Timer (TT) - Tmeout timer is enabled.

*Table 301.*GRDMAC capability register

10:	9	Not used
	8	Second AHB Master (H1) - If set to one, the second AHB master interface (AHBM1) is enabled.
7:	4	Channel Number (NCH) - The maximum number of supported DMA channels in the core is 15+1.
3:	0	Version (VER) - GRDMAC version number.

28.8.8 Interrupt Flag Register

*Table 302.*GRDMAC interrupt flag register

31	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RESERVED		IFF	IFE	IFD	IFC	IFB	IFA	IF9	IF8	IF7	IF6	IF5	IF4	IF3	IF2	IF1	IF0
		NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
		rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

15: 0 Interrupt flag for channel - When set to one, an interrupt event (descriptor completion or error) was generated on channel. This field is cleared by writing a one to it.

28.8.9 M2B Descriptor Address Register*

*Table 303.*GRDMAC M2B descriptor address register*

31	0
ADDR	
NR	
rw	

31: 0 M2B Address (ADDR) - Starting address the core will read data from.

28.8.10 M2B Descriptor Control Register*

*Table 304.*GRDMAC M2B descriptor control register*

31	16	15	3	2	1	0
SIZE		RESERVED		IE	R	EN
NR		0		NR	0	NR
rw		r		rw	r	rw*

31: 16 M2B descriptor size (SIZE) - Size in Bytes of the data that will be fetched from the address specified in the M2B address register.

2 M2B descriptor Interrupt Enable (IE) - If set to one, an interrupt will be generated when the M2B descriptor is completed. Descriptor interrupt generation also depends on interrupt mask for channel 0 and global interrupt enable.

0 M2B descriptor Enable (EN) - Set to one when the descriptor is written the first time. Write value ignored.

28.8.11 M2B Descriptor Status Register*

*Table 305.*GRDMAC M2B descriptor status register*

31	3	2	1	0
RESERVED		E	S	C
0		0	0	0
r		rw	rw	rw

31 M2B Destination type (DT) - If set to zero, descriptor's address points to an AHB address. If set to one, it points to an APB address.

2 M2B descriptor error - If set to one, an error was generated during execution of the M2B descriptor. See error register for more information.

1 M2B descriptor status (S) - If set to one, the descriptor is being executed and running. Otherwise set to zero.

0 M2B descriptor completion (C) - If set to one, the descriptor was completed successfully.

28.8.12 B2M Descriptor Address Register*

*Table 306.*GRDMAC B2M descriptor address register*

31	0
ADDR	
NR	
rw	

31: 0 B2M Address (ADDR) - Starting address the core will write data to.

28.8.13 B2M Descriptor Control Register*

*Table 307.*GRDMAC B2M descriptor control register*

31 16	15 3	2	1	0
SIZE	RESERVED	IE	R	EN
NR	0	NR		NR
rw	r	rw		rw*

31: 16 B2M descriptor size (SIZE) - Size in Bytes of the data that will be written to the address specified in the B2M address register.

2 B2M descriptor Interrupt Enable (IE) - If set to one, an interrupt will be generated when the B2M descriptor is completed. Descriptor interrupt generation also depends on interrupt mask for channel 0 and global interrupt enable.

0 B2M descriptor Enable (EN) - Set to one when the descriptor is written the first time. Write value ignored.

28.8.14 B2M Descriptor Status Register*

*Table 308.*GRDMAC B2M descriptor status register*

31 3	2	1	0
RESERVED	E	S	C
r	0	0	0
0	rw	rw	rw

31 B2M Destination type (DT) - If set to zero, descriptor's address points to an AHB address. If set to one, it points to an APB address.

2 B2M descriptor error - If set to one, an error was generated during execution of the B2M descriptor. See error register for more information.

1 B2M descriptor status (S) - If set to one, the descriptor is being executed and running. Otherwise set to zero.

0 B2M descriptor completion (C) - If set to one, the descriptor was completed successfully.

*Register used only when the core is set to work in Simplified mode of operation.

28.9 DMA Transfer Example

In this example a single DMA channel will be set-up, using conditional descriptors, to gather data from the UART and write it into main memory.

The GRDMAC core is configured with its register address-space starting at address 0xCCC00200 and main memory starts at 0x40000000. The UART core register is mapped at 0xCCC00100 and the UART receiver FIFO queue is configured as 4 bytes.

The DMA channel will need two descriptors in the M2B chain: a conditional descriptor bound to a data descriptor. The B2M chain will only need one data descriptor.

The conditional descriptor will poll the UART status register, mapped at 0xCCC00104, and will use the mask 0x00000100 for the termination condition. This mask will be ANDed with the status regis-

ter, and the result of this operation will only show the value of the “Receiver FIFO half-full” field in the status register. This will enable the conditional register to stop polling when this bit becomes ‘1’. At this point the data descriptor will be executed for the amount of bytes specified in the conditional descriptor, which in this case is 1 bytes (half of the FIFO size). For the data transfer to read and accumulate correct data, the core must perform a single-byte access. The UART data register contains only one byte of relevant data. The size limit per transfer is therefore 1 byte and the address is marked as fixed, so the core will not increment it after every transfer.

The polling counter for the conditional descriptor is set according to the UART speed. If the UART baud rate is 38.4K and the system frequency is 100 MHz, one can assume that there is going to be 1 Byte available in the UART every 26k clock cycles. Setting the polling period to a value less than 26K will let the DMA get all the characters from the UART without missing any. The conditional counter reset value is set to its maximum, a period of 4095 clock cycles (0xFFF).

The polling will restart after the last read and the transfers will go on until the total size specified in the data descriptor is reached. At this point the M2B chain is completed and the core will proceed with the B2M chain, emptying the contents of its buffer into memory, at the address specified.

Table 309. Memory Content

Address	Data	Description
0x40000080	0x40020010	Channel Vector - Channel 0 M2B descriptor chain pointer
0x40000084	0x40020040	Channel Vector - Channel 0 B2M descriptor chain pointer
...	...	
0x40020010	0x40020031	M2B conditional descriptor 0 - next descriptor pointer (lsb set to 1 for cond. desc.)
0x40020014	0xCCC00104	M2B conditional descriptor 0 - address (UART status register address)
0x40020018	0x0001FFF1	M2B conditional descriptor 0 - control (poll every 4095 cycles, get 1 Byte)
0x4002001C	0x00000080	M2B conditional descriptor 0 - mask (only check “Receiver FIFO half-full”)
...	...	
0x40020030	0x00000000	M2B data descriptor 0 - next descriptor pointer (NULL, end of chain)
0x40020034	0xCCC00100	M2B data descriptor 0 - address (UART data register address)
0x40020038	0x04000011	M2B data descriptor 0 - control (1024 Bytes from fixed address)
0x4002003C	-	M2B data descriptor 0 - status (written by core)
...	...	
0x40020040	0x00000000	B2M data descriptor 0 - next descriptor pointer (NULL, end of chain)
0x40020044	0x40000	B2M data descriptor 0 - address (DMA write address for UART data)
0x40020048	0x04000001	B2M data descriptor 0 - control (1024 Bytes)
0x4002004C	-	B2M data descriptor 0 - status (written by core)
...	...	
0x40000	-	UART data written by the DMA controller
...	...	
0xCCC00200	0x	GRDMAC Control register
0xCCC00204	-	GRDMAC Status register (written by core)
0xCCC00208	0x	GRDMAC interrupt mask register
0xCCC0020C	-	GRDMAC error register (written by core)
0xCCC00200	0x40000080	GRDMAC channel vector pointer
0xCCC00204	-	Reserved
0xCCC00208	0x	GRDMAC capability register
0xCCC0020C	-	GRDMAC interrupt flag register (written by core)

28.9.1 Using the DMA to sample long sequences using conditional descriptor type 1

The build in DMA controller can be used in order to support long autonomous sampling (or low noise sampling) with out processor intervention.

For this example we extend the previous example in chapter 12.2.3 by using the DMA to transfer 8 samples from the ADC to the local memory before interrupting the processor. The DMA can be programmed to transfer a pre-defined or infinite number samples. (The software needs to disable the DMA if infinite transfer mode is enabled and no interrupt). The DMA controller can be programmed

to generate an interrupt after each transfer or at the end of the transfer. In this example we only generate an interrupt when all samples has been transfered in order to minimize the interrupt load.

In order to accomplish this we need to:

- Setup timer and ADC according to chapter 12.2.3
- Setup the DMA controller channel to respond to interrupt from ADC controller
- Program the DMA controller to read sample from fixed address when interrupt occur
- Program the DMA controller to write sample using incremental address

The correct sequence should be as the following address and data table:

TABLE 310. Example of transferring data from ADC to local processor memory using DMA

Address	Data	Description
...	...	
0x80050018	0x00000009	ADC0 - Mask register (Enable events from ADC0)
0x8005000C	0x00000800	ADC0 - Select trigger (counter 2 in timer unit 1)
0x80500008	0xB0000000	ADC0 - Sequencer control (Enable synchronization to ext trigger, continuously enabled)
0x80500004	0x000000FF	ADC0 - Sampling configuration (Oversampling, no consecutive)
0x80500000	0x00081	ADC0 - Configuration (Speed, Channel, Enable)

0x80200080	0x01000	Channel Vector - Channel 0 M2B descriptor chain pointer
0x80200084	0x01040	Channel Vector - Channel 0 B2M descriptor chain pointer
...	...	
0x01000	0x01023	M2B conditional descriptor 0 - next descriptor pointer (lsb set to 1 for cond. desc.)
0x01004	0x0000001C	M2B conditional descriptor 0 - address (ADC0 Interrupt register address)
0x01008	0x00040013	M2B conditional descriptor 0 - control (conditional trigger enable, get 4 Byte)
0x0100C	0x00000009	M2B conditional descriptor 0 - mask (check “End of Conversion” and "End of sequence")
0x01010	0x00000009	M2B conditional descriptor 0 - data (check “End of Conversion” and "End of sequence")
0x01014	0x0000001C	M2B conditional descriptor 0 - ADC0 event to trigger GRDMAC0
0x01018	0x00040004	M2B conditional descriptor 0 - Transfer 4 samples and configure retry to 8
0x0101C	0x80005A5A	M2B conditional descriptor 0 - Protection bits for checking DMA descriptor
...	...	
0x01020	0x00000002	M2B data descriptor 0 - next descriptor pointer (NULL, end of chain)
0x01024	0x80500010	M2B data descriptor 0 - address (DMA status register address)
0x01028	0x00040015	M2B data descriptor 0 - control (4 Bytes from fixed address)
0x0102C	-	M2B data descriptor 0 - status (written by core)
...	...	
0x01040	0x00000000	B2M data descriptor 0 - next descriptor pointer (NULL, end of chain)
0x01044	0x02000	B2M data descriptor 0 - address (DMA write address for ADC data)
0x01048	0x00040001	B2M data descriptor 0 - control (4 Bytes, Increment address)
0x0104C	-	B2M data descriptor 0 - status (written by core)
...	...	
0x02000	-	ADC data written by the DMA controller
0x02004	-	..
0x02008	-	..
0x0200C	-	..
0x02010	-	..
0x02014	-	..
0x02018	-	..
0x0201C	-	..
...	...	
0x01080	0x01000	Channel Vector - Channel 0 M2B descriptor chain pointer
0x01084	0x01040	Channel Vector - Channel 0 B2M descriptor chain pointer

TABLE 310. Example of transferring data from ADC to local processor memory using DMA

--	--	
0x80200000	0x0000002	GRDMAC Control register (Reset i.e. re-start core)
0x80200008	0x0000FFFF	GRDMAC interrupt mask register
0x80200010	0x31001080	GRDMAC channel vector pointer
0x80200000	0x001004D	GRDMAC Control register (Enable channel in extended mode)
---	---	
0x80050018	0x00000009	ADC0 - Mask register (Enable events from ADC0)
0x8005000C	0x00000800	ADC0 - Select trigger (counter 2 in timer unit 1)
0x80500008	0xB0000000	ADC0 - Sequencer control (Enable synchronization to ext trigger, continuously enabled)
0x80500004	0x000000FF	ADC0 - Sampling configuration (Oversampling, no consecutive)
0x80500000	0x00081	ADC0 - Configuration (Speed, Channel, Enable)
---	---	

After completion 4 oversampled values should be located in the local processor data ram at 0x02000.

29 General Purpose I/O Port

The GR716 microcontroller has 2 separate General Purpose I/O port (GRGPIO) units. Each General Purpose I/O port (GRGPIO) units controls its own external pins and has a unique AMBA address described in chapter 2.11.

The General Purpose I/O port (GRGPIO) units are located on APB bus in the address range from 0x8030C000 to 0x8030CFFF and 0x8030D000 to 0x8030DFFF. See General Purpose I/O port (GRGPIO) units connections in the next drawing. The figure shows memory locations and functions used for General Purpose I/O port (GRGPIO) configuration and control.

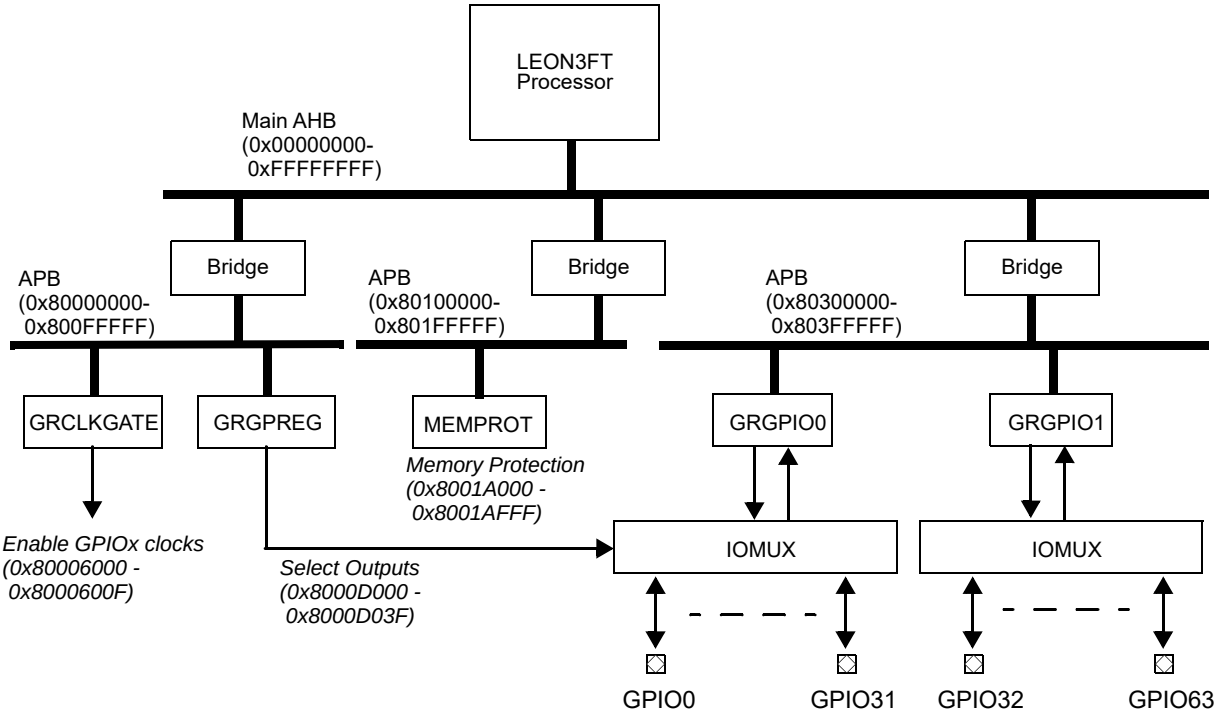


Figure 48. GR716 GRGPIO bus and pin connection

The primary clock gating unit **GRCLKGATE** described in section 26 is used to enable/disable individual General Purpose I/O port (GRGPIO) units. The unit **GRCLKGATE** can also be used to perform reset of individual General Purpose I/O port (GRGPIO) units. Software must enable clock and release reset described in section 26 before General Purpose I/O port (GRGPIO) configuration and transmission can start.

External IO selection per General Purpose I/O port (GRGPIO) unit is made in the system IO configuration register (**GRGPREG**) in the address range from 0x8000D000 to 0x8000D03F. See section 7.1 for further information.

Each **GRGPIOx** unit controls its own external pins and has a unique AMBA address described in chapter 2.11. GRGPIO unit 0 and 1 have identical configuration and status registers. Configuration and status registers are described in section 29.6.

The system can be configured to protect and restrict access to individual General Purpose I/O port (GRGPIO) unit in the **MEMPROT** unit. See section 47 for more information.

29.1 Overview

All 64 external pins can be configured as general purpose I/O. Each external pin in the general purpose mode can be individually set to input or output, and can optionally generate an interrupt. For interrupt generation, the input can be filtered for polarity and level/edge detection.

The GR716 microcontroller implements sequencer and sampler support for up to 8 individual general purpose I/O. Each sequencer/sampler supports a input/output sequence up to 32 bits. Longer sequences can be supported by cascading multiple general purpose I/O sequencer. By cascading the maximum sequence length is 4x32 bits.

The GR716 microcontroller comprises two GPIO units with support of 32 general purpose I/O each. Each separate GPIO unit has 4 sequencers. The split of the GPIOs into 2 units also separates the sequencers into 2 groups of 4 individual sequencers. Hence it is only possible to cascade sequencers within the same GPIO unit. Sequencer units 0, 1, 2 and 3 are connected and controlled via GPIO unit 0 while sequencer units 4, 5, 6 and 7 are connected and controlled via GPIO unit 1.

This chapter describes one GPIO unit. The two GPIO units in the GR716 are identical except for the physical external pin connected to GPIO unit 1 and GPIO unit 2. For separation in this document GPIO unit 1 are connected to external pins 0 to 31 and includes sequencer 0, 1, 2 and 3. GPIO unit 2 are connected to external pins 32 to 64 and includes sequencer 4, 5, 6 and 7. Each GPIO unit have a unique AMBA address described in chapter 2.11.

Note sequencer pins included in a cascaded chain doesn’t occupy a physical pin or pad

29.2 Operation

All external I/Os have bi-directional buffers with programmable output enable. The input from each buffer is synchronized by two flip-flops in series to remove potential meta-stability. The synchronized values can be read-out from the I/O port data register. The output enable is controlled by the I/O port direction register. A ‘1’ in a bit position will enable the output buffer for the corresponding I/O line. The output value driven is taken from the I/O port output register.

The GPIO interrupts has been implemented to support dynamic mapping of interrupts, each I/O line can be mapped using the Interrupt map register(s) to an interrupt line.

Interrupt generation is controlled by three registers: interrupt mask, polarity and edge registers. To enable an interrupt, the corresponding bit in the interrupt mask register must be set. If the edge register is ‘0’, the interrupt is treated as level sensitive. If the polarity register is ‘0’, the interrupt is active low. If the polarity register is ‘1’, the interrupt is active high. If the edge register is ‘1’, the interrupt is edge-triggered. The polarity register then selects between rising edge (‘1’) or falling edge (‘0’).

The GPIO core includes an Interrupt flag register that can be used to determine if, and which, GPIO pin that caused an interrupt to be asserted.

29.3 Pulse command

The pulse command outputs use one of the GR716 microcontroller common counter for establishing the pulse command start and length. The pulse command length defines the logical active part of the pulse. It is possible to select which of the channels shall generate a pulse command. The pulse command outputs are generated in phase with a selected trigger source. To send synchronized pulse commands on multiple outputs simultaneously the same trigger source shall be enabled for the selected outputs.

29.4 Pulse sequencer

GPIO output pin can be programmed to output a predefined sequence. The sequence is defined in the sequence memory and have the following configuration options:

- Divisor register controls the sequence-rate for the GPIO output pin.
- Sequence length register to determine the sequence length if the full length of the sequence memory isn't to be used
- Sequence loop register determines how many times the sequence should be looped
- Optionally generation of interrupt when sequence has finished
- Synchronize output sequence to another GPIO port
- Configurable delay before the start of the sequence

29.4.1 Operation modes

The sequencer can be programmed to output the sequence in the register SEQDATA using a system timer event or a internal prescaler. Default is to use a internal prescaler and the bit field Sequence synchronization Enable (SE) enables the use trigger events from system timers. The system timer synchronization source is determine by the register Sequence Synchronization Control register (SEQSYNC).

In the prescaler mode the sequence output frequency is determined by the prescaler SEQDIV and SDEL with the formula:

Table 311. GRGPIO prescaler output frequency

$$\frac{SystemClockFrequency}{SEQDIV \times SDEL}$$

In trigger mode the sequence output frequency is determined by the timer setup. See chapter for 35 form more information.

The output sequence is enabled by the bit field SE and is considered complete when the complete sequence length SEQLEN has been output SEQCNT number of times.

An interrupt can be generated when sequencer is complete if enabled in mask register. Note that SEQCNT can be set to infinite and sequencer will need to be disabled manually.

29.4.2 Cascade mode

Multiple sequencer memories can combined in order to generate sequences with more than 32 bits. Any GPIO sequencer can be connected to its neighbor. E.g. GPIO(n+1) can be connected to is neighbors GPIO(n) and GPIO(n+2). It is also possible to connect a chain of GPIO sequencers e.g. from GPIO(n) to GPIO(n+3) to create a sequence of 4x32 bits. Each GPIO used for creating longer sequences needs to be manually configured to be included in the chain. The GPIO sequencer outputting the sequence to an external pin should be marked as START and the final GPIO also determining how long the sequence will be should be marked as END. The GPIO not marked as START do not occupy any physical pins. It is possible to use the 4 GPIOs to create simultaneously two different chains, i.e. GPIO(n) connected with GPIO(n+1) and GPIO(n+2) connected with GPIO(n+3).

The sequence can be configured to loop infinitively or in a range from 1 to $\lfloor 255/N_{CHAIN} \rfloor$, where N_{CHAIN} is the number of GPIO sequencers in the cascade. When configured to infinite loop mode the software needs to stop the sequence manually by disabling the sequencer for the GPIO outputting the sequence to external pin.

In the example of using GPIO1 to GPIO4 the following configuration should be used in order to output a sequence of 4x32 states per port:

GPIO1: Cascade mode and START

GPIO2: Cascade mode

GPIO3: Cascade mode

GPIO4: Cascade mode and END

When enabled the sequencer starts with outputting the least significant bit of the GPIO selected as END in the sequence.

The sequence output starts with outputting the least significant bit of the GPIO selected as END in the sequence. In the example above the output sequence will be GPIO4.SEQDATA[0], ... ,GPIO4.SEQDATA[31], GPIO3.SEQDATA[0], ... ,GPIO2.SEQDATA[31], GPIO2.SEQDATA[0], ... ,GPIO1.SEQDATA[31], GPIO1.SEQDATA[0], ... ,GPIO1.SEQDATA[31].

Cascading the sequencer memories are restricted to its neighbors and the START GPIO always has to be selected to be at a lower GPIO index than the selected END GPIO.

The GPIOs included the cascade chain do not block its external ouput pin the external pin can be used for other user functions. This is because the sequencer function is separated from the all other functions including the general purpose IO.

29.5 Pulse sampler

GPIO inputs can be sampled and up to 32 states can be stored per input port. The sampler can be programmed to sample using internal trigger event and start when event is detected on the input. The sampler can be enabled manually or by any of the interrupt requests on the APB bus. Samples will be stored in the SAMPSEQ and interrupts can be optional generated at sample start or when SAMPSEQ is full.

29.5.1 Operation modes

Sampler is enabled by setting the sampler enable bit in sequence control register 1. The sampling will start if any of the following conditions are met:

- Sample the state of the GPIO input when selected trigger event occur if the bit TR is set and bit CT is set to 0 in sequence control register 1. (Repeated for every event until SAMPDATA is full)
- A change in state on the input occur and the bit FD is set in sequence control register 1. (Repeated for every event until SAMPDATA is full)
- Consecutive sampling of the GPIO input until the register SAMPDATA is full.

Trigger and FD mode can be combined with the consecutive mode:

- Sampling using combination of trigger and consecutive mode will start consecutive sampling of the input when trigger event occurs until SAMPDATA is full.
- Sampling using combination of FD and consecutive mode will start consecutive sampling of the input when GPIO input state change occurs until SAMPDATA is full.

29.6 Registers

The core is programmed through registers mapped into APB address space.

Table 312. General Purpose I/O Port registers

APB address offset	Register
0x00	I/O port data register
0x04	I/O port output register
0x08	I/O port direction register
0x0C	Interrupt mask register
0x10	Interrupt polarity register
0x14	Interrupt edge register
0x1C	Capability register
0x20 - 0x3C	Interrupt map register(s).
0x40	Interrupt available register
0x44	Interrupt flag register
0x48	Input enable register
0x4C	Pulse register
0x50	Input enable register, logical-OR
0x54	I/O port output register, logical-OR
0x58	I/O port direction register, logical-OR
0x5C	Interrupt mask register, logical-OR
0x60	Input enable register, logical-AND
0x64	I/O port output register, logical-AND
0x68	I/O port direction register, logical-AND
0x6C	Interrupt mask register, logical-AND
0x70	Input enable register, logical-XOR
0x74	I/O port output register, logical-XOR
0x78	I/O port direction register, logical-XOR
0x7C	Interrupt mask register, logical-XOR
0x80	Input enable register, logical-Set&Clear[1)]
0x88	Input enable register, logical-Set&Clear[1)]
0x90	I/O port output register, logical-Set&Clear[1)]
0x98	I/O port output register, logical-Set&Clear[1)]
0xA0	I/O port direction register, logical-Set&Clear[1)]
0xA8	I/O port direction register, logical-Set&Clear[1)]
0xB0	Interrupt mask register, logical-Set&Clear[1)]
0xB8	Interrupt mask register, logical-Set&Clear[1)]
GPIO input Sequencer/sampling functionality	
0x100 + n*0x20[3)]	Sequence control register 0[2)]

Table 312. General Purpose I/O Port registers

APB address offset	Register
0x104 + n*0x20[3)]	Sequence control register 1[2)]
0x108 + n*0x20[3)]	Synchronization control register[2)]
0x10C + n*0x20[3)]	Sequence output data register[2)]
0x110 + n*0x20[3)]	Sample input data register[2)]
0x114 + n*0x20[3)]	Sequencer interrupt register[2)]
0x118 + n*0x20[3)]	Sequencer mask register[2)]
0x180	Sequencer start offset register

Note 1: For the Set&Clear function to take place 2 consecutive writes needs to be performed. The first write access must always be to the address with the lowest address. An access to the GPIO address space in-between the 2 consecutive writes would make the first write to the set&clear register invalid and the Set&Clear will not take place. It is recommended to use the SPARC feature 'double store' and the addresses for the Set&Clear function has been aligned to addresses suitable for the SPARC feature 'double store'.

For the LEON3FT microcontroller it is recommended to use the build in ATOMIC operation supported by the APB controller, see chapter 2.2.6

Note 2: Each GPIO pin have separate control register, synchronization and data register for sampling and generating output sequences

Note 3: Each GPIO unit have 4 separate GPIO sequencer i.e. base address for sequencers are:

Sequencer 0: 0x100
Sequencer 1: 0x120
Sequencer 2: 0x140
Sequencer 3: 0x160

29.6.1 I/O Port Data Register

*Table 313.*0x00 - DATA - I/O port data register

31	0
DATA	
*	
r	

31: 0 I/O port input value (DATA) - Data value read from GPIO lines

29.6.2 I/O Port Output Register

*Table 314.*0x04 - OUTPUT - I/O port output register

31	0
DATA	
0	
rw	

31: 0 I/O port output value (DATA) - Output value for GPIO lines

29.6.3 I/O Port Direction Register

*Table 315.*0x08 - DIRECTION - I/O port direction register

31	0
DIR	
0	
rw	

31: 0 I/O port direction value (DIR) - 0=output disabled, 1=output enabled

29.6.4 Interrupt Mask Register

*Table 316.*0x0C - IMASK - Interrupt mask register

31	0
MASK	
0	
rw	

31: 0 Interrupt mask (MASK) - 0=interrupt masked, 1=intrrupt enabled

29.6.5 Interrupt Polarity Register

*Table 317.*0x10 - IPOL - Interrupt polarity register

31	0
POL	
NR	
rw	

31: 0 Interrupt polarity (POL) - 0=low/falling, 1=high/rising

29.6.6 Interrupt Edge Register

*Table 318.*0x14 - IEDGE - Interrupt edge register

31	0
EDGE	
NR	
rw	

31: 0 Interrupt edge (EDGE) - 0=level, 1=edge

29.6.7 Capability Register

*Table 319.*0x1C - CAP - Capability register

31	18	17	16	15	13	12	8	7	5	4	0
RESERVED		PU	IER	IFL	r		IRQGEN	r		NLINES	
0		1	1	1	0		0x4	0		0x1F	
r		r	r	r	r		r	r		r	

31: 19 Reserved and not used

18 PU: Pulse register implemented: If this field is '1' then the core implements the Pulse register.

17 IER: Input Enable register implemented. If this field is '1' then the core implements the Input enable register.

16 IFL: Interrupt flag register implemented. If this field is '1' then the core implements the Interrrupt available and Interrupt flag registers (registers at offsets 0x40 and 0x44).

12 8 IRQGEN: Software can dynamically configure each I/O to drive either of the 4 interrupt lines associated with each GPIO unit (cf. section 2.13).

4: 0 NLINES. Number of pins in GPIO port - 1.

29.6.8 Interrupt Map Register n

*Table 320.*0x20 - 0x3C - IRQMAPRn - Interrupt map register n

31	29	28	24	23	21	20	16	15	13	12	8	7	6	4	0
RESERVED		IRQMAP[4*n]		RESERVED		IRQMAP[4*n+1]		RESERVED		IRQMAP[4*n+2]		RESERVED		IRQMAP[4*n+3]	
0		un+i		0		un+i+1		0		un+i+2		0		uni+i+3	
r		rw		r		rw		r		rw		r		rw	

31: 0 IRQMAP[i] : The field IRQMAP[i] determines to which interrupt I/O line i is connected. If IRQMAP[i] is set to *x*, IO[i] will drive interrupt *pirq*+*x*. Where *pirq* is the first interrupt assigned to the core (cf. section 2.13). Several I/O can be mapped to the same interrupt.

The core has one IRQMAP field per I/O line. The Interrupt map register at offset 0x20+*4*n* contains the IRQMAP fields for IO[*4*n* : *4*n+3*]. This means that the fields for IO[0:3] are located on offset 0x20, IO[4:7] on offset 0x24, IO[8:11] on offset 0x28, and so on. An I/O line's interrupt generation must be enabled in the Interrupt mask register in order for the I/O line to drive the interrupt specified by the IRQMAP field.

29.6.9 Interrupt Available Register

*Table 321.*0x40 - IAVAIL - Interrupt available register

31	0
IMASK	
*	
r	

31: 0 IMASK: Interrupt mask bit field. If IMASK[n] is 1 then GPIO line n can generate interrupts.

29.6.10 Interrupt Flag Register

*Table 322.*0x44 - IFLAG - Interrupt flag register

31	0
IFLAG	
0	
wc	

31: 0 IFLAG : If IFLAG[n] is set to '1' then GPIO line n has generated an interrupt. Write '1' to the corresponding bit to clear. Writes of '0' have no effect.

29.6.11 Input Enable Register

*Table 323.*0x48 - IPEN - Input enable register

31	0
IPEN	
0	
rw	

31: 0 IPEN : If IPEN[n] is set to '1' then values from GPIO line n will be visible in the data register. Otherwise the GPIO line input is gated-off to disable input signal propagation.

29.6.12 Pulse Register

*Table 324.*0x4C - PULSE - Pulse register

31	0
PULSE	
0	
rw	

31: 0 PULSE : If PULSE[n] is set to '1' then I/O port output register bit n will be inverted whenever selected synchronization source is active. Synchronization source is selected in register SEQSYNC.

29.6.13 Logical-OR/AND/XOR Register

*Table 325.*0x54-0x7C - LOR,LAND,LXOR - Logical-OR/AND/XOR registers

31	0
VALUE	
-	
w*	

31: 0 The logical-OR/AND/XOR registers will update the corresponding register according to:

New value = <Old value> logical-op <Write data>

There exists logical-OR, AND and XOR registers for the Input enable, I/O port output, I/O port direction and Interrupt mask registers.

29.6.14 Logical-Set&Clear Register

*Table 326.*0x80-0xB8 - Logical Set&Clear - Logical-OR/AND/XOR registers

31	0
VALUE	
-	
w*	

*Table 326.*0x80-0xB8 - Logical Set&Clear - Logical-OR/AND/XOR registers

31:	0	The logical-Set&Clear registers will update the corresponding register according to: New value = (<Old value> OR < First write>) OR (<Old value> AND NOT <Second write>) The first write is used to 'set' bits and second write is used to 'clear' bits.

29.6.15 Sequence Control Register 0

Table 327. 0x100+n*0x20 - SEQCTRL0 - Sequence control register 0

31	30	29	28 21	20 13	12 8	7 0
SQ	SI	SE	SDEL	SEQCNT	SEQLEN	SEQDIV
0	0	0	0x00	0x00	0x00	0x00
rw	rw	rw	rw	rw	rw	rw

31 SQ: Sequence synchronization enable. If set to 1, the output sequence from GPIO output pin n will be synchronized to synchronization source selected in register SEQSYNC. If set to 0, SEQDIV will be used to generate internally the sequence rate. The latter case is not supported in cascade mode, and this bit must be set to 1 in all the GPIOs in the cascade.

30 SI: Sequence Interrupt enable. By enable this bit an interrupt will be generated when the sequence is complete

29 SE: Sequence enable. When this bit is set, the sequence will be enabled and the sequencer (if CMODE=0 or CSTART=1) will be granted access to the physical pin. This bit will self-clear when sequence is complete. If SQ is set to 1 a final trigger event is necessary to set this bit to 0, disconnecting the GPIO sequencer from the physical pin. In case of SEQLEN is set to continuously output the sequence the software needs to disable the sequence. When manual termination of the current sequence will always finish. This field must be set to 1 in all the sequencers in a cascade. When sequence is enabled, SEQDATA(0) or SEQDATA(31) (depending on REV field) will be outputted. After this operation, if SQ is set to 0 the count of the delay and data rate will start autonomously. If SQ is set to 1, the sequencer will wait for an initial triggering event to start counting events, providing margin for an initial delay of the first bit.

28: 21 SDEL: Set the clock cycle delay between each repetition. By setting this register to ’0’ creates contiguous sequences.

20: 13 SEQCNT: Set the number of times to repeat the loop for GPIO output pin n. The sequence will be looped SEQCNT + 1 times i.e. ’0’ means the sequence will be looped once. Setting the register 0xFF configures the GPIO sequencer to continuously output the sequence until it is disabled.

When in cascade mode, this value in the GPIO marked as START indicates the number of segments in the cascade outputted. For this reason this field must follow the equation below:

$$SEQCNT = (K \times N_{CHAIN}) - 1$$

where K is the times the entire cascade will be outputted and N_{CHAIN} the number of GPIO sequencers in the cascade. When a different value is selected, the sequence will be correctly outputted, although writing 1 to the RE field in Sequence Control Register 1 is required for correct termination. A’0’ in the SEQCNT field will output the entire cascade once (i.e. it is equivalent to $N_{CHAIN} - 1$).

12: 8 SEQLEN: Sequence length. The sequence length is defined as SEQLEN + 1 by the sequencer logic. In cascade mode it must be set to the same value in each GPIO sequencer of the cascade.

7: 0 SEQDIV: Sequence divisor determines the sequence-rate for the GPIO port

29.6.16 Sequence Control Register 1

Table 328. 0x104+n*0x20 - SEQCTRL1 - Sampling Sequence control register

31	30	29	28	27	26	25	24	23	22	21	20	19 14	13 1	0
SE	CT	TR	IR	FD	R	RS	CM	CS	CE	RV	EI	INT	Reserved	RE
0	0	0	0	0	0	0	0	0	0	0	0	0x00	0	0
rw	rw	rw	rw	rw	r	rw	rw	rw	rw	rw	rw	rw	r	wc

31 SE: Sampling Enable of GPIO input. Sampling will be enabled when this bit field is set to ’1’. Sampling enable bit will be self-cleared when sampling fifo is full.

30 CT: Continuously sampling of GPIO input. This feature will continuously sample at every clock cycle or when selected trigger event occur. If this feature isn’t selected sampling will stop immediately when sampling buffer is full.

29 TR: Sample input using external trigger source selected in SEQSYNC

Table 328. 0x104+n*0x20 - SEQCTRL1 - Sampling Sequence control register

28		IR: Generate interrupt when sampling fifo is full
27		FD: Flank Detection. If this feature is enabled sampling will not occur until an event is detected on the GPIO input. An event is when a transition from 0 to 1 or 1 to 0 occurs on the GPIO input.
26		Reserved
25		RS: Restart Sampling If set to '0' the sampling enable bit will be cleared when sampling sequencer memory is full. If set to '1' sampling will restart when sampling sequencer memory is full.
24		CM: Cascade mode. If set to '1' this GPIO sequencer data memory is connected to the neighbor GPIO
23		CS: Cascade Start, If set to '1' this GPIO is selected as master and will control the cascaded sequence
22		CE: Cascade End. If set to '1' this GPIO will terminate the cascade chain.
21		RV: Reverse. If set to 1 the sequence will be outputted from the MSB to the LSB, if set to 0 from the LSB to MSB.
20		EI: Enable on Interrupt. If set to 1, SE in this register will be automatically set high when the interrupt request defined in INT occurs. This bit is cleaned automatically when such event happens.
19:	14	INT: number of the interrupt request enabling the pulse sampler.
13:	1	Reserved
0		RE: Reset Sequencer and sampler to default values.

29.6.17 Sequence Synchronization Control Register

Table 329. 0x108+n*0x20 - SEQSYNC - Sequence Synchronization Control register

31 5	4 3 2 1 0
Reserved	SYNC
0x0	0
r	r/w

31: 5		Reserved
4: 0		Synchronization trigger (SYNC) - Select the trigger.
	31: 24 -	Synchronize GPIO n to trigger on GPIO 56 to 63
	23: 16 -	Synchronize GPIO n to trigger on GPIO 0 to 7
	15 -	Synchronize GPIO n to Timer unit 1 counter 6
	14 -	Synchronize GPIO n to Timer unit 1 counter 5
	13 -	Synchronize GPIO n to Timer unit 1 counter 4
	13 -	Synchronize GPIO n to Timer unit 1 counter 3
	11 -	Synchronize GPIO n to Timer unit 1 counter 2
	10 -	Synchronize GPIO n to Timer unit 1 counter 1
	9 -	Synchronize GPIO n to Timer unit 1 counter 0
	8 -	Synchronize GPIO n to Timer unit 1 scaler tick
	7 -	Synchronize GPIO n to Timer unit 0 counter 6
	6 -	Synchronize GPIO n to Timer unit 0 counter 5
	5 -	Synchronize GPIO n to Timer unit 0 counter 4
	4 -	Synchronize GPIO n to Timer unit 0 counter 3
	3 -	Synchronize GPIO n to Timer unit 0 counter 2
	2 -	Synchronize GPIO n to Timer unit 0 counter 1
	1 -	Synchronize GPIO n to Timer unit 0 counter 0
	0 -	Synchronize GPIO n to Timer unit 0 scaler tick

29.6.18 Sequence Memory Register

Table 330. 0x10C+n*0x20 - SEQDATA - Sequence memory register

31	0
VALUE	
0x00000000	
rw	

31: 0 GPIO output pin sequence memory. The output sequence will be the following: 0, 1, .. 31

29.6.19 Sampling Sequence Memory Register n

*Table 331.*0x110+n*0x20 - SAMPSEQ - Sampling Sequence memory register

31	0
VALUE	
0x00000000	
r	

31: 0 GPIO input pin sampling sequence

29.6.20 Sequencer interrupt register

*Table 332.*0x114+n*0x20 - SEQINT- GPIO Sequencer interrupt register

31	3	2	1	0
Reserved		ST	SF	SE
0x00000000		0	0	0
r		wc	wc	wc

31: 3 Reserved

2 Sampler trigger detected (ST)

1 Sampler FIFO full (SF)

0 Sequence ended (SE)

29.6.21 Sequencer mask register

*Table 333.*0x118+n*0x20 - SEQMASK - Sequencer mask register

31	3	2	1	0
Reserved		ST	SF	SE
0x00000000		0	0	0
r		wc	wc	wc

31: 3 Reserved

2 Sampler trigger detected (ST)

1 Sampler FIFO full (SF)

0 Sequence ended (SE)

29.6.22 Sequencer start offset register

*Table 334.*0x180 - SEQOFFSET - Sequencer start offset register

31	5	4	3	2	1	0
Reserved					OFFSET	
0x00000000					0x0	
r					rw	

31: 5 Reserved

4: 0 Sequence start offset (OFFSET) - This register shifts the sequencer within the physical GPIO group.For group #1 this set start GPIO pad from 0 to 31. For GPIO group #2 this register sets the start pin from 32 to 64.

30 Pulse Width Modulation Generator

The GR716 comprises 2 separate pulse width modulator generator (PWM) units. PWM unit number 0 can generate 8 pairs of output signals in normal and complementary format. For example PWM output 1 (PWM1) is the complementary version of PWM output 0 (PWM0). PWM unit 1 is only connected to complementary outputs, i.e. PWM unit 1 can generate outputs PWM1, PWM3... PWM15. PWM unit 0 and PWM unit 1 are identical and each unit has its own set of status and configuration registers described in this chapter. Each PWM unit has a unique AMBA address described in chapter 2.11.

The PWM units are located on APB bus in the address range from 0x80310000 to 0x8031FFFF and 0x80410000 to 0x8041FFFF. See PWM units connections in the next drawing. The figure shows memory locations and functions used for PWM configuration and control.

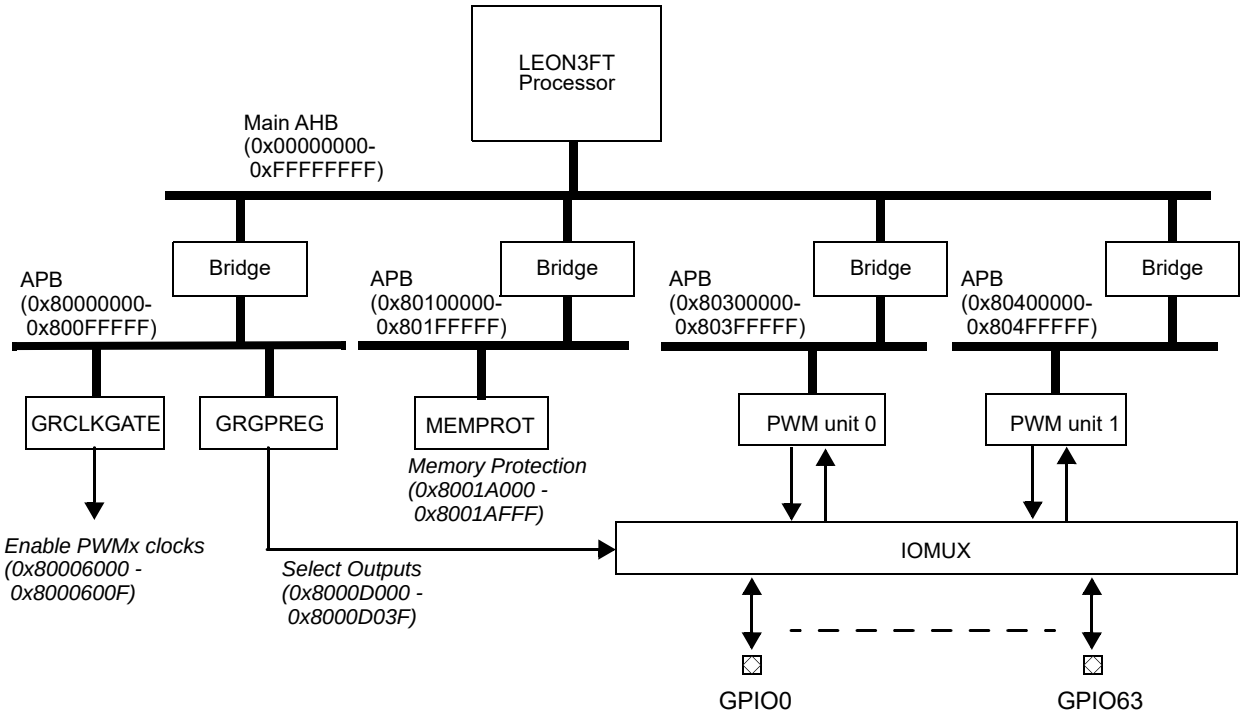


Figure 49. GR716 PWM bus and pin connection

The primary clock gating unit **GRCLKGATE** described in section 26 is used to enable/disable individual PWM units. The unit **GRCLKGATE** can also be used to perform reset of individual PWM units. Software must enable clock and release reset described in section 26 before PWM configuration and transmission can start.

External IO selection per PWM unit is made in the system IO configuration register (**GRGPREG**) in the address range from 0x8000D000 to 0x8000D03F. See section 7.1 for further information.

Each **PWMx** unit controls its own external pins and has a unique AMBA address described in chapter 2.11. PWM unit 0 and 1 have identical configuration and status registers. Configuration and status registers are described in section 30.3.

The system can be configured to protect and restrict access to individual PWM units in the **MEMPROT** unit. See section 47 for more information.

30.1 Overview

GRPWM is a pulse width modulation (PWM) generator that supports several outputs, with different frequencies. The core is configured through a set of APB registers, described in section 30.3. The core supports both asymmetric and symmetric PWM generation. Each of the PWM outputs can be configured to be either a single PWM signal or a pair of PWM signals (where the two signals are each others' inverse), with configurable amount of dead band time in between them. The core also supports programming of the output polarity, setting the outputs to fixed values, and configurable interrupt schemes.

30.2 Operation

30.2.1 System clock scaling

In order to support a wide range of system clock and PWM frequencies the core includes programmable clock scalers. Each scaler is clocked by the system clock and decrement on each clock cycle. When a scaler underflows it is reloaded with the value of its reload register and a tick is generated. This tick can then be used to increment (or decrement) one or more PWM counters. The reload value(s) of the scaler(s) can be read and written through the APB register called *Scaler reload register*, described in section 30.3.

30.2.2 Asymmetric and symmetric PWM generation

An asymmetric PWM is a pulse signal that is inactive at the beginning of its period and after a certain amount of time goes active, and then stays active for the rest of the period. A symmetric PWM is a pulse signal that is inactive for a certain amount of time at the beginning of the period and a certain amount of time at the end of the period, and stays active in between. The two inactive time periods are normally, but not necessarily, equally long.

For the core to generate a PWM, independent of whether asymmetric or symmetric method is used, software need to do the following (also see section 30.3 for more detailed description of register interface):

- Enable the core by writing the *en* bit in *Core control register*.
- Configure the scaler (see section 30.2.1) and set the PWM period in the *PWM period register*.
- Write the *PWM compare register* with the value at which the PWM's counter should match and switch the outputs.
- If dead band time should be generated, write the value at which the current PWM's dead band time counter should match to the *PWM dead band compare register*. Also set the *dben* bit in the *PWM control register* to 1. See section 30.2.3 for information on dead band time.
- Set the meth bit in PWM control register to either asymmetric or symmetric.
- Set the polarity of the PWM output be setting the *pol* bit in the *PWM control register*.
- If the PWM output should be paired with its inverse then set the *pair* bit in the *PWM control register* to 1, otherwise set it to 0. Note that each PWM always has two outputs, but if the *pair* bit is set to 0 then the second output is constantly inactive.
- Program the interrupt, see section 30.2.4.
- Enable the PWM generation by writing the *en* bit in *PWM control register* to 1.
- If software wants the PWM output(s) to assume fix value(s) it can write the *fix* bits in the PWM *control register* appropriately.

Specific configuration required for symmetric PWM if dual compare mode should be used:

- If the core should update the PWM's compare register twice every PWM period, user has to configure *dcen* bit and *c2e* bit in the *PWM control register* accordingly.

- *If dcen* bit is set and *c2e* bit is cleared in the *PWM control register,* PWM output switch state for the first time after the PWM counter reaches the value *comp1*, which is configured in the *PWM compare register*. After half of PWM period, the counter counts downwards and on matching the value *comp1*, PWM output switches state for the second time.
- *If dcen* bit is cleared and *c2e* bit is set in the *PWM control register,* PWM output switch state for the first time after the PWM counter reaches the value *comp1*, which is configured in the *PWM compare register*. The counter increments further and on matching the value *comp2* which is configured in *PWM compare register*, PWM output switches state for the second time.
- If dual compare mode is selected, it is desired that the two inactive time periods are not of equal length, software needs to continuously update the *PWM compare register* with new values. Since the core updates its internal register at the start of and middle of the PWM period, software need to update the *PWM compare register* sometime during the first half of the period.

Note that the core's internal period register is updated from the *PWM period register* at the start of every period, both for asymmetric and symmetric PWM generation.

30.2.3 Dead band time

It is often desired to have a delay between when one of the PWM signals of a PWM pair goes inactive and when the other signal goes active. This delay is called dead band time. By default the core does not generate any dead band time, but can be configured to do so by setting the *dben* bit in the *PWM control register* to 0b1. When dead band time is enabled the core will start a counter each time a PWM pair switch its outputs. The output going inactive is not delayed while the output going active is delayed until the counter matches the value in the *PWM dead band compare register*. To support a wide range of applications the amount of dead band time inserted is programmable.

30.2.4 Idle state

Single PWM or PWM pair outputs can be dynamically disabled without disabling counters for synchronization. This dynamic disable state is called idle state. Idle state generation is only supported in dual compare mode and is entered when compare registers are set to 0xFFFF. The idle state is kept as long as the compare registers are set to 0xFFFF. Output state of PWM be will reset to state before entering idle state. In figure 50 is an example of entering and leaving IDLE state of a PWM pair. The example describes what user needs to write to the compare registers in order to enter and leaving idel state. The PWM period in the example is 0x0800 and PWM signal is assumed to be activated at 0x0000 and 0x0200.

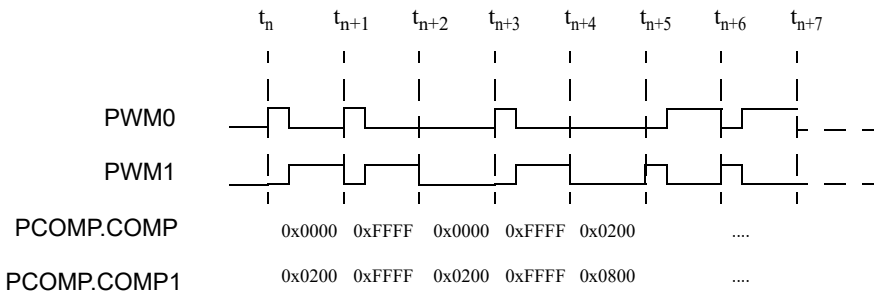


Figure 50. Example of entering and leaving IDLE states.

The use of dual compare points enable generation of PWM patterns to be activated and disabled within same PWM period. To invert a PWM signal activated and decapitated within same PWM period requires user control. Figure 51 shows an example of using idle state usage for a PWM pattern activated and deactivated within the same PWM period. The PWM period in the example is 0x0800 and PWM signal is assumed to be activated at 0x0200 and 0x0400.

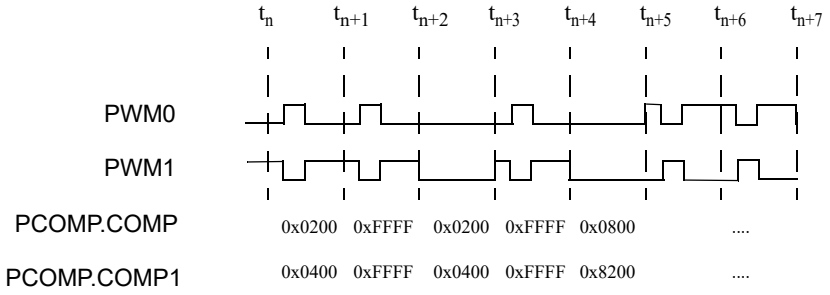


Figure 51. Example of entering and leaving IDLE states.

30.2.5 Interrupts

Interrupts can programmed individually for each PWM to be generated at PWM compare match, at PWM period match, or not generated at all. This is programmed in each PWM's *PWM control register.* Each PWM also has a 6-bit interrupt counter that can be used to scale down the frequency at which the interrupts occur. When an interrupt is generated the bit in the *Interrupt pending register* for the PWM in question is set. The bits in the *Interrupt pending register* stay set until software clears them by writing 1 to them.

When an interrupt is generated, or when the interrupt scaler counter is increased, an output tick is generated on the core's *tick* output signal. The output tick bit has the same index as the PWM in question.

30.3 Registers

The core is programmed through registers mapped into APB address space.

*Table 335.*GRPWM registers

APB address offset	Register
0x00	Core control register
0x04	Scaler reload register
0x08	Interrupt pending register
0x0C	Capability register 1
0x10	Capability register 2
0x14	Reserved
0x18 - 0x1C	Reserved, always zero.
0x20*	PWM period register
0x24*	PWM compare register
0x28*	PWM dead band compare register
0x2C*	PWM control register

* This register is implemented once for every PWM (the LEON3FT microcontroller have support for 8 PWM), with an offset of 0x10 from the previous PWM's register. The functionality is the same for each PWM.

30.3.1 Core Control Register

*Table 336.*0x00 - CTRL - Core control register

31 28	27 20	19 12	11 2	1	0
R	pwmen	noup	R	dis	en
0	0	0	0	0	0
r	rw	rw	r	rw	rw

31:18 Reserved, always zero.

27:20 Enable/disable PWM. Bit 20 is for the first PWM, bit 21 for the second etc. Bits to be used to enable/disable multiple PWM outputs at the sametime.

19:12 Bit 12 is for the first PWM, bit 13 for the second etc. If a bit is set to 0b1 then that PWM's internal period register, compare register, and dead band compare registers are not updated from the corresponding APB registers. These bits can be used by software if it wants to change more than one of the values and it is required that all values change in the same PWM period. It can also be used to synchronize the use of new values for different PWMs. Reset value 0b0..0.

11:2 Reserved, always zero.

1 Disable multiple PWM outputs by writing to bit field 'pwmen'

0 Core enable bit. 0b0 = Core is disabled, no operations are performed and all outputs are disabled. 0b1 = Core is enabled, PWM outputs can be generated. Reset value is 0b0.

30.3.2 Scaler Reload Register

*Table 337.*0x04 - SCALER - Scaler reload register

31 16	15 0
R	reload
0	all 1
r	rw

31:16 Reserved, always zero.

15:0 The value of this field is used to reload the system clock scaler when it underflows. Reset value is 0b1..1 (all ones).

30.3.3 Interrupt Pending Register

*Table 338.*0x08 - IPEND - Interrupt pending register

31 6	5 0
R	irq pending
0	0
r	wc

31:6 Reserved, always zero.

5:0 Interrup pending bits for the PWM(s). When an interrupt event for a specific PWM occurs the core sets the corresponding bit in the interrupt pending register and generates an interrupt. Software can read this register to see which PWM that generated the interrupt.

30.3.4 Capability Register 1

*Table 339.*0x0C - CAP1 - Capability register 1

31 29	28	27	26 25	24	23	22	21	20 16	15 13	12 8	7 3	2 0
R	def-pol	dcmode	sepirq	R	sympwm	asypwm	dbscaler	dbbits	nscalers	sbits	pbits	npwm
0	1	1	0	0	1	1	1	7	0	30	63	7
r	r	r	r	r	r	r	r	r	r	r	r	r

31:29 Reserved, always zero.

28 Default polarity is active high (outputs are low after reset/power-up).

27 Dual compare mode implemented.

26:25 Reports interrupt configuration. Read only.

24 Reserved, always zero.

23 Symmetric PWM generation is implemented. Read only.

22 Asymmetric PWM generation is implemented. Read only.

21 Dead band time scaler(s) is implemented. Read only.

20:16 Reports number of bits, -1, for the PWM's dead band time counters. Read only.

15:13 Reports number of implemented scalers, -1. Read only.

12:8 Reports number of bits for the scalers, -1. Read only.

7:3 Reports number of bits for the PWM counters, -1. Read only.

2:0 Reports number of implemented PWMs. Read only.

30.3.5 Capability Register 2

*Table 340.*0x10 - CAP2 - Capability register 2

31 11	10	9 6	5 1	0
R	wsync	wabits	wdbits	wpwm
0	0	7	7	0
r	r	r	r	r

31:11 Reserved, always zero

10 Waveform PWM synch signal generation is not implemented, Read only

9:6 Reports the number of address bits - 1 used for the waveform RAM. Read only.

5:1 Reports number of bits -1 for each word in the waveform RAM. Read only

0 Waveform PWM generation is NOT implemented

30.3.6 PWM Period Register

*Table 341.*0x20 - PPERIOD - PWM period register

31 16	15 0
R	per
0	0
r	rw

31:16 Reserved, always zero.

15:0 When the PWM counter reaches this value a PWM period has passed. Depending on the method used to generate the PWM the output could then be switched. When this register is written the actual PWM period value used inside the core is not updated immediately, instead a shadow register is used to hold the new value until a new PWM period starts. Reset value 0b0..0 (all zeroes).

30.3.7 PWM Compare Register

*Table 342.*0x24 - PCOMP - PWM compare register

31	30 16	15 0
inv	comp2	comp1
0	0	0
rw	rw	rw

31 When PCTRL.IDLE bit is activated this bit can be used to invert state of the PWM at reactivation of an inactive PWM

30:16 When the PWM counter reaches this value the PWM output is switched. Depending on the method used to generate the PWM this register is used once or twice during each PWM period. When this register is written the actual PWM compare value used inside the core is not updated immediately, instead a shadow register is used to hold the new value until a new PWM period starts. Reset value 0b0..0 (all zeroes).

15:0 When the PWM counter reaches this value the PWM output is switched. Depending on the method used to generate the PWM this register is used once or twice during each PWM period. When this register is written the actual PWM compare value used inside the core is not updated immediately, instead a shadow register is used to hold the new value until a new PWM period starts. Reset value 0b0..0 (all zeroes).

30.3.8 PWM Dead Band Compare Register

*Table 343.*0x28 - PDEAD - PWM dead band compare register

31 8	7 0
R	dbcomp
0	0
r	rw

31:16 Reserved, always zero

15:0 The dead band time has passed once the dead band counter reach the value of this field. When this register is written the actual compare value used inside the core is not updated immediately, instead a shadow register is used to hold the new value until a new PWM period starts. Reset value 0b0..0 (all zeroes).

30.3.9 PWM Control Register

*Table 344.*0x2C - PCTRL - PWM control register

31 29	28	27	26	25 22	21	20 15	14	13	12 9	8	7	6	5 3	2	1	0
R	idle	c2e	flip	dbscaler	dben	irqscaler	irqt	irqen	R	dcen	R	meth	fix	pair	pol	en
0	0	0	0	0	0	0	0	0	0	0	0	*	0	1	*	0
r	rw	rw	rw	rw	rw	rw	rw	rw	r	rw*	r	rw	rw	rw	rw	rw

31:29 Reserved, always zero.

28 Enable feature to keep PWM synchronized when disabled. When this feature is enabled PWM can be disabled by writing the value 0xFFFF to bitfiles PCOMP.PCOMP and PCOMP.COMP2. The PWM will be disabled and when activated again return to last state when enabled again. To invert state set highest bit in PCOMP.INV to '1' for next state.

27 Enable two compare points for PWM output

26 Output flip bit. When this bit is set to 0b1 the PWM outputs are flipped.

25:22 Dead band scaler. These bits are used to scale the system clock when generating dead band time. When these bits are written the dead band scaler register inside the core is not updated immediately. Instead these bits are written to a reload register which updates the actual scaler when it underflows. This is done in order to prevent the dead band scaler register to change during the actual dead band time. Reset value is 0b0..0 (all zeroes).

*Table 344.*0x2C - PCTRL - PWM control register

21	Dead band enable. 0b0 = Dead band time generation is disabled, no dead band time will be inserted when the PWM output switch from deactive to active. 0b1 = Dead band time will be inserted when the PWM output switch from deactive to active. Reset value is 0b0.
20:15	Interrupt scaler. Determines how many compare/period matches that need to occur before an interrupt is generated. All zeroes means that an interrupt will occur every compare/period match, a one means that an interrupt will occur every second match etc. Note that when generating a symmetric PWM two compare matches occur during a PWM period but when generating an asymmetric PWM only one compare match occur during a period. Reset value is 0b0..0 (all zeroes).
14	Interrupt type. 0b0 = Generate interrupt on PWM period match. 0b1 = Generate interrupt on PWM compare match. Reset value is 0b0.
13	Interrupt enable/disable bit. 0b0 = Interrupt is disabled. 0b1 = Interrupt is enabled. Reset value is 0b0.
12:9	Reserved, always zero.
8	Dual compare mode enable. If this bit is set to 0b1 and the *meth* bit (see below) is set to 0b1 (symmetric) then the core will update its internal PWM compare register twice every PWM period, once when the counter is zero and once when a period match occur and the counter starts counting downwards again. In this way it is possible to have two different compare values, one when counter is counting upwards and one when counter is counting downwards. If this bit is 0b0 the compare register is only updated when the counter is zero. This bit has no effect if an asymmetric PWM is generated. Reset value is 0b0.
7	When this pair_zero bit is set to 0b1 and the pair bit is set to 0b0 the complement output is always set to zero. When this bit is set to 0b0 and the pair bit is set to 0b0 the complement output is inactive (depending on the polarity). When the pair bit is set to 0b1, this bit has no function.
6	PWM generation method select bit. This bit selects if an asymmetric or symmetric PWM will be generated, where 0b0 = asymmetric and 0b1 = symmetric. This bit can only be set if the PWM is disabled, i.e. *en* bit (see below) set to 0b0. The core prevents software from setting this bit to an invalid value. Reset value is 0b0 if asymmetric PWM is supported otherwise 0b1.
5:3	PWM fix value select bits. These bits can be used to set the PWM output to a fix value. If bit 3 is set to 0b1 then bit 4 decides what value the PWM output will have. If the *pair* bit (see below) is set to 0b1 while bit 3 is set to 0b1 as well then bit 5 determines what value the complement output will have. Reset value is 0b000.
2	PWM pair bit. If this bit is set to 0b1 a complement output for this PWM will be generated, creating a PWM pair instead of a single PWM. The complement output will be the first ouput's inverse, with the exception that dead band time might be added when the values switch from deactive to active. Reset value is 0b1.
1	PWM polarity select bit. 0b0 = PWM is active low, 0b1 = PWM is active high. This bit can only be set if the PWM is disabled, i.e. *en* bit (see below) set to 0b0. Reset value equals *defpol* bit in *Capability Register 1*.
0	PWM enable/disable bit. 0b0 = PWM is disabled. 0b1 = PWM is enabled. When this bit is set to 1 (from 0) and the *wen* bit (see bit 9 above) is set the core's internal address counter for the waveform RAM is reset. Reset value is 0b0.

31 PacketWire Receiver

31.1 Overview

The PacketWire Receiver implements a receiver function with Direct Memory Access (DMA) support. Packets (or blocks of data, normally CCSDS Space Packets) are automatically stored to memory, for which the user configures a descriptor table with descriptors that point to each individual packet or one or more packets stored in a fixed length fields (framing mode).

The core provides the following external and internal interfaces:

- Packet Wire interface (serial bit data, bit clock, packet delimiter, abort, ready, busy)
- AMBA AHB master interface, with sideband signals as per [GRLIB]
- AMBA APB slave interface, with sideband signals as per [GRLIB]

The operation of the receiver is highly programmable by means of control registers.

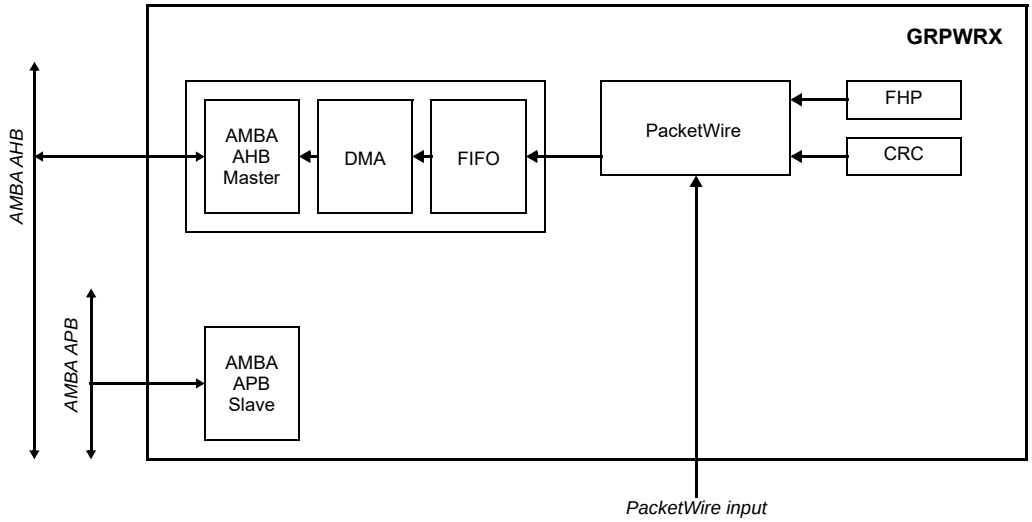


Figure 52. Block diagram

31.2 PacketWire interface

A PacketWire link comprises four ports for transmitting the message delimiter, the bit clock, the serial bit data and an abort signal. A link also comprises additional ports for busy signalling, indicating when the receiver is ready to receive the next octet, and for ready signalling, indicating that the receiver is ready to receive a complete packet. The waveform format shown in figure 53.

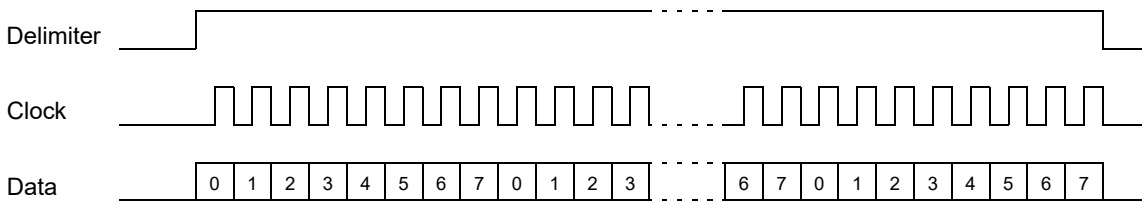


Figure 53. Synchronous bit serial waveform

The PacketWire protocol follows the CCSDS transmission convention, the most significant bit being sent first, both for octet transfers (control), and for word transfer (address or data). Transmitted data should consist of multiples of eight bits otherwise the last bits will be lost. The message delimiter port

is used to delimit messages (commands). It should be asserted while a message is being input, and deasserted in between. In addition, the message delimiter should define the octet boundaries in the data stream, the first octet explicitly and the following octets each subsequent eight bit clock cycles. The delimiter should be de-asserted for at least eight bit periods between messages.

The handshaking between the PacketWire link and the interface is implemented with a busy port. When a message is sent, the busy signal on the PacketWire link will be asserted as soon as the first data bit is detected, it will then be deasserted as soon as the interface is ready to receive the next octet. This gives the transmitter ample time to stop transmitting after the completion of the first octet and wait for the busy signal deassertion before starting the transmission of the next octet. The handshaking is continued through out the message. At the end of message, the busy signal will be asserted until the completion of the message.

31.3 Operation

31.4 Operation

31.4.1 Introduction

The DMA interface provides a means for the user to receive blocks of data of arbitrary length (maximum 65535 bytes), normally these are packet structures such as CCSDS Space Packets. It also supports reception of one or more blocks of data into a fixed length field such as a CCSDS Telemetry Transfer Frame Data Field (framing mode).

31.4.2 Descriptor setup

The DMA interface is used for receiving data. The reception is done using descriptors located in memory. A single descriptor is shown in tables 345 through 346. The address field of the descriptor should point to the start of where the received data is to be stored. The address need not be word-aligned. If the interrupt enable (IE) bit is set, an interrupt will be generated when the transfer has completed (this requires that the interrupt enable bit in the control register is also set). The interrupt will be generated regardless of whether the transfer was successful or not. The wrap (WR) bit is also a control bit that should be set before reception and it will be explained later in this section..

*Table 345.*GRPWRX descriptor word 0 (address offset 0x0)

31 16	15 9	8	7	6 4	3	2	1	0
LEN	RESERVED	CERR	OV	RESERVED	FHP	WR	IE	EN

31: 16	(LEN) - Length in bytes (note that length is limited to 2048 bytes for framing mode) In packet mode, the LEN field is written by the hardware after the reception. In framing mode, the LEN field is written by the software before reception.
15: 9	RESERVED
8:	Cyclic Redundancy Code Error (CERR) - (read only) Set to one when a CRC error was detected in a packet (speculative, only useful if CRC is present in received packet)
7:	Overrun (OV) - (read only) Overrun detected during transmission.
6: 3	RESERVED
3:	First Header Pointer (FHP) - First Header Pointer to be stored (2 bytes)
2:	Wrap (WR) - Set to one to make the descriptor pointer wrap to zero after this descriptor has been used. If this bit is not set the pointer will increment by 16. The pointer automatically wraps to zero when the 16 kB boundary of the descriptor table is reached.
1:	Interrupt Enable (IE) - an interrupt will be generated when data for this descriptor has been received provided that the receive interrupt enable bit in the control register is set. The interrupt is generated regardless if the data was transferred successfully or if it terminated with an error.
0:	Enable (EN) - Set to one to enable the descriptor. Should always be set last of all the descriptor fields.

*Table 346.*GRPWRX descriptor word 1 (address offset 0x4)

31	0
ADDRESS	

31: 0 Address (ADDRESS) - Pointer to the buffer area to where data will be stored.

To enable a descriptor the enable (EN) bit should be set and after this is done, the descriptor should not be touched until the enable bit has been cleared by the core.

31.4.3 Packet mode

In packet mode, each descriptor corresponds to one received packet. The maximum length of a packet can be 65535 bytes. There is no check for too long packets. Reception of any too long packet will result in indeterministic behavior. The length of the received packet is automatically written into descriptor word 0.

31.4.4 Framing mode

In framing mode, each pair of descriptors correspond to one fixed length field as the CCSDS Telemetry Transfer Frame Data Field. The first descriptor defines the length (fixed for a field) and position in memory where the data is to be stored. The second descriptor in a pair defines the fixed length (2 bytes) and position of the memory where the First Header Pointer (FHP) calculated for the data received in a field belonging to the previous descriptor is to be stored. The First Header Pointer is calculated according to CCSDS: if the first packet starts at the beginning of the field then it is all zeros, if no packet starts in the field then it is all ones, any other location of the start of the first packet in a field is its count from the start of the field minus one. The First Header Pointer write-back is enabled by setting the FHP bit in the descriptor word 0. Normally the start location of First Header Pointer is two bytes in front of the field when CCSDS Telemetry Transfer Frames are used.

31.4.5 Starting transmission

Enabling a descriptor is not enough to start transmission. A pointer to the memory area holding the descriptors must first be set in the core. This is done in the descriptor pointer register. The address must be aligned to a 16 kByte boundary. Bits 31 to 14 hold the base address of descriptor area while bits 13 to 4 form a pointer to an individual descriptor. The first descriptor should be located at the base address and when it has been used by the core, the pointer field is incremented by 16 to point at the next descriptor. The pointer will automatically wrap back to zero when the next 16 kByte boundary has been reached. The WR bit in the descriptors can be set to make the pointer wrap back to zero before the 16 kByte boundary.

The pointer field has also been made writable for maximum flexibility but care should be taken when writing to the descriptor pointer register. It should never be touched when reception is active.

The final step to activate the reception is to set the enable bit in the DMA control register. This tells the core that there are more active descriptors in the descriptor table. This bit should always be set when new descriptors are enabled, even if transmission is already active. The descriptors must always be enabled before the transmission enable bit is set.

31.4.6 Descriptor handling after transmission

When the reception of a packet (or field in framing mode) has finished, status is written to the first word in the corresponding descriptor, while the second word is left untouched. The other bits in the first descriptor word are set to zero after reception. The enable bit should be used as the indicator when a descriptor can be used again, which is when it has been cleared by the core.

If the Cyclic Redundancy Code (CRC) bit is set, a CRC calculated over all but the two last octets, will be checked and the results stored in the descriptor. The CRC is defined in

There are multiple bits in the DMA status register that hold status information.

The Receiver Interrupt (RI) bit is set each time a DMA reception ended successfully. The Receiver Error (RE) bit is set each time an DMA reception ended with an error. For either event, an interrupt is generated for transfers for which the Interrupt Enable (IE) was set in the descriptor. The interrupt is maskable with the Interrupt Enable (IE) bit in the control register.

The Receiver AMBA error (RA) bit is set when an AMBA AHB error was encountered either when reading a descriptor or when writing data. Any active reception was aborted and the DMA channel was disabled. It is recommended that the receiver is reset after an AMBA AHB error. The interrupt is maskable with the Interrupt Enable (IE) bit in the control register.

31.5 Registers

The core is programmed through registers mapped into APB address space.

*Table 347.*GRPWRX registers

APB address offset	Register
0x00	GRPWRX DMA Control register
0x04	GRPWRX DMA Status register
0x08	GRPWRX DMA Descriptor Pointer register
0x80	GRPWRX Control register
0x84	GRPWRX Status register
0x88	GRPWRX Configuration register
0x8C	GRPWRX Physical Layer register

31.5.1 DMA Control Register

*Table 348.*0x00 - DCR - DMA control register

31 2	1	0
RESERVED	IE	EN
0	0	0
r	rw	rw

31: 2 RESERVED

1: Interrupt Enable (IE) - enable interrupts RA, RI, and RE

0: Enable (EN) - enable DMA transfers

31.5.2 DMA Status Register

*Table 349.*0x04 - DSR - DMA status register

31 4	3	2	1	0
RESERVED	ACTIVE	RA	RI	RE
0	NR	0	0	0
r	r	wc	wc	wc

31: 4 RESERVED

3: Active (ACTIVE) - DMA access ongoing

2: Receiver AMBA Error (RA) - DMA AMBA AHB error, cleared by writing a logical 1

1: Receiver Interrupt (RI) - DMA interrupt, cleared by writing a logical 1

0: Receiver Error (RE) - DMA receiver error, cleared by writing a logical 1

31.5.3 DMA Descriptor Pointer Register

Table 350. 0x08 - DDP - DMA descriptor pointer register

31 14	13 4	3 0
BASE	INDEX	RESERVED
NR	NR	0
rw	rw	r

31: 14 Descriptor base (BASE) - most significant bits of the base address of descriptor table

13: 4 Descriptor index (INDEX) - index of active descriptor in descriptor table

3: 0 Reserved - fixed to “0000”

31.5.4 Control Register

Table 351. 0x80 - CTRL - control register

31 3	2	1	0
RESERVED	RST	RES	RxEN
0	0	1	0
r	r	r	r

31: 3 RESERVED

2: Reset (RST) - resets complete core

1: RESERVED

0: Receiver Enable (RxEN) - enables receiver (should be done after the complete configuration of the receiver)

31.5.5 Status Register

Table 352. 0x84 - STAT - Status register

31 ... 3	2	1	0
RESERVED	VALID	BUSY	READY
0	0	1	0
r	r	r	r

31: 3 RESERVED

2: Packet valid delimiter (VALID) - External valid signal

1: Busy with octet (BUSY) - External busy signal

0: Ready for packet (READY) - External ready signal

31.5.6 Configuration Register

Table 353. 0x88 - CONF - configuration register

31 ... 24	23 ... 8	7 ... 1	0
REVISION	FIFOSIZE	RESERVED	MODE
*	*	0	0
r	r	r	rw

31: 24 (REVISION) - Revision number (read-only)

23: 8 (FIFOSIZE) - FIFO size in bytes (read-only)

23: 1 RESERVED

0: (MODE) - Enable framing mode when set, else packet mode when cleared

31.5.7 Physical Layer Register

Table 354. 0x8C - PLR - physical layer register

31 ... 20	19 ... 8	7	6	5	4	3 ... 0
HALFBAUD	RESERVED	BUSY POS	READY POS	VALID POS	CLK RISE	RESERVED
0	0	0	1	1	1	0
r	r	rw	rw	rw	rw	r

31: 20 (HALFBAUD) - Received clock rate division factor with respect to the system clock - 1. Corresponds to the high phase of the incoming PacketWire bit clock. (read only)

19: 8 RESERVED

7: (BUSYPOS) - Positive polarity of busy input signal

6: (READYPOS) - Positive polarity of ready input signal

5: (VALIDPOS) - Positive polarity of valid output signal

4: (CLKRISE) - Rising clock edge in the middle of the serial data bit

3: 0 RESERVED

32 PacketWire Transmitter

32.1 Overview

The PacketWire Transmitter implements a transmit function with Direct Memory Access (DMA) suppport. Packets (or blocks of data, normally CCSDS Space Packets) are automatically fetched from memory, for which the user configures a descriptor table with descriptors that point to each individual packet.

The core provides the following external and internal interfaces:

- Packet Wire interface (serial bit data, bit clock, packet delimiter, abort, ready, busy)
- AMBA AHB master interface, with sideband signals as per [GRLIB]
- AMBA APB slave interface, with sideband signals as per [GRLIB]

The operation of the transmitter is highly programmable by means of control registers.

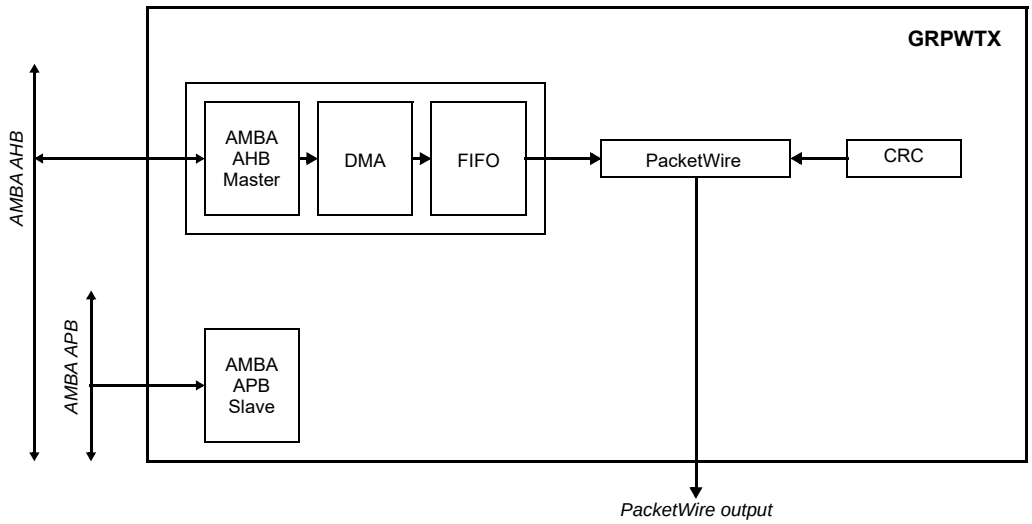


Figure 54. Block diagram

32.2 PacketWire interface

A PacketWire link comprises four ports for transmitting the message delimiter, the bit clock, the serial bit data and an abort signal. A link also comprises additional ports for busy signalling, indicating when the receiver is ready to receive the next octet, and for ready signalling, indicating that the receiver is ready to receive a complete packet. The waveform format shown in figure 55.

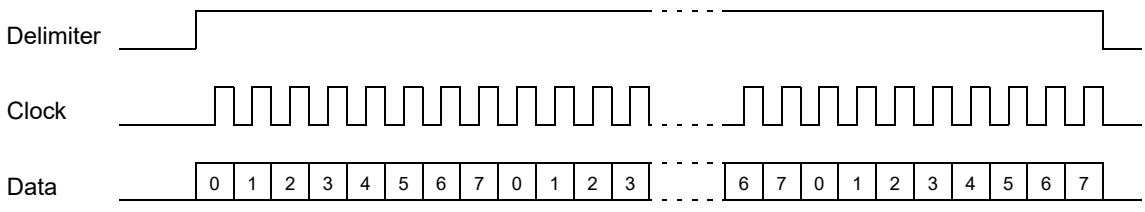


Figure 55. Synchronous bit serial waveform

The PacketWire protocol follows the CCSDS transmission convention, the most significant bit being sent first, both for octet transfers (control), and for word transfer (address or data). Transmitted data should consist of multiples of eight bits otherwise the last bits will be lost. The message delimiter port

is used to delimit messages (commands). It should be asserted while a message is being input, and deasserted in between. In addition, the message delimiter port should define the octet boundaries in the data stream, the first octet explicitly and the following octets each subsequent eight bit clock cycles.

The handshaking between the PacketWire link and the interface is implemented with a busy port. When a message is sent, the busy signal on the PacketWire link will be asserted as soon as the first data bit is detected, it will then be deasserted as soon as the interface is ready to receive the next octet. This gives the transmitter ample time to stop transmitting after the completion of the first octet and wait for the busy signal deassertion before starting the transmission of the next octet. The handshaking is continued through out the message. At the end of message, the busy signal will be asserted until the completion of the message.

32.3 Operation

32.3.1 Introduction

The DMA interface provides a means for the user to send blocks of data of arbitrary length, normally these are packet structures such as CCSDS Space Packets

32.3.2 Descriptor setup

The DMA interface is used for sending data on the uplink. The transmission is done using descriptors located in memory. A single descriptor is shown in tables 355 through 356. The address field of the descriptor should point to the start of the data to be sent. The address need not be word-aligned. If the interrupt enable (IE) bit is set, an interrupt will be generated when the transfer has completed (this requires that the interrupt enable bit in the control register is also set). The interrupt will be generated regardless of whether the transfer was successful or not. The wrap (WR) bit is also a control bit that should be set before transmission and it will be explained later in this section.

*Table 355.*GRPWTX descriptor word 0 (address offset 0x0)

31 16	15 8	7	6 4	3	2	1	0
LEN	RESERVED	UR	RESERVED	CRC	WR	IE	EN

31: 16	(LEN) - length in bytes
15: 8	RESERVED
7:	Underrun (UR) - Underrun detected during transmission.
6: 4	RESERVED
3:	Cyclic Redundancy Code (CRC) - Insert CRC, overwriting the two last octets of a data block
2:	Wrap (WR) - Set to one to make the descriptor pointer wrap to zero after this descriptor has been used. If this bit is not set the pointer will increment by 16. The pointer automatically wraps to zero when the 16 kB boundary of the descriptor table is reached.
1:	Interrupt Enable (IE) - an interrupt will be generated when the data from this descriptor has been sent provided that the transmitter interrupt enable bit in the control register is set. The interrupt is generated regardless if the data was transferred successfully or if it terminated with an error.
0:	Enable (EN) - Set to one to enable the descriptor. Should always be set last of all the descriptor fields.

*Table 356.*GRPWTX descriptor word 1 (address offset 0x4)

31 0
ADDRESS

31: 0	Address (ADDRESS) - Pointer to the buffer area to where data will be fetched.

To enable a descriptor the enable (EN) bit should be set and after this is done, the descriptor should not be touched until the enable bit has been cleared by the core.

32.3.3 Starting transmission

Enabling a descriptor is not enough to start transmission. A pointer to the memory area holding the descriptors must first be set in the core. This is done in the descriptor pointer register. The address must be aligned to a 16 kByte boundary. Bits 31 to 14 hold the base address of descriptor area while bits 13 to 4 form a pointer to an individual descriptor. The first descriptor should be located at the base address and when it has been used by the core, the pointer field is incremented by 16 to point at the next descriptor. The pointer will automatically wrap back to zero when the next 16 kByte boundary has been reached. The WR bit in the descriptors can be set to make the pointer wrap back to zero before the 16 kByte boundary.

The pointer field has also been made writable for maximum flexibility but care should be taken when writing to the descriptor pointer register. It should never be touched when transmission is active.

If the Cyclic Redundancy Code (CRC) bit is set, a CRC calculated over all but the two last octets, will be inserted overwriting the two last octets of a data block. The CRC is defined in

The final step to activate the transmission is to set the enable bit in the DMA control register. This tells the core that there are more active descriptors in the descriptor table. This bit should always be set when new descriptors are enabled, even if transmission is already active. The descriptors must always be enabled before the transmission enable bit is set.

32.3.4 Descriptor handling after transmission

When the transmission has finished, status is written to the first word in the corresponding descriptor. The other bits in the first descriptor word are set to zero after transmission, while the second word is left untouched. The enable bit should be used as the indicator when a descriptor can be used again, which is when it has been cleared by the core.

There are multiple bits in the DMA status register that hold status information.

The Transmitter Interrupt (TI) bit is set each time a DMA transmission ended successfully. The Transmitter Error (TE) bit is set each time an DMA transmission ended with an error. For either event, an interrupt is generated for which the Interrupt Enable (IE) was set in the descriptor. The interrupt is maskable with the Interrupt Enable (IE) bit in the control register.

The Transmitter AMBA error (TA) bit is set when an AMBA AHB error was encountered either when reading a descriptor or data. Any active transmission was aborted and the DMA channel was disabled. It is recommended that the transmitter is reset after an AMBA AHB error. The interrupt is maskable with the Interrupt Enable (IE) bit in the control register.

32.4 Registers

The core is programmed through registers mapped into APB address space.

*Table 357.*GRPWTX registers

APB address offset	Register
0x00	GRPWTX DMA Control register
0x04	GRPWTX DMA Status register
0x08	GRPWTX DMA Descriptor Pointer register
0x80	GRPWTX Control register
0x84	GRPWTX Status register
0x88	GRPWTX Configuration register
0x8C	GRPWTX Physical Layer register

32.4.1 DMA Control Register

*Table 358.*0x00 - DCR - DMA control register

31 2	1	0
RESERVED	IE	EN
0	0	0
r	rw	rw

31: 2 RESERVED

1: Interrupt Enable (IE) - enable interrupts TA, TI, and TE

0: Enable (EN) - enable DMA transfers

32.4.2 DMA Status Register

*Table 359.*0x04 - DSR - DMA status register

31 4	3	2	1	0
RESERVED	ACTIVE	TA	TI	TE

31: 4 RESERVED

3: Active (ACTIVE) - DMA access ongoing

2: Transmitter AMBA Error (TA) - DMA AMBA AHB error, cleared by writing a logical 1

1: Transmitter Interrupt (TI) - DMA interrupt, cleared by writing a logical 1

0: Transmitter Error (TE) - DMA transmitter error, cleared by writing a logical 1

32.4.3 DMA Descriptor Pointer Register

Table 360. 0x08 - DDP - DMA descriptor pointer register

31 14	13 4	3 0
BASE	INDEX	RESERVED
NR	NR	0
rw	rw	r

31: 14 Descriptor base (BASE) - most significant bits of the base address of descriptor table

13: 4 Descriptor index (INDEX) - index of active descriptor in descriptor table

3: 0 Reserved - fixed to “0000”

32.4.4 Control Register

Table 361. 0x80 - CTRL - control register

31 3	2	1	0
RESERVED	RST	R	TxEN
0	0	0	0
r	rw	r	rw

31: 3 RESERVED

2: Reset (RST) - resets complete core

1: RESERVED

0: Transmitter Enable (TxEN) - enables transmitter (should be done after the complete configuration of the transmitter)

32.4.5 Status Register

Table 362. 0x84 - STAT - Status register (read-only)

31 2	1	0
RESERVED	BUSY	READY
0	1	0
r	r	r

31: 2 RESERVED

1: Busy with octet (BUSY) - External busy signal

0: Ready for packet (READY) - External ready signal

32.4.6 Configuration Register

Table 363. 0x88 - CONF - configuration register (read-only)

31 24	23 8	7 0
REVISION	FIFOSIZE	RESERVED
*	*	0
r	r	r

31: 24 (REVISION) - Revision number (read-only)

23: 8 (FIFOSIZE) - FIFO size in bytes (read-only)

7: 0 RESERVED

32.4.7 Physical Layer Register

Table 364. 0x8C - PLR - physical layer register

31 20	19 8	7	6	5	4	3	2 0
HALFBAUD	RESERVED	BUSY POS	READY POS	VALID POS	CLK RISE	CLK MODE	RESERVED
1	0	0	1	1	1	0	0
rw	r	rw	rw	rw	rw	rw	r

31: 20 (HALFBAUD) - System clock division factor (indicates the width of the high and low phases of the outgoing PacketWire bit clock in number of system clock periods -1)

19: 8 RESERVED

7: (BUSYPOS) - Positive polarity of busy input signal

6: (READYPOS) - Positive polarity of ready input signal

5: (VALIDPOS) - Positive polarity of valid output signal

4: (CLKRISE) - Rising clock edge in the middle of the serial data bit

3: (CLKMODE) - 0=when valid (default), 1=always (experimental)

2: 0 RESERVED

33 SpaceWire Interface and RMAP target

The GR716 microcontroller comprises a SpaceWire interface with RMAP support (GRSPW2) units. The SpaceWire interface with RMAP controls its own external pins and has a unique AMBA address described in chapter 2.11. The nominal SpaceWire interface is connected via LVDS transceivers to external pins and the redundant interface is connected to external pins via the IOMUX.

The SpaceWire interface control and status registers are located on APB bus in the address range from 0x80100000 to 0x80100FFF. See GRSPW2 unit connections in the next drawing. The figure shows memory locations and functions used for GRSPW2 configuration and control.

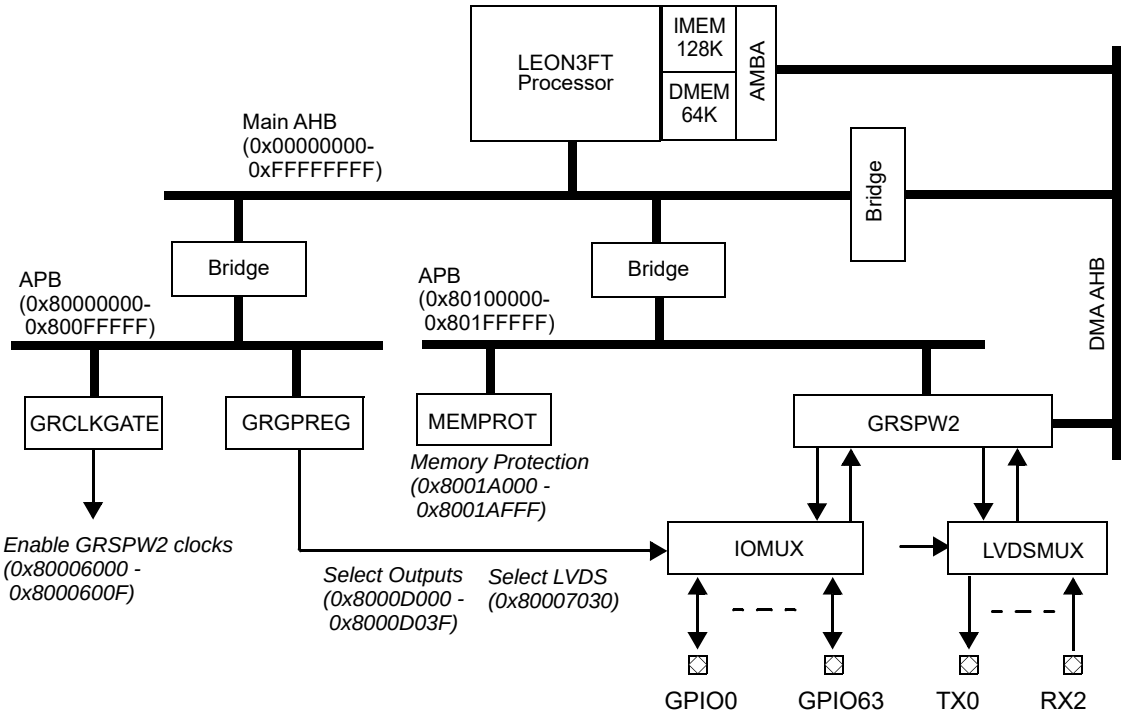


Figure 56. GR716 GRSPW2 bus and pin connection

The primary clock gating unit **GRCLKGATE** described in section 26 is used to enable/disable the SpaceWire interface. The unit **GRCLKGATE** can also be used to perform reset of the SpaceWire interface Software must enable clock and release reset described in section 26 before configuration and transmission can start.

External IO selection and configuration is made in the system IO and LVDS configuration registers (**GRGPREG**) in the address range from 0x8000D000 to 0x8000D03F and 0x80007030. See section 7.1 for further information.

The system can be configured to protect and restrict access to the SpaceWire controller in the **MEMPROT** unit. See section 47 for more information.

33.1 Overview

The SpaceWire core provides an interface between the AHB bus and a SpaceWire network. It implements the SpaceWire standard (ECSS-E-ST-50-12C) with the protocol identification extension (ECSS-E-ST-50-51C). The Remote Memory Access Protocol (RMAP) target implements the ECSS standard (ECSS-E-ST-50-52C).

The SpaceWire interface is configured through a set of registers accessed through an APB interface. Data is transferred through DMA channels using an AHB master interface.

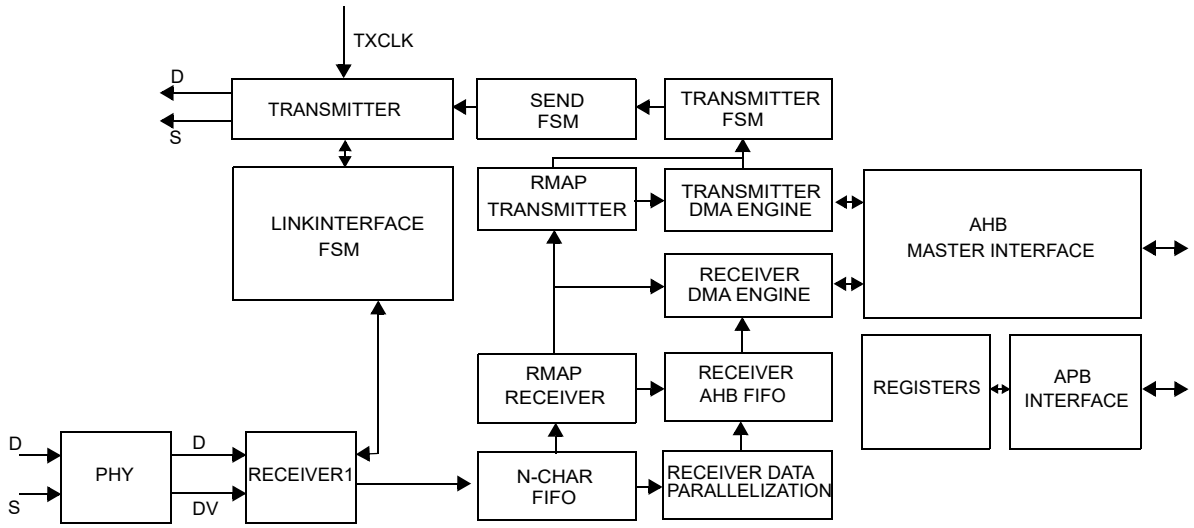


Figure 57. Block diagram

33.2 Operation

33.2.1 Overview

The main sub-blocks of the core are the link interface, the RMAP target and the AMBA interface. A block diagram of the internal structure can be found in figure 57.

The link interface consists of the receiver, transmitter, and the link interface FSM. They handle communication on the SpaceWire network. The PHY block provides a common interface for the receiver to the four different data recovery schemes and is external to this core. The AMBA interface consists of the DMA engines, the AHB master interface and the APB interface. The link interface provides FIFO interfaces to the DMA engines. These FIFOs are used to transfer N-Chars between the AMBA and SpaceWire domains during reception and transmission.

The RMAP target handles incoming packets which are determined to be RMAP commands instead of the receiver DMA engine. The RMAP command is decoded and if it is valid, the operation is performed on the AHB bus. If a reply was requested it is automatically transmitted back to the source by the RMAP transmitter.

33.2.2 Protocol support

The core only accepts packets with a valid destination address in the first received byte. Packets with address mismatch will be silently discarded (except in promiscuous mode, which is covered in section 33.6.10).

The second byte is sometimes interpreted as a protocol ID a described hereafter. The RMAP protocol (ID=0x1) is the only protocol handled separately in hardware while other packets are stored to a DMA channel. If the RMAP target is present and enabled all RMAP commands will be processed, executed and replied automatically in hardware. Otherwise RMAP commands are stored to a DMA channel in the same way as other packets. RMAP replies are always stored to a DMA channel. More information on the RMAP protocol support is found in section 33.8. When the RMAP target is not present or disabled, there is no need to include a protocol ID in the packets and the data can start immediately after the address.

All packets arriving with the extended protocol ID (0x00) are stored to a DMA channel. This means that the hardware RMAP target will not work if the incoming RMAP packets use the extended proto-

col ID. Note also that packets with the reserved extended protocol identifier (ID = 0x000000) are not ignored by the core. It is up to the client receiving the packets to ignore them.

When transmitting packets, the address and protocol-ID fields must be included in the buffers from where data is fetched. They are *not* automatically added by the core.

Figure 58 shows the packet types accepted by the core. The core also allows reception and transmission with extended protocol identifiers but without support for RMAP CRC calculations and the RMAP target.

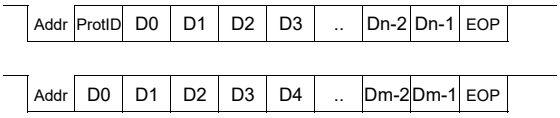


Figure 58. The SpaceWire packet types supported by the core.

33.3 Link interface

The link interface handles the communication on the SpaceWire network and consists of a transmitter, receiver, a FSM and FIFO interfaces. An overview of the architecture is found in figure 57.

33.3.1 Link interface FSM

The FSM controls the link interface (a more detailed description is found in the SpaceWire standard). The low-level protocol handling (the signal and character level of the SpaceWire standard) is handled by the transmitter and receiver while the FSM handles the exchange level.

The link interface FSM is controlled through the Control register (CTRL). The link can be disabled through the CTRL.LD bit, which depending on the current state, either prevents the link interface from reaching the started state or forces it to the error-reset state. When the link is not disabled, the link interface FSM is allowed to enter the started-state when either the CTRL.LS bit is set or when a NULL character has been received and the CTRL.AS bit is set.

The state of the link interface determines which type of characters that are allowed to be transmitted, which together with the requests made from the host interfaces determine what character will be sent.

Time-codes are sent when the FSM is in the run-state and a request is made through the time-interface (described in section 33.4).

When the link interface is in the connecting- or run-state it is allowed to send FCTs. FCTs are sent automatically by the link interface when possible. This is done based on the maximum value of 56 for the outstanding credit counter and the currently free space in the receiver N-Char FIFO. FCTs are sent as long as the outstanding counter is less than or equal to 48 and there are at least 8 more empty FIFO entries than the counter value.

N-Chars are sent in the run-state when they are available from the transmitter FIFO and there are credits available. NULLs are sent when no other character transmission is requested, or when the FSM is in a state where no other transmissions are allowed.

The credit counter (incoming credits) is automatically increased when a FCTs is received, and decreased when N-Chars are transmitted. Received N-Chars are stored to the receiver N-Char FIFO for further handling by the DMA interface. Received Time-codes are handled by the time-interface.

33.3.2 Transmitter

The state of the FSM, credit counters, requests from the time-interface and requests from the DMA-interface are used to decide the next character to be transmitted. The type of character and the charac-

ter itself (for N-Chars and Time-codes) to be transmitted are presented to the low-level transmitter which is located in a separate clock-domain.

The transmitter logic in the host clock domain decides what character to send next and sets the proper control signal and presents any needed character to the low-level transmitter as shown in figure 59. The transmitter sends the requested characters and generates parity and control bits as needed. If no requests are made from the host domain, NULLs are sent as long as the transmitter is enabled. Most of the signal and character levels of the SpaceWire standard is handled in the transmitter. External LVDS drivers are needed for the data and strobe signals.

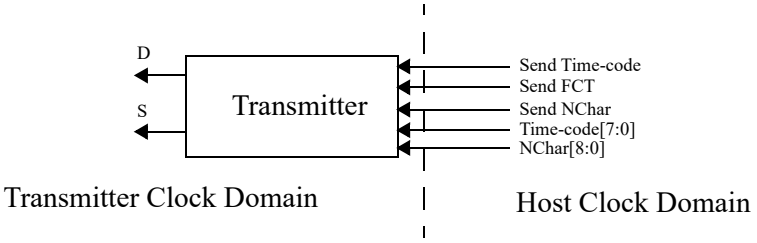


Figure 59. Schematic of the link interface transmitter.

A transmission FSM reads N-Chars for transmission from the transmitter FIFO. It is given packet lengths from the DMA interface and appends EOPs/EEPs and RMAP CRC values if requested. When it is finished with a packet the DMA interface is notified and a new packet length value is given.

33.3.3 Receiver

The receiver detects connections from other nodes and receives characters as a bit stream recovered from the data and strobe signals by the GRSPW2_PHY module, which presents it as a data and data-valid signal. The receiver and GRSPW2_PHY are located in a separate clock domain which runs on a clock outputed by the GRSPW2_PHY.

The receiver is activated as soon as the link interface leaves the error reset state. Then after a NULL is received it can start receiving any characters. It detects parity, escape and credit errors which causes the link interface to enter the error reset state. Disconnections are handled in the link interface part in the tx clock domain because no receiver clock is available when disconnected.

Received Characters are flagged to the host domain and the data is presented in parallel form. The interface to the host domain is shown in figure 60. L-Chars are the handled automatically by the host domain link interface part while all N-Chars are stored in the receiver FIFO for further handling. If two or more consecutive EOPs/EEPs are received all but the first one are discarded.

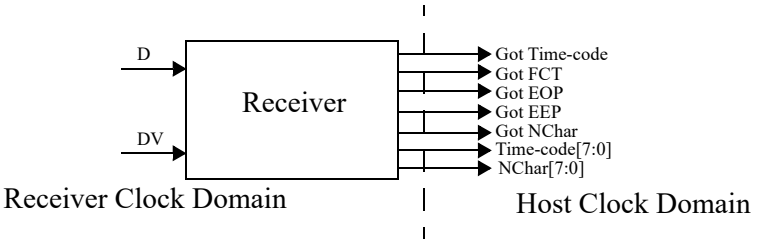


Figure 60. Schematic of the link interface receiver.

33.3.4 Dual port support

With dual ports the transmitter drives an additional pair of data/strobe output signals and one extra receiver is added to handle a second pair of data/strobe input signals.

One of the ports is set as active (how the active port is selected is explained below) and the transmitter drives the data/strobe signals of the active port with the actual output values as explained in section 33.3.2. The inactive port is driven with zero on both data and strobe.

Both receivers will always be active but only the active port's interface signals (see figure 60) will be propagated to the link interface FSM. Each time the active port is changed, the link will be reset so that the new link is started in a controlled manner.

When the CTRL.NP bit is zero, the CTRL.PS bit selects the active port. When the CTRL.NP bit is set to one, the active port is automatically selected during initialization. For the latter mode, the port on which the first bit is received will be selected as the active port. If the initialization attempt fails on that port the link is reset and the active port is again sected based on which port the first bit is received.

33.3.5 Setting link-rate

The register field CLKDIV.CLKDIVSTART determines the link-rate during initialization (all states up to and including the connecting-state). The register is also used to calculate the link interface FSM timeouts (6.4 us and 12.8 us, as defined in the SpaceWire standard). The CLKDIV.CLKDIVSTART field should always be set so that a 10 Mbit/s link-rate is achieved during initialization. In that case the timeout values will also be calculated correctly.

To achieve a 10 Mbit/s link-rate, for a given transmitter input clock(*TXCLK*), the CLKDIV.CLK-DIVSTART field should be set according to the following formula:

With single data rate (SDR) outputs:

CLKDIV.CLKDIVSTART = (<frequency in MHz of TXCLK> / 10) - 1

The link-rate in run-state is controlled with the run-state divisor, the CLKDIV.CLKDIVRUN register field. The link-rate in run-state is calculated according to the following formula:

With SDR outputs:

<link-rate in Mbits/s> = <frequency in MHz of TXCLK> / (CLKDIV.CLKDIVRUN+1)

The value of CLKDIV.CLKDIVRUN only affects the link-rate in run-state, and does not affect the 6.4 us or 12.8 us timeouts values.

An example of clock divisor and resulting link-rate, with a TXCLK frequency of 50 MHz, is shown in the table 365.

*Table 365.*SpaceWire link-rate example with 50 MHz TXCLK

	Link-rate in Mbit/s
Clock divisor value	**SDR output**
0	50
1	25
2	16.67
3	12.5
4	10
5	8.33
6	7.14
7	6.25
8	5.56
9	5

33.4 Time-code distribution

Time-codes are control codes that consists of two control flags (bits 7:6) and a time value (bits 5:0), and they are used to distribute time over the SpaceWire network. The current time value (value of latest received or transmitted time-code), and control flags, can be read from the Time-code register (TC).

33.4.1 Receiving time-codes

When a control-code is received, and either the control flags (bits 7:6) have value “00”, or both control flag filtering and interrupt receive is disabled (CTRL.TF bit, and INTCTRL.IR bit both set to 0), then the received control code is considered to be a Time-Code. If Time-Code reception is enabled (CTRL.TR bit set to 1) then the received time value is stored in the TC.TIMECNT field. If the received time value equals TC.TIMECNT+1 (modulo 64), then the Time-Code is considered valid.

When a valid Time-Code is received, in addition to the time value being updated, the received control flags are stored to the TC.TCTRL field. Also, when a valid Time-Code is received, the TICKOUT output signal is asserted for one system clock cycle, the STS.TO bit is set to 1, and an AMBA interrupt is generated if the CTRL.IE bit and CTRL.TQ bit are both set to 1.

For all received control codes, Time-Codes or not, the control flags together with the time value are outputted on the TIMEOUT[7:0] signals, and the TICKOUTRAW signal is asserted for one system clock cycle.

33.4.2 Transmitting time-codes

Time-codes can be transmitted either through the AMBA APB registers.

In order to send a Time-code, Time-Code transmission must be enabled by setting the CTRL.TT bit to 1. To transmit a time-code through the register interface the CTRL.TI bit should be written to 1. When the bit is written the current time value (TC.TIMECNT field) is incremented, and a Time-Code consisting of the new time value together with the current control flags (TC.TCTRL field) is sent. The CTRL.TI bit will stay high until the Time-Code has been transmitted. If time-code transmission is disabled, writing the CTRL.TI bit has no effect.

To transmit a time-code using the TICKIN signal the sender must wait until the TICKINDONE output is low, then assert TICKIN. When TICKINDONE is asserted again, the TICKIN signal should be de-asserted the same cycle. Following this procedure will make the core transmit a Time-Code consisting of the current control flags and the current time value + 1 (modulo 64). This also requires that time-code transmission is enabled through the CTRL.TT bit.

To transmit a Time-Code using the TICKINRAW signal the sender must wait until TICKINDONE is low, then assert TICKINRAW and place the value of the Time-Code to be sent on the TIMEIN[7:0] signals. When TICKINDONE is asserted again, the TICKINRAW signal should be de-asserted the same cycle. Note that sending Time-Codes by using TICKINRAW does not require that Time-Code transmission is enabled from the Control register. However, in order to send Time-Codes with control flags different than “00”, interrupt transmit must be disabled (INTCTRL.IT bit set to 0). If interrupt transmit is enabled then control codes “10” are interpreted as interrupt-codes, while control codes “01” and “11” are discarded.

Note that the link interface must be in run-state in order to be able to send a Time-Code.

33.5 Interrupt distribution

The core supports interrupt distribution functionality. Whether or not this functionality is implemented is indicated by the CTRL.ID bit, and the number of supported interrupt numbers is indicated by the INTCFG.NUMINT field. Either 1, 2, 4, or 32 interrupt numbers (in the range 0-31) can be supported. When less than 32 interrupt numbers are supported it is programmable through the INTCFG

register which interrupt numbers in the range 0-31 that are allowed to be sent and received. When extended interrupt mode is enabled (INTCFG.EE bit set to 1), the supported interrupt number in “interrupt mode” is extended to 0-63).

The interrupts are distributed as control codes with the control flags (bits 7:6) set to “10”. Bit 5 of the control code specifies if the code is an interrupt-code (bit 5 = ‘0’) or an interrupt-acknowledge-code (bit 5 = ‘1’). An interrupt-code is generated by the source of the interrupt event, while the interrupt-acknowledge-code is sent by the interrupt handler for the corresponding interrupt number. When extended interrupt mode is enabled (INTCFG.EE bit set to 1), then interrupt-acknowledge-code is interpret as interrupt-codes in the range 32-63.

An Interrupt distribution ISR register holds the current state of all the interrupt numbers in the SpaceWire network. A bit in the ISR register is set to 1 when an interrupt-code with the corresponding interrupt number is received / transmitted, and the bit is set to 0 when an interrupt-acknowledge-code with the corresponding interrupt number is received / transmitted.

Each interrupt number also has its own timer that is used to clear the ISR bit if an interrupt-acknowledge-code is not received before the timer expires. There is also a timer for each interrupt-number that controls the minimum time between and interrupt-code and interrupt-acknowledge-code (and vice versa), in order to allow propagation of the codes through the whole network before a new code with the same interrupt number is sent.

33.5.1 Interrupt distribution timers

Each interrupt number has three corresponding timers, called the ISR timer, INT/ACK-timer, and ISR change timer. All three timers are implemented in GR716 with the width of 10 bits. A generic software can detect whether or not these timers are implemented in hardware, and how large they are, by probing the ISRTIMER, IATIMER, and ICTIMER registers respectively.

If the ISR timers are enabled (ISRTIMER.EN bit set to 1), the ISR timer is started and reloaded with the value from the ISRTIMER.RL field each time an interrupt-code is received such that the corresponding ISR bit is set to 1. If a matching interrupt-acknowledge-code is received, the corresponding ISR timer is stopped. If the ISR timer expires before an interrupt-acknowledge-code is received, the corresponding ISR bit is cleared. The purpose of the ISR timer is to recover from situations where an interrupt-acknowledge-code is lost. If an interrupt-acknowledge-code is lost and there were no ISR timer, then the corresponding ISR bit would stay set forever, and prevent future interrupt-codes with that interrupt number to be distributed. It is important to configure the reload value for the ISR timer correctly. The reload value shall not be less than the worst network propagation delay for the interrupt-code, plus the maximum delay in the interrupt handler, plus the worst network propagation delay for the interrupt-acknowledge-code. Note that use of the ISR timer is mandatory, so if the hardware timers are either disabled, software must handle the timers.

The INT/ACK-timer is used to control the minimum time between an interrupt-code and interrupt-acknowledge-code with the same interrupt number, and vice versa. The purpose of the INT/ACK-timer is to make sure that each interrupt- / interrupt-acknowledge-code gets enough time to propagate through the complete network before the next interrupt- / interrupt-acknowledge-code is sent, ensuring that no interrupt- / interrupt-acknowledge-code is received out of order. If the INT/ACK-timers are enabled (IATIMER.EN bit set to 1), then each time an interrupt- / interrupt-acknowledge-code is received the corresponding INT/ACK-timer is started and reloaded with the value from the IATIMER.RL field. As long as the timer is running, an interrupt- / interrupt-acknowledge-code with that interrupt number will not be sent.

The ISR change timer is used to control the minimum time between two consecutive changes to the same ISR bit. The purpose of the timer is to protect against unexpected occurrences of interrupt- / interrupt-acknowledge-codes that could occur, for example, due to a network malfunction or a babbling idiot. If the ISR change timers are enabled (ICTIMER.EN bit set to 1), then the timer for an ISR bit is started and reloaded with the value from the ICTIMER.RL field each time a received interrupt- / interrupt-acknowledge-code makes the ISR bit change value. Until the timer has expired, the corre-

sponding ISR bit is not allowed to change value, and any received interrupt- / interrupt-acknowledge-codes with that interrupt number are discarded.

33.5.2 Receiving interrupt- / interrupt-acknowledge-codes

When a control code with control flags set to “10” is received, and interrupt receive is enable (IR bit in Interrupt distribution control register set to 1), the control code is considered an interrupt-code if bit 5 is 0, and an interrupt-acknowledge-code if bit 5 is 1. If an interrupt-code is received and the interrupt number’s corresponding ISR bit is already set to 1, or an interrupt-acknowledge-code when the ISR bit is 0, then the received interrupt- / interrupt-acknowledge-code is discarded without any further action.

When an interrupt-code is received, and the corresponding ISR bit is 0, the ISR bit is set to 1. If the interrupt number’s corresponding bit in the Interrupt tick-out mask register is set to 1 then the corresponding bit in the Interrupt-code receive register is set to 1, the TICKOUT signal is asserted for one clock cycle, and an AMBA interrupt is generated (if the IE bit in the Control register, and IQ bit in the Interrupt distribution control register are both set to 1). If the interrupt number’s corresponding bit in the Interrupt-code auto acknowledge mask register is set to 1, then an interrupt-acknowledge-code will be automatically sent once the INT/ACK-timer has expired, and the ISR bit will be cleared again.

When an interrupt-acknowledge-code is received, and the corresponding ISR bit is 1, the ISR bit is set to 0. If the interrupt number’s corresponding bit in the Interrupt tick-out mask register is set to 1, and the interrupt-code that made the ISR bit get set to 1 in the first place was sent by software (through register access), then the corresponding bit in the Interrupt-acknowledge-code receive register is set to 1. The TICKOUT signal is asserted for one clock cycle as well, and an AMBA interrupt is generated (if the IE bit in the Control register, and IQ bit in the Interrupt distribution control register are both set to 1).

Note that all received control codes, interrupt- / interrupt-acknowledge-codes or not, are outputted on the TIMEOUT[7:0] signals, and the TICKOUTRAW signal is asserted for one clock cycle.

For more details regarding interrupt- / interrupt-acknowledge-code reception, please see the description of the interrupt distribution registers in section 33.11.

33.5.3 Transmitting interrupt- / interrupt-acknowledge-codes

Interrupt- / interrupt-acknowledge-codes can be transmitted either through the AMBA APB registers or through the signals TICKINRAW, TIMEIN, and TICKINDONE.

To transmit an interrupt- / interrupt-acknowledge-code through the register interface the II bit in the Interrupt distribution control register should be written to 1. When the bit is written the value of the TXINT field determine which interrupt- / interrupt-acknowledge-code that will be sent.

To transmit an interrupt- / interrupt-acknowledge-code using the TICKINRAW signal the sender must wait until TICKINDONE is low, then assert TICKINRAW and place the value of the interrupt- / interrupt-acknowledge-code to be sent on the TIMEIN[7:0] signals. When TICKINDONE is asserted again, the TICKINRAW signal should be de-asserted the same cycle.

Both methods of sending an interrupt- / interrupt-acknowledge-code requires that interrupt transmission is enabled (IT bit in Interrupt distribution control register set to 1). The actual sending of the interrupt- / interrupt-acknowledge-code is delayed until the corresponding INT/ACK-timer has expired.

For more details regarding interrupt- / interrupt-acknowledge-code transmission, please see the description of the interrupt distribution registers in section 33.11.

33.5.4 Interrupt-code generation

Interrupt-codes can be generated automatically due to a number of internal events. Which events that should force an interrupt-code to be sent, and what interrupt-number to use, is controlled from the

Interrupt distribution control register, and the DMA control/status register. Interrupt transmission must also be enabled (IT bit in Interrupt distribution control register) for interrupt-codes to be generated. Internally generated interrupt-codes are sent in the same manner as interrupt-codes transmitted through the register interface and the TICKINRAW signal, as described in section 33.5.3. For more details regarding interrupt-code generation please see the description of the Interrupt distribution control register and DMA control/status register in section 33.11.

33.6 Receiver DMA channels

The receiver DMA engine handles reception of data from the SpaceWire network to different DMA channels.

33.6.1 Address comparison and channel selection

Packets are received to different channels based on the address and whether a channel is enabled or not. When the receiver N-Char FIFO contains one or more characters, N-Chars are read by the receiver DMA engine. The first character is interpreted as the logical address and is compared with the addresses of each channel starting from 0. The packet will be stored to the first channel with an matching address. The complete packet including address and protocol ID but excluding EOP/EEP is stored to the memory address pointed to by the descriptors (explained later in this section) of the channel.

Each SpaceWire address register has a corresponding mask register. Only bits at an index containing a zero in the corresponding mask register are compared. This way a DMA channel can accept a range of addresses. There is a Default address register which is used for address checking in all implemented DMA channels that do not have separate addressing enabled and for RMAP commands in the RMAP target. With separate addressing enabled the DMA channels' own address/mask register pair is used instead.

If an RMAP command is received it is only handled by the target if the Default address register (including mask) matches the received address. Otherwise the packet will be stored to a DMA channel if one or more of them has a matching address. If the address does not match neither the default address nor one of the DMA channels' separate register, the packet is still handled by the RMAP target if enabled since it has to return the invalid address error code. The packet is only discarded (up to and including the next EOP/EEP) if an address match cannot be found and the RMAP target is disabled.

Packets, other than RMAP commands, that do not match neither the default address register nor the DMA channels' address register will be discarded. Figure 61 shows a flowchart of packet reception.

At least 2 non EOP/EEP N-Chars needs to be received for a packet to be stored to the DMA channel unless the promiscuous mode is enabled in which case 1 N-Char is enough. If it is an RMAP packet with hardware RMAP enabled 3 N-Chars are needed since the command byte determines where the packet is processed. Packets smaller than these sizes are discarded.

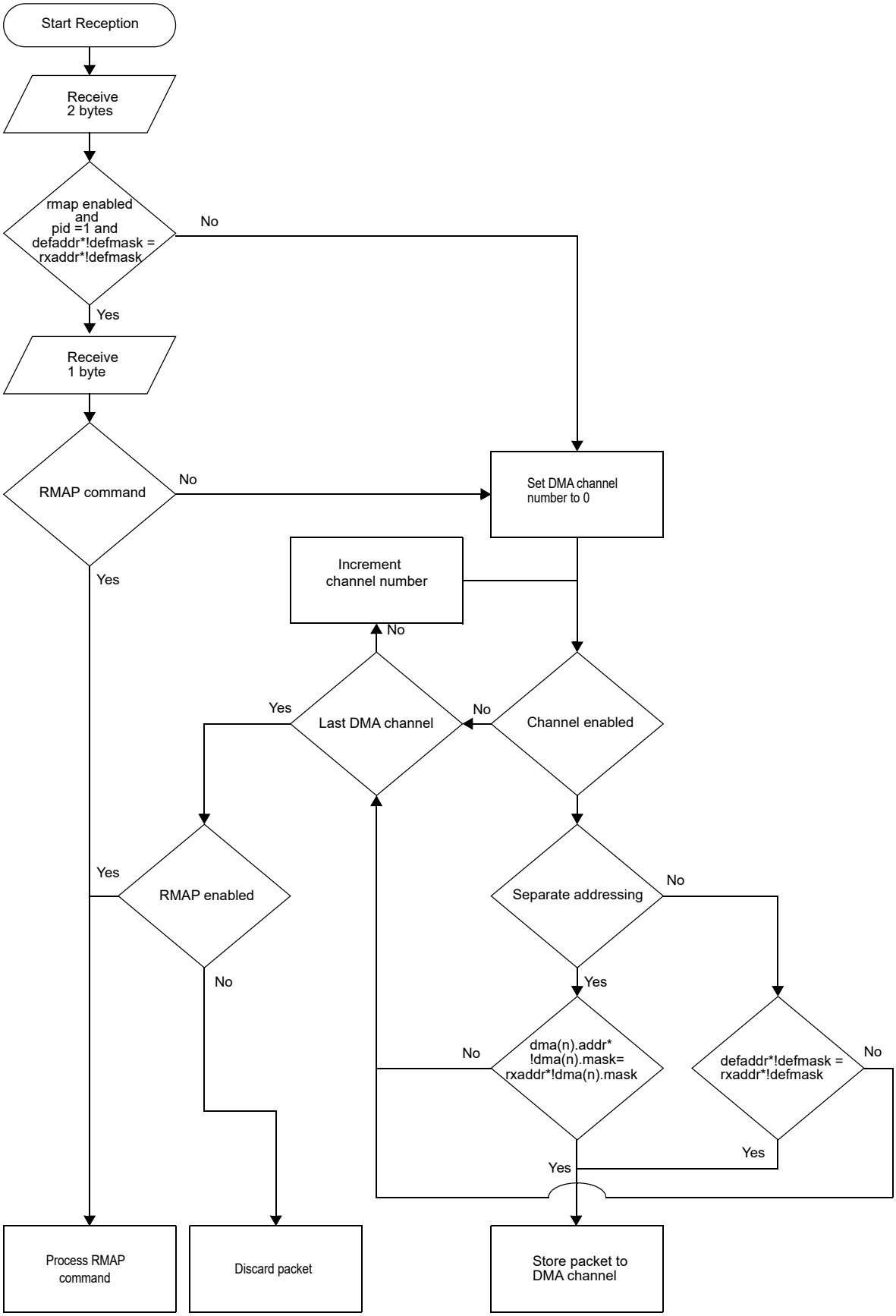


Figure 61. Flow chart of packet reception.

33.6.2 Basic functionality of a channel

Reception is based on descriptors located in a consecutive area in memory that hold pointers to buffers where packets should be stored. When a packet arrives at the core the channel which should receive it is first determined as described in the previous section. A descriptor is then read from the channels' descriptor area and the packet is stored to the memory area pointed to by the descriptor. Lastly, status is stored to the same descriptor and increments the descriptor pointer to the next one. The following sections will describe DMA channel reception in more detail.

33.6.3 Setting up the core for reception

A few registers need to be initialized before reception to a channel can take place. First the link interface need to be put in the run state before any data can be sent. The DMA channel has a maximum length register which sets the maximum packet size in bytes that can be received to this channel. Larger packets are truncated and the excessive part is spilled. If this happens an indication will be given in the status field of the descriptor. The minimum value for the receiver maximum length field is 4 and the value can only be incremented in steps of four bytes up to the maximum value 33554428. If the maximum length is set to zero the receiver will *not* function correctly.

Either the Default address register or the channel specific address register (the accompanying mask register must also be set) needs to be set to hold the address used by the channel. A control bit in the DMA channel control register determines whether the channel should use default address and mask registers for address comparison or the channel's own registers. Using the default register the same address range is accepted as for other channels with default addressing and the RMAP target while the separate address provides the channel its own range. If all channels use the default registers they will accept the same address range and the enabled channel with the lowest number will receive the packet.

Finally, the descriptor table and Control register must be initialized. This will be described in the two following sections.

33.6.4 Setting up the descriptor table address

The core reads descriptors from an area in memory pointed to by the receiver descriptor table address register. The register consists of a base address and a descriptor selector. The base address points to the beginning of the area and must start on an address that is aligned to the size of the descriptor table. The size of the descriptor table can be determined from the formula: STS.NRXD*8. The STS.NRXD field shows the number of entries in the descriptor table, and each descriptor size is 8 bytes.

The descriptor selector points to individual descriptors and is increased by 1 when a descriptor has been used. When the selector reaches the upper limit of the area it wraps to the beginning automatically. It can also be set to wrap at a specific descriptor before the upper limit by setting the wrap bit in the descriptor. The idea is that the selector should be initialized to 0 (start of the descriptor area) but it can also be written with another 8 bytes aligned value to start somewhere in the middle of the area. It will still wrap to the beginning of the area.

If one wants to use a new descriptor table the receiver enable bit has to be cleared first. When the rxactive bit for the channel is cleared it is safe to update the descriptor table register. When this is finished and descriptors are enabled the receiver enable bit can be set again.

33.6.5 Enabling descriptors

As mentioned earlier one or more descriptors must be enabled before reception can take place. Each descriptor is 8 byte in size and the layout can be found in the tables below. The descriptors should be written to the memory area pointed to by the receiver descriptor table address register. When new descriptors are added they must always be placed after the previous one written to the area. Otherwise they will not be noticed.

A descriptor is enabled by setting the address pointer to point at a location where data can be stored and then setting the enable bit. The WR bit can be set to cause the selector to be set to zero when reception has finished to this descriptor. IE should be set if an interrupt is wanted when the reception has finished. The DMA control register interrupt enable bit must also be set for an interrupt to be generated.

*Table 366.*GRSPW2 receive descriptor word 0 (address offset 0x0)

31	30	29	28	27	26	25	24 ... 0
TR	DC	HC	EP	IE	WR	EN	PACKETLENGTH

31	Truncated (TR) - Packet was truncated due to maximum length violation.
30	Data CRC (DC) - 1 if a CRC error was detected for the data and 0 otherwise.
29	Header CRC (HC) - 1 if a CRC error was detected for the header and 0 otherwise.
28	EEP termination (EP) - This packet ended with an Error End of Packet character.
27	Interrupt enable (IE) - If set, an interrupt will be generated when a packet has been received if the receive interrupt enable bit in the DMA channel control register is set.
26	Wrap (WR) - If set, the next descriptor used by the GRSPW will be the first one in the descriptor table (at the base address). Otherwise the descriptor pointer will be increased with 0x8 to use the descriptor at the next higher memory location. The descriptor table is limited to 1 kbytes in size and the pointer will be automatically wrap back to the base address when it reaches the 1 kbytes boundary.
25	Enable (EN) - Set to one to activate this descriptor. This means that the descriptor contains valid control values and the memory area pointed to by the packet address field can be used to store a packet.
24: 0	Packet length (PACKETLENGTH) - The number of bytes received to this buffer. Only valid after EN has been set to 0 by the GRSPW.

*Table 367.*GRSPW2 receive descriptor word 1 (address offset 0x4)

31 ... 0
PACKETADDRESS

31: 0	Packet address (PACKETADDRESS) - The address pointing at the buffer which will be used to store the received packet.

33.6.6 Setting up the DMA control register

The final step to receive packets is to set the control register in the following steps: The receiver must be enabled by setting the rxen bit in the DMA control register. This can be done anytime and before this bit is set nothing will happen. The rxdescav bit in the DMA control register is then set to indicate that there are new active descriptors. This must always be done after the descriptors have been enabled or the core might not notice the new descriptors. More descriptors can be activated when reception has already started by enabling the descriptors and writing the rxdescav bit. When these bits are set reception will start immediately when data is arriving.

33.6.7 The effect to the control bits during reception

When the receiver is disabled all packets going to the DMA-channel are discarded if the packet's address does not fall into the range of another DMA channel. If the receiver is enabled and the address falls into the accepted address range, the next state is entered where the rxdescav bit is checked. This bit indicates whether there are active descriptors or not and should be set by the external application using the DMA channel each time descriptors are enabled as mentioned above. If the rxdescav bit is '0' and the nospill bit is '0' the packets will be discarded. If nospill is '1' the core waits until rxdescav is set and the characters are kept in the N-Char fifo during this time. If the fifo becomes full further N-char transmissions are inhibited by stopping the transmission of FCTs.

When rxdescav is set the next descriptor is read and if enabled the packet is received to the buffer. If the read descriptor is not enabled, rxdescav is set to '0' and the packet is spilled depending on the value of nospill.

The receiver can be disabled at any time and will stop packets from being received to this channel. If a packet is currently received when the receiver is disabled the reception will still be finished. The rxdescav bit can also be cleared at any time. It will not affect any ongoing receptions but no more descriptors will be read until it is set again. Rxdescav is also cleared by the core when it reads a disabled descriptor.

33.6.8 Status bits

When the reception of a packet is finished the enable bit in the current descriptor is set to zero. When enable is zero, the status bits are also valid and the number of received bytes is indicated in the length field. The DMA control register contains a status bit which is set each time a packet has been received. The core can also be made to generate an interrupt for this event.

The RMAP CRC calculation is always active for all received packets and all bytes except the EOP/EEP are included. The packet is always assumed to be an RMAP packet and the length of the header is determined by checking byte 3 which should be the command field. The calculated CRC value is then checked when the header has been received (according to the calculated number of bytes) and if it is non-zero the HC bit is set indicating a header CRC error.

The CRC value is not set to zero after the header has been received, instead the calculation continues in the same way until the complete packet has been received. Then if the CRC value is non-zero the DC bit is set indicating a data CRC error. This means that the core can indicate a data CRC error even if the data field was correct when the header CRC was incorrect. However, the data should not be used when the header is corrupt and therefore the DC bit is unimportant in this case. When the header is not corrupted the CRC value will always be zero when the calculation continues with the data field and the behaviour will be as if the CRC calculation was restarted

If the received packet is not of RMAP type the header CRC error indication bit cannot be used. It is still possible to use the DC bit if the complete packet is covered by a CRC calculated using the RMAP CRC definition. This is because the core does not restart the calculation after the header has been received but instead calculates a complete CRC over the packet. Thus any packet format with one CRC at the end of the packet calculated according to RMAP standard can be checked using the DC bit.

If the packet is neither of RMAP type nor of the type above with RMAP CRC at the end, then both the HC and DC bits should be ignored.

33.6.9 Error handling

If a packet reception needs to be aborted because of congestion on the network, the suggested solution is to set link disable to '1'. Unfortunately, this will also cause the packet currently being transmitted to be truncated but this is the only safe solution since packet reception is a passive operation depending on the transmitter at the other end. A channel reset bit could be provided but is not a satisfactory solution since the untransmitted characters would still be in the transmitter node. The next character (somewhere in the middle of the packet) would be interpreted as the node address which would probably cause the packet to be discarded but not with 100% certainty. Usually this action is performed when a reception has stuck because of the transmitter not providing more data. The channel reset would not resolve this congestion.

If an AHB error occurs during reception the current packet is spilled up to and including the next EEP/EOP and then the currently active channel is disabled and the receiver enters the idle state. A bit in the channels control/status register is set to indicate this condition.

33.6.10 Promiscuous mode

The core supports a promiscuous mode where all the data received is stored to the first DMA channel enabled regardless of the node address and possible early EOPs/EEPs. This means that all non-EOP/EEP N-Chars received will be stored to the DMA channel. The rxmaxlength register is still checked and packets exceeding this size will be truncated.

RMAP commands will still be handled by the hardware RMAP target when promiscuous mode is enabled, if the RMAP enable bit in the core's Control register is set. If the RMAP enable bit is cleared, RMAP commands will also be stored to a DMA channel.

33.7 Transmitter DMA channels

The transmitter DMA engine handles transmission of data from the DMA channels to the SpaceWire network. Each receive channel has a corresponding transmit channel which means there can be up to 4 transmit channels. It is however only necessary to use a separate transmit channel for each receive channel if there are also separate entities controlling the transmissions. The use of a single channel with multiple controlling entities would cause them to corrupt each other's transmissions. A single channel is more efficient and should be used when possible.

Multiple transmit channels with pending transmissions are arbitrated in a round-robin fashion.

33.7.1 Basic functionality of a channel

A transmit DMA channel reads data from the AHB bus and stores them in the transmitter FIFO for transmission on the SpaceWire network. Transmission is based on the same type of descriptors as for the receiver and the descriptor table has the same alignment and size restrictions. When there are new descriptors enabled the core reads them and transfer the amount data indicated.

33.7.2 Setting up the core for transmission

Four steps need to be performed before transmissions can be done with the core. First the link interface must be enabled and started by writing the appropriate value to the ctrl register. Then the address to the descriptor table needs to be written to the transmitter descriptor table address register and one or more descriptors must also be enabled in the table. Finally, the txen bit in the DMA control register is written with a one which triggers the transmission. These steps will be covered in more detail in the next sections.

33.7.3 Enabling descriptors

The core reads descriptors from an area in memory pointed to by the transmit descriptor table address register. The register consists of a base address and a descriptor selector. The base address points to the beginning of the area and must start on an address that is aligned to the size of the descriptor table. The size of the descriptor table can be determined from the formula: STS.NTXD*16. The STS.NTXD field shows the number of entries in the descriptor table, and each descriptor size is 16 bytes.

To transmit packets one or more descriptors have to be initialized in memory which is done in the following way: The number of bytes to be transmitted and a pointer to the data has to be set. There are two different length and address fields in the transmit descriptors because there are separate pointers for header and data. If a length field is zero the corresponding part of a packet is skipped and if both are zero no packet is sent. The maximum header length is 255 bytes and the maximum data length is 16 Mbyte - 1. When the pointer and length fields have been set the enable bit should be set to enable the descriptor. This must always be done last. The other control bits must also be set before enabling the descriptor.

The transmit descriptors are 16 bytes in size so the maximum number in a single table is 64. The different fields of the descriptor together with the memory offsets are shown in the tables below.

The HC bit should be set if RMAP CRC should be calculated and inserted for the header field and correspondingly the DC bit should be set for the data field. The header CRC will be calculated from the data fetched from the header pointer and the data CRC is generated from data fetched from the data pointer. The CRCs are appended after the corresponding fields. The NON-CRC bytes field is set to the number of bytes in the beginning of the header field that should not be included in the CRC calculation.

The CRCs are sent even if the corresponding length is zero, but when both lengths are zero no packet is sent not even an EOP.

33.7.4 Starting transmissions

When the descriptors have been initialized, the transmit enable bit in the DMA control register has to be set to tell the core to start transmitting. New descriptors can be activated in the table on the fly (while transmission is active). Each time a set of descriptors is added the transmit enable bit in the corresponding DMA channel control/status register should be set. This has to be done because each time the core encounters a disabled descriptor this register bit is set to 0.

*Table 368.*GRSPW2 transmit descriptor word 0 (address offset 0x0)

31 18	17	16	15	14	13	12	11 8	7 0
RESERVED	DC	HC	LE	IE	WR	EN	NONCRCLEN	HEADERLEN

31: 18	RESERVED
17	Append data CRC (DC) - Append CRC calculated according to the RMAP specification after the data sent from the data pointer. The CRC covers all the bytes from this pointer. A null CRC will be sent if the length of the data field is zero.
16	Append header CRC (HC) - Append CRC calculated according to the RMAP specification after the data sent from the header pointer. The CRC covers all bytes from this pointer except a number of bytes in the beginning specified by the non-crc bytes field. The CRC will not be sent if the header length field is zero.
15	Link error (LE) - A Link error occurred during the transmission of this packet.
14	Interrupt enable (IE) - If set, an interrupt will be generated when the packet has been transmitted and the transmitter interrupt enable bit in the DMA control register is set.
13	Wrap (WR) - If set, the descriptor pointer will wrap and the next descriptor read will be the first one in the table (at the base address). Otherwise the pointer is increased with 0x10 to use the descriptor at the next higher memory location.
12	Enable (EN) - Enable transmitter descriptor. When all control fields (address, length, wrap and crc) are set, this bit should be set. While the bit is set the descriptor should not be touched since this might corrupt the transmission. The core clears this bit when the transmission has finished.
11: 8	Non-CRC bytes (NONCRCLEN)- Sets the number of bytes in the beginning of the header which should not be included in the CRC calculation. This is necessary when using path addressing since one or more bytes in the beginning of the packet might be discarded before the packet reaches its destination.
7: 0	Header length (HEADERLEN) - Header Length in bytes. If set to zero, the header is skipped.

*Table 369.*GRSPW2 transmit descriptor word 1 (address offset 0x4)

31 0
HEADERADDRESS

31: 0	Header address (HEADERADDRESS) - Address from where the packet header is fetched. Does not need to be word aligned.

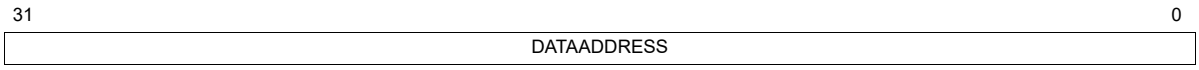
*Table 370.*GRSPW2 transmit descriptor word 2 (address offset 0x8)

31 24	23 0
RESERVED	DATALEN

*Table 370.*GRSPW2 transmit descriptor word 2 (address offset 0x8)

31: 24	RESERVED
23: 0	Data length (DATALEN) - Length in bytes of data part of packet. If set to zero, no data will be sent. If both data- and header-lengths are set to zero no packet will be sent.

*Table 371.*GRSPW2 transmit descriptor word 3(address offset 0xC)



31: 0	Data address (DATAADDRESS) - Address from where data is read. Does not need to be word aligned.

33.7.5 The transmission process

When the transmitter enable bit in the DMA channel control/status register is set the core starts reading descriptors immediately. The number of bytes indicated are read and transmitted. When a transmission has finished, status will be written to the first field of the descriptor and a packet sent bit is set in the DMA control register. If an interrupt was requested it will also be generated. Then a new descriptor is read and if enabled a new transmission starts, otherwise the transmit enable bit is cleared and nothing will happen until it is enabled again.

33.7.6 The descriptor table address register

The internal pointer which is used to keep the current position in the descriptor table can be read and written through the APB interface. This pointer is set to zero during reset and is incremented each time a descriptor is used. It wraps automatically when the limit for the descriptor table is reached, or it can be set to wrap earlier by setting a bit in the current descriptor.

The descriptor table register can be updated with a new table anytime when no transmission is active. No transmission is active if the transmit enable bit is zero and the complete table has been sent or if the table is aborted (explained below). If the table is aborted one has to wait until the transmit enable bit is zero before updating the table pointer.

33.7.7 Error handling

Abort Tx

The DMA control register contains a bit called Abort TX which if set causes the current transmission to be aborted, the packet is truncated and an EEP is inserted. This is only useful if the packet needs to be aborted because of congestion on the SpaceWire network. If the congestion is on the AHB bus this will not help (This should not be a problem since AHB slaves should have a maximum of 16 wait-states). The aborted packet will have its LE bit set in the descriptor. The transmit enable register bit is also cleared and no new transmissions will be done until the transmitter is enabled again.

AHB error

When an AHB error is encountered during transmission the currently active DMA channel is disabled and the transmitter goes to the idle mode. A bit in the DMA channel's control/status register is set to indicate this error condition and, if enabled, an interrupt will also be generated. Further error handling depends on what state the transmitter DMA engine was in when the AHB error occurred. If the descriptor was being read the packet transmission had not been started yet and no more actions need to be taken.

If the AHB error occurs during packet transmission the packet is truncated and an EEP is inserted. Lastly, if it occurs when status is written to the descriptor the packet has been successfully transmitted but the descriptor is not written and will continue to be enabled (this also means that no error bits are set in the descriptor for AHB errors).

The client using the channel has to correct the AHB error condition and enable the channel again. No more AHB transfers are done again from the same unit (receiver or transmitter) which was active during the AHB error until the error state is cleared and the unit is enabled again.

Link error

When a link error occurs during the transmission, the remaining part of the packet is discarded up to, and including, the next EOP/EEP. When this is done, status is immediately written back to the descriptor (with the LE bit set) and the descriptor pointer is incremented. The link will be disconnected when the link error occurs but the core will automatically try to connect again, provided that the link-start bit (LS bit in Control register) is asserted, and the link-disabled bit (LD bit in Control register) is deasserted. If the LE bit in the DMA channel's control register is not set the transmitter DMA engine will wait for the link to enter run-state, and start a new transmission immediately when possible, assuming there are packets pending. If the LE bit in the DMA channel's control register is set, the transmitter will be disabled when a link error occurs during a transmission of a packet. In that case, no more packets will be transmitted until the transmitter is enabled again. See description of the DMA channel's control register for more details.

33.8 RMAP

The Remote Memory Access Protocol (RMAP) is used to implement access to resources in the node via the SpaceWire link. Some common operations are reading and writing to memory, registers and FIFOs. The core has an optional hardware RMAP target. Whether or not the RMAP target is implemented is indicated by the CTRL.RA bit. This section describes the basics of the RMAP protocol and the target implementation.

33.8.1 Fundamentals of the protocol

RMAP is a protocol which is designed to provide remote access via a SpaceWire network to memory mapped resources on a SpaceWire node. It has been assigned protocol ID 0x01. It provides three operations: write, read and read-modify-write. These operations are posted operations, which means that a source does not wait for an acknowledge or reply. It also implies that any number of operations can be outstanding at any time and that no timeout mechanism is implemented in the protocol. Time-outs must instead be implemented in the user application which sends the commands. Data payloads of up to 2^{24} - 1 bytes is supported by the protocol. A destination can be requested to send replies and to verify data before executing an operation. For a complete description of the protocol, see the RMAP standard (ECSS-E-ST-50-52C).

33.8.2 Implementation

The core includes a target for RMAP commands which processes all incoming packets with protocol ID = 0x01, type field (bit 7 and 6 of the 3rd byte in the packet) equal to 01b and an address falling in the range set by the default address and mask register. When such a packet is detected it is not stored to the DMA channel, instead it is passed to the RMAP receiver.

The core implements all three commands defined in the standard with some restrictions. Support is only provided for 32-bit big-endian systems. This means that the first byte received is the msb in a word. The target will not receive RMAP packets using the extended protocol ID which are always dumped to the DMA channel.

The RMAP receiver processes commands. If they are correct and accepted the operation is performed on the AHB bus and a reply is formatted. If an acknowledge is requested the RMAP transmitter automatically send the reply. RMAP transmissions have priority over DMA channel transmissions.

There is a user accessible destination key register which is compared to destination key field in incoming packets. If there is a mismatch and a reply has been requested the error code in the reply is set to 3. Replies are sent if and only if the ack field is set to '1'.

When a failure occurs during a bus access the error code is set to 1 (General Error). There is predetermined order in which error-codes are set in the case of multiple errors in the core. It is shown in table 372.

*Table 372.*The order of error detection in case of multiple errors. The error detected first has number 1.

Detection Order	Error Code	Error
1	12	Invalid destination logical address
2	2	Unused RMAP packet type or command code
3	3	Invalid destination key
4	9	Verify buffer overrun
5	11	RMW data length error
6	10	Authorization failure
7*	1	General Error (AHB errors during non-verified writes)
8	5/7	Early EOP / EEP (if early)
9	4	Invalid Data CRC
10	1	General Error (AHB errors during verified writes or RMW)
11	7	EEP
12	6	Cargo Too Large
*The AHB error is not guaranteed to be detected before Early EOP/EEP or Invalid Data CRC. For very long accesses the AHB error detection might be delayed causing the other two errors to appear first.		

Read accesses are performed on the fly, that is they are not stored in a temporary buffer before transmitting. This means that the error code 1 will never be seen in a read reply since the header has already been sent when the data is read. If the AHB error occurs the packet will be truncated and ended with an EEP.

Errors up to and including Invalid Data CRC (number 8) are checked before verified commands. The other errors do not prevent verified operations from being performed.

The details of the support for the different commands are now presented. All defined commands which are received but have an option set which is not supported in this specific implementation will not be executed and a possible reply is sent with error code 10.

33.8.3 Write commands

The write commands are divided into two subcategories when examining their capabilities: verified writes and non-verified writes. Verified writes have a length restriction of 4 bytes and the address must be aligned to the size. That is 1 byte writes can be done to any address, 2 bytes must be halfword aligned, 3 bytes are not allowed and 4 bytes writes must be word aligned. Since there will always be only one AHB operation performed for each RMAP verified write command the incrementing address bit can be set to any value.

Non-verified writes have no restrictions when the incrementing bit is set to 1. If it is set to 0 the number of bytes must be a multiple of 4 and the address word aligned. There is no guarantee how many words will be written when early EOP/EEP is detected for non-verified writes.

33.8.4 Read commands

Read commands are performed on the fly when the reply is sent. Thus if an AHB error occurs the packet will be truncated and ended with an EEP. There are no restrictions for incrementing reads but non-incrementing reads have the same alignment restrictions as non-verified writes. Note that the “Authorization failure” error code will be sent in the reply if a violation was detected even if the length field was zero. Also note that no data is sent in the reply if an error was detected i.e. if the status field is non-zero.

33.8.5 RMW commands

All read-modify-write sizes are supported except 6 which would have caused 3 B being read and written on the bus. The RMW bus accesses have the same restrictions as the verified writes. As in the verified write case, the incrementing bit can be set to any value since only one AHB bus operation will be performed for each RMW command. Cargo too large is detected after the bus accesses so this error will not prevent the operation from being performed. No data is sent in a reply if an error is detected i.e. the status field is non-zero.

33.8.6 Control

The RMAP target mostly runs in the background without any external intervention, but there are a few control possibilities.

There is an enable bit in the control register of the core which can be used to completely disable the RMAP target. When it is set to ‘0’ no RMAP packets will be handled in hardware, instead they are all stored to the DMA channel.

There is a possibility that RMAP commands will not be performed in the order they arrive. This can happen if a read arrives before one or more writes. Since the target stores replies in a buffer with more than one entry several commands can be processed even if no replies are sent. Data for read replies is read when the reply is sent and thus writes coming after the read might have been performed already if there was congestion in the transmitter. To avoid this the RMAP buffer disable bit can be set to force the target to only use one buffer which prevents this situation.

The last control option for the target is the possibility to set the destination key which is found in a separate register.

*Table 373.*GRSPW2 hardware RMAP handling of different packet type and command fields.

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Command	Action
Reserved	Command / Response	Write / Read	Verify data before write	Acknow-ledge	Increment Address		
0	0	-	-	-	-	Response	Stored to DMA-channel.
0	1	0	0	0	0	Not used	Does nothing. No reply is sent.
0	1	0	0	0	1	Not used	Does nothing. No reply is sent.
0	1	0	0	1	0	Read single address	Executed normally. Address has to be word aligned and data size a multiple of four. Reply is sent. If alignment restrictions are violated error code is set to 10.
0	1	0	0	1	1	Read incre-menting address.	Executed normally. No restric-tions. Reply is sent.
0	1	0	1	0	0	Not used	Does nothing. No reply is sent.
0	1	0	1	0	1	Not used	Does nothing. No reply is sent.
0	1	0	1	1	0	Not used	Does nothing. Reply is sent with error code 2.
0	1	0	1	1	1	Read-Mod-ify-Write incrament-ing address	Executed normally. If length is not one of the allowed rmw val-ues nothing is done and error code is set to 11. If the length was correct, alignment restric-tions are checked next. 1 byte can be rmw to any address. 2 bytes must be halfword aligned. 3 bytes are not allowed. 4 bytes must be word aligned. If these restrictions are violated nothing is done and error code is set to 10. If an AHB error occurs error code is set to 1. Reply is sent.
0	1	1	0	0	0	Write, sin-gle-address, do not verify before writ-ing, no acknowledge	Executed normally. Address has to be word aligned and data size a multiple of four. If alignment is violated nothing is done. No reply is sent.
0	1	1	0	0	1	Write, incre-menting address, do not verify before writ-ing, no acknowledge	Executed normally. No restric-tions. No reply is sent.
0	1	1	0	1	0	Write, sin-gle-address, do not verify before writ-ing, send acknowledge	Executed normally. Address has to be word aligned and data size a multiple of four. If alignment is violated nothing is done and error code is set to 10. If an AHB error occurs error code is set to 1. Reply is sent.

*Table 373.*GRSPW2 hardware RMAP handling of different packet type and command fields.

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Command	Action
Reserved	Command / Response	Write / Read	Verify data before write	Acknow-ledge	Increment Address		
0	1	1	0	1	1	Write, incre-menting address, do not verify before writ-ing, send acknowledge	Executed normally. No restric-tions. If AHB error occurs error code is set to 1. Reply is sent.
0	1	1	1	0	0	Write, single address, ver-ify before writing, no acknowledge	Executed normally. Length must be 4 or less. Otherwise nothing is done. Same alignment restric-tions apply as for rmw. No reply is sent.
0	1	1	1	0	1	Write, incre-menting address, ver-ify before writing, no acknowledge	Executed normally. Length must be 4 or less. Otherwise nothing is done. Same alignment restric-tions apply as for rmw. If they are violated nothing is done. No reply is sent.
0	1	1	1	1	0	Write, single address, ver-ify before writing, send acknowledge	Executed normally. Length must be 4 or less. Otherwise nothing is done and error code is set to 9. Same alignment restrictions apply as for rmw. If they are vio-lated nothing is done and error code is set to 10. If an AHB error occurs error code is set to 1. Reply is sent.
0	1	1	1	1	1	Write, incre-menting address, ver-ify before writing, send acknowledge	Executed normally. Length must be 4 or less. Otherwise nothing is done and error code is set to 9. Same alignment restrictions apply as for rmw. If they are vio-lated nothing is done and error code is set to 10. If an AHB error occurs error code is set to 1. Reply is sent.
1	0	-	-	-	-	Unused	Stored to DMA-channel.
1	1	-	-	-	-	Unused	Stored to DMA-channel.

33.9 AMBA interface

The AMBA interface consists of an APB interface, an AHB master interface and DMA FIFOs. The APB interface provides access to the user registers. The DMA engines have 32-bit wide FIFOs to the AHB master interface which are used when reading and writing to the bus.

The transmitter DMA engine reads data from the bus in bursts which are half the FIFO size in length. A burst is always started when the FIFO is half-empty or if it can hold the last data for the packet. The burst containing the last data might have shorter length if the packet is not an even number of bursts in size.

The receiver DMA works in the same way except that it checks if the FIFO is half-full and then performs a burst write to the bus which is half the fifo size in length. The last burst might be shorter. Byte accesses are used for non word-aligned buffers and/or packet lengths that are not a multiple of four bytes. There might be 1 to 3 single byte writes when writing the beginning and end of the received packets.

33.9.1 APB slave interface

As mentioned above, the APB interface provides access to the user registers which are 32-bits in width. The accesses to this interface are required to be aligned word accesses. The result is undefined if this restriction is violated.

33.9.2 AHB master interface

The core contains a single master interface which is used by both the transmitter and receiver DMA engines. The arbitration algorithm between the channels is done so that if the current owner requests the interface again it will always acquire it. This will not lead to starvation problems since the DMA engines always deassert their requests between accesses.

AHB accesses can be of size byte, halfword and word (HSIZE = 0x000, 0x001, 0x010) otherwiseByte and halfword accesses are always NONSEQ. Note that read accesses are always word accesses (HSIZE = 0x010), which can result in destructive read.

The burst length will be half the AHB FIFO size except for the last transfer for a packet which might be smaller. Shorter accesses are also done during descriptor reads and status writes.

The AHB master also supports non-incrementing accesses where the address will be constant for several consecutive accesses. HTRANS will always be NONSEQ in this case while for incrementing accesses it is set to SEQ after the first access. This feature is included to support non-incrementing reads and writes for RMAP.

If the core does not need the bus after a burst has finished there will be one wasted cycle (HTRANS = IDLE).

BUSY transfer types are never requested and the core provides full support for ERROR, RETRY and SPLIT responses.

33.10 SpaceWire Plug-and-Play

The core supports parts of the SpaceWire Plug-and-Play protocol. The supported fields are listed in table 376, and explained in more detail in tables 377 through 391. Table 376 also shows which type of SpaceWire Plug-and-Play access type (read, write, compare-and-swap) that is allowed for the field. Note that two different amount of SpaceWire Plug-and-Play support may be included. Either only device identification through the Device Information fields is supported, or device configuration through the SpaceWire Protocol fields is supported as well. The amount of support is indicated by the CTRL.PNPA field. Note also that the CTRL.PE must be set in order to enable the SpaceWire Plug-and-Play support.

The SpaceWire Plug-and-Play protocol uses standard RMAP commands and replies with the same requirements as presented in section 33.8, but with the following differences:

- Protocol Identifier field of a command shall be set to 0x03.
- A command's address fields shall contain a word address. The SpaceWire Plug-and-Play addresses are encoded as shown in table 374.
- The increment bit in the command's instruction field shall be set to 1, otherwise a reply with Status field set to 0x0A (authorization failure) is sent.
- RMAP read-modify-write command is replaced by a compare-and-swap command. The command's data fields shall contain the new data to be written, while the mask fields shall contain the

value that the current data must match in order for the new data to be written. If there is a mismatch, a reply with Status field set to 0x0A (authorization failure) is sent.

- The reply packet's Status field can contain the additional status codes described in table 375.

Table 374. SpaceWire Plug-and-Play address encoding

31 24	23 19	18 14	13 0
Application Index	Protocol Index	FieldSet ID	Field ID

Table 375. SpaceWire Plug-and-Play status codes

Value	Description
0xF0	Unauthorized access - A write, or compare-and-swap command, with an address other then the Device ID field's address, arrived when the core was not configured (Device ID field = 0), or the command did not match the owner information saved in the Link Information field and Owner Address fields.
0xF1	Reserved field set - A read, write, or compare-and-swap command's address field points to a non existing field set. [1)]
0xF2	Read-only field - A write, or compare-and-swap command's address points to a read-only field.
0xF3	Compare-and-swap-only-field - A write command's address points to a field that is only writable through a compare-and-swap-only.
Note 1: An access to a non existing field, within a existing field set, does not generate an error response. The data returned in a read access is zero, while a write access has no effect.	

Table 376. SpaceWire Plug-and-Play support

SpW PnP Address	Name	Acronym	Service - Field set - Field	Access type
0x00000000	SpaceWire Plug-and-Play - Device Vendor and Product ID	PNPVEND	Device Information - Device Identification - Device Vendor and Product ID	read
0x00000001	SpaceWire Plug-and-Play - Version	PNPVER	Device Information - Device Identification - Version	read
0x00000002	SpaceWire Plug-and-Play - Device Status	PNPDEVSTS	Device Information - Device Identification - Device Status	read
0x00000003	SpaceWire Plug-and-Play - Active Links	PNPALINK	Device Information - Device Identification - Active Links	read
0x00000004	SpaceWire Plug-and-Play - Link Information	PNPLINFO	Device Information - Device Identification - Link Information	read
0x00000005	SpaceWire Plug-and-Play - Owner Address 0	PNPOA0	Device Information - Device Identification - Owner Address 0	read
0x00000006	SpaceWire Plug-and-Play - Owner Address 1	PNPOA1	Device Information - Device Identification - Owner Address 1	read
0x00000007	SpaceWire Plug-and-Play - Owner Address 2	PNPOA2	Device Information - Device Identification - Owner Address 2	read
0x00000008	SpaceWire Plug-and-Play - Device ID	PNPDEVID	Device Information - Device Identification - Device ID	read, cas
0x00000009	SpaceWire Plug-and-Play - Unit Vendor and Product ID	PNPUVEND	Device Information - Device Identification - Unit Vendor and Product ID	read

Table 376. SpaceWire Plug-and-Play support

SpW PnP Address	Name	Acronym	Service - Field set - Field	Access type
0x0000000A	SpaceWire Plug-and-Play - Unit Serial Number	PNPUSN	Device Information - Device Identification - Unit Serial Number	read
0x00004000	SpaceWire Plug-and-Play - Vendor String Length	PNPVSTRL	Device Information - Vendor / Product String - Vendor String Length	read
0x00006000	SpaceWire Plug-and-Play - Product String Length	PNPPSTRL	Device Information - Vendor / Product String - Product String Length	read
0x00008000	SpaceWire Plug-and-Play - Protocol Count	PNPPCNT	Device Information - Protocol Support - Protocol Count	read
0x00008001	SpaceWire Plug-and-Play - Protocol Identification 1	PNPPID1	Device Information - Protocol Support - Protocol Identification 1	read
0x00008002	SpaceWire Plug-and-Play - Protocol Identification 2	PNPPID2	Device Information - Protocol Support - Protocol Identification 2	read
0x0000C000	SpaceWire Plug-and-Play - Application Count	PNPACNT	Device Information - Application Support- Application Count	read
0x00080000	SpaceWire Plug-and-Play - Time-Code Counter 1)	PNPTCC	SpaceWire Protocol - Device Configuration - Time-Code Counter	read, write, cas
0x00084008	SpaceWire Plug-and-Play - Link Status 1)	PNPLSTS	SpaceWire Protocol - Link Configuration - Link Status	read, write, cas
0x00084009	SpaceWire Plug-and-Play - Link Control 1)	PNPLCTRL	SpaceWire Protocol - Link Configuration - Link Control	read, write, cas
0x00100000	SpaceWire Plug-and-Play - Maximum Write Length 1)	PNPMWLEN	SpaceWire PnP Protocol - Protocol Information - Maximum Write Length	read
0x00100001	SpaceWire Plug-and-Play - Maximum Read Length 1)	PNPMRLEN	SpaceWire PnP Protocol - Protocol Information - Maximum Read Length	read
Note 1: Register is only available when device configuration through SpaceWire Plug-and-Play is supported, which is indicated by the value of the CTRL.PNPA field.				

The layout of the SpaceWire Plug-and-Play registers used in this section is the same as for the registers described in section 33.11, and is examplified in table 397. The reset value field and bit-field type definitions are also the same as in section 33.11, and are explained in tables 398 and 399 respectively.

*Table 377.*0x00000000 - PNPVEND - SpaceWire Plug-and-Play - Device Vendor and Product ID

31 16	15 0
VEND	PROD
*	*
r	r

31: 16 Vendor ID (VEND) - SpaceWire vendor ID assigned at implementation time.

15: 0 Product ID (PROD) - Product ID assigned at implementation time.

*Table 378.*0x00000001 - PNPVER - SpaceWire Plug-and-Play - Version

31 24	23 16	15 8	7 0
MAJOR	MINOR	PATCH	RESERVED

*Table 378.*0x00000001 - PNPVER - SpaceWire Plug-and-Play - Version

*	*	*	*
r	r	r	r

31: 24 Major version number (MAJOR) - Major version number set at implementation time.

23: 16 Minor version number (MINOR) - Minor version number set at implementation time.

15: 8 Patch / Build number (PATCH) - Patch / Build number set at implementation time.

7: 0 RESERVED

*Table 379.*0x00000002 - PNPDEVSTS - SpaceWire Plug-and-Play - Device Status

31 8	7 0
RESERVED	STATUS
0x000000	0x00
r	r

31: 8 RESERVED

7: 0 Device status (STATUS) - Constant value of 0x00.

*Table 380.*0x00000003 - PNPALINK - SpaceWire Plug-and-Play - Active Links

31 2	1	0
RESERVED	AC	R
0x00000000	0	0
r	r	r

31: 20 RESERVED

19: 1 Link active (AC) - Indicates if the link interface is in run-state. 0 = Not run-state, 1 = run-state.

0 RESERVED

*Table 381.*0x00000004 - PNPLINFO -SpaceWire Plug-and-Play - Link Information

31 24	23 22	21	20 16	15 13	12 8	7	6	5	4 0
OLA	OAL	R	OL	RES	RL	T	U	R	LC
0x00	0x0	0	0x0	0x0	0x0	1	0	0	0x13
r	r	r	r	r	r	r	r	r	r

31: 24 Owner logical address (OLA) - Shows the value of the Initiator Logical Address field from the last successful compare-and-swap command that set the Device ID field.

23: 22 Owner address length (OAL) - Shows how many of the three Owner Address fields that contain valid data.

21 RESERVED

20: 16 Owner link (OL) - Shows the number of the port which was used for the last successful operation to set the value of the Device ID field.

15: 13 RESERVED

12: 8 Return link (RL) - Shows the number of the port through which the reply to the current read command will be transmitted.

7 Device type (T) - Constant value of 0, indicating a node.

6 Unit information (U) - Indicates if the unit identification information (Unit Vendor and Product ID field, and Unit Serial Number field) are valid. 0 = invalid, 1 = valid. This bit will be 0 after reset / power-up. Once the Unit Vendor and Product ID field has been written with a non-zero value, this bit will be set to 1.

5 RESERVED

4: 0 Link count (LC) - Shows the number of router ports. Constant value of 0x13.

*Table 382.*0x00000005 - PNPOA0 - SpaceWire Plug-and-Play - Owner Address 0

31 0
RA
0x00000000
r

*Table 382.*0x00000005 - PNPOA0 - SpaceWire Plug-and-Play - Owner Address 0

31: 0 Reply address (RA) - Shows byte 0-3 of the Reply Address from the last successful compare-and-swap command that set to the Device ID field. If there was no Reply Address, then this field is zero.

*Table 383.*0x00000006 - PNPOA1 - SpaceWire Plug-and-Play - Owner Address 1

31	0
RA	
0x00000000	
r	

31: 0 Reply address (RA) - Shows byte 4-7 of the Reply Address from the last successful compare-and-swap command that set to the Device ID field. If the Reply Address was four bytes or less, then this field is zero.

*Table 384.*0x00000007 - PNPOA2 - SpaceWire Plug-and-Play - Owner Address 2

31	0
RA	
0x00000000	
r	

31: 0 Reply address (RA) - Shows byte 8-11 of the Reply Address from the last successful compare-and-swap command that set to the Device ID field. If the Reply Address was eight bytes or less, then this field is zero.

*Table 385.*0x00000008 - PNPDEVID - SpaceWire Plug-and-Play - Device ID

31	0
DID	
0x00000000	
cas	

31: 0 Device ID (DID) - Shows the device identifier. This field is set to zero after reset / power-up, and when the link-interface is not in run-state.

*Table 386.*0x00000009 - PNPUVEND - SpaceWire Plug-and-Play - Unit Vendor and Product ID

31 16	15 0
VEND	PROD
*	*
r	r

31: 16 Unit vendor ID (VEND) - Shows the unit vendor identifier. This field is read-only through the SpaceWire Plug-and-Play protocol, however it is writable through an APB register (see section 33.11). Reset value is taken from the input signal PNPUVENDID. Whenever this field, or the PROD field, is set to a non-zero value, the PNPLINFO.U bit is set to 1.

15: 0 Unit product ID (PROD) - Shows the unit product identifier. This field is read-only through the SpaceWire Plug-and-Play protocol, however it is writable through an APB register (see section 33.11). Reset value is taken from the input signal PNPUPRODID. Whenever this field, or the VEND field, is set to a non-zero value, the PNPLINFO.U bit is set to 1.

*Table 387.*0x0000000A - PNPUSN - SpaceWire Plug-and-Play - Unit Serial Number

31	0
USN	
*	
r	

31: 0 Unit serial number (USN) - Shows the unit serial number. This field is read-only through the SpaceWire Plug-and-Play protocol, however it is writable through the APB register (see section 33.11). Reset value is taken from the input signal PNPUSN.

*Table 388.*0x00004000 - PNPVSTRL - SpaceWire Plug-and-Play - Vendor String Length

31 15	14 0
RESERVED	LEN
0x00000	0x0000
r	r

31: 15 RESERVED

14: 0 Vendor string length (LEN) - Constant value of 0, indicating that no vendor string is present.

*Table 389.*0x00006000 - PNPPSTRL - SpaceWire Plug-and-Play - Product String Length

31 15	14 0
RESERVED	LEN
0x00000	0x0000
r	r

31: 15 RESERVED

14: 0 Product string length (LEN) - Constant value of 0, indicating that no product string is present.

*Table 390.*0x00008000 - PNPPCNT - SpaceWire Plug-and-Play - Protocol Count

31 5	4 0
RESERVED	PC
0x0000000	*
r	r

31: 5 RESERVED

4: 0 Protocol count (PC) - Constant value of 0 when only device identification is supported (CTRL.PNPA = 1). Constant value of 2 when device configuration is supported (CTRL.PNPA = 2).

*Table 391.*0x0000C000 - PNPACNT - SpaceWire Plug-and-Play - Application Count

31 8	7 0
RESERVED	AC
0x000000	0x00
r	r

31: 8 RESERVED

7: 0 Application count (AC) - Constant value of 0, indicating that no applications can be managed by using SpaceWire Plug-and-Play.

*Table 392.*0x00080000 - PNPTCC - SpaceWire Plug-and-Play - Time-Code Counter

31 6	5 0
RESERVED	TC
0x0000000	0x00
r	rw*

31: 6 RESERVED

5: 0 Time Count (TC) - Current time value. This bitfield can be reset by writing zero to it. Writing any other value has no effect. Double map of TC.TIMECNT value (see TC register in section 33.11 for a functional description).

*Table 393.*0x00084008 - PNPLSTS - SpaceWire Plug-and-Play - Link Status

31	30	29 19	18 16	15 8	7	6	5	4	3	2	1	0
ND	LT	RESERVED	LS	RESERVED	R	CE	ER	PE	DE	R	IA	R
1	1	0x000	0x0	0x00	0	0	0	0	0	0	0	0
r	r	r	r	r	r	rw*	rw*	rw*	rw*	r	rw*	r

31 Network discovery (ND) - Constant value of 1, indicating that the link can be used for network discovery.

30 Link type (LT) - Constant value of 1, indicating that the link is a SpaceWire link.

*Table 393.*0x00084008 - PNPLSTS - SpaceWire Plug-and-Play - Link Status

29: 19 RESERVED

18: 16 Link State (LS) - The current state of the link interface. 0 = Error-reset, 1 = Error-wait, 2 = Ready, 3 = Started, 4 = Connecting, 5 = Run.

25: 8 RESERVED

7 RESERVED

6 Credit Error (CE) - A credit has occurred. Cleared when complete PNPLSTS is written with zero.

5 Escape Error (ER) - An escape error has occurred. Cleared when complete PNPLSTS is written with zero.

4 Parity Error (PE) - A parity error has occurred. Cleared when complete PNPLSTS is written with zero.

3 Disconnect Error (DE) - A disconnection error has occurred. Cleared when complete PNPLSTS is written with zero.

2 RESERVED

1 Invalid Address (IA) - Set to one when a packet is received with an invalid destination address field, i.e it does not match the DEFADDR register. Cleared when complete PNPLSTS is written with zero.

0 RESERVED

*Table 394.*0x00084009 - PNPLCTRL - SpaceWire Plug-and-Play - Link Control

31 5	4	3	2	1	0
RESERVED	TT	R	LD	LS	AS
	0	0	0	0	*
	rw	r	rw	rw	rw

31: 5 RESERVED

4 Time-Code transmission (TT) - Enable Time-Code transmission.

3 RESERVED

2 Link Disable (LD) - Disable the SpaceWire codec link-interface.

1 Link Start (LS) - Start the link, i.e. allow a transition from ready-state to started-state.

0 Autostart (AS) - Automatically start the link when a NULL has been received. Reset value is set from input signal RMAPEN if RMAP target is available (CTRL.RA bit = 1), otherwise the reset value is '0'.

*Table 395.*0x00100000 - PNPMWLEN - SpaceWire Plug-and-Play - Maximum Write Length

31 15	14 0
RESERVED	LEN
0x00000	0x0002
r	r

31: 15 RESERVED

14: 0 Length (LEN) - Constant value, indicating the maximum number of fields that can be written with a single write command.

*Table 396.*0x00100001 - PNPMRLEN - SpaceWire Plug-and-Play - Maximum Read Length

31 15	14 0
RESERVED	LEN
0x00000	0x4000
r	r

31: 15 RESERVED

14: 0 Length (LEN) - Constant value, indicating the maximum number of fields that can be read with a single read command.

33.11 Registers

The core is programmed through registers mapped into APB address space. The registers are listed in table, 400 and described in detail in the subsequent tables. Addresses not listed in table 400 are reserved. A read access to a reserved register, or reserved field with a register, will always return zero,

and a write access has no effect. The register layout used is exemplified in table 397, and the values used in the reset value row and field type row are explained in tables 398 and 399.

Table 397.<APB ddress offset> - <Register acronym> - <Register name>

31 24	23 16	15 8	7 0
EF3	EF2	EF1	EF0
<Reset value for EF3>	<Reset value for EF2>	<Reset value for EF1>	<Reset value for EF0>
<Bit-field type for EF3>	<Bit-field type for EF2>	<Bit-field type for EF1>	<Bit-field type for EF0>

31: 24 Example bit-field 3 (EF3) - <Bit-field description>

23: 16 Example bit-field 2 (EF2) - <Bit-field description>

15: 8 Example bit-field 1 (EF1) - <Bit-field description>

7: 0 Example bit-field 0 (EF0) - <Bit-field description>

Table 398. Reset value definitions

Value	Description
0	Reset value 0. Used for single-bit fields.
1	Reset value 1. Used for single-bit fields.
0xNN	Hexadecimal representation of reset value. Used for multi-bit fields.
n/r	Field not reseted
*	Special reset condition, described in textual description of the bit-field. Used for example when reset value is taken from an input signal.

Table 399. Bit-field type definitions

Value	Description
r	Read-only. Writes have no effect.
rw	Readable and writable.
rw*	Readable and writeable. Special condition for write, described in textual description of the bit-field.
wc	Write-clear. Readable, and cleared when written with a 1. Writing 0 has no effect.

*Table 400.*GRSPW2 registers

APB address offset	Register acronym	Register name
0x00	CTRL	Control
0x04	STS	Status
0x08	DEFADDR	Default address
0x0C	CLKDIV	Clock divisor
0x10	DKEY	Destination key
0x14	TC	Time-code
0x18 - 0x1C	-	RESERVED
0x20	DMACTRL	DMA control/status, channel 1
0x24	DMAMAXLEN	DMA RX maximum length, channel 1
0x28	DMATXDESC	DMA transmit descriptor table address, channel 1
0x2C	DMARXDESC	DMA receive descriptor table address, channel 1
0x30	DMAADDR	DMA address, channel 1
0x34, 0x54, 0x74, 0x94	-	RESERVED
0x38, 0x58, 0x78, 0x98	-	RESERVED
0x3C, 0x5C, 0x7C, 0x9C	-	RESERVED
0xA0	INTCTRL	Interrupt distribution control
0xA4	INTRX	Interrupt receive
0xA8	ACKRX / INTRXEXT	Interrupt-acknowledge receive / Interrupt receive extended
0xAC	INTTO	Interrupt timeout
0xB0	INTTOEXT	Interrupt timeout extended
0xB4	TICKMASK	Interrupt tick-out mask
0xB8	TICKMASKEXT / AUTO-ACK	Interrupt auto acknowledge mask / Interrupt tick-out mask extended
0xBC	INTCFG	Interrupt distribution configuration
0xC0	-	RESERVED
0xC4	ISR	Interrupt distribution ISR
0xC8	ISREXT	Interrupt distribution Extended ISR
0xCC	-	RESERVED
0xD0	PRESCALER	Interrupt distribution prescaler reload
0cD4	ISRTIMER	Interrupt distribution ISR timer reload
0xD8	IATIMER	Interrupt distribution INT / ACK timer reload
0xDC	ICTIMER	Interrupt distribution change timer reload
0xE0	PNPVEND	SpaceWire PnP Device Vendor and Product ID
0xE4	PNPLINKINFO	SpaceWire PnP Link Information
0xE8	PNPOA0	SpaceWire PnP Owner Address 0
0xEC	PNPOA1	SpaceWire PnP Owner Address 1
0xF0	PNPOA2	SpaceWire PnP Owner Address 2
0xF4	PNPDEVID	SpaceWire PnP Device ID
0xF8	PNPUVEND	SpaceWire PnP Unit Vendor and Product ID
0xFC	PNPUSN	SpaceWire PnP Unit Serial Number

33.11.1 Control Register

*Table 401.*0x00 - CTRL - Control

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RA	RX	RC	NCH		PO	CC	ID	R	LE	PS	NP	PNPA		RD	RE	PE	R	TL	TF	TR	TT	LI	TQ	R	RS	PM	TI	IE	AS	LS	LD
1	1	1	0		1	0	1	0	0	0	*	1		0	*	*	0	0	0	0	0	0	0	0	0	0	0	0	*	0	0
r	r	r	r		r	r	r	r	rw	rw	rw	r		rw	rw	rw	r	rw	rw	rw	rw	rw	rw	r	rw	rw	rw	rw	rw	rw	rw	rw

31 RMAP available (RA) - Set to one if the RMAP target is available.

30 RX unaligned access (RX) - Set to one if unaligned writes are available for the receiver.

29 RMAP CRC available (RC) - Set to one if RMAP CRC is enabled in the core.

28: 27 Number of DMA channels (NCH) - The number of available DMA channels minus one (Number of channels = NCH+1).

26 Number of ports (PO) - The number of available SpaceWire ports minus one.

25 CCSDS/CCITT CRC-16 and 16-bit ISO-checksum available (CC) - Set to one if this crc logic is enabled in the core.

24 Interrupt distribution available (ID) - Set to 1 if interrupt distribution support is available, otherwise set to 0. If set to 1, then the INTCTRL.NUMINT field indicates the number of supported interrupt numbers.

23 RESERVED

22 Loop-back enable (LE). The value of this bit is driven on the LOOPBACK output signal.

21 Port select (PS) - Selects the active port when the CTRL.NP bit is zero. ‘0’ selects the port connected to data and strobe on index 0, while ‘1’ selects index data and strobe on 1. Only available in two-port configurations, which is indicated by CTRL.PO bit. This bit is reserved in one-port-configurations.

20 No port force (NP) - Disable port force. When this bit is set, the CTRL.PS bit cannot be used to select the active port. Instead, the active port is automatically selected by checking the activity on the respective receive links. Only available in two-port configurations, which is indicated by CTRL.PO bit. Reserved bit in one-port configurations. Reset value is ’1’ if the boot strap signals are configured for SpaceWire RMAP enable, see section 3.1, otherwise the reset value is ’0’.

19: 18 SpaceWire Plug-and-Play available (PNPA) - Indicates SpaceWire Plug-and-Play support. 0 = No support, 1 = Support for the device identification, 2 = Support for device identification and configuration. See section 33.10 for details.

17 RMAP buffer disable (RD) - If set, only one RMAP buffer is used. This ensures that all RMAP commands will be executed consecutively.

16 RMAP Enable (RE) - Enable RMAP target. Reset value is ’1’ if the boot strap signals are configured for SpaceWire RMAP enable, see section 3.1, otherwise the reset value is ’0’.

15 SpaceWire Plug-and-Play enable (PE) - Enable SpaceWire Plug-and-Play support. Only available if the CTRL.PA bit is 1, otherwise this bit is reserved. Reset value is ’1’ if the boot strap signals are configured for SpaceWire RMAP enable, see section 3.1, otherwise the reset value is ’0’.

14 RESERVED

13 Transmitter enable lock control (TL) - Enables / disables the transmitter enable lock functionality described by the DMACTRL.TL bit. 0 = Disabled, 1 = Enabled.

12 Time-code control flag filter (TF) - When set to 1, a received time-code must have its control flag bits set to “00” to be considered valid. When set to 0, all control flag bits are allowed. Note that if the interrupt code receive enable bit (INTCTRL.IR) is set to 1, then the only time-code control flag bits of “00” are allowed, regardless of the setting of this bit.

11 Time Rx Enable (TR) - Enable time-code reception.

10 Time Tx Enable (TT) - Enable time-code transmission.

9 Link error IRQ (LI) - Enables / disables AMBA interrupt generation when a link error occurs. Note that the CTRL.IE bit also must be set for this bit to have any effect.

8 Tick-out IRQ (TQ) - Enables / disables AMBA interrupt generation when a valid time-code is received. Note that the CTRL.IE bit also must be set for this bit to have any effect.

7 RESERVED

6 Reset (RS) - Make complete reset of the SpaceWire node. Self clearing.

*Table 401.*0x00 - CTRL - Control

5	Promiscuous Mode (PM) - Enable promiscuous mode. See section 33.6.10.
4	Tick In (TI) - The host can generate a tick by writing a one to this bit. This incrementd the timer counter (TC.TIMECNT), and the new value is transmitted. This bit will stay high until the time-code has been sent. Note that the link interface must be in run-state for the time-code to be sent.
3	Interrupt Enable (IE) - If set, AMBA interrupt generation is enabled for the events that are individually maskable by the CTRL.TQ, CTRL.LI, INTCTRL.IQ, INTCTRL.AQ, and INTCTRL.TQ bits.
2	Autostart (AS) - Automatically start the link when a NULL has been received. Reset value is ’1’ if the boot strap signals are configured for SpaceWire RMAP enable, see section 3.1, otherwise the reset value is ’0’.
1	Link Start (LS) - Start the link, i.e. allow a transition from ready-state to started-state.
0	Link Disable (LD) - Disable the SpaceWire codec.

33.11.2 Status Register

*Table 402.*0x04 - STS - Status

31 28	27 26	25 24	23 22 21	20 19 18 17 16 15 14 13 12 11 10	9	8	7	6 5	4	3	2	1	0
RESERVED	NRXD	NTXD	LS	RESERVED	AP	EE	IA	RES	PE	DE	ER	CE	TO
0x00	*	*	0x0	0x000	0	0	0	0x0	0	0	0	0	0
r	r	r	r	r	r	wc	wc	r	wc	wc	wc	wc	wc

31: 28 RESERVED

27: 26 Number of receive descriptors (NRXD) - Shows the size of the DMA receive descriptor table. 0b00 = 128, 0b01 = 256, 0b10 = 512, 0b11 = 1024

25 24 Number of transmit descriptors (NTXD) - Shows the size of the DMA transmit descriptor table. 0b00 = 64, 0b01 = 128, 0b10 = 256, 0b11 = 512

23: 21 Link State (LS) - The current state of the start-up sequence. 0 = Error-reset, 1 = Error-wait, 2 = Ready, 3 = Started, 4 = Connecting, 5 = Run.

20: 10 RESERVED

9 Active port (AP) - Shows the currently active port. '0' = Port 0 and '1' = Port 1 where the port numbers refer to the index number of the data and strobe signals.

8 Early EOP/EEP (EE) - Set to one when a packet is received with an EOP after the first byte for a non-rmap packet and after the second byte for an RMAP packet.

7 Invalid Address (IA) - Set to one when a packet is received with an invalid destination address field, i.e it does not match the DEFADDR register.

6: 5 RESERVED

4 Parity Error (PE) - A parity error has occurred.

3 Disconnect Error (DE) - A disconnection error has occurred.

2 Escape Error (ER) - An escape error has occurred.

1 Credit Error (CE) - A credit has occurred.

0 Tick Out (TO) - A new time count value was received and is stored in the time counter field.

33.11.3 Default Address Register

*Table 403.*0x08 - DEFADDR - Default address

31 16	15 8	7 0
RESERVED	DEFMASK	DEFADDR
0x0000	0x00	*
r	rw	rw

31: 8 RESERVED

15: 8 Default mask (DEFMASK) - Default mask used for node identification on the SpaceWire network. This field is used for masking the address before comparison. Both the received address and the DEFADDR.DEFADDR field are anded with the inverse of this field before the address check.

7: 0 Default address (DEFADDR) - Default address used for node identification on the SpaceWire network. Reset value: 254

33.11.4 Clock Divisor Register

*Table 404.*0x0C - CLKDIV - Clock divisor

31 16	15 8	7 0
RESERVED	CLKDIVSTART	CLKDIVRUN
0x0000	*	*
r	rw	rw

31: 16 RESERVED

15: 8 Clock divisor startup (CLKDIVSTART) - The value of this field is used as a clock divider during startup (link interface is in other states than run-state). See 33.3.5 for details on how to set this field. Reset value taken from the CLKDIV10 input signal.

7: 0 Clock divisor run (CLKDIVRUN) - The value of this field is used as a clock divider when the link-interface is in run-state. See 33.3.5 for details on how to set this field. Reset value taken from the CLKDIV10 input signal.

33.11.5 Destination Key Register

*Table 405.*0x10 - DKEY - Destination key

31 8	7 0
RESERVED	DESTKEY
0x000000	*
r	rw

31: 8 RESERVED

7: 0 Destination key (DESTKEY) - RMAP destination key.

33.11.6 Time-code Register

*Table 406.*0x14 - TC - Time-code

31 8	7 6	5 0
RESERVED	TCTRL	TIMECNT
0x000000	0x0	0x00
r	rw	rw

31: 8 RESERVED

7: 6 Time control flags (TCTRL) - The current value of the time-code control flags. Sent in a time-code each time the TICKIN signal is set, or the CTRL.TI bit is written. This field is also updated with the control flags from all received time-codes, and with the value of the TIMEIN[7:6] signals if TICKINRAW is asserted.

5: 0 Time counter (TIMECNT) - The current time value. Incremented, and transmitted in a time-code, each time the TICKIN signal is set, or the CTRL.TI bit is written. This field is also updated with the time value from all received time-codes, and with the value of the TIMEIN[5:0] signals if TICKINRAW is asserted. Note that the register can be written, but that the written value is not transmitted, since the value is incremented before transmission.

33.11.7 DMA Control/Status

*Table 407.*0x20 - DMACTRL - DMA control/status

31 26	25 24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
INTNUM	RES	EP	TR	IE	IT	RP	TP	TL	LE	SP	SA	EN	NS	RD	RX	AT	RA	TA	PR	PS	AI	RI	TI	RE	TE
*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
rw	r	wc	wc	rw	rw	wc	wc	wc	rw	rw	rw	rw	rw	rw	r	rw	wc	wc	wc	wc	rw	rw	rw	rw	rw

31: 26 Interrupt-number (INTNUM) - The interrupt-number used for this DMA channel when sending an interrupt-code that was generated due to any of the events maskable by the DMACTRL.IE and DMACTRL.IT bits. Reset value is taken from the IRQTXDEFAULT input signal. Field is only present if interrupt distribution is supported, which is indicated by the CTRL.ID bit. Note that this field must be set to a value within the range defined by the INCTRL.NUMINT and INTCTRL.BASEINT fields. A value outside the range will result in no interrupt-code being sent.

25: 24 RESERVED

23 EEP termination (EP) - Set to 1 when a received packet for the corresponding DMA channel ended with an Error End of Packet (EEP) character.

22 Truncated (TR) - Set to 1 when a received packet for the corresponding DMA channel is truncated due to a maximum length violation.

21 Interrupt-code transmit enable on EEP (IE) - When set to 1, and the interrupt-code transmit enable bit (INTCTRL.IT) is set, an interrupt-code is generated when a received packet on this DMA channel ended with an Error End of Packet (EEP) character. Field is only present if interrupt distribution is supported, which is indicated by the CTRL.ID bit.

20 Interrupt-code transmit enable on truncation (IT) - When set to 1, and the interrupt-code transmit enable (INTCTRL.IT) bit in the Interrupt distribution control register is set, an interrupt-code is generated when a received packet on this DMA channel is truncated due to a maximum length violation. Field is only present if interrupt distribution is supported, which is indicated by the CTRL.ID bit.

19 Receive packet IRQ (RP) - This bit is set to 1 when an AMBA interrupt was generated due to the fact that a packet was received for the corresponding DMA channel.

18 Transmit packet IRQ (TP) - This bit is set to 1 when an AMBA interrupt was generated due to the fact that a packet was transmitted for the corresponding DMA channel.

17 Transmitter enable lock (TL) - This bit is set to 1 if the CTRL.TL bit is set, and the transmitter for the corresponding DMA channel is disabled due to a link error (controlled by the DMACTRL.LE bit). While this bit is set, it is not possible to re-enable the transmitter (e.g. not possible to set the DMACTRL.TE bit to 1).

16 Link error disable (LE) - Disable transmitter when a link error occurs. No more packets will be transmitted until the transmitter is enabled again.

15 Strip pid (SP) - Remove the pid byte (second byte) of each packet. The address byte (first byte) will also be removed when this bit is set, independent of the value of the DMACTRL.SA bit.

14 Strip addr (SA) - Remove the addr byte (first byte) of each packet.

13 Enable addr (EN) - Enable separate node address for this channel.

12 No spill (NS) - If cleared, packets will be discarded when a packet is arriving and there are no active descriptors. If set, the core will wait for a descriptor to be activated.

11 Rx descriptors available (RD) - Set to one, to indicate to the core that there are enabled descriptors in the descriptor table. Cleared by the core when it encounters a disabled descriptor.

10 RX active (RX) - Is set to ‘1’ if a reception to the DMA channel is currently active, otherwise it is ‘0’.

9 Abort TX (AT) - Set to one to abort the currently transmitting packet and disable transmissions. If no packet is currently being transmitted, the only effect is to disable transmissions. Self clearing.

*Table 407.*0x20 - DMACTRL - DMA control/status

8	RX AHB error (RA) - An error response was detected on the AHB bus while this receive DMA channel was accessing the bus.
7	TX AHB error (TA) - An error response was detected on the AHB bus while this transmit DMA channel was accessing the bus.
6	Packet received (PR) - This bit is set each time a packet has been received.
5	Packet sent (PS) - This bit is set each time a packet has been sent.
4	AHB error interrupt (AI) - If set, an interrupt will be generated each time an AHB error occurs when this DMA channel is accessing the bus.
3	Receive interrupt (RI) - If set, an interrupt will be generated when a packet is received, if the interrupt enable (IE) bit in the corresponding receive descriptor is set as well. This happens both if the packet is terminated by an EEP or EOP.
2	Transmit interrupt (TI) - If set, an interrupt will be generated when a packet is transmitted, if the interrupt enable (IE) bit in the corresponding transmit descriptor is set as well. The interrupt is generated regardless of whether the transmission was successful or not.
1	Receiver enable (RE) - Set to one when packets are allowed to be received to this channel.
0	Transmitter enable (TE) - Enables the transmitter for the corresponding DMA channel. Setting this bit to 1 will cause the SW-node to read a new descriptor and try to transmit the packet it points to. Note that it is only possible to set this bit to 1 if the TL bit is 0. This bit is automatically cleared when the SW-node encounters a descriptor which is disabled, or if a link error occurs during the transmission of a packet, and the LE bit is set.

33.11.8 DMA RX Maximum Length

*Table 408.*0x24 - DMAMAXLEN - DMA RX maximum length

31 25	24 2	1 0
RESERVED	RXMAXLEN	RES
0x00	n/r	0x0
r	rw	r

31: 25 RESERVED

24: 2 RX maximum length (RXMAXLEN) - Receiver packet maximum length, counted in 32-bit words.

1: 0 RESERVED

33.11.9 DMA Transmit Descriptor Table Address

*Table 409.*0x28 - DMATXDESC - DMA transmit descriptor table address

31 x+1	x 4	3 0
DESCBASEADDR	DESCSEL	RESERVED
n/r	0x00	0x0
rw	rw	r

31: x+1 Descriptor table base address (DESCBASEADDR) - Sets the base address of the descriptor table. The number of bits in this field depends on the size of the DMA transmit descriptor table. The value of x is given by the formula: 9 + STS.NTXD.

x: 4 Descriptor selector (DESCSEL) - Offset into the descriptor table. Shows which descriptor is currently used by the core. For each new descriptor read, the selector will increase with 16 and eventually wrap to zero again. The number of bits in this field depends on the size of the DMA transmit descriptor table. The value of x is given by the formula: 9 + STS.NTXD.

3: 0 RESERVED

33.11.10 DMA Receive Descriptor Table Address

*Table 410.*0x2C - DMARXDESC - DMA receive descriptor table address

31 x+1	x 3	2 0
DESCBASEADDR	DESCSEL	RESERVED
n/r	0x00	0x0
rw	rw	r

31: 10 Descriptor table base address (DESCBASEADDR) - Sets the base address of the descriptor table. The number of bits in this field depends on the size of the DMA receive descriptor table. The value of x is given by the formula: 9 + STS.NRXD.

9: 3 Descriptor selector (DESCSEL) - Offset into the descriptor table. Shows which descriptor is currently used by the core. For each new descriptor read, the selector will increase with 8 and eventually wrap to zero again. The number of bits in this field depends on the size of the DMA receive descriptor table. The value of x is given by the formula: 9 + STS.NRXD

2: 0 RESERVED

33.11.11 DMA Address

*Table 411.*0x30 - DMAADDR - DMA address

31 16	15 8	7 0
RESERVED	MASK	ADDR
0x0000	n/r	n/r
r	rw	rw

31: 8 RESERVED

15: 8 Mask (MASK) - Mask used for node identification on the SpaceWire network. This field is used for masking the address before comparison. Both the received address and the ADDR field are anded with the inverse of MASK before the address check.

7: 0 Address (ADDR) - Address used for node identification on the SpaceWire network for the corresponding dma channel when the EN bit in the DMA control register is set.

33.11.12 Interrupt Distribution Control

*Table 412.*0xA0 - INTCTRL - Interrupt distribution control

31 26	25	24	23	22 21	20	19	18	17 16	15	14	13	12 8	7	6	5 0
INTNUM	RS	EE	IA	RES	TQ	AQ	IQ	RES	AA	AT	IT	RES	ID	II	TXINT
*	0	0	0	0	0	0	0	0	0	0	0	0x00	0	0	*
rw	rw	rw	rw	r	rw	rw	rw	r	rw	rw	rw	r	wc	rw	rw

31: 26 Interrupt number (INTNUM) - The interrupt-number used when sending an interrupt-code that was generated due to any of the events maskable by the RS, ER or IA bits. Reset value is taken from the IRQTXDEFAULT input signal. Note that this field must be set to a value within the range defined by the NUMINT and BASEINT fields. A value outside the range will result in no interrupt-code being sent.

25 Interrupt-code transmit on run-state entry (RS) - If set to 1, and interrupt-code with the interrupt number specified in the INTNUM field is sent each time the link interface enters run-state.

24 Interrupt-code transmit on early EOP/EEP (EE) - If set to 1, an interrupt-code with the interrupt number specified in the INTNUM field is sent each time an event occurs such that the STS.EE bit is set to 1 (even if the bit was already set when the event occurrepriod).

23 Interrupt-code transmit on invalid address (IA) - If set to 1, an interrupt-code with the interrupt number specified in the INTNUM field is sent each time an event occurs such that the STS.IA bit is set to 1 (even if the bit was already set when the event occurred).

22: 21 RESERVED

20 Interrupt-code timeout IRQ enable (TQ) - When set to 1, an AMBA interrupt is generated when a bit in the INTTO register is set. Note that the IE bit in the Control register also must be set for this bit to have any effect. Bit is only available if support for the Interrupt distribution ISR timer is implemented.

19 Interrupt-code-acknowledge receive IRQ enable (AQ) - When set to 1, an AMBA interrupt is generated when an interrupt-acknowledge-code is received for which the corresponding bit in the Interrupt tick-out mask register is set, and the core was the source of the matching interrupt-code. Note that the IE bit in the Control register also must be set for this bit to have any effect.

18 Interrupt-code receive IRQ enable (IQ) - When set to 1, an AMBA interrupt is generated when an interrupt-code is received for which the corresponding bit in the Interrupt tick-out mask register is set to 1. Note that the IE bit in the Control register also must be set for this bit to have any effect.

17: 16 RESERVED

15 Handle all interrupt acknowledgement codes (AA) - Is set to 0, only those received interrupt acknowledgement codes that match an interrupt code sent by software are handled. If set to 1, all received interrupt acknowledgement codes are handled.

14 Interrupt acknowledgement / extended interrupt tickout enable (AT) - When set to 1, the internal tickout signal is set when an interrupt acknowledgement code or extended interrupt code is received such that a bit in the AUTOACK / INTRXEXT register is set to 1 (even if the bit was already set when the code was received).

*Table 412.*0xA0 - INTCTRL - Interrupt distribution control

13	Interrupt tickout enable (IT) - When set to 1, the internal tickout signal is set when an interrupt code is received such that a bit in the INTRX register is set to 1 (even if the bit was already set when the code was received).
12: 8	RESERVED
7	Interrupt-code discarded (ID) - This bit is set to 1 when and interrupt-code that software tried to send by writing the II bit was discarded, either because there already was a pending request to send an interrupt-code with the same interrupt-number, or because the corresponding ISR bit is 1. There is a one clock cycle delay between the II bit being written and this bit being set.
6	Interrupt-code tick-in (II) - When this field is written to 1 the interrupt- / interrupt-acknowledge-code specified in the TXINT field will be sent. The actual sending of the interrupt- / interrupt-acknowledge-code might be delayed, depending on the value for the corresponding ISR bit and INT/ACK-timer. Note that the interrupt-code transmit enable bit (IT) must be set to '1', otherwise writing this bit has no effect. This bit is automatically cleared and always reads '0'. Writing a '0' has no effect.
5: 0	Transmit interrupt- / interrupt-code (TXINT) - The interrupt- / interrupt-acknowledge-code that the core will send when the Interrupt-code tick-in bit (II) is written with 1. Reset value for bit 5 is '0', while bits 4:0 are set from the input signal IRQTXDEFAULT. Note that bits 4:0 of this field must be set to a value within the range defined by the NUMINT and BASEINT fields. A value outside the range will result in no interrupt-code being sent.

33.11.13 Interrupt Receive

*Table 413.*0xA4 - INTRX - Interrupt-code receive

31	0
RXIRQ	
0x00000000	
wc	

31: 0 Received interrupt-code (RXIRQ) - Each bit corresponds to the interrupt number with the same number as the bit index. The core sets a bit to 1 when it receives an interrupt-code for which the corresponding bit in the Interrupt tick out mask register is set to 1. Note that the number of implemented bits depends on the number of supported interrupts (INTCTRL.NUMINT field).

33.11.14 Interrupt-acknowledge-code Receive

*Table 414.*0xA8 - ACKRX / INTRXEXT - Interrupt-acknowledge-code receive / Interrupt receive extended

31	0
RXACK / INTRXEXT	
0x00000000	
wc	

31: 0 Received interrupt-acknowledge-code (RXACK) / Interrupt receive extended (INTRXEXT) - Each bit corresponds to the interrupt number with the same number as the bit index. The core sets a bit to 1 when it receives a interrupt-acknowledge-code for which the corresponding bit in the Interrupt tick out mask register is set, and for which the matching interrupt-code was sent by software (valid for interrupt-acknowledge). Note that the number of implemented bits depends on the number of supported interrupts (INTCTRL.NUMINT field). When extended interrupt mode is enabled this register is an extension of the Interrupt Receive register for interrupt 32-63.

33.11.15 Interrupt Timeout

*Table 415.*0xAC - INTTO - Interrupt timeout

31	0
INTTO	
0x00000000	
wc	

31: 0 Interrupt-code timeout (INTTO) - Each bit corresponds to the interrupt number with the same number as the bit index. The core sets a bit to 1 when an interrupt-code that was sent by software doesn't receive an interrupt-acknowledge-code for the duration of a timeout period (specified in the Interrupt distribution ISR timer reload registers), and if the corresponding bit in the Interrupt-code tick out mask register is set. Note that the number of implemented bits depends on the number of supported interrupts (INTCTRL.NUMINT field).

33.11.16 Interrupt Timeout Extended

*Table 416.*0xB0 - INTTOEXT - Interrupt timeout extended

31	0
INTTOEXT	
0x00000000	
wc	

31: 0 Interrupt timeout extended (INTTOEXT) - When extended interrupt mode is enabled, each bit corresponds to the interrupt number between 32 and 63. The core sets a bit to 1 when an interrupt-code that was sent by software and the time specified in the Interrupt distribution ISR timer reload registers has past and if the corresponding bit in the Interrupt-code tick out mask register is set. Note that the number of implemented bits depends on the number of supported interrupts (INTCTRL.NUMINT field).

33.11.17 Interrupt Tick-out Mask

*Table 417.*0xB4 - TICKMASK - Interrupt tick-out mask

31	0
MASK	
0x00000000	
rw*	

31: 0 Interrupt tick-out mask (MASK) - Each bit corresponds to the interrupt number with the same value as the bit index. If a bit is set, the TICKOUT signal as well as the corresponding bit in the Interrupt-code receive register, Interrupt-acknowledge-code receive register, and Interrupt-code timeout register is set when respective event occurs. Note that the number of implemented bits depends on the number of supported interrupts (INTCTRL.NUMINT field).

33.11.18 Interrupt-code Auto Acknowledge Mask

*Table 418.*0xB8 - AUTOACK / TICKMASKEXT - Interrupt-code auto acknowledge mask / Interrupt tick-out mask extended.

31	0
AAMASK	
0x00000000	
rw*	

31: 0 Auto acknowledge mask (AAMASK) - For each bit set to 1, the core will automatically send an interrupt-acknowledge-code when it receives an interrupt-code with the corresponding interrupt number. If the interrupt distribution timers are implemented and enabled, then the core will reload the INT-to-ACK timer and wait until it expires before the interrupt-acknowledge-code is sent. Note that the number of implemented bits depends on the number of supported interrupts (INTCTRL.NUMINT field). When extended interrupt mode is enabled this register is an extension of the Interrupt Tick-out Mask register.

33.11.19Interrupt Distribution Configuration

*Table 419.*0xBC - INTCFG - Interrupt distribution control

31 26	25 20	19 14	13 8	7 4	3	2	1	0
INTNUM3	INTNUM2	INTNUM1	INTNUM0	NUMINT	PR	IR	IT	EE
*	*	*	*	0	0	0	0	0
rw	rw		rw	r	rw	rw	rw	rw

31: 26 Interrupt number (INTNUM3) - Defines the which interrupt number to support when the device supports less then 32 interrupts.

25: 20 Interrupt number (INTNUM2) - Defines the which interrupt number to support when the device supports less then 32 interrupts.

19: 14 Interrupt number (INTNUM1) - Defines the which interrupt number to support when the device supports less then 32 interrupts.

13: 8 Interrupt number (INTNUM0) - Defines the which interrupt number to support when the device supports less then 32 interrupts.

7: 4 Number of interrupts (NUMINT) - Indicates the number of supported interrupts according to the formula: *Number of interrupts* = 2^{NUMINT}.

3 Interrupt- / interrupt-acknowledge-code priority (PR) - When set to 0, interrupt-codes have priority over interrupt-acknowledge-codes when there are multiple codes waiting to be sent. When set to 1, interrupt-acknowledge-codes have priority.

2 Interrupt receive enable (IR) - Enable interrupt- / interrupt-acknowledge-code reception.

1 Interrupt transmit enable (IT) - Enable interrupt- / interrupt-acknowledge-code transmission. Must be set to 1 in order for any interrupt- / interrupt-acknowledge-codes to be sent.

0 Enable external interrupt (EE) - Enable the external interrupt mode, which enable the core to use and interpret the interrupt-acknowledge-code as interrupt 32-63.

33.11.20 Interrupt Distribution ISR

*Table 420.*0xC4 - ISR - Interrupt distribution ISR

31	0
ISR	
0x00000000	
wc	

31: 0 Interrupt distribution ISR (ISR) - Each bit index holds the ISR bit value for the corresponding interrupt number. A bit value of 1 indicates that a interrupt-code with the corresponding interrupt number has been received, and that it has not yet been acknowledged (and not yet timed-out). A bit value of 0 indicates that either no interrupt-code with that interrupt number has been received, or that the interrupt has been acknowledged (or timed out). This register is write-clear, but should normally only be used for diagnostics and/or FDIR. Note that the number of implemented bits depends on the number of supported interrupts (INTCTRL.NUMINT field).

33.11.21 Interrupt Distribution ISR Extended

*Table 421.*0xC4 - ISREXT - Interrupt distribution ISR extended

31	0
ISR	
0x00000000	
wc	

31: 0 Interrupt distribution ISR (ISR) - Each bit index holds the ISR bit value for the corresponding interrupt number. A bit value of 1 indicates that a interrupt-code with the corresponding interrupt number has been received, and that it has not yet been acknowledged (and not yet timed-out). A bit value of 0 indicates that either no interrupt-code with that interrupt number has been received, or that the interrupt has been acknowledged (or timed out). This register is write-clear, but should normally only be used for diagnostics and/or FDIR. Note that the number of implemented bits depends on the number of supported interrupts (INTCTRL.NUMINT field).

33.11.22 Interrupt Distribution Prescaler Reload

*Table 422.*0xD0 - PRESCALER - Interrupt distribution prescaler reload

31 10	9 0
RESERVED	RL
0	*
r	rw

31: 10 RESERVED

9: 0 Prescaler reload (RL) - Reload value for the interrupt distribution prescaler. The prescaler runs on the system clock, and an internal tick is generated every RL+1 cycle. The number of bits implemented for this field might be lower than the 31 depicted here. Any unimplemented bits are reserved. Reset value set from the input signal INTPRELOAD.

33.11.23 Interrupt Distribution ISR Timer Reload

*Table 423.*0xD4 - ISRTIMER - Interrupt distribution ISR timer reload

31	30 ... 10	9 ... 0
EN	RESERVED	RL
1	0	*
rw	r	rw

31 Timer enable (EN) - Enables the use of ISR timer for each ISR bit. One global timer enable bit used for all ISR bits. If this bit is set to 1, the timer for each ISR bit is reloaded with the value in the RL field when the ISR bit is set. If the timer expires before an interrupt-code-acknowledge has been received, then ISR bit is cleared.

30: 10 RESERVED

9: 0 Timer reload (RL) - Common reload value for the interrupt distribution ISR timers. The number of bits implemented for this field might be lower than the 31 depicted here. Any unimplemented bits are reserved. Reset value set from the input signal INTTRELOAD.

33.11.24 Interrupt Distribution INT/ACK Timer Reload

*Table 424.*0xD8 - IATIMER - Interrupt distribution INT / ACK timer reload

31	30 ... 10	9 ... 0
EN	RESERVED	RL
1	0	*
rw	r	rw

31 Timer enable (EN) - Enables the use of timers to control the time between an interrupt-code and an interrupt-acknowledge-code, and vice versa. One global timer enable bit is used for all ISR bits. If this bit is set to 1, the timer for each ISR bit is reloaded with the value in the RL field each time an interrupt-code is received. The core will then wait until the timer expires before an interrupt-code-acknowledge with the same interrupt number is sent. The same applies when an interrupt-code-acknowledge is received and a new interrupt-code with the same number should be sent.

30: 10 RESERVED

9: 0 Timer reload (RL) - The number of bits implemented for this field might be lower than the 31 depicted here. Any unimplemented bits are reserved. Reset value set from the input signal INTIARELOAD.

33.11.25 Interrupt Distribution Change Timer Reload

*Table 425.*0xDC - ICTIMER - Interrupt distribution change timer reload

31	30 ... 10	9 ... 0
EN	RESERVED	RL
1	0	*
rw	r	rw

31 Timer enable (EN) - Enables the use of timers to control the time that must pass between two changes in value for the same ISR bit. One global timer enable bit is used for all ISR bits. If this bit is set to 1, the timer for each ISR bit is reloaded with the value in the RL field each time the ISR bit changes value. All potential interrupt- / interrupt-acknowledge-codes received before the timer expires is discarded.

30: 10 RESERVED

30: 0 Timer reload (RL) - The number of bits implemented for this field might be lower than the 31 depicted here. Any unimplemented bits are reserved. Reset value set from the input signal INTCRELOAD.

33.11.26 SpaceWire Plug-and-Play - Device Vendor and Product ID

*Table 426.*0xE0 - PNPVEND - SpaceWire Plug-and-Play - Device Vendor and Product ID

31 16	15 0
VEND	PROD
*	*
r	r

Note: Register is double mapped from SpaceWire Plug-and-Play address space into APB address space. See section 33.10 for details.

33.11.27 SpaceWire Plug-and-Play - Link Information

*Table 427.*0xE4 - PNPLINFO -SpaceWire Plug-and-Play - Link Information

31 24	23	22	21	20 16	15 13	12 8	7	6	5	4 0
OLA	OAL	R		OL	RES	RL	T	U	R	LC
0x00	0x0	0		0x0	0x0	0x0	1	0	0	0x13
r	r	r		r	r	r	r	r	r	r

Note: Register is double mapped from SpaceWire Plug-and-Play address space into APB address space. See section 33.10 for details.

33.11.28 SpaceWire Plug-and-Play - Owner Address 0

*Table 428.*0xE8 - PNPOA0 - SpaceWire Plug-and-Play - Owner Address 0

31 0
RA
0x00000000
r

Note: Register is double mapped from SpaceWire Plug-and-Play address space into APB address space. See section 33.10 for details.

33.11.29 SpaceWire Plug-and-Play - Owner Address 1

*Table 429.*0xEC - PNPOA1 - SpaceWire Plug-and-Play - Owner Address 1

31 0
RA
0x00000000
r

Note: Register is double mapped from SpaceWire Plug-and-Play address space into APB address space. See section 33.10 for details.

33.11.30 SpaceWire Plug-and-Play - Owner Address 2

*Table 430.*0xF0 - PNPOA2 - SpaceWire Plug-and-Play - Owner Address 2

31 0
RA
0x00000000
r

Note: Register is double mapped from SpaceWire Plug-and-Play address space into APB address space. See section 33.10 for details.

33.11.31 SpaceWire Plug-and-Play - Device ID

*Table 431.*0xF4 - PNPDEVID - SpaceWire Plug-and-Play - Device ID

31	0
DID	
0x00000000	
r	

Note: Register is double mapped from SpaceWire Plug-and-Play address space into APB address space. See section 33.10 for details.

33.11.32 SpaceWire Plug-and-Play - Unit Vendor and Product ID

*Table 432.*0xF8 - PNPUVEND - SpaceWire Plug-and-Play - Unit Vendor and Product ID

31	16	15	0
VEND		PROD	
*		*	
rw		rw	

Note: Register is double mapped from SpaceWire Plug-and-Play address space into APB address space. See section 33.10 for details. This register is read-only in SpaceWire Plug-and-Play interface, while it is writable from the APB address space.

33.11.33 SpaceWire Plug-and-Play - Unit Serial Number

*Table 433.*0xFC - PNPUSN - SpaceWire Plug-and-Play - Unit Serial Number

31	0
USN	
*	
rw	

Note: Register is double mapped from SpaceWire Plug-and-Play address space into APB address space. See section 33.10 for details. This register is read-only in SpaceWire Plug-and-Play interface, while it is writable from the APB address space.

34 SpaceWire - Time Distribution Protocol

34.1 Overview

This interface implements the SpaceWire - Time Distribution Protocol (TDP). The protocol provides capability to transfer time values and synchronise them between onboard users of SpaceWire network. The time values are transferred as CCSDS Time Codes and synchronisation is performed through SpaceWire Time-Codes. The core also provides datation services. The core operates in an AMBA APB bus system. The AMBA APB bus is used for configuration, control and status handling. The interface is coupled with a SpaceWire node with AMBA AHB master and RMAP target implementation.

34.2 Protocol

The initiator and target maintain their own time locally. The Time Distribution Protocol provides the means for transferring time of initiator to targets and for providing a synchronization point in time. The time is transferred by means of an RMAP write command carrying a CCSDS Time Code (time message). The synchronization event is signaled by means of transferring a SpaceWire Time-Code. The transfer of the SpaceWire Time-Code is synchronized with time maintained by the initiator. To distinguish which SpaceWire Time-Code is to be used for synchronization, the value of SpaceWire Time-Code is transferred from initiator to target by means of an RMAP write command prior to actual transmission of SpaceWire Time-Code itself.

34.3 Functionality

The block diagram below explains the complete system.

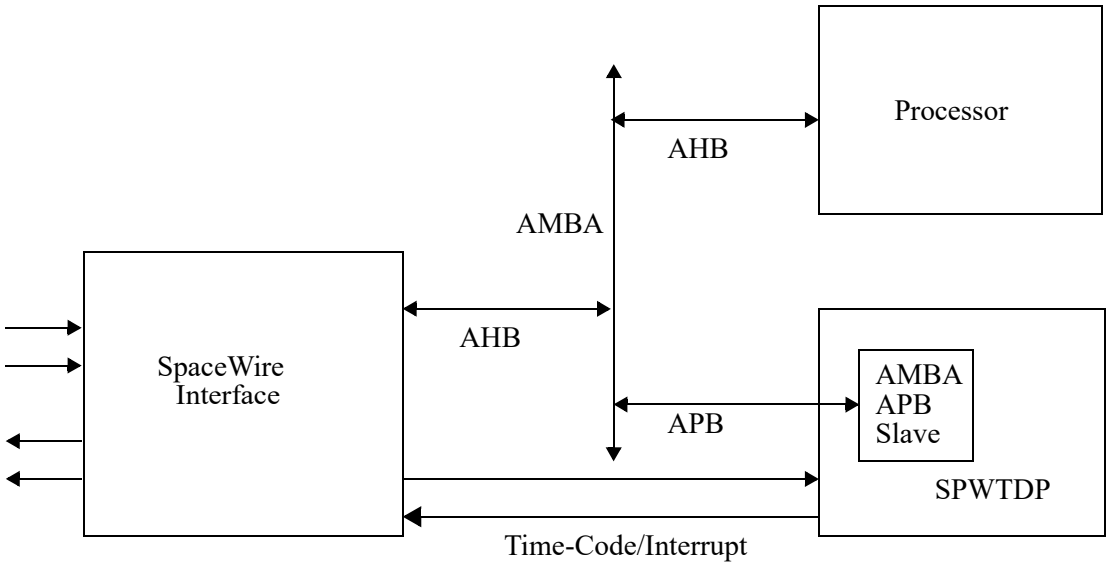


Figure 62. Block diagram

The system can act as initiator (time master) and target being able to send and receive SpaceWire Time-Codes. The initiator requires SpaceWire link interface implements an RMAP initiator. The Target requires SpaceWire link interface implements an RMAP target. The SPWTDP component is a part of this system providing SpaceWire Time-Codes, CCSDS Time Codes, datation, time-stamping of distributed interrupts, support for transmission of CCSDS Time Codes through RMAP and support for latency measurement and correction. In this implementation the CCSDS Time Codes carried between the SpaceWire network is based on CCSDS Unsegmented Code format. The table below

shows an example Preamble Field (P-Field) which corresponds to 40 bits of coarse time and 24 bits of fine time.

34.3.1 CCSDS Unsegmented Code: Preamble Field (P-Field)

*Table 434.*CCSDS Unsegmented Code P-Field definition

Bit	Value		Interpretation
0	“1”		Extension flag, P-Field extended with 2nd octet
1-3	“010”	Agency-defined epoch (Level 2)	Time code identification
4 - 5	“11”	(number of octets of coarse time) + 1	Detail bits for information on the code
6 - 7	“11”	(number of octets of fine time)	
8	“0”		Extension flag, P-Field not extended with 3rd octet
9-10	“01”	Number of additional octets of the coarse time.	added to octet 1
11-13	“000”	Number of additional octets of the fine time.	added to octet 1
14-15			RESERVED

34.3.2 CCSDS Unsegmented Code: Time Field (T-Field)

For the unsegmented binary time codes described herein, the T-Field consists of a selected number of contiguous time elements, each element being one octet in length. An element represents the state of 8 consecutive bits of a binary counter, cascaded with adjacent counters, which rolls over at a modulo of 256.

*Table 435.*Example CCSDS Unsegmented Code T-Field with 32 bit coarse and 24 bit fine time

CCSDS Unsegmented Code								
Preamble Field	Time Field							
	Coarse time				Fine time			
-	2^{31} 2^{24}	2^{23} 2^{16}	2^{15} 2^{8}	2^{7} 2^{0}	2^{-1} 2^{-8}	2^{-9} 2^{-15}	2^{-16} 2^{-24}	
0:15	0			31	32		55	

The basic time unit is the second. The T-Field coarse time (seconds) can be maximum 56 bits and minimum 8 bits. The T-Field fine time (sub seconds) can be maximum 80 bits and minimum of 0 bits.

The number of bits representing coarse and fine time implemented in this core can be obtained by reading the DPF bits of Datation Preamble Field register.

The coarse time code elements are a count of the number of seconds elapsed from the initial time value. This code is not UTC-based and leap second corrections do not apply according to CCSDS.

34.3.3 Time generation

The core consist of time generator which is the source for time in this system. The core may act as initiator or a target but both have their respective time generator. The Elapsed Time (ET) counter is implemented complying with the CUC T-Field. The number of bits representing coarse and fine time of a ET counter implemented in a design can be obtained by reading the DPF bits of Datation Preamble Field register.

The counter is incremented on the system clock only when enabled by the frequency synthesizer. The binary frequency required to determine the counter increment is derived from the system clock using a frequency synthesizer (FS). The frequency synthesizer is incremented with a pre-calculated increment value, which matches the available system clock frequency. The frequency synthesizer generates a tick every time it wraps around, which makes the ET time counter to step forward with the pre-cal-

culated increment value. The output of frequency synthesizer is used for enabling the increment of ET counter. The increment rate of the ET counter and frequency synthesizer counter should be set according to the system clock frequency. The ET counter increment rate is set by providing values to ETINC bits in Configuration 2 register and frequency synthesizer counter is set by providing values to FSINC bits in Configuration 1 register. The following table specifies some example ETINC and FSINC values for some frequencies. The below values are also obtained for Coarse time width 32, Fine time width 24 and Frequency synthesizer width of 30. To calculate for other frequencies and configuration refer the spreadsheet provided along with this document.

*Table 436.*Example values of ETINC and FSINC for corresponding frequencies

Frequency	ETINC	FSINC
50 MHz	0	360287970
250 MHz	0	72057594
33333333	2	135107990

The following section describes the cores capabilities if it configured as initiator or target.

34.3.4 Initiator

An initiator is a SpaceWire node distributing CCSDS Time Codes and SpaceWire Time-Codes. It is also an RMAP initiator, capable of transmitting RMAP commands and receiving RMAP replies. There is only one active initiator in a SpaceWire network during a mission phase.

The initiator performs the following tasks

- Transmission of SpaceWire Time-Codes

The SpaceWire Time-Codes are provided by this component and transmission of those codes to targets should be performed by a SpaceWire interface.

- Transmission of CCSDS Time Codes through RMAP
- Datation, time-stamping and latency measurement

34.3.5 Target

A target is a SpaceWire node receiving CCSDS Time Codes and SpaceWire Time-Codes. A target is also an RMAP target, capable of receiving RMAP commands and transmitting RMAP replies. There can be one or more targets in a SpaceWire network.

The target performs the following tasks

- Reception of SpaceWire Time-Codes

The SpaceWire Time-Codes sent from initiator are received by SpaceWire interface and provided to this component in target.

- Reception of CCSDS Time Codes through RMAP
- Qualification of received time messages (CCSDS Time Codes) using SpaceWire Time-Codes
- Initialization and Synchronisation of received CCSDS Time Codes with Elapsed Time counter available in this component
- Datation, time-stamping and latency correction

34.3.6 Configuring initiator and target

The core is interfaced via an AMBA Advanced Peripheral Bus (APB) slave interface, providing a register view that is compatible with the Time Distribution Protocol (TDP). The core must be configured according to the requirement either as initiator or target.

- Initializing initiator

The initiator transmits the SpaceWire Time-Codes out of the core only when the Transmit Enable TE bit in Configuration 0 register is enabled. The ET counter in initiator can be initialized (to provide any initial value). Initialization is done by writing a time value into the Command Elapsed Time registers available in the command field, the NC bit in the Control register of command field should be enabled to initialize the time value stored in the Command Elapsed Time registers to be the local time (Transmit Enable TE bit in Configuration 0 register must be enabled). The NC bit in the Control register will disable itself when the time is initialized. The INSYNC bit in Status 0 register will enable when initialization is performed. The MAPPING bits in Configuration 0 register determines the interval between SpaceWire Time-Code transmissions which is explained in detail in the section below.

The target time must be configured with time values from the initiator. The targets register space must be configured and controlled through RMAP by an initiator to achieve time synchronisation. The target time synchronisation is explained in detail under the section initialization and synchronisation of target through RMAP.

34.3.7 SpaceWire Time-Code

SpaceWire Time-Codes are continuously transmitted from an initiator node (time master) to all slave nodes. The transmission of the SpaceWire Time-Code is synchronized with the ET counter in the initiator node. The six bits of the Time-Code time information correspond to six bits of the local ET counter (MAPPING bits in Configuration 0 register determines its exact mapping and interval between SpaceWire Time-Code transmissions). Value of 0b00000 for MAPPING bits in Configuration 0 register will send SpaceWire Time-Code at every Second. When the value is 0b00001 SpaceWire Time-Codes are sent at every 0.5 Seconds interval and so on (maximum value of MAPPING can be 0b11111 but this value cannot be more than the number of bits implemented as fine time). The ET bits with lower weights than the size bits mapped to Time Codes time information bits are all zero at time of SpaceWire Time-Codes transmission. The Table below shows an example Local ET counter and Mapping. If the Coarse time is 32 bits and Fine time is 24 bits and mapping value is 6 then 0 to 31 is coarse(32 bits), 32 to 55 is fine time and mapped SpaceWire Time-Code is 32 to 37.

*Table 437.*Example Local ET counter with Mapping values

0																25	26	27	28	29	30	31	32	33	34	35	36	37	38				55
Mapping Values																						0	1	2	3	4	5	6	7				24
If the Mapping value is 6 then the mapped SpaceWire Time-Codes is 32 to 37																							32	33	34	35	36	37					
If the Mapping value is 0 then the mapped SpaceWire Time-Codes is 26 to 31																	26	27	28	29	30	31											
If the Mapping value is 5 then the mapped SpaceWire Time-Codes is 31 to 36																						31	32	33	34	35	36						
If the Mapping value is 7 then the mapped SpaceWire Time-Codes is 33 to 38																								33	34	35	36	37	38				

34.3.8 Initialization and synchronisation of target through RMAP

An initiator must provide the time values and set the target in order to get the time synchronized. The below text explains how an initiator can synchronise the target.

The SPWTC in Control register of initiator core component should be configured initially with a SpaceWire Time-Code value at which the time message needed to be transferred. When the SpaceWire Time-Code generated internally using the ET counter matches the SPWTC in Control register a Time Message TM interrupt will be generated (TME bit Time Message Enable should be enabled in the Interrupt Enable register). Based on this interrupt the local time (ET counter) in initiator should be accessed from the Datation registers and used to calculate the time message needed to be transmitted.

- Time message generation

The Time message transmitted using RMAP should be an exact mapping of the Command field (explained under Registers section). The Time message transmitted should write the Command field available in target. Control register available in Command field specify weather the target should be initialized or synchronized, at which SpaceWire Time-Codes it should happen (synchronization event) and details of coarse and fine time available in the time message. The New code NC bit available in Control register should be enabled and if the target should be initialized then Init Sync IS bit in Control register must be enabled otherwise target will be synchronized.

The Command Elapsed Time in time message are calculated from the local time (ET counter) available in the initiator. The local time can be obtained by reading the Datation Field of initiator component. While reading the Datation registers always the total implemented coarse time and fine time must be read in order (from 0 till the implemented Datation Elapsed Time registers). The DPF of Datation Preamble Field register gives the coarse and fine time implemented which gives the total local ET counter (coarse + fine width).

For example if the implementation has 32 bit coarse and 24 bit fine time then it is enough to access the first two Datation Elapsed Time registers (0 and 1). The 32 bits of Datation Elapsed Time 0 and only the most significant 24 bits (31 to 8) of Datation Elapsed Time 1 registers (32 + 24 =56 bits) represents the local time. These 56 bits only be used for Command Elapsed time (time message) calculation.

The SpaceWire Time-Codes at which the Time Message interrupt generated is embedded in the local ET counter. The Command Elapsed time which is transmitted as time message should be an incremented time value of this SpaceWire Time-Code and Command Elapsed time bits with lower weights than the size bits mapped to SpaceWire Time-Code time information bits are all must be zero.

The incremented time value is to make the initialization or synchronisation of time message in target will happen after the reception of qualifying SpaceWire Time-Codes. The qualifying SpaceWire Time-Code is embedded in the Command Elapsed time (part of time message) sent from initiator. This qualifying SpaceWire Time-Code value should also be written in the SPWTC in Control section of the time message.

- Time qualification in target

In target, the Command field will contain the time message when it is written by the initiator through RMAP. When the SPWTC of Control register in Command field matches with a received SpaceWire Time-Code then initialization or synchronization will occur (according to NC bit and IS bit in the Control register) to the local ET counter of the target SPWTDP component. When the local ET counter is initialized or synchronized the NC bit in the control register will disable itself. The INSYNC bit in Status 0 register will enable when initialization is performed specifying the target is initialized. Initialization completely writes time message values into the implemented local Elapsed time counter and synchronisation verifies whether the time message Command Elapsed Time and local Elapsed Time counter matches till the mapped SpaceWire Time-Code level (with a tolerance of previous value) and only modifies the local Elapsed Time if their is a mismatch. Since the GR716 target is not implemented with a jitter and mitigation unit the synchronisation forces the target time (ET counter) with the time message received.

For example, the initiator can create time message exactly at 0x00000001 coarse time and 0x040000 fine time (32 bit coarse time and 24 bit fine time, mapping value of 6 i.e. 64 SpaceWire Time-Codes per second, time message is generated at 0b000001 SpaceWire Time-Code), the value in the time message to be sent to the target can be coarse time 0x00000002 and 0x040000 fine time, (32 bit coarse time and 24 bit fine time, mapping value of 6, time message is qualified at the next reception of 0b000001 SpaceWire Time-Code, i.e. after a second). Both SPWTC in Control registers available in the initiator and target can be 0b000001 for this example. The time is synchronized after a second in this example. Depending on the frequency of SpaceWire Time-Codes and data link rate several different combination of ways to achieve time synchronisation is possible.

34.3.9 Latency measurement using Time-Stamps

The incoming and outgoing SpaceWire Distributed Interrupts are time stamped in initiator and target. The initiator calculates latency based on these time stamp values. The time stamped values in target are accessed from initiator through RMAP. The Latency Enable LE bit in Configuration 0 register must be enabled between the two nodes in the SpaceWire network for which the latency is to be calculated. The core supports 32 distributed interrupts and acknowledgement (Interrupt and acknowledgement numbers 0 to 31). The distributed interrupt transmission from initiator (which is the origin for latency calculation) is controlled by a mask register STM available in Configuration 3 register and SpaceWire time code register TSTC available in Time-Stamp SpaceWire Time-Code and Preamble Field Tx register, these registers specifies how often and at which time code distributed interrupt is transmitted and time stamping is performed.

The time stamping can be performed in two methods (only Interrupts or Interrupts and Acknowledgement), the DI bit in Configuration 3 register of SPWTDP component in target should be configured to specify which type of method is used. If only distributed interrupts (no acknowledgement) are used then DI bit should be 0. The transmitted and received distributed interrupts INTX and INRX in the Configuration 0 registers of both initiator and target must be configured with the interrupt number which will be used for the latency measurement. For example if the INTX in initiator Configuration 0 is configured with 0b00100 then the target INRX should be configured with the same value. Similarly if the INTX in target Configuration 0 is configured to be 0b00101 then the initiator INRX should be configured with the same value. Initially initiator sends a distributed interrupt when the conditions are matched (STM and TSTC registers match) and when the target received this distributed interrupt it will send another interrupt which will be received by the initiator. At each end transmission and reception is time stamped (current local time is stored in Time Stamp registers) and interrupt transmitted is INTX and received interrupt is checked whether it received INRX.

If both distributed interrupts and acknowledgement method is to be used then DI bit should be 1. The transmitted and received distributed interrupts INTX and INRX in the Configuration 0 registers of both initiator and target can have the same interrupt number (the acknowledgement number for a particular interrupt will be same as interrupt number). Similar to the previous method at each end transmission and reception is time stamped which will be used for latency calculations.

The Latency calculation can be started in initiator based on DIR (distributed interrupt received) interrupt available in Interrupt Status register (the interrupt should be enabled in the Interrupt Enable register). The latency is calculated form the time stamp registers based on the equation explained below

Latency = ((initiator time stamp Rx - initiator time stamp Tx) - (target time stamp Tx - target time stamp Rx)) /2

By calculating the Latency value repeatedly (at least for about 128 times, more number of times provides increased accuracy) and taking an average of it will provide the final latency value. The initiator should transfer the latency correction information to the Latency Field registers in the target by means of RMAP transfer. When the latency values are written it will be adjusted to local time in the target.

34.3.10 Mitigation of jitter and drift

No jitter and drift mitigation unit for SPWTDP is implemented in GR716.

34.3.11 External Datation

The external signals latch and save are used to provide external datation services. The Elapsed Time is continuously latched when the latch input signal goes high, the corresponding External datation mask register must be enabled for that particular signal. When save input goes high the latched value will remain same (at when the previous latch condition met) and all the mask bit previously enabled will be cleared. The EDS bit in Status Register 0 will go high when the latch and save condition matches and cleared when the latched elapsed time is read. The purpose of this status register is to ensure that all the implemented coarse and fine time are read. Reading the lowest implemented fine time makes

the status register to go low. An output pulse is also produced when conditions for external datation is met. The pulse is driven for one system clock period on the occurrence of external save condition.

If a simpler version of latching the time is needed based on a signal going high at any instance then the latch and save signals can be provided with the same input.

There are four External datation services implemented and each of them has its own mask EDMx, status EDS and time EDxETx registers. All the four External datation services are based on the input latch and save signal vectors. The external datation pulse vector consist of four outputs corresponding to each of the external datation services.

34.4 Data formats

All Elapsed Time (ET) information is compliant with the CCSDS Unsegmented Code defined in [CCSDS] and repeated hereafter.

34.4.1 Numbering and naming conventions

Convention according to the CCSDS recommendations, applying to time structures:

- The most significant bit of an array is located to the left, carrying index number zero.
- An octet comprises eight bits.

*Table 438.*CCSDS n-bit field definition

CCSDS n-bit field		
most significant		least significant
0	1 to n-2	n-1

Convention according to AMBA specification:

- The least significant bit of an array is located to the right, carrying index number zero.
- Big-endian support.

*Table 439.*AMBA n-bit field definition

AMBA n-bit field		
most significant		least significant
n-1	n-2 down to 1	0

34.5 Registers

The core is programmed through registers mapped into AMBA APB address space.

*Table 440.*Registers

APB address offset	Register
0x000-0x00F	Configuration Field
0x000	Configuration 0
0x004	Configuration 1
0x008	Configuration 2
0x00C	Configuration 3
0x010 - 0x01F	Status Field
0x010	Status 0
0x014	Status 1
0x018	RESERVED
0x01C	RESERVED
0x020 - 0x03F	Command Field
0x020	Control
0x024	Command Elapsed Time 0
0x028	Command Elapsed Time 1
0x02C	Command Elapsed Time 2
0x030	Command Elapsed Time 3
0x034	Command Elapsed Time 4
0x038	RESERVED
0x03C	RESERVED
0x040 - 0x05F	Datation Field
0x040	Datation Preamble Field
0x044	Datation Elapsed Time 0
0x048	Datation Elapsed Time 1
0x04C	Datation Elapsed Time 2
0x050	Datation Elapsed Time 3
0x054	Datation Elapsed Time 4
0x058	RESERVED
0x05C	RESERVED
0x060 - 0x09F	Time-Stamp Field
0x060	Time-Stamp Preamble Field Rx
0x064	Time-Stamp Elapsed Time 0 Rx
0x068	Time-Stamp Elapsed Time 1 Rx
0x06C	Time-Stamp Elapsed Time 2 Rx
0x070	Time-Stamp Elapsed Time 3 Rx
0x074	Time-Stamp Elapsed Time 4 Rx
0x078	RESERVED
0x07C	RESERVED
0x080	Time-Stamp SpaceWire Time-Code and Preamble Field Tx
0x084	Time-Stamp Elapsed Time 0 Tx

APB address offset	Register
0x088	Time-Stamp Elapsed Time 1 Tx
0x08C	Time-Stamp Elapsed Time 2 Tx
0x090	Time-Stamp Elapsed Time 3 Tx
0X094	Time-Stamp Elapsed Time 4 Tx
0x098	RESERVED
0x09C	RESERVED
0x0A0-0x0BF	Latency Field
0x0A0	Latency Preamble Field
0x0A4	Latency Elapsed Time 0
0x0A8	Latency Elapsed Time 1
0x0AC	Latency Elapsed Time 2
0x0B0	Latency Elapsed Time 3
0x0B4	Latency Elapsed Time 4
0x0B8	RESERVED
0x0BC	RESERVED
0x0C0	Interrupt Enable
0x0C4	Interrupt Status
0x0C8	Delay Count
0x0CC-0x0FF	RESERVED
0x100-0x18F	External Datation Field
0x100	External Datation 0 Mask
0x104	External Datation 1 Mask
0x108	External Datation 2 Mask
0x10C	External Datation 3 Mask
0x110-0x12F	External Datation 0 Time
0x110	External Datation 0 Preamble Field
0x114	External Datation 0 Elapsed Time 0
0x118	External Datation 0 Elapsed Time 1
0x11C	External Datation 0 Elapsed Time 2
0x120	External Datation 0 Elapsed Time 3
0x124	External Datation 0 Elapsed Time 4
0x128	RESERVED
0x12C	RESERVED
0x130-0x14F	External Datation 1 Time
0x150-0x16F	External Datation 2 Time
0x170-0x18F	External Datation 3 Time
0x190-0x1FF	RESERVED

34.5.1 Configuration 0

*Table 441.*0x000 - CONF0 - Configuration 0

31 25	24	23 17	16	15	14 13	12 8	7	6	5 4	3	2	1	0
RESERVED	R	RESERVED	LE	AE	RES	MAPPING	TD	R	SEL	ME	RE	TE	RS
0	0	0	0	0	0	*	0	0	0	0	0	0	0
r	rw	r	rw	rw	r	rw	rw	r	rw	rw	rw	rw	rw

31: 25	RESERVED	
24:	RESERVED	
23: 17	RESERVED	
16:	LE	Latency Enable. To calculate latency between an initiator and target this bit must be enabled in both of them. Reset value: ‘0’.
15:	AE	AMBA Interrupt Enable The interrupts (explained in interrupt registers) in this core will generate an AMBA interrupt only when this bit is enabled. Reset value: ‘0’
14 13	RESERVED	
12: 8	MAPPING	Defines mapping of SpaceWire Time-Codes versus CCSDS Time-code. Value 0b00000 will send SpaceWire Time-Codes every Second, Value 0b00001 will send SpaceWire Time-Codes every 0.5 Second, Value 0b00010 will send SpaceWire Time-Codes every 0.25 Second, Value 0b00011 will send SpaceWire Time-Codes every 0.125 Second The maximum value it can take is 0b11111 but this value cannot be more than the number of bits implemented as fine time. Reset value: Implementation dependent.
7:	TD	Enable TDP when set. Reset value: ‘0’.
6:	RESERVED	
5: 4	SEL	Select for SpaceWire Time-Codes and Distributed Interrupt transmission and reception, one of 0 through 3. Reset value: 0b00
3:	ME	Mitigation Enable (only for target) The drift correction process in target will start when this bit is enabled. Reset value: ‘0’. (valid only when Mitigation unit available)
2:	RE	Receiver Enable (only for target) Reset value: ‘0’.
1	TE	Transmit Enable (only for initiator) Reset value: ‘0’.
0	RS	Reset core. Makes complete reset when enabled. Reset value: ‘0’.

34.5.2 Configuration 1

*Table 442.*0x004 - CONF1 - Configuration 1

31 30 29	0
R	FSINC
0	0
r	rw

31: 30 RESERVED

29: 0 FSINC

Increment value of the Frequency Synthesizer which is added to the counter every system clock cycle. It defines the frequency of the synthesized reference time.

Refer the spreadsheet provided along with this document to obtain this value.

Reset value: Implementation dependent

All implemented registers are writable and readable.

34.5.3 Configuration 2

*Table 443.*0x008 - CONF2 - Configuration 2

31	8	7	0
CV		ETINC	
*		*	
rw		rw	

31: 8 CV Compensation Value

Value added to FSINC for variations of drift of the target clock.(only for target)

Refer the spreadsheet provided along with this document to obtain this value.

This value also depends on the MAPPING value in configuration 0 register. Specify the needed MAPPING value in the spreadsheet while calculating this value.

Reset value: Implementation Dependent

(valid only when Mitigation unit available)

7: 0 ETINC Value of the Elapsed Time counter is to be incremented each time when the Frequency Synthesizer wraps around.

Refer the spreadsheet provided along with this document to obtain this value.

Reset value: Implementation dependent

34.5.4 Configuration 3

*Table 444.*0x00C - CONF3 - Configuration 3

31 22	21 16	15 11	10	9 5	4 0
RESERVED	STM	RESERVED	DI	INRX	INTX
0	0	0	0	0	0
r	rw	r	rw	rw	rw

31: 22	RESERVED	
21: 16	STM	SpaceWire Time-Code Mask Mask For TSTC register available at Time-Stamp SpaceWire Time-Code and Preamble Field Tx register. Value all bits zero will send Distributed interrupts at all SpaceWire Time-Codes irrespective of any values in TSTC register. Value all ones will send Distributed interrupts at complete match of SpaceWire Time-Code with TSTC register. (only for initiator)
15: 11	RESERVED	
10:	DI	Distributed Interrupt method, when set interrupt and acknowledge mode else only interrupt mode. (only for target) Reset value: ‘0’
9: 5	INRX	Interrupt Received.(Distributed) The distributed interrupt number received by initiator or target. Reset value: 0b000000
4: 0	INTX	Interrupt Transmitted.(Distributed) The distributed interrupt number transmitted by initiator or target. Reset value: 0b000000

34.5.5 Status Register 0

*Table 445.*0x010 - STAT0 - Status Register 0

31	30 28	27 24	23	22 16	15 14	13 8	7 3	2	1	0
MA	RES	EDS	R	FW	RES	CW	RES	LC	TCQ	INSYNC
0	0	0	0	0	0	0	0	0	0	0
r	r	r	r	r	r	r	r	r	r	r

31:	MA	Mitigation unit available 0 Drift and Jitter mitigation unit not available
30: 28	RESERVED	
27: 24	EDS	External Datation Status 24: External Datation 0 Status bit 25: External Datation 1 Status bit 26: External Datation 2 Status bit 27: External Datation 3 Status bit When conditions matched for external datation this bit will go high. This bit will go low when all the implemented time values are read.
23	RESERVED	
22: 16	FW	Fine width of command CCSDS Time Code received. Calculated from Preamble field of Command Register.
15: 14	RESERVED	
13: 8	CW	Coarse width of command CCSDS Time Code received, calculated from Preamble field of Command Register.
7: 3	RESERVED	
2	LC	Latency Corrected (only for target)
1	TCQ	Time message is qualified by SpaceWire Time-Codes
0	INSYNC	In Sync at Time code level, enabled when time values are Initialized or Synchronized

34.5.6 Status Register 1

*Table 446.*0x014 - STAT1 - Status Register 1

31 30 29	0
R	IV
0	*
r	r

31: 30	RESERVED	
29: 0	IV	Increment Variation. The variation in FSINC while achieving the time synchronisation (only for target) Reset value: Implementation dependent (valid only when Mitigation unit available)

34.5.7 Control

*Table 447.*0x20 - CTRL - Control

31	30	29 24	23 16	15 0
NC	IS	R	SPWTC	CPF
0	0	0	0	0
rw	rw	r	rw	rw

31:	NC	New Command
30:	IS	Init or Sync 1 Initialization of received time message 0 Synchronisation of received time message (only for target)
29: 24	RESERVED	
23: 16	SPWTC	Spacewire Time-code value used for initialization and synchronisation In initiator the SpaceWire Time-Codes generated internally using the local ET counter matches this register a Time Message TM interrupt will be generated which is used to send Time message over the SpaceWire network. In target this register should match the received SpaceWire Time-code for time qualification.
15: 0	CPF	Command Preamble Field. The number of coarse and fine time available in Command Elapsed Time registers should be mentioned in this field. Based on this preamble field the target will initialize or synchronise the local ET counter.(only for target)

34.5.8 Command Elapsed Time 0

*Table 448.*0x024 - CET0 - Command Elapsed Time 0

31 0
CET0
0
rw

31: 0	CET0	Command Elapsed Time 0 Initialize or Synchronise local ET counter value (0 to 31).

34.5.9 Command Elapsed Time 1

*Table 449.*0x028 - CET1 - Command Elapsed Time 1

31 0
CET1
0
rw

31: 0	CET1	Command Elapsed Time 1 Initialize or Synchronise local ET counter value (32 to 63)

34.5.10 Command Elapsed Time 2

*Table 450.*0x02C - CET2 - Command Elapsed Time 2

31	0
CET2	
0	
rw	

31: 0 CET2 Command Elapsed Time 2

Initialize or Synchronise local ET counter value (64 to 95).

34.5.11 Command Elapsed Time 3

*Table 451.*0x030 - CET3 - Command Elapsed Time 3

31	0
CET3	
0	
rw	

31: 0 CET3 Command Elapsed Time 3

Initialize or Synchronise local ET counter value (96 to 127).

34.5.12 Command Elapsed Time 4

*Table 452.*0x034 - CET4 - Command Elapsed Time 4

31 24	23 0
CET4	RESERVED
0	0
rw	r

31: 24 CET4 Command Elapsed Time 4

Initialize or Synchronise local ET counter value (128 to 135).

23: 0 RESERVED

34.5.13 Datation Preamble Field

*Table 453.*0x040 - DPF - Datation Preamble Field

31 16	15 0
RESERVED	DPF
0	0x2F00
r	r

31: 16 RESERVED

15: 0 DPF Datation Preamble Field

The number of coarse and fine time implemented can be obtained from this Preamble Field.

34.5.14 Datation Elapsed Time 0

*Table 454.*0x044 - DET0 - Datation Elapsed Time 0

31	0
DET0	
0	
r	

31: 0	DET0	Datation Elapsed Time 0 CCSDS Time Code value (0 to 31) of local ET counter value.

34.5.15 Datation Elapsed Time 1

*Table 455.*0x048 - DET1 - Datation Elapsed Time 1

31	0
DET1	
0	
r	

31: 0	DET1	Datation Elapsed Time 1 CCSDS Time Code value (32 to 63) of local ET counter value.

34.5.16 Datation Elapsed Time 2

*Table 456.*0x04C - DET2 - Datation Elapsed Time 2

31	0
DET2	
0	
r	

31: 0	DET2	Datation Elapsed Time 2 CCSDS Time Code value (64 to 95) of local ET counter value.

34.5.17 Datation Elapsed Time 3

*Table 457.*0x050 - DET3 - Datation Elapsed Time 3

31	0
DET3	
0	
r	

31: 0	DET3	Datation Elapsed Time 3 CCSDS Time Code value (96 to 127) of local ET counter value.

34.5.18 Datation Elapsed Time 4

*Table 458.*0x054 - DET4 - Datation Elapsed Time 4

31 24	23 0
DET4	RESERVED
0	0
r	r

31: 24 DET4 Datation Elapsed Time 4

CCSDS Time Code value (128 to 135) of local ET counter value.

23: 0 RESERVED

34.5.19 Time-Stamp Preamble Field Rx

*Table 459.*0x060 - TRPFRx - Time-Stamp Preamble Field Rx

31 16	15 0
RESERVED	TRPF
0	0x2F00
r	r

31: 16 RESERVED

15: 0 TRPF Time stamp Preamble Field

The number of coarse and fine time implemented can be obtained from this Preamble Field.

34.5.20 Time Stamp Elapsed Time 0 Rx

*Table 460.*0x064 - TR0 - Time Stamp Elapsed Time 0 Rx

31 0
TR0
0
r

31: 0 TR0 Time stamped local ET value (0 To 31) when distributed interrupt received.

34.5.21 Time Stamp Elapsed Time 1 Rx

*Table 461.*0x068 - TR1 - Time Stamp Elapsed Time 1 Rx

31 0
TR1
0
r

31: 0 TR1 Time stamped local ET value (32 to 63) when distributed interrupt received.

34.5.22 Time Stamp Elapsed Time 2 Rx

*Table 462.*0x06C - TR2 - Time Stamp Elapsed Time 2 Rx

31 0
TR2
0
r

31: 0 TR2 Time stamped local ET value (64 to 95) when distributed interrupt received.

34.5.23 Time Stamp Elapsed Time 3 Rx

*Table 463.*0x070 - TR3 - Time Stamp Elapsed Time 3 Rx

31	0
TR3	
0	
r	

31: 0 TR3 Time stamped local ET value (96 to 127) when distributed interrupt received.

34.5.24 Time Stamp Elapsed Time 4 Rx

*Table 464.*0x074 - TR4 - Time Stamp Elapsed Time 4 Rx

31 24	23 0
TR4	RESERVED
0	0
r	r

31: 24 TR4 Time stamped local ET value (128 to 135) when distributed interrupt received.

23: 0 RESERVED

34.5.25 Time-Stamp SpaceWire Time-Code and Pramble Field Tx

*Table 465.*0x080 - TTPFTx - Time-Stamp SpaceWire Time-Code and Preamble Field Tx

31 24	23 16	15 0
TSTC	RESERVED	TTPF
0	0	0x2800
rw	r	r

31: 24 TSTC Time stamp time code

Time stamp on this time-code value, used for time stamping when this register matched with SpaceWire Time-Codes. The mask for this matching is available in configuration register 3. (only for initiator)

23: 16 RESERVED

15: 0 TTPF Time stamp Preamble Field

The number of coarse and fine time implemented can be obtained from this Preamble Field.

34.5.26 Time Stamp Elapsed Time 0 Tx

*Table 466.*0x084 - TT0 - Time Stamp Elapsed Time 0 Tx

31	0
TT0	
0	
r	

31: 0 TT0 Time stamped local ET value (0 to 31) when distributed interrupt transmitted.

34.5.27 Time Stamp Elapsed Time 1 Tx

*Table 467.*0x088 - TT1 - Time Stamp Elapsed Time 1 Tx

31	0
TT1	
0	
r	

31: 0 TT1 Time stamped local ET value (32 to 63) when distributed interrupt transmitted.

34.5.28 Time Stamp Elapsed Time 2 Tx

*Table 468.*0x08C - TT2 - Time Stamp Elapsed Time 2 Tx

31	0
TT2	
0	
r	

31: 0 TT2 Time stamped local ET value (64 to 95) when distributed interrupt transmitted.

34.5.29 Time Stamp Elapsed Time 3 Tx

*Table 469.*0x090 - TT3 - Time Stamp Elapsed Time 3 Tx

31	0
TT3	
0	
r	

31: 0 TT3 Time stamped local ET value (96 to 127) when distributed interrupt transmitted.

34.5.30 Time Stamp Elapsed Time 4 Tx

*Table 470.*0x094 - TT4 - Time Stamp Elapsed Time 4 Tx

31 24	23 0
TTT0	RESERVED
0	0
r	r

31: 24 TT4 Time stamped local ET value (128 to 135) when distributed interrupt transmitted.

23: 0 RESERVED

34.5.31 Latency Preamble Field

*Table 471.*0x0A0 - LPF - Latency Preamble Field

31 16	15 0
RESERVED	LPF
0	0x2F00
r	r

31: 16 RESERVED

15: 0 LPF Latency Preamble Field

The number of coarse and fine time implemented can be obtained from this Preamble Field. (only for target)

34.5.32 Latency Elapsed Time 0

*Table 472.*0x0A4 - LE0 - Latency Elapsed Time 0

31	0
LE0	
0	
rw	

31: 0 LE0 Latency Value (0 to 31) written by initiator. (only for target)

34.5.33 Latency Elapsed Time 1

*Table 473.*0x0A8 - LE1 - Latency Elapsed Time 1

31	0
LE1	
0	
rw	

31: 0 LE1 Latency Value (32 to 63) written by initiator. (only for target)

34.5.34 Latency Elapsed Time 2

*Table 474.*0x0AC - LE2 - Latency Elapsed Time 2

31	0
LE2	
0	
rw	

31: 0 LE2 Latency Value (64 to 95) written by initiator. (only for target)

34.5.35 Latency Elapsed Time 3

*Table 475.*0x0B0 - LE3 - Latency Elapsed Time 3

31	0
LE3	
0	
rw	

31: 0 LE3 Latency Value (96 to 127) written by initiator. (only for target)

34.5.36 Latency Elapsed Time 4

*Table 476.*0x0B4 - LE4 - Latency Elapsed Time 4

31 24	23 0
LE4	RESERVED
0	0
rw	r

31: 24 LE4 Latency Value (128 to 135) written by initiator. (only for target)

23: 0 RESERVED

34.5.37 Interrupt Enable

*Table 477.*0x0C0 - IE - Interrupt Enable

31 10	9	8	7	6	5	4	3	2	1	0
RESERVED	EDIE3	EDIE2	EDIE1	EDIE0	DITE	DIRE	TTE	TME	TRE	SE
0	0	0	0	0	0	0	0	0	0	0
r	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

31: 10	RESERVED	
9	EDIE3	External Datation 3 Interrupt Enable
8	EDIE2	External Datation 2 Interrupt Enable
7	EDIE1	External Datation 1 Interrupt Enable
6	EDIE0	External Datation 0 Interrupt Enable
5	DITE	Distributed Interrupt Transmitted Interrupt Enable
4	DIRE	Distributed Interrupt Received Interrupt Enable
3	TTE	SpaceWire Time-Code Transmitted Interrupt Enable (only for initiator)
2	TME	Time Message transmit Interrupt Enable (only for initiator)
1	TRE	SpaceWire Time-Code Received Interrupt Enable (only for target)
0	SE	Sync Interrupt Enable (only for target)

34.5.38 Interrupt Status

*Table 478.*0x0C4 - IS - Interrupt Status

31 10	9	8	7	6	5	4	3	2	1	0
RESERVED	EDI3	EDI2	EDI1	EDI0	DIT	DIR	TT	TM	TR	S
0	0	0	0	0	0	0	0	0	0	0
r	wc	wc	wc	wc	wc	wc	wc	wc	wc	wc

31: 10	RESERVED	
9	EDI3	Generated when conditions for External Datation 3 is matched
8	EDI2	Generated when conditions for External Datation 2 is matched
7	EDI1	Generated when conditions for External Datation 1is matched
6	EDI0	Generated when conditions for External Datation 0 is matched
5	DIT	Generated when distributed interrupt is transmitted (Latency calculation should be enabled)
4	DIR	Generated when distributed interrupt is Received (Latency calculation should be enabled)
3	TT	Generated when SpaceWire Time-Codes is transmitted (only for initiator)
2	TM	Generated when the conditions for transmitting time message occurred, based on this time message should be transmitted from initiator (only for initiator)
1	TR	Generated when SpaceWire Time-Code is received (only for target)
0	S	Generated when the target is initialized or synchronized with initiator (only for target)

The interrupts are cleared by writing value 1 on respective bits.

34.5.39 Delay Count

*Table 479.*0x0C8 - DC - Delay Count

31 15	14 0
RESERVED	DC
0	0x7FFF
r	r

31: 15 RESERVED

14: 0 DC Delay Count

Delay induced between SpaceWire Time-Codes and Distributed Interrupt transmission in system clock units. The delay introduced is the value in this register multiplied by the system clock.

(only for initiator)

34.5.40 External Datation 0 Mask

*Table 480.*0x100 - EDM0 - External Datation 0 Mask

31 0
EDM0
0
rw

31: 0 EDM0 External datation can be enabled by writing ‘1’ into the bit for that corresponding external input. When conditions are matched the Elapsed Time will be latched.

The latched values are available at External Datation 0 Time Register.

All the mask bits will go low after any one of the conditions with respect to the enabled mask bits.are matched.

34.5.41 External Datation 0 Preamble Field

*Table 481.*0x110 - EDPF0 - External Datation 0 Preamble Field

31 16	15 0
RESERVED	EDPF0
0	0x2F00
r	r

31: 16 RESERVED

15: 0 EDPF0 External Datation Preamble Field

The number of coarse and fine time implemented can be obtained from this Preamble Field.

34.5.42 External Datation 0 Elapsed Time 0

*Table 482.*0x114 - ED0ET0 - External Datation 0 Elapsed Time 0

31 0
ED0ET0
0
r

31: 0 ED0ET0 External Datation Elapsed Time 0

Latched CCSDS Time Code value (0 to 31) of local ET counter.

34.5.43 External Datation 0 Elapsed Time 1

*Table 483.*0x118 - ED0ET1 - External Datation 0 Elapsed Time 1

31	0
ED0ET1	
0	
r	

31: 0	ED0ET1	External Datation Elapsed Time 1 Latched CCSDS Time Code value (32 to 63) of local ET counter.

34.5.44 External Datation 0 Elapsed Time 2

*Table 484.*0x11C - ED0ET2 - External Datation 0 Elapsed Time 2

31	0
ED0ET2	
0	
r	

31: 0	ED0ET2	External Datation 0 Elapsed Time 2 Latched CCSDS Time Code value (64 to 95) of local ET counter.

34.5.45 External Datation 0 Elapsed Time 3

*Table 485.*0x120 - ED0ER3 - External Datation 0 Elapsed Time 3

31	0
ED0ET3	
0	
r	

31: 0	ED0ET3	External Datation 0 Elapsed Time 3 Latched CCSDS Time Code value (96 to 127) of local ET counter.

34.5.46 External Datation 0 Elapsed Time 4

*Table 486.*0x124 - ED0ET4 - External Datation 0 Elapsed Time 4

31 24	23 0
ED0ET4	RESERVED
0	0
r	r

31: 24	ED0ET4	External Datation 0 Elapsed Time 4 Latched CCSDS Time Code value (128 to 135) of local ET counter.
23: 0	RESERVED	

Note: The registers which are not mentioned either as only for initiator or target are used in both initiator and target.

The Definition of External Datation 1 Mask, External Datation 2 Mask and External Datation 3 Mask registers are exactly same as External Datation 0 Mask Register.

The Definition of External Datation 1 Time, External Datation 2 Time and External Datation 3 Time registers are exactly same as External Datation 0 Time Registers (i.e. External Datation 0 Preamble Field and External Datation 0 Elapsed Time 0,1,2,3,4).

35 General Purpose Timer Unit with Watchdog

35.1 Overview

The General Purpose Timer Unit provides a common prescaler and 7 decrementing timers. The unit is capable of asserting interrupts on timer underflow. The timer also provides the system with watchdog functionality. The watchdog is of window-watchdog type i.e. the watchdog timer can be configured to have a lower boundary and for how often the watchdog timer can be triggered or reloaded by the software.

.

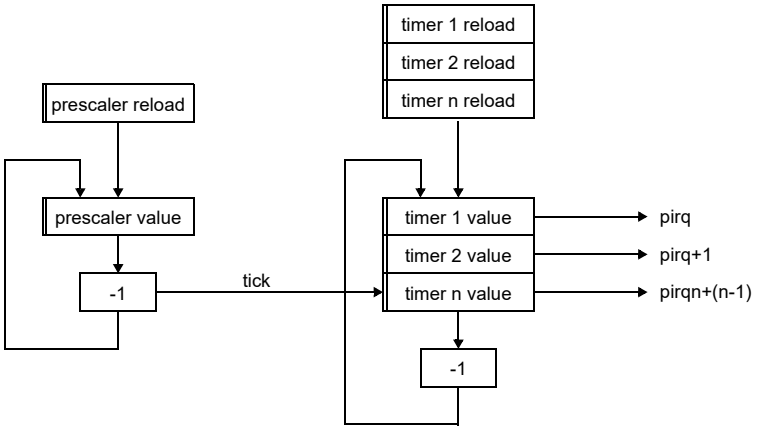


Figure 63. General Purpose Timer Unit block diagram

35.2 Operation

The prescaler is clocked by the system clock and decremented on each clock cycle. When the prescaler underflows, it is reloaded from the prescaler reload register and a timer tick is generated.

The operation of each timers is controlled through its control register. A timer is enabled by setting the enable bit in the control register. The timer value is then decremented on each prescaler tick. When a timer underflows, it will automatically be reloaded with the value of the corresponding timer reload register if the restart bit in the control register is set, otherwise it will stop at -1 and reset the enable bit.

The shared interrupt will be raised when any of the timers with interrupt enable bit underflows. The timer unit will signal an interrupt on appropriate line when a timer underflows (if the interrupt enable bit for the current timer is set). The interrupt pending bit in the control register of the underflown timer will be set and remain set until cleared by writing ‘1’.

To minimize complexity, timers share the same decrementer. This means that the minimum allowed prescaler division factor is *8* (reload register = *7*) where *7* is the number of timers. By setting the chain bit in the control register timer *n* can be chained with preceding timer *n*-1. Timer *n* will be decremented each time when timer *n*-1 underflows.

Each timer can be reloaded with the value in its reload register at any time by writing a ‘one’ to the load bit in the control register. The last timer acts as a watchdog, asserting the external RESET_OUT_N output signal when expired. The watchdog timer also implements a window functionality. This enables a decrementing counter which reloads each time the timer is reloaded. If the timer is reloaded and the window counter hasn’t reach zero, this will also assert the RESET_OUT_N output.

Each timer can be configured to latch its value to a dedicated register when an event is detected on the interrupt. All timers can be forced to reload when an event is detected on the interrupt bus A dedicated mask register is provided to filter the interrupts.

Simultaneous start of multiple timers are supported via timer configuration register CONFIG.TIMEREN. To simultaneously start two or more counters set the corresponding bits in the register CONFIG.TIMEREN.

At reset, all timer are disabled except the watchdog timer. The prescaler value and reload registers are set to all ones, while the watchdog timer 7 is set to 0xFFF. All other registers are uninitialized except for the WDOGDIS and WDOGNMI fields that are reset to ‘0’.

35.2.1 Window-watchdog

The watchdog has an optional lower boundary for reloading the watchdog timer. Application can optionally specify the least number of system clock cycles between 2 reload events of the watchdog timer.

When a watchdog window is programmed, an early watchdog reload is also treated as a watchdog event. This allows preventing situations where a system failure may still reload the watchdog. For example, application code could be stuck in an interrupt service that contains a watchdog feed. Setting the window such that this would result in an early reload will generate a watchdog event, allowing for system recovery.

The watchdog window functionality is enabled when the bit field WDOGWINC is greater than 0x0 and smaller or equal to 0xFFFF. The programmed number specify the number of system clock cycles between 2 watchdog reload events.

35.3 Registers

The core is programmed through registers mapped into APB address space. The number of implemented registers depend on the number of implemented timers.

*Table 487.*General Purpose Timer Unit registers

APB address offset	Register
0x80003000	Scaler value
0x80003004	Scaler reload value
0x80003008	Configuration register
0x8000300C	Timer latch configuration register
0x80003010	Timer 1 counter value register
0x80003014	Timer 1 reload value register
0x80003018	Timer 1 control register
0x8000301C	Timer 1 latch register
0x80003020	Timer *2* counter value register
0x80003024	Timer *2* reload value register
0x80003028	Timer *2* control register
0x8000302C	Timer *2* latch register
0x80003030	Timer *3* counter value register
0x80003034	Timer *3* reload value register
0x80003038	Timer *3* control register
0x8000303C	Timer *3* latch register
0x80003040	Timer *4* counter value register
0x80003044	Timer *4* reload value register
0x80003048	Timer *4* control register
0x8000304C	Timer *4* latch register
0x80003050	Timer *5* counter value register
0x80003054	Timer *5* reload value register
0x80003058	Timer *5* control register
0x8000305C	Timer *5* latch register
0x80003060	Timer *6* counter value register
0x80003064	Timer *6* reload value register
0x80003068	Timer *6* control register
0x8000306C	Timer *6* latch register
0x80003070	Timer *7* counter value register
0x80003074	Timer *7* reload value register
0x80003078	Timer *7* control register
0x8000307C	Timer *7* latch register

35.3.1 Scaler Value Register

*Table 488.*0x00 - SCALER - Scaler value register

31 16	16-1 0
RESERVED	SCALER
0	all 1
r	rw

16-1: 0 Scaler value. This value will also be set by writes to the Scaler reload value register.
Any unused most significant bits are reserved. Always reads as ‘000...0’.

35.3.2 Scaler Reload Value Register

*Table 489.*0x04 - SRELOAD - Scaler reload value register

31 16	16-1 0
RESERVED	SCALER RELOAD VALUE
0	all 1
r	rw

16-1: 0 Scaler reload value. Writes to this register also set the scaler value.
Any unused most significant bits are reserved. Always read as ‘000...0’.

35.3.3 Configuration Register

*Table 490.*0x08 - CONFIG - Configuration register

31 23	22 16	15 14	13	12	11	10	9	8	7 3	2 0
"000..0"	TIMEREN	R	EV	ES	EL	EE	DF	SI	RESERVED	TIMERS
0	0	0	0	0	0	0	0	1	*	7
r	rw	r	rw	rw	rw	rw	rw	r	r	r

31: 23 Reserved. Always reads as '000...0'.

22: 16 Enable bits for each timer. Writing '1' to one of this bits sets the enable bit in the corresponding timers control register. Writing '0' has no effect to the timers. bit[16] corresponds to timer0, bit[17] to timer 1,...

15: 14 Reserved

13 External Events (EV). If EV is set to 0 then the latch and set events are taken from the least significant 32 bit of the interrupt bus, otherwise they are from some of the most significant ones and some external signals (see table 35.3.4)

12 Enable set (ES). If set, on the next matching interrupt, the timers will be loaded with the corresponding timer reload values. The bit is then automatically cleared, not to reload the timer values until set again.

11 Enable latching (EL). If set, on the next matching interrupt, the latches will be loaded with the corresponding timer values. The bit is then automatically cleared, not to load a timer value until set again.

10 Enable external clock source (EE). If set the prescaler is clocked from the external clock source.

9 Disable timer freeze (DF). If set the timer unit can not be freezed, otherwise signal GPTI.DHALT freezes the timer unit.

8 Separate interrupts (SI). Reads '1' if the timer unit generates separate interrupts for each timer, otherwise '0'. Read-only.

7: 3 Reserved

2: 0 Number of implemented timers. Read-only.

35.3.4 Timer Latch Configuration Register

*Table 491.*0x0C - CATCHCFG - Timer latch configuration register

31 0
LATCHSEL
0
rw

31: 0 This field specifies which bits of the interrupt bus or of the external signals (depending on EV field in table 35.3.3) cause the set and latch events. If EV is 0, the latching is done based on events on the 31:0 bits of the interrupt bus with a direct mapping. If the EV field is '1', the bits 29:0 correspond to the 61:32 bits of the interrupt bus, while the bit 30 corresponds to the TICKOUT signal from the SpaceWire Interface (see chapter 33) and the bit 31 corresponds to the rtsync signal from the MIL-STD-1553B / AS15531 Interface (see chapter 23).

35.3.5 Timer N Counter Value Register

*Table 492.*0xn0, when n selects the times - TCNTVALn - Timer n counter value register

32-1 0
TCVAL
0
rw

32-1: 0 Timer Counter value. Decremented by 1 for each prescaler tick.

Any unused most significant bits are reserved. Always reads as '000...0'.

35.3.6 Timer N Reload Value Register

*Table 493.*0xn4, when n selects the times - TRLDVALn - Timer n reload value register

32-1	0
TRCDUAL	
*	
rw	

32-1: 0 Timer Reload value. This value is loaded into the timer counter value register when ‘1’ is written to load bit in the timers control register or when the RS bit is set in the control register and the timer underflows.

Any unused most significant bits are reserved. Always reads as ‘000...0’.

35.3.7 Timer N Control Register

*Table 494.*0xn8, when n selects the times - TCTRLn - Timer n control register

31 16	15 9	8	7	6	5	4	3	2	1	0
WDOGWINC	RESERVED	WS	WN	DH	CH	IP	IE	LD	RS	EN
0	0	0	0	0	0	0	0	0	*	*
rw	r	rw	rw	r	rw	wc	wc	rw	rw	rw

31: 16 Reload value for the watchdog window counter. The window counter is reloaded with this value each time the watchdog counter is reloaded. This register is only available for counter timer 7 in timer unit #1.

15: 9 Reserved. Always reads as ‘000...0’.

8 Disable Watchdog Output (WS/WDOGDIS): If this field is set to ‘1’ then the GPTO.WDOG and GPTO.WDOGN outputs are disabled (fixed to ‘0’ and ‘1’ respectively). This functionality is only available for the last timer.

7 Enable Watchdog NMI (WN/WDOGNMI): If this field is set to ‘1’ then the watchdog timer will also generate a non-maskable interrupt (interrupt 15) when an interrupt is signalled. This functionality is only available for the last timer

6 Debug Halt (DH): Value of GPTI.DHALT signal which is used to freeze counters (e.g. when a system is in debug mode). Read-only.

5 Chain (CH): Chain with preceding timer. If set for timer *n*, timer *n* will be decremented each time when timer (*n*-1) underflows.

4 Interrupt Pending (IP): The core sets this bit to ‘1’ when an interrupt is signalled. This bit remains ‘1’ until cleared by writing ‘1’ to this bit, writes of ‘0’ have no effect.

3 Interrupt Enable (IE): If set the timer signals interrupt when it underflows.

2 Load (LD): Load value from the timer reload register to the timer counter value register.

1 Restart (RS): If set, the timer counter value register is reloaded with the value of the reload register when the timer underflows

0 Enable (EN): Enable the timer.

35.3.8 Timer N Latch Register

*Table 495.*0xnC, when n selects the times - TLATCHn - Timer n latch register

31	0
LTCV	
0	
r	

31: 0 Latched timer counter value (LTCV): Valued latched from corresponding timer. Read-only.

36 General Purpose Timer Unit (Secondary)

36.1 Overview

The secondary LEON3FT microcontroller have 2 General Purpose Timer Units. The General Purpose Timer Unit provides a common prescaler and 7 decrementing timers. The unit is capable of asserting interrupts on timer underflow.

.

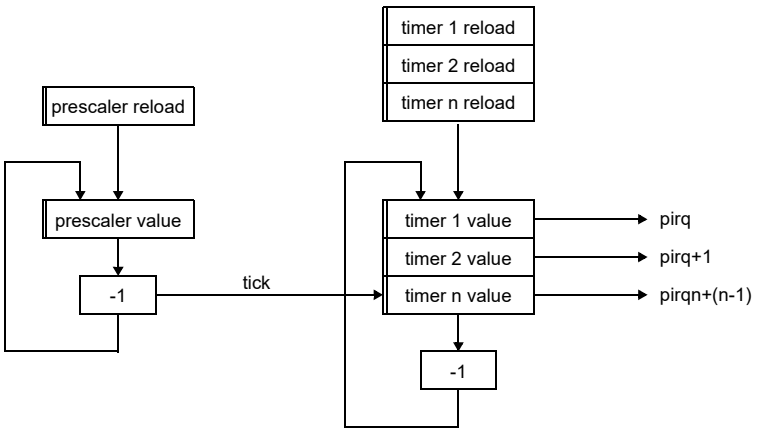


Figure 64. General Purpose Timer Unit block diagram

36.2 Operation

The prescaler is clocked by the system clock and decremented on each clock cycle. When the prescaler underflows, it is reloaded from the prescaler reload register and a timer tick is generated.

The operation of each timers is controlled through its control register. A timer is enabled by setting the enable bit in the control register. The timer value is then decremented on each prescaler tick. When a timer underflows, it will automatically be reloaded with the value of the corresponding timer reload register if the restart bit in the control register is set, otherwise it will stop at -1 and reset the enable bit.

The shared interrupt will be raised when any of the timers with interrupt enable bit underflows. The timer unit will signal an interrupt on appropriate line when a timer underflows (if the interrupt enable bit for the current timer is set). The interrupt pending bit in the control register of the underflown timer will be set and remain set until cleared by writing '1'.

To minimize complexity, timers share the same decrementer. This means that the minimum allowed prescaler division factor is *8* (reload register = *7*) where *7* is the number of timers. By setting the chain bit in the control register timer *n* can be chained with preceding timer *n*-1. Timer *n* will be decremented each time when timer *n*-1 underflows.

Each timer can be reloaded with the value in its reload register at any time by writing a 'one' to the load bit in the control register.

Each timer can be configured to latch its value to a dedicated register when an event is detected on the interrupt. All timers can be forced to reload when an event is detected on the interrupt bus A dedicated mask register is provided to filter the interrupts.

Simultaneous start of multiple timers are supported via timer configuration register CONFIG.TIMEREN. To simultaneously start two or more counters set the corresponding bits in the register CONFIG.TIMEREN.

36.3 Registers

The core is programmed through registers mapped into APB address space. The number of implemented registers depend on the number of implemented timers.

*Table 496.*General Purpose Timer Unit registers

APB address offset	Register
0x80004000	Scaler value
0x80004004	Scaler reload value
0x80004008	Configuration register
0x8000400C	Timer latch configuration register
0x80004010	Timer 1 counter value register
0x80004014	Timer 1 reload value register
0x80004018	Timer 1 control register
0x8000401C	Timer 1 latch register
0x80004020	Timer *2* counter value register
0x80004024	Timer *2* reload value register
0x80004028	Timer *2* control register
0x8000402C	Timer *2* latch register
0x80004030	Timer *3* counter value register
0x80004034	Timer *3* reload value register
0x80004038	Timer *3* control register
0x8000403C	Timer *3* latch register
0x80004040	Timer *4* counter value register
0x80004044	Timer *4* reload value register
0x80004048	Timer *4* control register
0x8000404C	Timer *4* latch register
0x80004050	Timer *5* counter value register
0x80004054	Timer *5* reload value register
0x80004058	Timer *5* control register
0x8000405C	Timer *5* latch register
0x80004060	Timer *6* counter value register
0x80004064	Timer *6* reload value register
0x80004068	Timer *6* control register
0x8000406C	Timer *6* latch register
0x80004070	Timer *7* counter value register
0x80004074	Timer *7* reload value register
0x80004078	Timer *7* control register
0x8000407C	Timer *7* latch register

36.3.1 Scaler Value Register

*Table 497.*0x00 - SCALER - Scaler value register

31 16	16-1 0
RESERVED	SCALER
0	all 1
r	rw

16-1: 0 Scaler value. This value will also be set by writes to the Scaler reload value register.
Any unused most significant bits are reserved. Always reads as ‘000...0’.

36.3.2 Scaler Reload Value Register

*Table 498.*0x04 - SRELOAD - Scaler reload value register

31 16	16-1 0
RESERVED	SCALER RELOAD VALUE
0	all 1
r	rw

16-1: 0 Scaler reload value. Writes to this register also set the scaler value.
Any unused most significant bits are reserved. Always read as ‘000...0’.

36.3.3 Configuration Register

*Table 499.*0x08 - CONFIG - Configuration register

31 23	22 16	15 14	13	12	11	10	9	8	7 3	2 0
"000..0"	TIMEREN	R	EV	ES	EL	EE	DF	SI	RESERVED	TIMERS
0	0	0	0	0	0	0	0	1	*	7
r	rw	r	rw	rw	rw	rw	rw	r	r	r

31: 23 Reserved. Always reads as '000...0'.

22: 16 Enable bits for each timer. Writing '1' to one of this bits sets the enable bit in the corresponding timers control register. Writing '0' has no effect to the timers. bit[16] corresponds to timer0, bit[17] to timer 1,...

15: 14 Reserved

13 External Events (EV). If EV is set to 0 then the latch and set events are taken from the least significant 32 bit of the interrupt bus, otherwise they are from some of the most significant ones and some external signals (see table 35.3.4).

12 Enable set (ES). If set, on the next matching interrupt, the timers will be loaded with the corresponding timer reload values. The bit is then automatically cleared, not to reload the timer values until set again.

11 Enable latching (EL). If set, on the next matching interrupt, the latches will be loaded with the corresponding timer values. The bit is then automatically cleared, not to load a timer value until set again.

10 Enable external clock source (EE). If set the prescaler is clocked from the external clock source.

9 Disable timer freeze (DF). If set the timer unit can not be freezed, otherwise signal GPTI.DHALT freezes the timer unit.

8 Separate interrupts (SI). Reads '1' if the timer unit generates separate interrupts for each timer, otherwise '0'. Read-only.

7: 3 Reserved

2: 0 Number of implemented timers. Read-only.

36.3.4 Timer Latch Configuration Register

*Table 500.*0x0C - CATCHCFG - Timer latch configuration register

31 0
LATCHSEL
0
rw

31: 0 This field specifies which bits of the interrupt bus or of the external signals (depending on EV field in table 35.3.3) cause the set and latch events. If EV is 0, the latching is done based on events on the 31:0 bits of the interrupt bus with a direct mapping. If the EV field is '1', the bits 29:0 correspond to the 61:32 bits of the interrupt bus, while the bit 30 corresponds to the TICKOUT signal from the SpaceWire Interface (see chapter 33) and the bit 31 corresponds to the rtsync signal from the MIL-STD-1553B / AS15531 Interface (see chapter 23).

36.3.5 Timer N Counter Value Register

*Table 501.*0xn0, when n selects the times - TCNTVALn - Timer n counter value register

32-1 0
TCVAL
0
rw

32-1: 0 Timer Counter value. Decremented by 1 for each prescaler tick.

Any unused most significant bits are reserved. Always reads as '000...0'.

36.3.6 Timer N Reload Value Register

*Table 502.*0xn4, when n selects the times - TRLDVALn - Timer n reload value register

32-1	0
TRCDUAL	
*	
rw	

32-1: 0 Timer Reload value. This value is loaded into the timer counter value register when '1' is written to load bit in the timers control register or when the RS bit is set in the control register and the timer underflows.

Any unused most significant bits are reserved. Always reads as '000...0'.

36.3.7 Timer N Control Register

*Table 503.*0xn8, when n selects the times - TCTRLn - Timer n control register

31	9	8	7	6	5	4	3	2	1	0
RESERVED				DH	CH	IP	IE	LD	RS	EN
0				0	0	0	0	0	*	*
r				r	rw	wc	wc	rw	rw	rw

31: 7 Reserved. Always reads as '000...0'.

6 Debug Halt (DH): Value of GPTI.DHALT signal which is used to freeze counters (e.g. when a system is in debug mode). Read-only.

5 Chain (CH): Chain with preceding timer. If set for timer *n*, timer *n* will be decremented each time when timer (*n*-1) underflows.

4 Interrupt Pending (IP): The core sets this bit to '1' when an interrupt is signalled. This bit remains '1' until cleared by writing '1' to this bit, writes of '0' have no effect.

3 Interrupt Enable (IE): If set the timer signals interrupt when it underflows.

2 Load (LD): Load value from the timer reload register to the timer counter value register.

1 Restart (RS): If set, the timer counter value register is reloaded with the value of the reload register when the timer underflows

0 Enable (EN): Enable the timer.

36.3.8 Timer N Latch Register

*Table 504.*0xnC, when n selects the times - TLATCHn - Timer n latch register

31	0
LTCV	
0	
r	

31: 0 Latched timer counter value (LTCV): Valued latched from corresponding timer. Read-only.

37 I²C to AHB bridge

The GR716 microcontroller comprises an I2C to AHB bridge (I2C2AHB). The I2C to AHB bridge controls its own external pins and has a unique AMBA address described in chapter 2.11. The I2C to AHB bridge is connected to external pins via the IOMUX.

The control and status registers are located on APB bus in the address range from 0x80105000 to 0x80105FFF. See I2C to AHB bridge connections in the next drawing. The figure shows memory locations and functions used for I2C2AHB configuration and control.

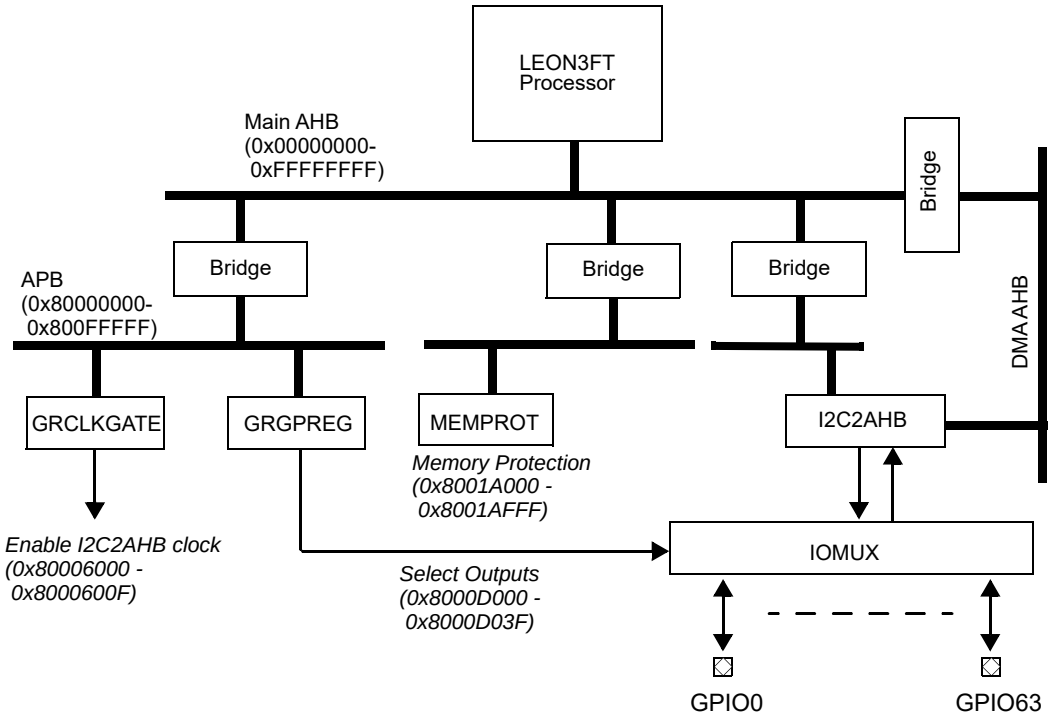


Figure 65. GR716 I2C2AHB bus and pin connection

The primary clock gating unit **GRCLKGATE** described in section 26 is used to enable/disable the I2C to AHB bridge. The unit **GRCLKGATE** can also be used to perform reset of the I2C to AHB bridge. Software must enable clock and release reset described in section 26 before configuration and transmission can start.

External IO selection and configuration is made in the system IO configuration registers (**GRGPREG**) in the address range from 0x8000D000 to 0x8000D03F. See section 7.1 for further information.

The system can be configured to protect and restrict access to the I2C to AHB bridge in the **MEMPROT** unit. See section 47 for more information.

37.1 Overview

The I²C slave to AHB bridge is an I²C slave that provides a link between the I²C bus and AMBA AHB. The core is compatible with the Philips I²C standard and external pull-up resistors must be supplied for both bus lines.

On the I²C bus the slave acts as an I²C memory device where accesses to the slave are translated to AMBA accesses. The core can translate I²C accesses to AMBA byte, halfword or word accesses. The core makes use of I²C clock stretching but can also be configured to use a special mode without clock

stretching in order to support systems where master or physical layer limitations prevent stretching of the I^{2}C clock period.

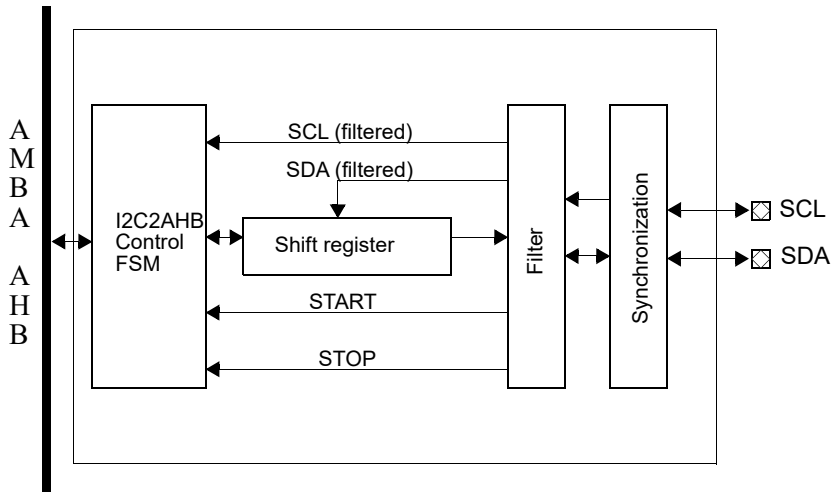


Figure 66. Block diagram

37.2 Operation

37.2.1 Transmission protocol

The I^{2}C-bus is a simple 2-wire serial multi-master bus with collision detection and arbitration. The bus consists of a serial data line (SDA) and a serial clock line (SCL). The I^{2}C standard defines three transmission speeds; Standard (100 kb/s), Fast (400 kb/s) and High speed (3.4 Mb/s).

A transfer on the I^{2}C-bus begins with a START condition. A START condition is defined as a high to low transition of the SDA line while SCL is high. Transfers end with a STOP condition, defined as a low to high transition of the SDA line while SCL is high. These conditions are always generated by a master. The bus is considered to be busy after the START condition and is free after a certain amount of time following a STOP condition. The bus free time required between a STOP and a START condition is defined in the I^{2}C-bus specification and is dependent on the bus bit rate.

Figure 67 shows a data transfer taking place over the I^{2}C-bus. The master first generates a START condition and then transmits the 7-bit slave address. The bit following the slave address is the R/$\overline{W}$ bit which determines the direction of the data transfer. In this case the R/$\overline{W}$ bit is zero indicating a write operation. After the master has transmitted the address and the R/$\overline{W}$ bit it releases the SDA line. The receiver pulls the SDA line low to acknowledge the transfer. If the receiver does not acknowledge the transfer, the master may generate a STOP condition to abort the transfer or start a new transfer by generating a repeated START condition.

After the address has been acknowledged the master transmits the data byte. If the R/$\overline{W}$ bit had been set to ‘1’ the master would have acted as a receiver during this phase of the transfer. After the data byte has been transferred the receiver acknowledges the byte and the master generates a STOP condition to complete the transfer.

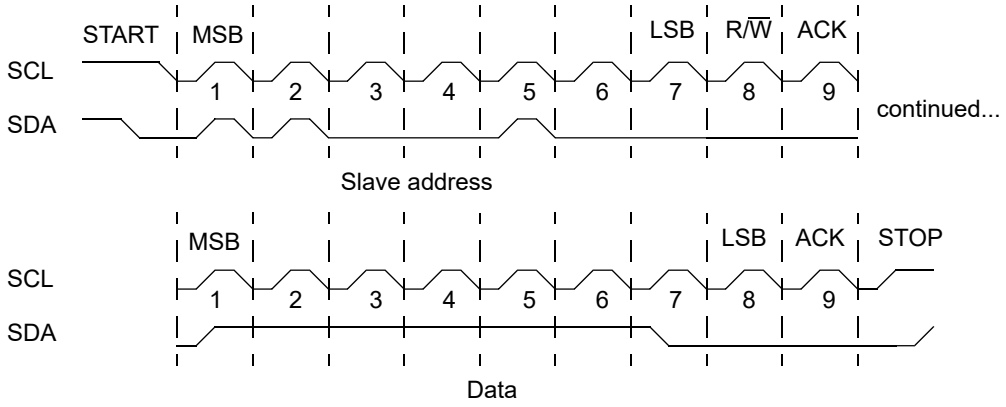


Figure 67. Complete I^{2}C data transfer

If the data bit rate is too high for a slave device or if the slave needs time to process data, it may stretch the clock period by keeping SCL low after the master has driven SCL low. Clock stretching is a configurable parameter of the core (see sections 37.2.4 and 37.2.6).

37.2.2 Slave addressing

The core responds to two addresses on the I^{2}C bus. Accesses to the I2C memory address are translated to AMBA AHB accesses and accesses to the I^{2}C configuration address access the core's configuration register. I2C memory and slave addresses can be configured via control registers see register SLVADDR and SLVCFG in section 37.3.5 and 37.3.6.

37.2.3 System clock requirements and sampling

The core samples the incoming I^{2}C SCL clock and does not introduce any additional clock domains into the system. Both the SCL and SDA lines first pass through two stage synchronizers and are then filtered with a low pass filter consisting of four registers.

START and STOP conditions are detected if the SDA line, while SCL is high, is at one value for two system clock cycles, toggles and keeps the new level for two system clock cycles.

The synchronizers and filters constrain the minimum system frequency. The core requires the SCL signal to be stable for at least four system clock cycles before the core accepts the SCL value as the new clock value. The core's reaction to transitions will be additionally delayed since both lines are taken through two-stage synchronizers before they are filtered. Therefore it takes the core over eight system clock cycles to discover a transition on SCL.

37.2.4 Configuration register access

The I^{2}C configuration register is accessed via a separate I^{2}C address (I^{2}C configuration address). The configuration register has the layout shown in table 505.

*Table 505.*I2C2AHB configuration register

7	6	5	4	3	2	1	0
Reserved		PROT	MEXC	DMAACT	NACK	HSIZE	

7:6	Reserved, always zero (read only)
5	Memory protection triggered (PROT) - '1' if last AHB access was outside the allowed memory area. Updated after each AMBA access (read only)
4	Memory exception (MEXC) - '1' if core receives AMBA ERROR response. Updated after each AMBA access (read only)
3	DMA active (DMAACT) - '1' if core is currently performing a DMA operation.

*Table 505.*I2C2AHB configuration register

2	NACK (NACK) - Use NACK instead of clock stretching. See documentation in section 37.2.6.
1:0	AMBA access size (HSIZE) - Controls the access size that the core will use for AMBA accesses. 0: byte, 1: halfword, 2: word. HSIZE = “11” is illegal.

Reset value: 0x02

Reads from the I^2C configuration address will return the current value of the configuration register. Writes to the I^2C configuration address will affect the writable bits in the configuration register.

37.2.5 AHB accesses

All AMBA accesses are done in big endian format. The first byte sent to or from the slave is the most significant byte.

To write a word on the AHB bus the following I2C bus sequence should be performed:

1. Generate START condition
2. Send I2C memory address with the R/$\overline{W}$ bit set to ‘0’.
3. Send four byte AMBA address, the most significant byte is transferred first
4. Send four bytes to write to the specified address
5. If more than four consecutive bytes should be written, continue to send additional bytes, otherwise go to 6.
6. Generate STOP condition

To perform a read access on the AHB bus, the following I2C bus sequence should be performed:

1. Generate START condition
2. Send I2C memory address with the R/$\overline{W}$ bit set to ‘0’.
3. Send four byte AMBA address, the most significant byte is transferred first
4. Generate (repeated) START condition
5. Send I2C memory address with the R/$\overline{W}$ bit set to ‘1’.
6. Read the required number of bytes and NACK the last byte
7. Generate stop condition

During consecutive read or write operations, the core will automatically increment the address. The access size (byte, halfword or word) used on AHB is set via the HSIZE field in the I2C2AHB configuration register.

The core always respects the access size specified via the HSIZE field. If a write operation writes fewer bytes than what is required to do an access of the specified HSIZE then the write data will be dropped, no access will be made on AHB. If a read operation reads fewer bytes than what is specified by HSIZE then the remaining read data will be dropped at a START or STOP condition. This means, for instance, that if HSIZE is “10” (word) the core will perform two word accesses if a master reads one byte, generates a repeated start condition, and reads one more byte. Between these two accesses the address will have been automatically increased, so the fist access will be to address *n* and the second to address *n+4*.

The automatic address increment means that it is possible to write data and then immediately read the data located at the next memory position. As an example, the following sequence will write a word to address 0 and then read a word from address 4:

1. Generate START condition
2. Send I2C memory address with the R/$\overline{W}$ bit set to ‘0’.
3. Send four byte AMBA address, all zero.
4. Send four bytes to write to the specified address

5. Generate (repeated) START condition
6. Send I2C memory address with the R/$\overline{W}$ bit set to ‘1’.
7. Read the required number of bytes and lack the last byte
8. Generate stop condition

The core will not mask any address bits. Therefore it is important that the I^2C master respects AMBA rules when performing halfword and word accesses. A halfword access must be aligned on a two byte address boundary (least significant bit of address must be zero) and a word access must be aligned on a four byte boundary (two least significant address bits must be zero).

37.2.6 Clock stretching or NACK mode

The core has two main modes of operation for AMBA accesses. In one mode the core will use clock stretching while performing an AHB operation and in the other mode the core will not acknowledge bytes (abort the I^2C access) when the core is busy. Clock stretching is the preferred mode of operation. The NACK mode can be used in scenarios where the I^2C master or physical layer does not support clock stretching. The mode to use is selected via the NACK field in the I^2C configuration register.

When clock stretching is enabled (NACK field is ‘0’) the core will stretch the clock when the slave is accessed (via the I2C memory address) and the slave is busy processing a transfer. Clock stretching is also used when a data byte has been transmitted, or received, to keep SCL low until a DMA operation has completed. In the transmit (AMBA read) case SCL is kept low before the rising edge of the first byte. In the receive case (AMBA write) the ACK cycle for the previous byte is stretched.

When clock stretching is disabled (NACK field is ‘1’) the core will never stretch the SCL line. If the core is busy performing DMA when it is addressed, the address will not be acknowledged. If the core performs consecutive writes and the first write operation has not finished the core will now acknowledge the written byte. If the core performs a read operation and the read DMA operation has not finished when the core is supposed to deliver data then the core will go to its idle state and not respond to more accesses until a START condition is generated on the bus. This last part means that the NACK mode is practically unusable in systems where the AMBA access can take longer than one I^2C clock period. This can be compensated by using a very slow I^2C clock.

37.2.7 Memory protection

Default configuration allows full access to the complete AHB address range. The access range can be restricted via configuration registers.

The registers PADDR and PMASK are used to assign the memory protection area’s address and mask in the following way

Before the core performs an AMBA access it will perform the check:

(((incoming address) xor (PADDR)) and PMASK) /= 0x00000000

If the above expression is true (one or several bits in the incoming address differ from the protection address, and the corresponding mask bits are set to ‘1’) then the access is inhibited. As an example, assume that *PADDR* is 0xA0000000 and *PMASK* is 0xF0000000. Since *PMASK* only has ones in the most significant nibble, the check above can only be triggered for these bits. The address range of allowed accessed will thus be 0xA0000000 - 0xAFFFFFFF.

The core will set the configuration register bit PROT if an access is attempted outside the allowed address range. This bit is updated on each AHB access and will be cleared by an access inside the allowed range.

37.3 Registers

The core is programmed through registers mapped into APB address space.

*Table 506.*I^{2}C slave registers

APB address offset	Register
0x00	Control register
0x04	Status register
0x08	Protection address register
0x0C	Protection mask register
0x10	I2C slave memory address register
0x14	I2C slave configuration address register

37.3.1 Control Register

*Table 507.*0x0 - CTRL - Control register

31 2	1	0
RESERVED	IRQEN	EN
0	0	1
r	rw	rw

31 : 2 RESERVED

1 Interrupt enable (IRQEN) - When this bit is set to '1' the core will generate an interrupt each time the DMA field in the status register transitions from '0' to '1'.

0 Core enable (EN) - When this bit is set to '1' the core is enabled and will respond to I2C accesses. Otherwise the core will not react to I2C traffic.

37.3.2 Status Register

*Table 508.*0x04 - STAT - Status register

31 3	2	1	0
RESERVED	PROT	WR	DMA
0x0	0	0	0
r	wc	r	wc

31 : 3 RESERVED

2 Protection triggered (PROT) - Full access is granted the I2C2AHB interface

1 Write access (WR) - Last AHB access performed was a write access. This bit is read only.

0 Direct Memory Access (DMA) - This bit gets set to '1' each time the core attempts to perform an AHB access. By setting the IRQEN field in the control register this condition can generate an interrupt. This bit can be cleared by software by writing '1' to this position.

37.3.3 Protection Address Register

*Table 509.*0x08 - PADDR - Protection address register

31 0
PROTADDR
0x0
rw

31 : 0 Protection address (PROTADDR) - Defines the base address for the memory area where the core is allowed to make accesses.

37.3.4 Protection Mask Register

*Table 510.*0x0C - PMASK - Protection mask register

31 0
PROTMASK
0x0
rw

31 : 0 Protection mask (PROTMASK) - Selects which bits in the Protection address register that are used to define the protected memory area.

37.3.5 I2C Slave Memory Address Register

Table 511. 0x10 - SLVADDR - I2C slave memory address register

31 7	6 0
RESERVED	I2CSLVADDR
0	0x50
r	rw

31 : 7 RESERVED

6 : 0 I2C slave memory address (I2CSLVADDR) - Address that slave responds to for AHB memory accesses

37.3.6 I2C Slave Configuration Address Register

*Table 512.*0x14 - SLVCFG - I2C slave configuration address register

31 7	6 0
RESERVED	I2CCFGADDR
0	0x51
r	rw

31 : 7 RESERVED

6 : 0 I2C slave configuration address (I2CCFGADDR) - Address that slave responds to for configuration register accesses.

38 I2C master

The LEON3FT microcontroller comprises two separate I2C master (I2CMST) units. Each I2C master unit controls its own external pins and has a unique AMBA address described in chapter 2.11.

The I2C master units are located on the APB bus in the address range from 0x8030E000 to 0x8030FFFF. See I2C master units connections in the next drawing. The figure shows memory locations and functions used for I2C master configuration and control.

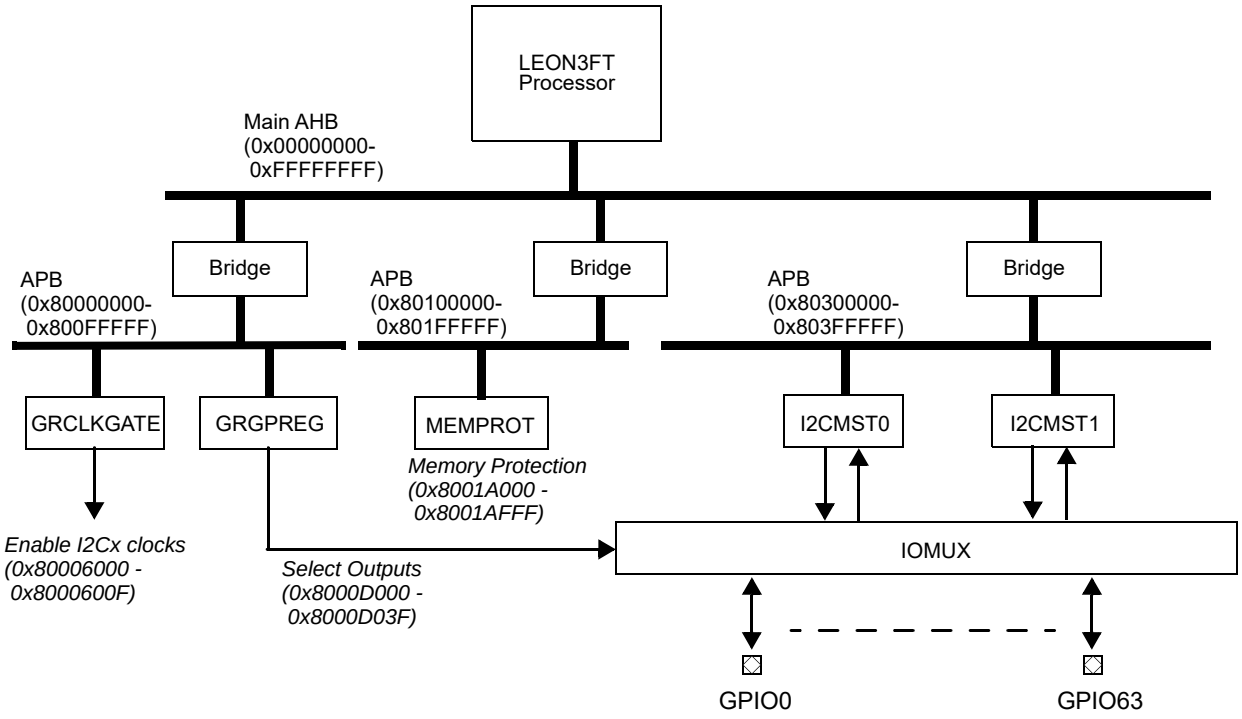


Figure 68. GR716 I2C-master bus and pin connection

The primary clock gating unit **GRCLKGATE** described in section 26 is used to enable/disable individual I2C master units. The unit **GRCLKGATE** can also be used to perform reset of individual I2C master units. Software must enable clock and release reset described in section 26 before I2C master configuration and transmission can start.

External IO selection per I2C master unit is made in the system IO configuration register (**GRGPREG**) in the address range from 0x8000D000 to 0x8000D03F. See section 7.1 for further information.

Each **I2CMSTx** unit controls its own external pins and has a unique AMBA address described in chapter 2.11. I2CMST unit 0 and 1 have identical configuration and status registers. Configuration and status registers are described in section 38.3.

The system can be configured to protect and restrict access to individual I2C-master unit in the **MEMPROT** unit. See section 47 for more information.

38.1 Overview

The I2C-master core is a modified version of the OpenCores I2C-Master with an AMBA APB interface. The core is compatible with Philips I2C standard and supports 7- and 10-bit addressing. Stan-

dard-mode (100 kb/s) and Fast-mode (400 kb/s) operation are supported directly. External pull-up resistors must be supplied for both bus lines.

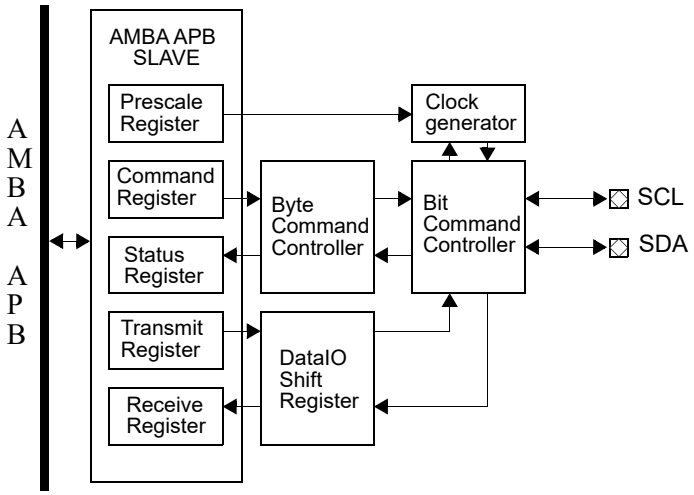


Figure 69. Block diagram

38.2 Operation

38.2.1 Transmission protocol

The I^2C-bus is a simple 2-wire serial multi-master bus with collision detection and arbitration. The bus consists of a serial data line (SDA) and a serial clock line (SCL). The I^2C standard defines three transmission speeds; Standard (100 kb/s), Fast (400 kb/s) and High speed (3.4 Mb/s).

A transfer on the I^2C-bus begins with a START condition. A START condition is defined as a high to low transition of the SDA line while SCL is high. Transfers end with a STOP condition, defined as a low to high transition of the SDA line while SCL is high. These conditions are always generated by a master. The bus is considered to be busy after the START condition and is free after a certain amount of time following a STOP condition. The bus free time required between a STOP and a START condition is defined in the I^2C-bus specification and is dependent on the bus bit rate.

Figure 70 shows a data transfer taking place over the I^2C-bus. The master first generates a START condition and then transmits the 7-bit slave address. The bit following the slave address is the R/$\overline{W}$ bit which determines the direction of the data transfer. In this case the R/$\overline{W}$ bit is zero indicating a write operation. After the master has transmitted the address and the R/$\overline{W}$ bit it releases the SDA line. The receiver pulls the SDA line low to acknowledge the transfer. If the receiver does not acknowledge the transfer, the master may generate a STOP condition to abort the transfer or start a new transfer by generating a repeated START condition.

After the first byte has been acknowledged the master transmits the data byte. If the R/$\overline{W}$ bit had been set to ‘1’ the master would have acted as a receiver during this phase of the transfer. After the data byte has been transferred the receiver acknowledges the byte and the master generates a STOP condition to complete the transfer. Section 38.2.3 contains three more example transfers from the perspective of a software driver.

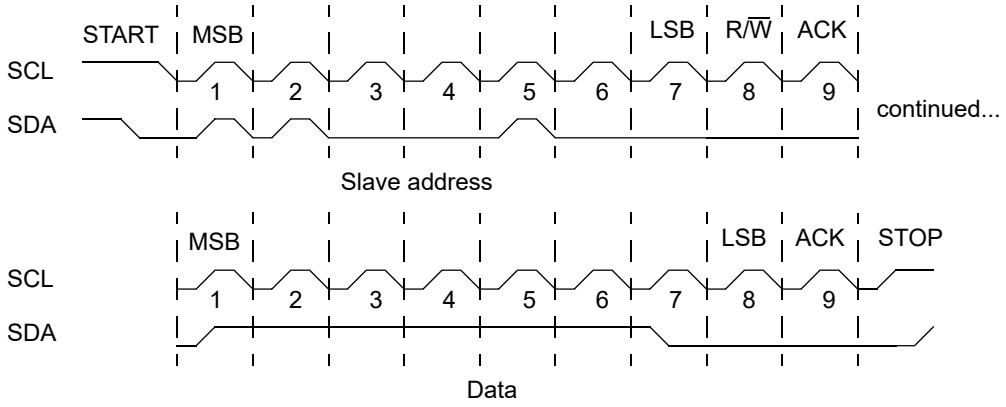


Figure 70. Complete I^{2}C data transfer

If the data bitrate is too high for a slave device, it may stretch the clock period by keeping SCL low after the master has driven SCL low.

38.2.2 Clock generation

The core uses the prescale register to determine the frequency of the SCL clock line and of the 5*SCL clock that the core uses internally. To calculate the prescale value use the formula:

$$Prescale = \frac{AMBAclockfrequency}{5 \cdot SCLfrequency} - 1$$

The *SCLfrequency* is 100 kHz for Standard-mode operation (100 kb/s) and 400 kHz for Fast mode operation. To use the core in Standard-mode in a system with a 60 MHz clock driving the AMBA bus the required prescale value is:

$$Prescale = \frac{60Mhz}{5 \cdot 100kHz} - 1 = 119 = 0x77$$

Note that the prescale register should only be changed when the core is disabled. The minimum recommended prescale value is 3 due to synchronization issues. This limits the minimum system frequency to 2 MHz for operation in Standard-mode (to be able to generate a 100 kHz SCL clock). However, a system frequency of 2 MHz will not allow the implementation fulfill the 100 ns minimum requirement for data setup time (required for Fast-mode operation). For compatibility with the I^{2}C Specification, in terms of minimum required data setup time, the minimum allowed system frequency is 20 MHz due to synchronization issues. If the core is run at lower system frequencies, care should be taken so that data from devices is stable on the bus one system clock period before the rising edge of SCL.

38.2.3 Software operational model

The core is initialized by writing an appropriate value to the clock prescale register and then setting the enable (EN) bit in the control register. Interrupts are enabled via the interrupt enable (IEN) bit in the control register.

To write a byte to a slave the I^{2}C-master must generate a START condition and send the slave address with the R/$\overline{W}$ bit set to ‘0’. After the slave has acknowledged the address, the master transmits the

data, waits for an acknowledge and generates a STOP condition. The sequence below instructs the core to perform a write:

1. Left-shift the I^{2}C-device address one position and write the result to the transmit register. The least significant bit of the transmit register (R/$\overline{W}$) is set to '0'.

2. Generate START condition and send contents of transmit register by setting the STA and WR bits in the command register.

3. Wait for interrupt, or for TIP bit in the status register to go low.

4. Read RxACK bit in status register. If RxACK is low the slave has acknowledged the transfer, proceed to step 5. If RxACK is set the device did not acknowledge the transfer, go to step 1.

5. Write the slave-data to the transmit register.

6. Send the data to the slave and generate a stop condition by setting STO and WR in the command register.

7. Wait for interrupt, or for TIP bit in the status register to go low.

8. Verify that the slave has acknowledged the data by reading the RxACK bit in the status register. RxACK should not be set.

To read a byte from an I^{2}C-connected memory much of the sequence above is repeated. The data written in this case is the memory location on the I^{2}C slave. After the address has been written the master generates a repeated START condition and reads the data from the slave. The sequence that software should perform to read from a memory device:

1. Left-shift the I^{2}C-device address one position and write the result to the transmit register. The least significant bit of the transmit register (R/W) is set to '0'.

2. Generate START condition and send contents of transmit register by setting the STA and WR bits in the command register.

3. Wait for interrupt or for TIP bit in the status register to go low.

4. Read RxACK bit in status register. If RxACK is low the slave has acknowledged the transfer, proceed to step 5. If RxACK is set the device did not acknowledge the transfer, go to step 1.

5. Write the memory location to be read from the slave to the transmit register.

6. Set the WR bit in the command register. Note that a STOP condition is not generated here.

7. Wait for interrupt, or for TIP bit in the status register to go low.

8. Read RxACK bit in the status register. RxACK should be low.

9. Address the I^{2}C-slave again by writing its left-shifted address into the transmit register. Set the least significant bit of the transmit register (R/W) to '1' to read from the slave.

10. Set the STA and WR bits in the command register to generate a repeated START condition.

11. Wait for interrupt, or for TIP bit in the status register to go low.

12. Read RxACK bit in the status register. The slave should acknowledge the transfer.

13. Prepare to receive the data read from the I^{2}C-connected memory. Set bits RD, ACK and STO on the command register. Setting the ACK bit NAKs the received data and signifies the end of the transfer.

14. Wait for interrupt, or for TIP in the status register to go low.

15. The received data can now be read from the receive register.

To perform sequential reads the master can iterate over steps 13 - 15 by not setting the ACK and STO bits in step 13. To end the sequential reads the ACK and STO bits are set. Consult the documentation of the I^{2}C-slave to see if sequential reads are supported.

The final sequence illustrates how to write one byte to an I^{2}C-slave which requires addressing. First the slave is addressed and the memory location on the slave is transmitted. After the slave has acknowledged the memory location the data to be written is transmitted without a generating a new START condition:

1. Left-shift the I^{2}C-device address one position and write the result to the transmit register. The least significant bit of the transmit register (R/W) is set to '0'.
2. Generate START condition and send contents of transmit register by setting the STA and WR bits in the command register.
3. Wait for interrupt or for TIP bit in the status register to go low.
4. Read RxACK bit in status register. If RxACK is low the slave has acknowledged the transfer, proceed to step 5. If RxACK is set the device did not acknowledge the transfer, go to step 1.
5. Write the memory location to be written from the slave to the transmit register.
6. Set the WR bit in the command register.
7. Wait for interrupt, or for TIP bit in the status register to go low.
8. Read RxACK bit in the status register. RxACK should be low.
9. Write the data byte to the transmit register.
10. Set WR and STO in the command register to send the data byte and then generate a STOP condition.
11. Wait for interrupt, or for TIP bit in the status register to go low.
12. Check RxACK bit in the status register. If the write succeeded the slave should acknowledge the data byte transfer.

The example sequences presented here can be generally applied to I^{2}C-slaves. However, some devices may deviate from the protocol above, please consult the documentation of the I^{2}C-slave in question. Note that a software driver should also monitor the arbitration lost (AL) bit in the status register.

38.3 Registers

The core is programmed through registers mapped into APB address space.

Table 513. I^{2}C-master registers

APB address offset	Register
0x00	Clock prescale register
0x04	Control register
0x08	Transmit register*
0x08	Receive register**
0x0C	Command register*
0x0C	Status register**
0x10	Dynamic filter register

* Write only

** Read only

38.3.1 I²C-Master Clock Prescale Register

*Table 514.*0x00 - PRESCALE - I²C-master Clock prescale register

31 16	15 0
RESERVED	Clock prescale
0	0xFFFF
r	rw

31 : 16 RESERVED

15:0 Clock prescale - Value is used to prescale the SCL clock line. Do not change the value of this register unless the EN field of the control register is set to '0'. The minimum recommended value of this register is 0x0003. Lower values may cause the master to violate I²C timing requirements due to synchronization issues.

38.3.2 I²C-Master Control Register

*Table 515.*0x04 - CTRL - I²C-master control register

31 8	7	6	5 0
RESERVED	EN	IEN	RESERVED
0	0	0	0
r	rw	rw	r

31 : 8 RESERVED

7 Enable (EN) - Enable I²C core. The core is enabled when this bit is set to '1'.

6 Interrupt enable (IEN) - When this bit is set to '1' the core will generate interrupts upon transfer completion.

5:0 RESERVED

38.3.3 I²C-Master Transmit Register

*Table 516.*0x08 - TX - I²C-master transmit register

31 8	7 1	0
RESERVED	TDATA	RW
0	0	0
-	w	w

31 : 8 RESERVED

7:1 Transmit data (TDATA) - Most significant bits of next byte to transmit via I²C

0 Read/Write (RW) - In a data transfer this is the data's least significant bit. In a slave address transfer this is the RW bit. '1' reads from the slave and '0' writes to the slave.

38.3.4 I²C-Master Receive Register

*Table 517.*0x08 - RX - I²C-master receive register

31 8	7 0
RESERVED	RDATA
	0
	r

31 : 8 RESERVED

7:0 Receive data (RDATA) - Last byte received over I²C-bus.

38.3.5 I²C-Master Command Register

*Table 518.*0x0C -CMD - I²C-master command register

31 … 8	7	6	5	4	3	2 … 1	0
RESERVED	STA	STO	RD	WR	ACK	RESERVED	IACK
0	0	0	0	0	0	0	0
r	w*	w*	w*	w*	w*	r	-

31 : 8 RESERVED

7 Start (STA) - Generate START condition on I²C-bus. This bit is also used to generate repeated START conditions.

6 Stop (STO) - Generate STOP condition

5 Read (RD) - Read from slave

4 Write (WR) - Write to slave

3 Acknowledge (ACK) - Used when acting as a receiver. ‘0’ sends an ACK, ‘1’ sends a NACK.

2:1 RESERVED

0 Interrupt acknowledge (IACK) - Clears interrupt flag (IF) in status register.

38.3.6 I²C-Master Status Register

*Table 519.*0x0C - STAT - I²C-master status register

31 … 8	7	6	5	4 … 2	1	0
RESERVED	RxACK	BUSY	AL	RESERVED	TIP	IF
0	0	0	0	0	0	0
r	r	r	r	r	r	wc

31 : 8 RESERVED

7 Receive acknowledge (RxACK) - Received acknowledge from slave. ‘1’ when no acknowledge is received, ‘0’ when slave has acked the transfer.

6 I²C-bus busy (BUSY) - This bit is set to ‘1’ when a start signal is detected and reset to ‘0’ when a stop signal is detected.

5 Arbitration lost (AL) - Set to ‘1’ when the core has lost arbitration. This happens when a stop signal is detected but not requested or when the master drives SDA high but SDA is low.

4:2 RESERVED

1 Transfer in progress (TIP) - ‘1’ when transferring data and ‘0’ when the transfer is complete. This bit is also set when the core will generate a STOP condition.

0 Interrupt flag (IF) - This bit is set when a byte transfer has been completed and when arbitration is lost. If IEN in the control register is set an interrupt will be generated. New interrupts will ge generated even if this bit has not been cleared.

38.3.7 I²C-Master Dynamic Filter Register

*Table 520.*0x10 - FILT - I²C-master dynamic filter register

31 … 2	1 … 0
RESERVED	FILT
0	0x3
r	rw

31 : 2 RESERVED

1 : 0 Dynamic filter reload value (FILT) - This field sets the reload value for the dynamic filter counter. The core will ignore all pulses on the bus shorter than 2 * (system clock period) and may also ignore pulses shorter than 2 * 2 * (system clock period) - 1.

39 I²C slave

The LEON3FT microcontroller comprises two separate I²C slave (I2CSLV) units. Each I²C slave unit controls its own external pins and has a unique AMBA address described in chapter 2.11.

The I²C slave units are located on the APB bus in the address range from 0x8040C000 to 0x8040DFFF. See I²C slave units connections in the next drawing. The figure shows memory locations and functions used for I²C slave configuration and control.

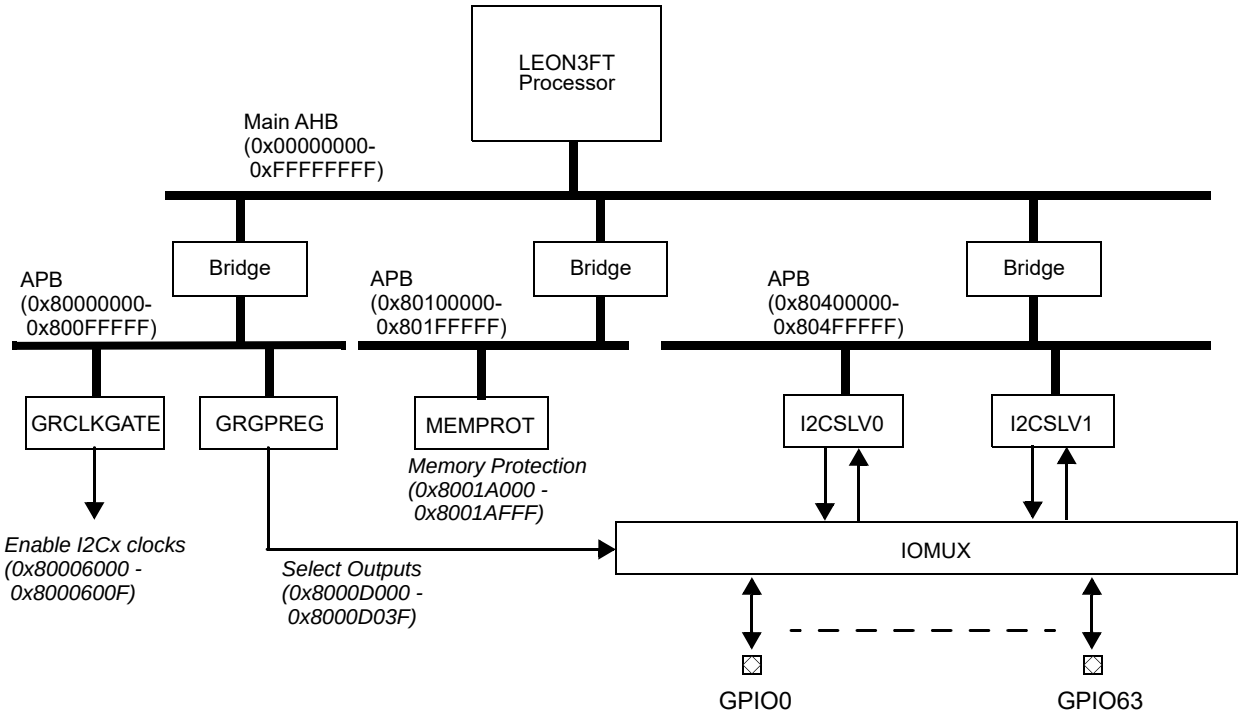


Figure 71. GR716 I²C-slave bus and pin connection

The primary clock gating unit **GRCLKGATE** described in section 26 is used to enable/disable individual I²C slave units. The unit **GRCLKGATE** can also be used to perform reset of individual I²C slave units. Software must enable clock and release reset described in section 26 before I²C slave configuration and transmission can start.

External IO selection per I²C slave unit is made in the system IO configuration register (**GRGPREG**) in the address range from 0x8000D000 to 0x8000D03F. See section 7.1 for further information.

Each **I2CSLVx** unit controls its own external pins and has a unique AMBA address described in chapter 2.11. I2CSLV unit 0 and 1 has identical configuration and status registers. Configuration and status registers are described in section 39.3.

System can be configured to protect and restrict access to individual I²C slave unit in the **MEMPROT** unit. See section 47 for more information.

39.1 Overview

The I²C slave core is a simple I²C slave that provides a link between the I²C bus and the AMBA APB. The core is compatible with Philips I²C standard and supports 7- and 10-bit addressing with an optionally software programmable address. Standard-mode (100 kb/s) and Fast-mode (400 kb/s) operation are supported directly. External pull-up resistors must be supplied for both bus lines.

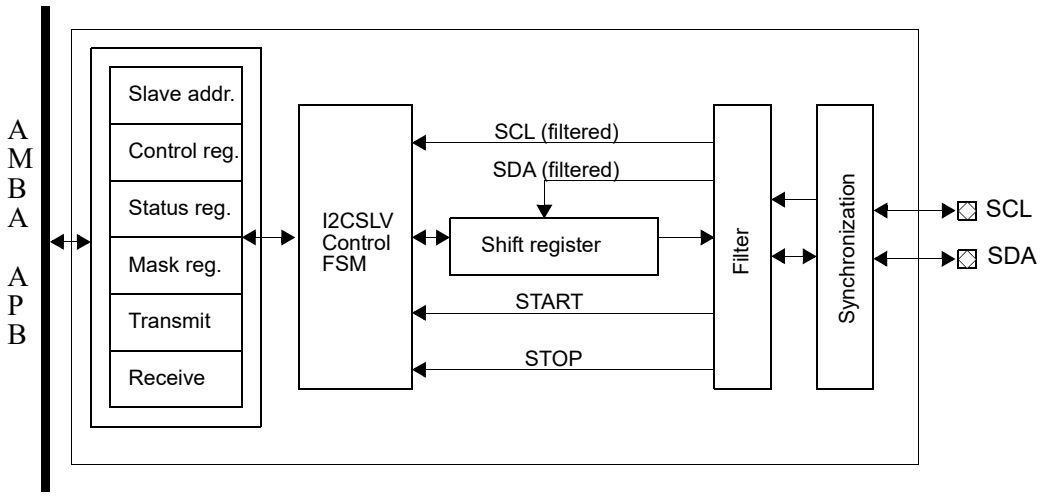


Figure 72. Block diagram

39.2 Operation

39.2.1 Transmission protocol

The I^2C-bus is a simple 2-wire serial multi-master bus with collision detection and arbitration. The bus consists of a serial data line (SDA) and a serial clock line (SCL). The I^2C standard defines three transmission speeds; Standard (100 kb/s), Fast (400 kb/s) and High speed (3.4 Mb/s).

A transfer on the I^2C-bus begins with a START condition. A START condition is defined as a high to low transition of the SDA line while SCL is high. Transfers end with a STOP condition, defined as a low to high transition of the SDA line while SCL is high. These conditions are always generated by a master. The bus is considered to be busy after the START condition and is free after a certain amount of time following a STOP condition. The bus free time required between a STOP and a START condition is defined in the I^2C-bus specification and is dependent on the bus bit rate.

Figure 73 shows a data transfer taking place over the I^2C-bus. The master first generates a START condition and then transmits the 7-bit slave address. I^2C also supports 10-bit addresses, which are discussed briefly below. The bit following the slave address is the R/$\overline{W}$ bit which determines the direction of the data transfer. In this case the R/$\overline{W}$ bit is zero indicating a write operation. After the master has transmitted the address and the R/$\overline{W}$ bit it releases the SDA line. The receiver pulls the SDA line low to acknowledge the transfer. If the receiver does not acknowledge the transfer, the master may generate a STOP condition to abort the transfer or start a new transfer by generating a repeated START condition.

After the address has been acknowledged the master transmits the data byte. If the R/$\overline{W}$ bit had been set to ‘1’ the master would have acted as a receiver during this phase of the transfer. After the data byte has been transferred the receiver acknowledges the byte and the master generates a STOP condition to complete the transfer.

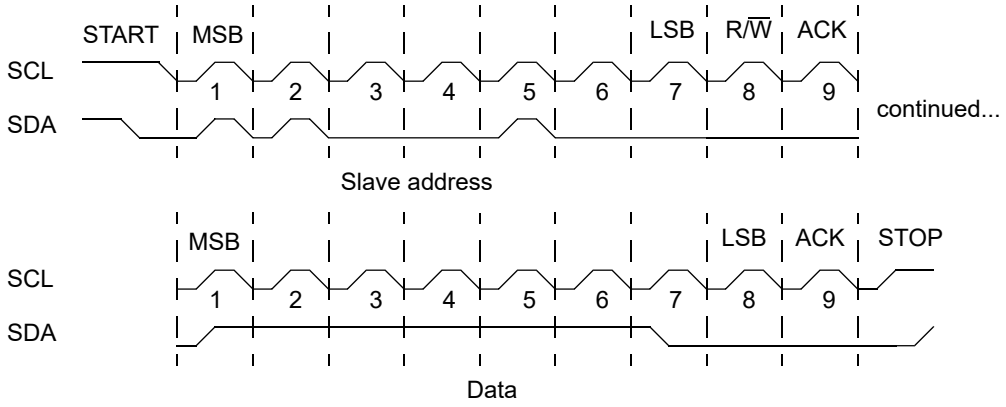


Figure 73. Complete I^{2}C data transfer

An I^{2}C slave may also support 10-bit addressing. In this case the master first transmits a pattern of five reserved bits followed by the two first bits of the 10-bit address and the R/$\overline{W}$ bit set to '0'. The next byte contains the remaining bits of the 10-bit address. If the transfer is a write operation the master then transmits data to the slave. To perform a read operation the master generates a repeated START condition and repeats the first part of the 10-bit address phase with the R/$\overline{W}$ bit set to '1'.

If the data bitrate is too high for a slave device or if the slave needs time to process data, it may stretch the clock period by keeping SCL low after the master has driven SCL low.

39.2.2 Slave addressing

The core have a programmable address and support for 7-bit and 10-bit addresses. The core is configured to use 10-bit address as default. The address mode controlled with the TBA bit in the Slave address register.

39.2.3 System clock requirements and sampling

The core samples the incoming I^{2}C SCL clock and does not introduce any additional clock domains into the system. Both the SCL and SDA lines first pass through two stage synchronizers and are then filtered with a low pass filter consisting of four registers.

START and STOP conditions are detected if the SDA line, while SCL is high, is at one value for two system clock cycles, toggles and keeps the new level for two system clock cycles.

The synchronizers and filters constrain the minimum system frequency. The core requires the SCL signal to be stable for at least four system clock cycles before the core accepts the SCL value as the new clock value. The core's reaction to transitions will be additionally delayed since both lines are taken through two-stage synchronizers before they are filtered. Therefore it takes the core over eight system clock cycles to discover a transition on SCL. To use the slave in Standard-mode operation at 100 kHz the recommended minimum system frequency is 2 MHz. For Fast-mode operation at 400 kHz the recommended minimum system frequency is 6 MHz.

39.2.4 Operational model

The core has four main modes of operation and is configured to use one of these modes via the Control register bits Receive Mode (RMOD) and Transmit Mode (TMOD). The mode setting controls the core's behavior after a byte has been received or transmitted.

The core will always NAK a received byte if the receive register is full when the whole byte is received. If the receive register is free the value of RMOD determines if the core should continue to listen to the bus for the master's next action or if the core should drive SCL low to force the master

into a wait state. If the value of the RMOD field is ‘0’ the core will listen for the master’s next action. If the value of the RMOD field is ‘1’ the core will drive SCL low until the Receive register has been read and the Status register bit Byte Received (REC) has been cleared. Note that the core has not accepted a byte if it does not acknowledge the byte.

When the core receives a read request it evaluates the Transmit Valid (TV) bit in the Control register. If the Transmit Valid bit is set the core will acknowledge the address and proceed to transmit the data held in the Transmit register. After a byte has been transmitted the core assigns the value of the Control register bit Transmit Always Valid (TAV) to the Transmit Valid (TV) bit. This mechanism allows the same byte to be sent on all read requests without software intervention. The value of the Transmit Mode (TMOD) bit determines how the core acts after a byte has been transmitted and the master has acknowledged the byte, if the master NAKs the transmitted byte the transfer has ended and the core goes into an idle state. If TMOD is set to ‘0’ when the master acknowledges a byte the core will continue to listen to the bus and wait for the master’s next action. If the master continues with a sequential read operation the core will respond to all subsequent requests with the byte located in the Transmit Register. If TMOD is ‘1’ the core will drive SCL low after a master has acknowledged the transmitted byte. SCL will be driven low until the Transmit Valid bit in the control register is set to ‘1’. Note that if the Transmit Always Valid (TAV) bit is set to ‘1’ the Transmit Valid bit will immediately be set and the core will have show the same behavior for both Transmit modes.

When operating in Receive or Transmit Mode ‘1’, the bus will be blocked by the core until software has acknowledged the transmitted or received byte. This may have a negative impact on bus performance and it also affects single byte transfers since the master is prevented to generate STOP or repeated START conditions when SCL is driven low by the core.

The core reports three types of events via the Status register. When the core NAKs a received byte, or its address in a read transfer, the NAK bit in the Status register will be set. When a byte is successfully received the core asserts the Byte Received (REC) bit. After transmission of a byte, the Byte Transmitted (TRA) bit is asserted. These three bits can be used as interrupt sources by setting the corresponding bits in the Mask register.

39.3 Registers

The core is programmed through registers mapped into APB address space.

Table 521.I^2C slave registers

APB address offset	Register
0x00	Slave address register
0x04	Control register
0x08	Status register
0x0C	Mask register
0x10	Receive register
0x14	Transmit register

39.3.1 Slave Address Register

*Table 522.*0x00 - SLVADDR - Slave address register

31	30 10	9 0
TBA	RESERVED	SLVADDR
1	0	0x50
rw	r	rw

31 Ten-bit Address (TBA) - When this bit is set the core will interpret the value in the SLVADDR field as a 10-bit address.

30 : 10 RESERVED

9:0 Slave address (SLVADDR) - Contains the slave I2C address.

39.3.2 Control Register

*Table 523.*0x04 - CTRL - Control register

31 5	4	3	2	1	0
RESERVED	RMOD	TMOD	TV	TAV	EN
0	NR	NR	NR	NR	NR
r	rw	rw	rw	rw	rw

31 : 5 RESERVED

4 Receive Mode (RMOD) - Selects how the core handles writes:

‘0’: The slave accepts one byte and NAKs all other transfers until software has acknowledged the received byte by reading the Receive register.

‘1’: The slave accepts one byte and keeps SCL low until software has acknowledged the received byte by reading the Receive register.

3 Transmit Mode (TMOD) - Selects how the core handles reads:

‘0’: The slave transmits the same byte to all if the master requests more than one byte in the transfer. The slave then NAKs all read requests as long as the Transmit Valid (TV) bit is unset.

‘1’: The slave transmits one byte and then keeps SCL low until software has acknowledged that the byte has been transmitted by setting the Transmit Valid (TV) bit.

2 Transmit Valid (TV) - Software sets this bit to indicate that the data in the transmit register is valid. The core automatically resets this bit when the byte has been transmitted. When this bit is ‘0’ the core will either NAK or insert wait states on incoming read requests, depending on the Transmit Mode (TMOD).

1 Transmit Always Valid (TAV) - When this bit is set, the core will not clear the Transmit Valid (TV) bit when a byte has been transmitted.

0 Enable core (EN) - Enables core. When this bit is set to ‘1’ the core will react to requests to the address set in the Slave address register. If this bit is ‘0’ the core will keep both SCL and SDA inputs in Hi-Z state.

39.3.3 Status Register

*Table 524.*0x08 - STAT - Status register

31	3	2	1	0
RESERVED		REC	TRA	NAK
0		0	0	0
r		*	wc	wc

31 : 3 RESERVED

2 Byte Received (REC) - This bit is set to '1' when the core accepts a byte and is automatically cleared when the Receive register has been read.

1 Byte Transmitted (TRA) - This bit is set to '1' when the core has transmitted a byte and is cleared by writing '1' to this position. Writes of '0' have no effect.

0 NAK Response (NAK) - This bit is set to '1' when the core has responded with NAK to a read or write request. This bit does not get set to '1' when the core responds with a NAK to an address that does not match the cores address. This bit is cleared by writing '1' to this position, writes of '0' have no effect.

39.3.4 Mask Register

*Table 525.*0x0C - MASK - Mask register

31	3	2	1	0
RESERVED		RECE	TRAE	NAKE
0		0	0	0
r		rw	rw	rw

31 : 3 RESERVED

2 Byte Received Enable (RECE) - When this bit is set the core will generate an interrupt when bit 2 in the Status register gets set.

1 Byte Transmitted Enable (TRAE) - When this bit is set the core will generate an interrupt when bit 1 in the Status register gets set.

0 NAK Response Enable (NAKE) - When this bit is set the core will generate an interrupt when bit 0 in the Status register gets set.

39.3.5 Receive Register

*Table 526.*0x10 - RX - Receive register

31	8	7	0
RESERVED		RECBYTE	
0		NR	
r		r	

31 : 8 RESERVED

7:0 Received Byte (RECBYTE) - Last byte received from master. This field only contains valid data if the Byte received (REC) bit in the status register has been set.

39.3.6 Transmit Register

*Table 527.*0x14 - TX - Transmit register

31 8	8 7 0
RESERVED	TRABYTE
0	NR
r	rw

31 : 8 RESERVED

7:0 Transmit Byte (TRABYTE) - Byte to transmit on the next master read request.

Reset value: Undefined

40 Interrupt Controller

The LEON3FT microcontroller have one Interrupt controller (IRQAMP). The Interrupt controller (IRQAMP) have a unique AMBA base address described in chapter 2.11.

The Interrupt controller (IRQAMP) is located on APB bus in the address range from 0x80002000 to 0x80002FFF. See the Interrupt controller (IRQAMP) control and status interface connection in next drawing. The drawing picture memory locations and functions used for Interrupt controller (IRQAMP) configuration and control.

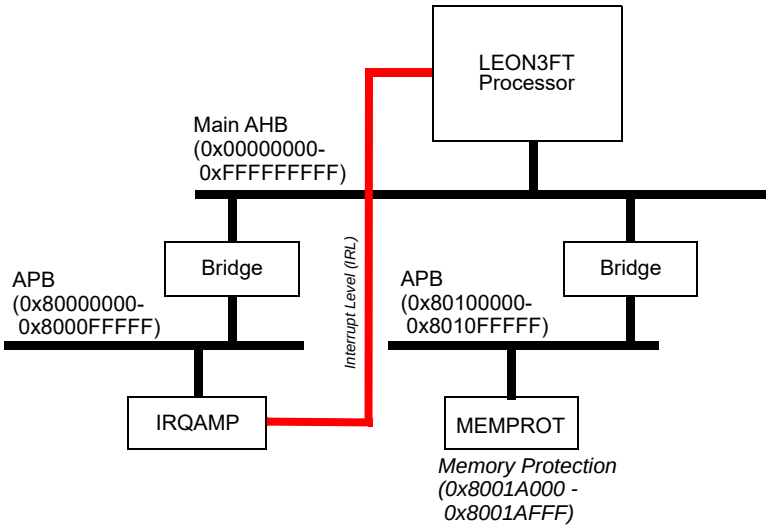


Figure 74. GR716 Interrupt controller bus connection

It is not possible to disable clock to the interrupt controller since the interrupt controller is used to wake-up the processor from deep-sleep i.e. when the clock to the processor is disabled.

The interrupt controllers configuration and status registers are describe in this section 40.3.

System can be configured to protect and restrict access to interrupt controller in the **MEMPROT** unit. For more information See section 47 for more information.

40.1 Overview

The LEON3FT microcontroller implements an interrupt scheme where interrupt lines are routed together with the remaining AHB/APB bus signals forming an interrupt bus. The interrupt controller core is attached to the AMBA bus as an APB slave and monitors the combined interrupt signals.

The interrupts generated on the interrupt bus are all forwarded to the interrupt controller. The interrupt controller prioritizes, masks and propagates the interrupt with the highest priority to the processor.

Interrupts from peripherals has been assigned a unique ID see chapter 2.13. The unique peripheral interrupt ID can be used for dynamically remapping of interrupts in the interrupt controller.

40.1.1 Definition

This chapter defines and explains the interrupt terminology used in this chapter. In the following chapters the following terms will be used:

- Bus interrupt line
- Interrupt ID number
- Extended Interrupt number

The ***bus interrupt line*** is the actual hardware interrupt used by the peripheral. The term ***bus*** is used since the internal hardware interrupt lines are distributed via the system bus architecture. The *bus interrupt line* is in the range from 0 to 63

The ***interrupt number*** refers to the interrupt line handled by the interrupt controller i.e. values between 1 to 15. Any arbitrary *bus interrupt line* can be mapped to any arbitrary *interrupt number* from 2 to 15. *Interrupt number 1* has the lowest priority and is reserved for *Extended interrupt numbers*.

Extended interrupt number is arbitrary bus interrupt lines mapped to arbitrary numbers between 16 to 32. *Extended interrupt numbers* is grouped into one *interrupt number* i.e. all *extended interrupt numbers* have the same priority and *interrupt number*.

40.1.2 Structure

This is a picture of the system interrupt generation and remapping functionality available in the GR716 device.

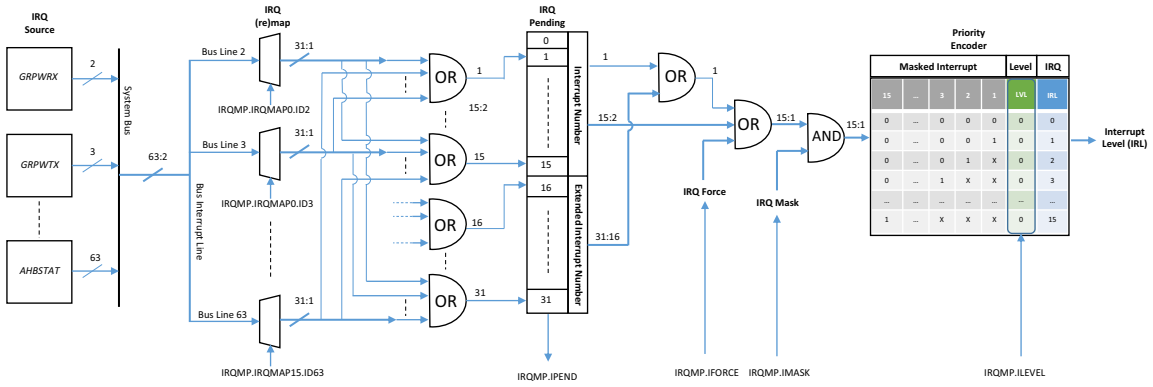


Figure 75. System and Interrupt controller block diagram

40.2 Operation

40.2.1 Interrupt prioritization

The interrupt controller monitors *interrupt number* 1 - 15 and *extended interrupt number* 16 - 32. When any of these interrupts are asserted high, the corresponding bit in the interrupt pending register is set. The pending bits will stay set until cleared by software or by an interrupt acknowledge from the processor.

Interrupt number 1 - 15 can be assigned to one of two levels (0 or 1) as programmed in the interrupt level register. Level 1 has higher priority than level 0. The interrupts are prioritised within each level, with interrupt 15 having the highest priority and interrupt 1 the lowest. The highest interrupt from level 1 will be forwarded to the processor. If no unmasked pending interrupt exists on level 1, then the highest unmasked interrupt from level 0 will be forwarded.

Extended interrupt number 16 - 32 are grouped and OR:ed into *Interrupt number 1* depict in figure 75. *Extended interrupt number* 16 - 32 has no level control an have no prioritization between individual interrupts.

When the LEON3FT processor acknowledges the interrupt, the corresponding pending bit will automatically be cleared. For *extended interrupt* the extended acknowledge register will identify which extended interrupt that was most recently acknowledged. This register can be used by software to invoke the appropriate interrupt handler for the extended interrupts.

Interrupt can also be forced by setting a bit in the interrupt force register. In this case, the processor acknowledgment will clear the force bit rather than the pending bit. After reset, the interrupt mask register is set to all zeros while the remaining control registers are undefined. Note that interrupt 15 cannot be maskable by the LEON3FT processor and should be used with care - most operating systems do not safely handle this interrupt.

40.2.2 Interrupt (re)map functionality

The LEON3FT microcontroller have 64 unique *bus interrupt line* sources listed in section 2.13, while the LEON3FT processor only supports 31 unique interrupt sources i.e. *interrupt ID number* 1 - 15 and *extended interrupt number* 16 - 32.

To accommodate all the 64 unique *bus interrupt line* sources the interrupt controller allow dynamic remapping between *bus interrupt lines* and any *interrupt ID number* 1 - 15 or any *extended interrupt number* 16 - 32. Individual remap logic on each incoming *bus interrupt line* will map the *bus interrupt line* sources to specified *interrupt ID number* 1 - 15 or *extended interrupt number* 16 - 32.

The Interrupt map registers is available starting at address 0x80002300 from the interrupt controller's base address. The interrupt map registers contain one field for each *bus interrupt line* in the system. The value within this field determines to which interrupt controller line the *bus interrupt line* is connected. In case several *bus interrupt lines* are mapped to the same *interrupt ID number* or *extended interrupt number* (several fields in the Interrupt map registers have the same value) then the *bus interrupt lines* will be OR:ed together.

Note that if *bus interrupt line X* is remapped to controller *interrupt ID number 2 - 15* then corresponding bit in the range 2 - 15 of the pending register will be set when a peripheral asserts interrupt *bus interrupt line X*. Where, the *bus interrupt line X* is remapped to controller *extended interrupt number* 16 - 32 then corresponding bit in the range 16 - 32 and bit 1 of the pending register will be set when a peripheral asserts interrupt *bus interrupt line X*

40.2.3 Processor status monitoring

The processor status can be monitored through the Processor Status Register. The STATUS field in this register indicates if a processor is halted (‘1’) or running (‘0’). A halted processor can be reset and restarted by writing a ‘1’ to its status field.

The interrupt controller also supports setting the reset start address dynamically. Please see section 40.2.7 for further information.

40.2.4 Interrupt timestamping description

Interrupt timestamping is controlled via the Interrupt Timestamp Control register(s). Each Interrupt Timestamp Control register contains a field (TSTAMP) that contains the number of timestamp registers sets that the core implements. A timestamp register sets consist of one Interrupt Timestamp Counter register, one Interrupt Timestamp Control register, one Interrupt Assertion Timestamp register and one Interrupt Acknowledge Timestamp register.

Software enables timestamping for a specific interrupt via a Interrupt Timestamp Control Register. When the selected interrupt line is asserted, software will save the current value of the interrupt timestamp counter into the Interrupt Assertion Timestamp register and set the S1 field in the Interrupt Timestamp Control Register. When the processor acknowledges the interrupt, the S2 field of the Interrupt Timestamp Control register will be set and the current value of the timestamp counter will be saved in the Interrupt Acknowledge Timestamp Register. The difference between the Interrupt Assertion timestamp and the Interrupt Acknowledge timestamp is the number of system clock cycles that was required for the processor to react to the interrupt and divert execution to the trap handler.

The core can be configured to stamp only the first occurrence of an interrupt or to continuously stamp interrupts. The behavior is controlled via the Keep Stamp (KS) field in the Interrupt Timestamp Con-

trol Register. If KS is set, only the first assertion and acknowledge of an interrupt is stamped. Software must then clear the S1 and S2 fields for a new timestamp to be taken. If Keep Stamp is disabled (KS field not set), the controller will update the Interrupt Assertion Timestamp Register every time the selected interrupt line is asserted. In this case the controller will also automatically clear the S2 field and also update the Interrupt Acknowledge Timestamp register with the current value when the interrupt is acknowledged.

40.2.5 Interrupt timestamping usage guidelines

Note that KS = '0' and a high interrupt rate may cause the Interrupt Assertion Timestamp register to be updated (and the S2 field reset) before the processor has acknowledged the first occurrence of the interrupt. When the processor then acknowledges the first occurrence, the Interrupt Acknowledge Timestamp register will be updated and the difference between the two Timestamp registers will not show how long it took the processor to react to the first interrupt request. If the interrupt frequency is expected to be high it is recommended to keep the first stamp (KS field set to '1') in order to get reliable measurements. KS = '0' should not be used in systems that include cores that use level interrupts, the timestamp logic will register each cycle that the interrupt line is asserted as an interrupt.

In order to measure the full interrupt handling latency in a system, software should also read the current value of the Interrupt Timestamp Counter when entering the interrupt handler. In the typical case, a software driver's interrupt handler reads a status register and then determines the action to take. Adding a read of the timestamp counter before this status register read can give an accurate view of the latency during interrupt handling.

The interrupt controller listens to the system interrupt vector when reacting to interrupt line assertions. This means that the Interrupt Assertion Timestamp Register(s) will not be updated if software writes directly to the pending or force registers. To measure the time required to serve a forced interrupt, read the value of the Interrupt Timestamp counter before forcing the interrupt and then read the Interrupt Acknowledge Timestamp and Interrupt Timestamp counter when the processor has reacted to the interrupt.

40.2.6 Watchdog

The interrupt controller supports for asserting a bit in the controller's Interrupt Pending Register when an external watchdog signal is asserted. This functionality can be used to implement a sort of soft watchdog for one or several processor cores. The controller's Watchdog Control Register contains a field that shows the number of external watchdog inputs supported and fields for configuring which watchdog inputs that should be able to assert a bit in the Interrupt Pending Register. The pending register will be assigned in each cycle that a selected watchdog input is high. Therefore it is recommended that the watchdog inputs are connected to sources which send a one clock cycle long pulse when a watchdog expires. Otherwise software should make sure that the watchdog signal is deasserted before re-enabling interrupts during interrupt handling.

The GR716 microcontroller supports soft watchdog events from GPTIMER0 timer 6 and GPTIMER0 timer 7.

40.2.7 Dynamic processor reset start address

The interrupt controller can be used to start processor execution from a specified start address. The interface provided to accomplish this is:

- Error mode status register
- Processor boot address registers

The register interface allows software to force a processor into debug or error mode. This means that the interface can be used to stop (and restart) a processor. Registers are available to allow starting a halted processor from an arbitrary 8 byte aligned entry point. The processor can be started with the

same register write as when the entry point is written, or the processor can be started later using the regular processor status register bit.

An error register is also added to allow monitoring processors for error mode, and to allow forcing a specific processor into error mode. This can be used to monitor and re-boot processors without reseting the system.

40.2.8 Restart processor from internal on-chip memory

To restart the processor from on-chip instruction memory set the register PROCBOOTADR=0x31000001.

40.2.9 Restart processor from external SRAM memory

To restart the processor from on-chip instruction memory set the register PROCBOOTADR=0x40000001.

40.3 Registers

The core is controlled through registers mapped into APB address space.

*Table 528.*Interrupt Controller registers

APB address offset	Register
0x80002000	Interrupt level register
0x80002004	Interrupt pending register
0x80002008	Interrupt force register
0x8000200C	Interrupt clear register
0x80002010	Status register
0x80002014	Reserved
0x80002018	Error Mode status register
0x8000201C	Watchdog control register
0x80002020	Reserved
0x80002024	Reserved
0x80002028	Reserved
0x8000202C	Reserved
0x80002030	Reserved
0x80002034	Extended Interrupt Clear Register
0x80002038	Reserved
0x8000203C	Reserved
0x80002040	Processor interrupt mask register
0x80002080	Processor interrupt force register
0x800020C0	Processor extended interrupt acknowledge register
0x80002100	Interrupt timestamp 0 counter register
0x80002104	Interrupt timestamp 0 control register
0x80002108	Interrupt assertion timestamp 0 register
0x8000210C	Interrupt acknowledge timestamp 0 register
0x80002110	Interrupt timestamp 1 counter register (mirrored in each set)
0x80002114	Interrupt timestamp *1* control register
0x80002118	Interrupt assertion timestamp *1* register
0x8000211C	Interrupt acknowledge timestamp *1* register
0x80002120	Interrupt timestamp 2 counter register (mirrored in each set)
0x80002124	Interrupt timestamp *2* control register
0x80002128	Interrupt assertion timestamp *2* register
0x8000212C	Interrupt acknowledge timestamp *2* register
0x80002130	Interrupt timestamp 3 counter register (mirrored in each set)
0x80002134	Interrupt timestamp *3* control register
0x80002138	Interrupt assertion timestamp *3* register
0x8000213C	Interrupt acknowledge timestamp *3* register
0x80002200	Processor boot address register
0x80002300 + 0x4 * *m*	Interrupt map register *m*

* Number of interrupts in LEON3FT microcontroller is 64 hence *m* is 16

40.3.1 Interrupt Level Register

*Table 529.*0x80002000 - ILEVEL - Interrupt Level Register

31 16	15 1	0
RESERVED	IL[15:1]	R
0	NR	0
r	rw	r

31:16 Reserved

15:1 Interrupt Level n (IL[n]) - Interrupt level for interrupt n

0 Reserved

40.3.2 Interrupt Pending Register

*Table 530.*0x80002004 - IPEND - Interrupt Pending Register

31 16	15 1	0
EIP[31:16]	IP[15:1]	R
0	0	0
rw	rw	r

31:16 Extended Interrupt Pending n (EIP[n])

15:1 Interrupt Pending n (IP[n]) - Interrupt pending for interrupt n

0 Reserved

40.3.3 Interrupt Force Register

*Table 531.*0x80002008 - IFORCE0 - Interrupt Force Register

31 16	15 1	0
RESERVED	IF[15:1]	R
0	0	0
r	rw	r

31:16 Reserved

15:1 Interrupt Force n (IF[n]) - Force interrupt nr n.

0 Reserved

40.3.4 Interrupt Clear Register

Table 532. 0x8000200C - ICLEAR - Interrupt Clear Register

31 16	15 1	0
EIC[31:16]	IC[15:1]	R
0	0	0
w	w	r

31:16 Extended Interrupt Clear n (EIC[n])

15:1 Interrupt Clear n (IC[n]) - Writing ‘1’ to IC[n] will clear interrupt n

0 Reserved

40.3.5 Status Register

Table 533. 0x80002010 - MPSTAT - Status Register

31 20	19 16	15 1	0
RESERVED	EIRQ		STATUS
0	1	0	*
r	r	r	rw

31:20 Reserved

19:16 Extended IRQ (EIRQ) - Interrupt number 1 used for extended interrupts.

15:1 Reserved

0 Power-down status of CPU (STATUS) - 0x1 = power-down, 0x0 = running. Write STATUS with 0x1 to start processor.

40.3.6 Error Mode Status Register

Table 534. 0x80002018 - ERRSTAT - Error Mode Status Register

31 1	0
RESERVED	EM
0	0
r	rw

31:1 Reserved

0 Error Mode register (EM) - Read operation of register shows the error mode of the LEON3FT processor(1 = 'error mode', '0'=debug/run/power-down). Write to register will force LEON3FT processor into error mode.

40.3.7 Watchdog Control Register

Table 535. 0x8000201C - WDOGCTRL - Watchdog Control Register

31 27	26 20	19 16	15 0
NWDOG	Reserved	WDOGIRQ	WDOGMSK
2	0	NR	0
r	r	rw	rw

31:27 Number of watchdog inputs (NWDOG) - Number of watchdog inputs that the core supports.

26:20 Reserved

19:16 Watchdog interrupt (WDOGIRQ) - Selects the bit in the pending register to set when any line watchdog line selected by the WDOGMSK field is asserted.

15:0 Watchdog Mask n (WDOGMSK[n]) - If WDOGMSK[n] = '1' then the assertion of watchdog input n will lead to the bit selected by the WDOGIRQ field being set in the controller's Interrupt Pending Register.

Configurable soft watchdog inputs:

Bit #0 - Enable soft watchdog for GPTIMER0 timer 7

Bit #1 - Enable soft watchdog for GPTIMER0 timer 6

Bit #2 to Bit #15 are unused

40.3.8 Processor Interrupt Mask Register

Table 536. 0x80002040 - PIMASK - Processor Interrupt Mask Register

31 16	15 1	0
EIM[31:16]	IM15:1]	R
0	0	0
rw	rw	r

31:16 Extended Interrupt Mask n (EIC[n]) - Interrupt mask for extended interrupts

15:1 Interrupt Mask n (IM[n]) - If IM[n] = '0' then interrupt n is masked, otherwise it is enabled.

0 Reserved

40.3.9 Processor Interrupt Force Register

Table 537. 0x80002080 - PCFORCE - Processor Interrupt Force Register

31 17	16	15 1	0
IFC[15:1]	R	IF15:1]	R
0	0	0	0
wc	r	rw*	r

31:17 Interrupt Force Clear n (IFC[n]) - Interrupt force clear for interrupt n

16 Reserved

15:1 Interrupt Force n (IF[n]) - Force interrupt nr n

0 Reserved

40.3.10 Extended Interrupt Acknowledge Register

Table 538. 0x800020C0 - PEXTACK - Extended Interrupt Acknowledge Register

31 6	5 0
RESERVED	EID[5:0]
0	0
r	r

31:6 Reserved

5:0 Extended interrupt ID (EID) - ID (16-63) of the most recent acknowledged extended interrupt

If this field is 0, and support for extended interrupts exist, the last assertion of interrupt *eirq* was not the result of an extended interrupt being asserted. If interrupt *eirq* is forced, or asserted, this field will be cleared unless one, or more, of the interrupts 63 - 16 are enabled and set in the pending register.

40.3.11 Interrupt Timestamp Counter Register

Table 539. 0x80002100 - TCNT0 - Interrupt Timestamp 0 Counter register

31 0
TCNT
0
r

31:0 Timestamp Counter (TCNT) - Current value of timestamp counter. The counter increments whenever a TSISEL field in a Timestamp Control Register is non-zero. The counter will wrap to zero upon overflow and is read only.

Table 540. 0x80002110 - TCNT1 - Interrupt Timestamp 1 Counter register

31	0
TCNT	
0	
r	

31:0 Timestamp Counter (TCNT) - Current value of timestamp counter. The counter increments whenever a TSISEL field in a Timestamp Control Register is non-zero. The counter will wrap to zero upon overflow and is read only.

Table 541. 0x80002120 - TCNT2 - Interrupt Timestamp 2 Counter register

31	0
TCNT	
0	
r	

31:0 Timestamp Counter (TCNT) - Current value of timestamp counter. The counter increments whenever a TSISEL field in a Timestamp Control Register is non-zero. The counter will wrap to zero upon overflow and is read only.

Table 542. 0x80002130 - TCNT3 - Interrupt Timestamp 3 Counter register

31	0
TCNT	
0	
r	

31:0 Timestamp Counter (TCNT) - Current value of timestamp counter. The counter increments whenever a TSISEL field in a Timestamp Control Register is non-zero. The counter will wrap to zero upon overflow and is read only.

40.3.12 Timestamp Control Register

Table 543. 0x80002104 - ITSTMPC0 - Timestamp 0 Control Register

31 27	26	25	24 6	5	4 0
TSTAMP	S1	S2	RESERVED	KS	TSISEL
0x4	0	0	0	0	0
r	wc	wc	r	rw	rw

31:27 Number of timestamp register sets (TSTAMP) - The number of available timestamp register sets.

26 Assertion Stamped (S1) - Set to ‘1’ when the assertion of the selected line has received a timestamp. This bit is cleared by writing ‘1’ to its position. Writes of ‘0’ have no effect.

25 Acknowledge Stamped (S2) - Set to ‘1’ when the processor acknowledge of the selected interrupt has received a timestamp. This bit can be cleared by writing ‘1’ to this position, writes of ‘0’ have no effect. This bit can also be cleared automatically by the core, see description of the KS field below.

24:6 RESERVED

5 Keep Stamp (KS) - If this bit is set to ‘1’ the core will keep the first stamp value for the first interrupt until the S1 and S2 fields are cleared by software. If this bit is set to ‘0’ the core will time stamp the most recent interrupt. This also has the effect that the core will automatically clear the S2 field whenever the selected interrupt line is asserted and thereby also stamp the next acknowledge of the interrupt.

4:0 Timestamp Interrupt Select (TSISEL) - This field selects the interrupt number (1 - 31) to timestamp.

Table 544. 0x80002114 - ITSTMPC1 - Timestamp 1 Control Register

31 27	26	25	24 6	5	4 0
TSTAMP	S1	S2	RESERVED	KS	TSISEL
0x4	0	0	0	0	0
r	wc	wc	r	rw	rw

31:27 Number of timestamp register sets (TSTAMP) - The number of available timestamp register sets.

26 Assertion Stamped (S1) - Set to ‘1’ when the assertion of the selected line has received a timestamp. This bit is cleared by writing ‘1’ to its position. Writes of ‘0’ have no effect.

25 Acknowledge Stamped (S2) - Set to ‘1’ when the processor acknowledge of the selected interrupt has received a timestamp. This bit can be cleared by writing ‘1’ to this position, writes of ‘0’ have no effect. This bit can also be cleared automatically by the core, see description of the KS field below.

24:6 RESERVED

5 Keep Stamp (KS) - If this bit is set to ‘1’ the core will keep the first stamp value for the first interrupt until the S1 and S2 fields are cleared by software. If this bit is set to ‘0’ the core will time stamp the most recent interrupt. This also has the effect that the core will automatically clear the S2 field whenever the selected interrupt line is asserted and thereby also stamp the next acknowledge of the interrupt.

4:0 Timestamp Interrupt Select (TSISEL) - This field selects the interrupt number (1 - 31) to timestamp.

Table 545. 0x80002124 - ITSTMPC2 - Timestamp 2 Control Register

31 27	26	25	24 6	5	4 0
TSTAMP	S1	S2	RESERVED	KS	TSISEL
0x4	0	0	0	0	0
r	wc	wc	r	rw	rw

31:27 Number of timestamp register sets (TSTAMP) - The number of available timestamp register sets.

26 Assertion Stamped (S1) - Set to ‘1’ when the assertion of the selected line has received a timestamp. This bit is cleared by writing ‘1’ to its position. Writes of ‘0’ have no effect.

25 Acknowledge Stamped (S2) - Set to ‘1’ when the processor acknowledge of the selected interrupt has received a timestamp. This bit can be cleared by writing ‘1’ to this position, writes of ‘0’ have no effect. This bit can also be cleared automatically by the core, see description of the KS field below.

24:6 RESERVED

5 Keep Stamp (KS) - If this bit is set to ‘1’ the core will keep the first stamp value for the first interrupt until the S1 and S2 fields are cleared by software. If this bit is set to ‘0’ the core will time stamp the most recent interrupt. This also has the effect that the core will automatically clear the S2 field whenever the selected interrupt line is asserted and thereby also stamp the next acknowledge of the interrupt.

4:0 Timestamp Interrupt Select (TSISEL) - This field selects the interrupt number (1 - 31) to timestamp.

Table 546. 0x80002104 - ITSTMPC3 - Timestamp 3 Control Register

31 27	26	25	24 6	5	4 0
TSTAMP	S1	S2	RESERVED	KS	TSISEL
0x4	0	0	0	0	0
r	wc	wc	r	rw	rw

31:27 Number of timestamp register sets (TSTAMP) - The number of available timestamp register sets.

26 Assertion Stamped (S1) - Set to ‘1’ when the assertion of the selected line has received a timestamp. This bit is cleared by writing ‘1’ to its position. Writes of ‘0’ have no effect.

25 Acknowledge Stamped (S2) - Set to ‘1’ when the processor acknowledge of the selected interrupt has received a timestamp. This bit can be cleared by writing ‘1’ to this position, writes of ‘0’ have no effect. This bit can also be cleared automatically by the core, see description of the KS field below.

24:6 RESERVED

5 Keep Stamp (KS) - If this bit is set to ‘1’ the core will keep the first stamp value for the first interrupt until the S1 and S2 fields are cleared by software. If this bit is set to ‘0’ the core will time stamp the most recent interrupt. This also has the effect that the core will automatically clear the S2 field whenever the selected interrupt line is asserted and thereby also stamp the next acknowledge of the interrupt.

4:0 Timestamp Interrupt Select (TSISEL) - This field selects the interrupt number (1 - 31) to timestamp.

40.3.13 Interrupt Assertion Timestamp Register

Table 547. 0x80002108 - ITSTMPAS0 - Interrupt Assertion Timestamp 0 register

31	0
TASSERTION	
0	
r	

31:0 Timestamp of Assertion (TASSERTION) - The current Timestamp Counter value is saved in this register when timestamping is enabled and the interrupt line selected by TSISEL is asserted.

Table 548. 0x80002118 - ITSTMPAS1 - Interrupt Assertion Timestamp 1 register

31	0
TASSERTION	
0	
r	

31:0 Timestamp of Assertion (TASSERTION) - The current Timestamp Counter value is saved in this register when timestamping is enabled and the interrupt line selected by TSISEL is asserted.

Table 549. 0x80002128 - ITSTMPAS2 - Interrupt Assertion Timestamp 2 register

31	0
TASSERTION	
0	
r	

31:0 Timestamp of Assertion (TASSERTION) - The current Timestamp Counter value is saved in this register when timestamping is enabled and the interrupt line selected by TSISEL is asserted.

Table 550. 0x80002138 - ITSTMPAS3 - Interrupt Assertion Timestamp 3 register

31	0
TASSERTION	
0	
r	

31:0 Timestamp of Assertion (TASSERTION) - The current Timestamp Counter value is saved in this register when timestamping is enabled and the interrupt line selected by TSISEL is asserted.

40.3.14 Interrupt Acknowledge Timestamp Register

Table 551. 0x8000210C - ITSTMPAS0 - Interrupt Acknowledge Timestamp 0 register

31	0
TACKNOWLEDGE	
0	
r	

31:0 Timestamp of Acknowledge (TACKNOWLEDGE) - The current Timestamp Counter value is saved in this register when timestamping is enabled, the Acknowledge Stamped (S2) field is ‘0’, and the interrupt selected by TSISEL is acknowledged by a processor connected to the interrupt controller.

Table 552. 0x8000211C - ITSTMPAS1 - Interrupt Acknowledge Timestamp 1 register

31	0
TACKNOWLEDGE	
0	
r	

31:0 Timestamp of Acknowledge (TACKNOWLEDGE) - The current Timestamp Counter value is saved in this register when timestamping is enabled, the Acknowledge Stamped (S2) field is ‘0’, and the interrupt selected by TSISEL is acknowledged by a processor connected to the interrupt controller.

Table 553. 0x8000212C - ITSTMPAS2 - Interrupt Acknowledge Timestamp 2 register

31	0
TACKNOWLEDGE	
0	
r	

31:0 Timestamp of Acknowledge (TACKNOWLEDGE) - The current Timestamp Counter value is saved in this register when timestamping is enabled, the Acknowledge Stamped (S2) field is ‘0’, and the interrupt selected by TSISEL is acknowledged by a processor connected to the interrupt controller.

Table 554. 0x8000213C - ITSTMPAS3 - Interrupt Acknowledge Timestamp 3 register

31	0
TACKNOWLEDGE	
0	
r	

31:0 Timestamp of Acknowledge (TACKNOWLEDGE) - The current Timestamp Counter value is saved in this register when timestamping is enabled, the Acknowledge Stamped (S2) field is ‘0’, and the interrupt selected by TSISEL is acknowledged by a processor connected to the interrupt controller.

40.3.15 Processor Boot Address Register

Table 555. 0x80002200 - PROCBOOTADR -Processor boot address register

31	3	2	1	0
BOOTADDR[31:3]		RES		AS
-		-		-
w		-		w

31:3	Entry point for booting up processor, 8-byte aligned
2:1	Reserved (write 0)
0	Start processor immediately after setting address

* For usage of this register see chapter 40.2.7

40.3.16 Interrupt Map Register

Table 556. 0x80002300 + 0x4 * *n* - IRQMAP*n* - Interrupt map register

31 24	23 16	15 8	7 0
IID[n*4+0]	IID[n*4+1]	IID[n*4+2]	IID[n*4+3]
**	**	**	**
rw	rw	rw	rw

31 : 24	Interrupt bus map *n* (ID[*n**4+0]) - Map register for bus interrupt line [*n**4+0]
23 : 16	Interrupt bus map *n* (ID[*n**4+1]) - Map register for bus interrupt line [*n**4+1]
15 : 8	Interrupt bus map *n* (ID[*n**4+2]) - Map register for bus interrupt line [*n**4+2]
7 : 0	Interrupt bus map *n* (ID[*n**4+3]) - Map register for bus interrupt line [*n**4+3]

* Number of interrupts in LEON3FT microcontroller is 64 hence *n* is 16

** Default values for interrupt bus ID is found in table 557

Table 557. Remap default settings

Address	Register	Bit field	Default	Interrupt Line	Core
0x80002300	IRQMAP0	ID0	-	0	n/a
		ID1	1	1	Extended
		ID2	2	2	GRPWRX
		ID3	3	3	GRPWTX
0x80002304	IRQMAP1	ID4	4	4	GR1553
		ID5	5	5	GRSPW2
		ID6	6	6	GRDMAC
		ID7	7	7	I2CS/2AHB/SPI2AHB
0x80002308	IRQMAP2	ID8	8	8	GRPWM
		ID9	9	9	GPTIMER0
		ID10	10	10	GPTIMER0
		ID11	11	11	GPTIMER0
0x8000230C	IRQMAP3	ID12	12	12	GPTIMER0
		ID13	13	13	GPTIMER0
		ID14	14	14	GPTIMER0
		ID15	15	15	GPTIMER0
0x80002310	IRQMAP4	ID16	16	16	GRADCDAC
		ID17	17	17	GRGPIO
		ID18	18	18	GRGPIO
		ID19	19	19	GRGPIO
0x80002314	IRQMAP5	ID20	20	20	GRGPIO
		ID21	21	21	GRCAN0&1
		ID22	22	22	GRCAN0&1
		ID23	23	23	GRCAN0&1
0x80002318	IRQMAP6	ID24	24	24	APBUART0
		ID25	25	25	APBUART1
		ID26	26	26	DAC
		ID27	27	27	DAC
0x8000231C	IRQMAP7	ID28	28	28	ADC0
		ID29	29	29	ADC1
		ID30	30	30	ADC2
		ID31	31	31	ADC3

Address	Register	Bit field	Default	Interrupt Line	Core
0x80002320	IRQMAP8	ID32	28	32	ADC4
		ID33	29	33	ADC5
		ID34	30	34	ADC6
		ID35	31	35	ADC7
0x80002324	IRQMAP9	ID36	26	36	DAC
		ID37	27	37	DAC
		ID38	16	38	GRGPIO
		ID39	17	39	GRGPIO
0x80002328	IRQMAP10	ID40	18	40	GRGPIO
		ID41	19	41	GRGPIO
		ID42	3	42	APBUART2
		ID43	4	43	GRSPWTDP
0x8000232C	IRQMAP11	ID44	5	44	APBUART4
		ID45	6	45	APBUART5
		ID46	7	46	APBUART6
		ID47	8	47	I2CSLV1 / I2C2AHB
0x80002330	IRQMAP12	ID48	11	48	SPICTRL
		ID49	12	49	SPICTRL
		ID50	13	50	I2CM
		ID51	14	51	I2CM
0x80002334	IRQMAP13	ID52	2	52	SPIMCTRL
		ID53	20	53	GPTIMER1
		ID54	21	54	GPTIMER1
		ID55	22	55	GPTIMER1
0x80002338	IRQMAP14	ID56	23	56	GPTIMER1
		ID57	24	57	GPTIMER1
		ID58	25	58	GPTIMER1
		ID59	26	59	GPTIMER1
0x8000233C	IRQMAP15	ID60	16	60	GRGPIOSEQ0
		ID61	17	61	GRGPIOSEQ1
		ID62	18	62	PLL
		ID63	19	63	AHBSTAT

41 LEON3 Statistics Unit

41.1 Overview

The LEON3 Statistics Unit (L3STAT) is used count events in the LEON3 processor and the AHB bus, in order to create performance statistics for various software applications.

The L3STAT core in the LEON3FT microcontroller consists of 4 32-bit counters, which increment on a certain event. The counters roll over to zero when reaching their maximum value, but can also be automatically cleared on reading to facilitate statistics building over longer periods. Each counter has a control register where the event type is selected. The table 558 below shows the event types that can be monitored.

*Table 558.*Event types and IDs for Main and DMA AMBA bus

ID	Event description
Processor events:	
0x10	Data write buffer hold
0x11	Total instruction count
0x12	Integer instructions
0x13	Floating-point unit instruction count
0x14	Branch prediction miss
0x15	Execution time, excluding debug mode
0x17	AHB utilization (per AHB master)
0x18	AHB utilization (total, master/CPU selection is ignored)
0x22	Integer branches
0x28	CALL instructions
0x30	Regular type 2 instructions
0x38	LOAD and STORE instructions
0x39	LOAD instructions
0x3A	STORE instructions
AHB events	
0x40	AHB IDLE cycles.
0x41	AHB BUSY cycles.
0x42	AHB NON-SEQUENTIAL transfers. Filtered on CPU/AHBM if SU(1) = ‘1’
0x43	AHB SEQUENTIAL transfers. Filtered on CPU/AHBM if SU(1) = ‘1’
0x44	AHB read accesses. Filtered on CPU/AHBM if SU(1) = ‘1’
0x45	AHB write accesses. Filtered on CPU/AHBM if SU(1) = ‘1’
0x46	AHB byte accesses. Filtered on CPU/AHBM if SU(1) = ‘1’
0x47	AHB half-word accesses. Filtered on CPU/AHBM if SU(1) = ‘1’
0x48	AHB word accesses. Filtered on CPU/AHBM if SU(1) = ‘1’
0x49	AHB double word accesses. Filtered on CPU/AHBM if SU(1) = ‘1’
0x4A	AHB quad word accesses. Filtered on CPU/AHBM if SU(1) = ‘1’
0x4B	AHB eight word accesses. Filtered on CPU/AHBM if SU(1) = ‘1’
0x4C	AHB waitstates. Filtered on CPU/AHBM if SU(1) = ‘1’
0x4D	AHB RETRY responses. Filtered on CPU/AHBM if SU(1) = ‘1’
0x4E	AHB SPLIT responses. Filtered on CPU/AHBM if SU(1) = ‘1’
0x4F	AHB SPLIT delay. Filtered on CPU/AHBM if SU(1) = ‘1’
0x50	AHB bus locked. Filtered on CPU/AHBM if SU(1) = ‘1’
0x51-0x5F	Reserved

*Table 558.*Event types and IDs for Main and DMA AMBA bus

ID	Event description
Implementation specific events:	
0x60	External event correctable error in Data on-chip RAM.
0x61	External event correctable error in Instruction on-chip RAM.
0x62	External event uncorrectable error in Data on-chip RAM.
0x63	External event uncorrectable error in Instruction on-chip RAM.
0x64	External event correctable error in Off-chip RAM/ROM.
0x65	External event correctable error in NVRAM RAM/ROM.
0x66	External event correctable error in SPI PROM0.
0x67	External event correctable error in SPI PROM1.
0x68	Not used
0x69	Not used
0x6A	Not used
0x6B	Not used
0x6C	Not used
0x6D	Not used
0x6E	Not used
0x6F	Not used
AHB events	
0x70	AHB IDLE cycles.
0x71	AHB BUSY cycles. Filtered on CPU/AHBM if SU(1) = ‘1’
0x72	AHB NON-SEQUENTIAL transfers. Filtered on CPU/AHBM if SU(1) = ‘1’
0x73	AHB SEQUENTIAL transfers. Filtered on CPU/AHBM if SU(1) = ‘1’
0x74	AHB read accesses. Filtered on CPU/AHBM if SU(1) = ‘1’
0x75	AHB write accesses. Filtered on CPU/AHBM if SU(1) = ‘1’
0x76	AHB byte accesses. Filtered on CPU/AHBM if SU(1) = ‘1’
0x77	AHB half-word accesses. Filtered on CPU/AHBM if SU(1) = ‘1’
0x78	AHB word accesses. Filtered on CPU/AHBM if SU(1) = ‘1’
0x79	AHB double word accesses. Filtered on CPU/AHBM if SU(1) = ‘1’
0x7A	AHB quad word accesses. Filtered on CPU/AHBM if SU(1) = ‘1’
0x7B	AHB eight word accesses. Filtered on CPU/AHBM if SU(1) = ‘1’
0x7C	AHB waitstates. Filtered on CPU/AHBM if SU(1) = ‘1’
0x7D	AHB RETRY responses. Filtered on CPU/AHBM if SU(1) = ‘1’
0x7E	AHB SPLIT responses. Filtered on CPU/AHBM if SU(1) = ‘1’
0x7F	AHB SPLIT delay. Filtered on CPU/AHBM if SU(1) = ‘1’
Events generated from REQ/GNT signals	
0x80 - 0x8F	Active when master selected by CPU/AHBM field has request asserted while grant is asserted for the master correspoding to the least significant nibble of the event ID. 0x80 is master 0 grant, 0x81 is master 1 grant, .., and so on. For the LEON3FT Microcontroller ID 0x80 to 0x83 is used for the main system bus and 0x80 to 0x87 is used for the DMA bus
0x80*	Request by LEON3FT
0x81*	Request by DMA => Main bridge
0x82*	Request by Scrubber
0x80**	Request by Debug UART
0x81**	Request by 1553 core
0x82**	Request by SpaceWire core

*Table 558.*Event types and IDs for Main and DMA AMBA bus

ID	Event description
0x83**	Request by CAN core 0
0x84**	Request by CAN core 1
0x85**	Request by AHBUART core
0x86**	Request by Main => DMA bridge
0x87**	Request by PWRX core
0x88**	Request by PWTX core
0x89**	Request by DMA core 0
0x8A**	Request by DMA core 1
0x90 - 0x9F	Active when master selected by CPU/AHBM field has request asserted while grant is deasserted for the master correspoding to the least significant nibble of the event ID. 0x90 is master 0 grant, 0x91 is master 1 grant, .., and so on.

* Only valid for L3STAT for Main system bus

** Only valid for L3STAT for DMA bus

Note that IDs 0x39 (LOAD instructions) and 0x3A (STORE instructions) will both count all LDST and SWAP instructions. The sum of events counted for 0x39 and 0x3A may therefore be larger than the number of events counted with ID 0x38 (LOAD and STORE instructions).

41.2 Using the LEON3 statistics unit

The debug monitor GRMON3 has build-in support for using LEON3 statistical unit. For more information see chapter for using the LEON3 statistical unit in the GRMON3 User's Manual [GRMON3].

41.3 Registers

The L3STAT core is programmed through registers mapped into APB address space.

Table 559. L3STAT counter control register*

APB address offset	Register
0x0	Counter 0 value register
0x4	Counter 1 value register
0x8	Counter 2 value register
0xC	Counter 3 value register
0x100	Counter 0 control register
0x104	Counter 1 control register
0x108	Counter 2 control register
0x10C	Counter 3 control register
0x200	Counter 0 max/latch register
0x204	Counter 1 max/latch register
0x208	Counter 2 max/latch register
0x20C	Counter 3 max/latch register
0x300	Timestamp register

41.3.1 Counter Value Register

*Table 560.*0x00+n.4 - CVALn - Counter value register

31	0
CVAL	
NR	
rw	

31: 0 Counter value (CVAL) - This register holds the current value of the counter. If the Counter control register field CD is '1', then the value displayed by this register will be the maximum counter value reached with the settings in the counter's control register. Writing to this register will write both to the counter and the hold register for the maximum counter value.

41.3.2 Counter Control Register

*Table 561.*0x100+n.4 - CCTRLn - Counter control register

31 28	27 23	22	21	20	19	18	17	16	15 14	13	12	11 4	3 0
NCPU	NCNT	MC	IA	DS	EE	AE	EL	CD	SU	CL	EN	EVENT ID	CPU/AHBM
0	3	1	1	1	1	1	NR	NR	NR	NR	0	NR	NR
r	r	r	r	r	r	r	rw	rw	rw	rw	rw	rw	rw

31: 28 Number of CPU (NCPU) - Number of supported processors - 1

27: 23 Number of counters (NCNT) - Number of implemented counters - 1

22 Maximum count (MC) - This field is '1' indicating that the counter has support for keeping the maximum count value

21 Internal AHB count (IA) - This field is '1' indicating that the core supports events 0x17 and 0x18

20 DSU support (DS) - This field is '1' indicating that the core supports events 0x40-0x5F

19 External events (EE) - This field is '1' indicating that the core supports external events (events 0x60 - 0x6F)

18 AHBTRACE Events (AE) - This field is '1' indicating that the core supports events 0x70 - 0x7F.

17 Event Level (EL) - The value of this field determines the level where the counter keeps running when the CD field below has been set to '1'. If this field is '0' the counter will count the time between event assertions. If this field is '1' the counter will count the cycles where the event is asserted.

16 Count maximum duration (CD) - If this bit is set to '1' the core will save the maximum time the selected event has been at the level specified by the EL field. This also means that the counter will be reset when the event is activated or deactivated depending on the value of the EL field.

When this bit is set to '1', the value shown in the counter value register will be the maximum current value which may be different from the current value of the counter.

15: 14 Supervisor/User mode filter (SU) - "01" - Only count supervisor mode events, "10" - Only count user mode events, others values - Count events regardless of user or supervisor mode. This setting only applies to events 0x0 - 0x3A.

When SU = "1x" only events generated by the CPU/AHB master specified in the CPU/AHBM field will be counted. This applies to events 0x40 - 0x7F.

: 13 Clear counter on read (CL) - If this bit is set the counter will be cleared when the counter's value is read. The register holding the maximum value will also be cleared.

If an event occurs in the same cycle as the counter is cleared by a read then the event will not be counted. The counter latch register can be used to guarantee that no events are lost

12 Enable counter (EN) - Enable counter

11: 4 Event ID to be counted

3: 0 CPU or AHB master to monitor.(CPU/AHBM) - The value of this field does not matter when selecting one of the events coming from the Debug Support Unit or one of the external events.

41.3.3 Counter max/latch Register

*Table 562.*0x200+4n - CSVALn - Counter max/latch register

31	0
CSVAL	
NR	
rw*	

31: 0 Counter max/latch value (CSVAL) - This register holds the current value of the counter max/latch register.

If the counter control register field CD is ‘1’, then the value displayed by this register will be the maximum counter value reached with the settings in the counter’s control register.

If the counter control register field CD is ‘0’, then the value displayed by this register is the latched (saved) counter value. The counter value is saved whenever a write access is made to the core in address range 0x100 - 0x1FC (all counters are saved simultaneously). If the counter control register CL field is set, then the current counter value will be cleared when the counter value is saved into this register.

41.3.4 Timestamp Register

*Table 563.*0x300 - TSTAMP - Timestamp register

31	0
TSTAMP	
NR	
rw*	

31: 0 Timestamp (TSTAMP) - Timestamp taken at latch of counters

42 Memory Scrubber and Status Register

The GR716 microcontroller have 1 AHB Memory Scrubber and Status Register unit (MEMSCRUB).

The MEMSCRUB unit monitors the system main bus or scrubber bus for accesses triggering an error response, and for correctable errors signaled from fault tolerant slaves on the bus. The MEMSCRUB unit can be programmed to scrub memories. The AHB Memory Scrubber and Status Register unit (MEMSCRUB) have a unique AMBA address described in chapter 2.11 for configuration and status.

The AHB Memory Scrubber and Status Register unit (MEMSCRUB) unit is located on AHB bus in the address range from 0xFFF00000 to 0xFFF00FFF.

See units connections in the next drawing. The drawing picture memory locations and functions used for configuration and control.

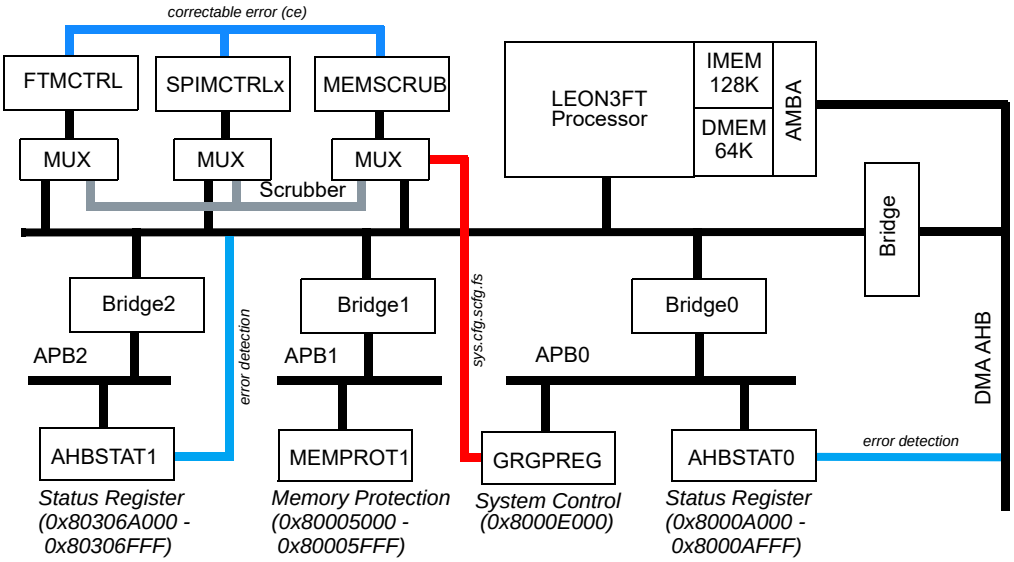


Figure 76. GR716 Scrubber and Status bus connection

42.1 Overview

The memory scrubber monitors an AMBA AHB bus for accesses triggering an error response, and for correctable errors signaled from fault tolerant slaves on the bus. The core can be programmed to scrub a memory area by reading through the memory and writing back the contents using a locked read-write cycle whenever a correctable error is detected. It can also be programmed to initialize a memory area to known values.

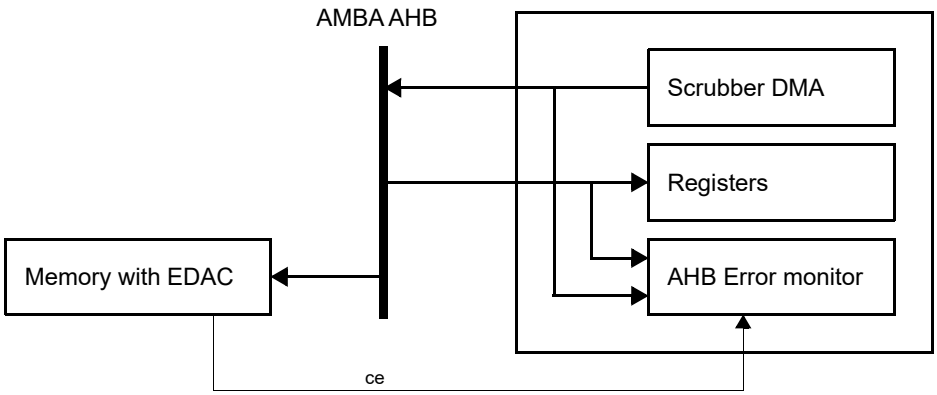


Figure 77. Memory scrubber block diagram

42.2 Operation

42.2.1 Errors

All AMBA AHB bus transactions are monitored and current HADDR, HWRITE, HMASTER and HSIZE values are stored internally. When an error response (HRESP = “01”) is detected, an internal counter is increased. When the counter exceeds a user-selected threshold, the status and address register contents are frozen and the New Error (NE) bit is set to one. At the same time an interrupt is generated, as described hereunder.

The default threshold is zero and enabled on reset so the first error on the bus will generate an interrupt.

Note that many of the fault tolerant units containing EDAC signal an un-correctable error as an AMBA error response, so that it can be detected by the processor as described above.

42.2.2 Correctable errors

Not only error responses on the AHB bus can be detected. Many of the fault tolerant units containing EDAC have a correctable error signal which is asserted each time a correctable error is detected. When such an error is detected, the effect will be the same as for an AHB error response. The only difference is that the Correctable Error (CE) bit in the status register is set to one when a correctable error is detected. Correctable and uncorrectable errors use separate counters and threshold values.

When the CE bit is set, the interrupt routine can acquire the address containing the correctable error from the failing address register and correct it. When it is finished it resets the CE bit and the monitoring becomes active again. Interrupt handling is described in detail hereunder.

42.2.3 Scrubbing

The memory scrubber can be commanded to scrub a certain memory area, by writing a start and end address to the scrubbers start/end registers, followed by writing “00” to the scrub mode field and ‘1’ to the scrub enable bit in the scrubber control register.

After starting, the core will proceed to read the memory region in bursts. The burst size is fixed and typically tuned to match the cache-line size or native block size of the slave. When a correctable error is detected, the scrubber performs a locked read-write cycle to correct the error, and then resumes the scrub operation.

If the correctable error detected is in the middle of a burst, the following read in the burst is completed before the read-write cycle begins. The core can handle the special case where that access also had a correctable error within the same locked scrub cycle.

If an uncorrectable error is detected, that location is left untouched.

Note that the status register functionality is running in parallel with the scrubber, so correctable and uncorrectable errors will be logged as usual. To prevent double logging, the core masks out the (expected) correctable error arising during the locked correction cycle.

To allow normal access to the bus, the core sleeps for a number of cycles between each burst. The number of cycles can be adjusted in the config register.

If the ID bit is set in the config register, the core will interrupt when the complete scrub is done.

42.2.4 Scrubber error counters

The core keeps track of the number of correctable errors detected during the current scrub run and the number of errors detected during processing of the current “count block”. The size of the count block is a fixed power of two equal or larger than the burst length .

The core can be set up to interrupt when the counters exceed given thresholds. When this happens, the NE bit, plus one of the SEC/SBC bits, is set in the status register.

42.2.5 External start and clear

If the ES bit is set in the config register, the scrub enable bit is set automatically when the start input signal goes high. This can be used to set up periodic scrubbing.

The external input signal clrerr can be used to clear the global error counters. If this is connected to a timer, it is possible to count errors that have occurred within a specific unit of time. This signal can be disabled through the EC bit in the config register.

42.2.6 Memory regeneration

The regeneration mode performs the same basic function as the scrub mode, but is optimised for the case where many (or all) locations have correctable errors.

In this mode, the whole memory area selected is scrubbed using locked read/write bursts.

If an uncorrectable error is encountered during the read burst, that burst block is processed once again using the regular scrub routine, and the regeneration mode resumes on the following block. This avoids overwriting uncorrectable error locations.

42.2.7 Initialization

The scrubber can be used to write a pre-defined pattern to a block of memory. This is often necessary on EDAC memory before it can be used.

Before running the initialization, the pattern to be written to memory should be written into the scrubber initialization data register. The pattern has the same size as the burst length, so the corresponding number of writes to the initialization data register must be made.

42.2.8 Interrupts

After an interrupt is generated, either the NE bit or the DONE bit in the status register is set, to indicate which type of event caused the interrupt.

The normal procedure is that an interrupt routine handles the error with the aid of the information in the status registers. When it is finished it resets the NE bit in the AHB status register or the DONE bit in the scrubber status register, and the monitoring becomes active again. Error interrupts can be generated for both AMBA error responses and correctable errors as described above.

42.2.9 Mode switching

Switching between scrubbing and regeneration modes can be done on the fly during a scrub by modifying the MODE field in the scrubber configuration register. The mode change will take effect on the following scrub burst.

If the address range needs to be changed, then the core should be stopped before updating the registers. This is done by clearing the SCEN bit, and waiting for the ACTIVE bit in the status register to go low. An exception is when making the range larger (i.e. increasing the end address or decreasing the start address), as this can be done on the fly.

42.2.10 Dual range support

The scrubber can work over two non-overlapping memory ranges. This feature is enabled by writing the start/end addresses of the second range into the scrubber's second range start/end registers and setting the SERA bit in the configuration register. The two address ranges should not overlap.

42.3 Registers

The core is programmed through registers mapped into an I/O region in the AHB address space. Only 32-bit accesses are supported.

*Table 564.*Memory scrubber registers

AHB address offset	Registers
AHB Memory Scrubber and Status Register unit (MEMSCRUB)	
0xFFF00000	AHB Status register
0xFFF00004	AHB Failing address register
0xFFF00008	AHB Error configuration register
0xFFF0000C	Reserved
0xFFF00010	Scrubber status register
0xFFF00014	Scrubber configuration register
0xFFF00018	Scrubber range low address register
0xFFF0001C	Scrubber range high address register
0xFFF00020	Scrubber position register
0xFFF00024	Scrubber error threshold register
0xFFF00028	Scrubber initialization data register
0xFFF0002C	Scrubber second range start address register
0xFFF00030	Scrubber second range end address register

42.3.1 AHB Status Register

Table 565. 0x00 - AHBS - AHB Status register

31 22	21 14	13	12	11	10	9	8	7 6	3	2 0
CECNT	UECNT	DONE	RES	SEC	SBC	CE	NE	HWRITE	HMASTER	HSIZE
0	0	0	0	0	0	0	0	NR	NR	NR
rw	rw	r	r	rw	rw	rw	rw	r	r	r

31: 22 CECNT: Global correctable error count

21: 14 UECNT: Global uncorrectable error count

13 DONE: Task completed. (read-only)

This is a read-only copy of the DONE bit in the status register.

12 RESERVED

11 SEC: Scrubber error counter threshold exceeded. Asserted together with NE.

10 SBC: Scrubber block error counter threshold exceeded. Asserted together with NE.

9 CE: Correctable Error. Set if the detected error was caused by a correctable error and zero otherwise.

8 NE: New Error. Deasserted at start-up and after reset. Asserted when an error is detected. Reset by writing a zero to it.

7 The HWRITE signal of the AHB transaction that caused the error.

6: 3 The HMASTER signal of the AHB transaction that caused the error.

2: 0 The HSIZE signal of the AHB transaction that caused the error

42.3.2 AHB Failing Address Register

Table 566. 0x04 - AHBFAR - AHB Failing address register

31 0
AHB FAILING ADDRESS
NR
r

31: 0 The HADDR signal of the AHB transaction that caused the error.

42.3.3 AHB Error Configuration Register

Table 567. 0x08 - AHBERC - AHB Error configuration register

31 22	21 14	13 2	1	0
CORRECTABLE ERROR COUNT THRESHOLD	UNCORR. ERROR COUNT THRESH.	RESERVED	CECTE	UECTE
0	0	0	0	0
rw	rw	r	rw	rw

31: 22 Interrupt threshold value for global correctable error count

21: 14 Interrupt threshold value for global uncorrectable error count

13: 2 RESERVED

1 CECTE: Correctable error count threshold enable

0 UECTE: Uncorrectable error count threshold enable

42.3.4 Scrubber Status Register

Table 568. 0x10 - STAT - Scrubber status register

31 22	21 14	13	12 5	4 1	0
SCRUB RUN ERROR COUNT	BLOCK ERROR COUNT	DONE	RESERVED	BURSTLEN	ACTIVE
0	0	0	0	*	0
r	r	wc	r	r	r

31: 22 Number of correctable errors in current scrub run (read-only)

21: 14 Number of correctable errors in current block (read-only)

13 DONE: Task completed.

Needs to be cleared (by writing zero) before a new task completed interrupt can occur.

12: 5 RESERVED

4: 1 Burst length in 2-log of AHB bus cycles; “0000”=1, “0001”=2, “0010”=4, “0011”=8, ...

0 Current state: 0=Idle, 1=Running (read-only)

42.3.5 Scrubber Configuration Register

*Table 569.*0x14 - CONFIG - Scrubber configuration register

31 16	15 8	7	6	5	4	3 2	1	0
RESERVED	DELAY	IRQD	EC	SERA	LOOP	MODE	ES	SCEN
0	0	0	0	0	0	0	0	0
r	rw	rw	r	rw	rw	rw	rw	rw

31: 16 RESERVED

15: 8 Delay time between processed blocks, in cycles

7 Interrupt when scrubber has finished

6 External clear counter enable

5 Second memory range enable

4 Loop mode, restart scrubber when run finishes

3: 2 Mode (00=Scrub, 01=Regenerate, 10=Initialize, 11=Undefined)

1 External start enable

0 Enable

42.3.6 Scrubber Range Low Address Register

Table 570. 0x18 - RANGEL - Scrubber range low address register

31 0
SCRUBBER RANGE LOW ADDRESS
0
rw

31: 0 The lowest address in the range to be scrubbed

The address bits below the burst size alignment are constant ‘0’

42.3.7 Scrubber Range High Address Register

Table 571. 0x1C - RANGEH - Scrubber range high address register

31	0
SCRUBBER RANGE HIGH ADDRESS	
0	
rw	

31: 0 The highest address in the range to be scrubbed

The address bits below the burst size alignment are constant ‘1’

42.3.8 Scrubber Position Register

Table 572. 0x20 - POS - Scrubber position register

31	0
SCRUBBER POSITION	
0	
rw	

31: 0 The current position of the scrubber while active, otherwise zero.

The address bits below the burst size alignment are constant ‘0’

42.3.9 Scrubber Error Threshold Register

Table 573. 0x24 - ERROR - Scrubber error threshold register

31 22	21 14	13 2	1	0
RECT	BECT	RESERVED	RECTE	BECTE
0	0	0	0	0
rw	rw	r	rw	rw

31: 22 Interrupt threshold value for current scrub run correctable error count

21: 14 Interrupt threshold value for current scrub block correctable error count

13: 2 RESERVED

1 RECTE: Scrub run correctable error count threshold enable

0 BECTE: Scrub block uncorrectable error count threshold enable

42.3.10 Scrubber Initialization Data Register

Table 574. 0x28 - INIT - Scrubber initialization data register (write-only)

31 0
SCRUBBER INITIALIZATION DATA
-
w

31: 0 Part of data pattern to be written in initialization mode. A write operation assigns the first part of the buffer and moves the rest of the words in the buffer one step.

42.3.11 Scrubber Second Range Low Address Register

Table 575. 0x2C - RANGEL2 - Scrubber second range low address register

31 0
SCRUBBER RANGE LOW ADDRESS
0
rw*

31: 0 The lowest address in the second range to be scrubbed

The address bits below the burst size alignment are constant ‘0’

42.3.12 Scrubber Second Range High Address Register

Table 576. 0x30 - RANGEH2 - Scrubber second range high address register

31 0
SCRUBBER RANGE HIGH ADDRESS
0
rw*

31: 0 The highest address in the second range to be scrubbed

The address bits below the burst size alignment are constant ‘1’

43 SPI to AHB bridge

The GR716 microcontroller comprises a SPI to AHB bridge (SPI2AHB). The SPI to AHB bridge controls its own external pins and has a unique AMBA address described in chapter 2.11. The SPI to AHB bridge is connected to external pins via the IOMUX.

The control and status registers are located on APB bus in the address range from 0x80104000 to 0x80104FFF. See SPI to AHB bridge connections in the next drawing. The figure shows memory locations and functions used for SPI2AHB configuration and control.

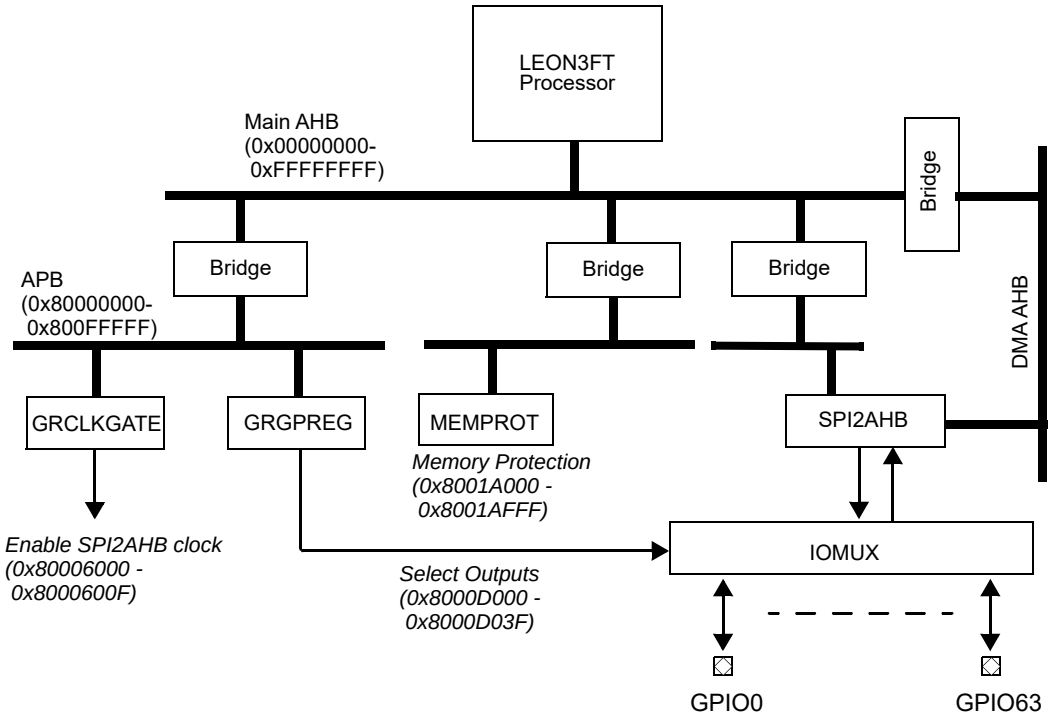


Figure 78. GR716 SPI2AHB bus and pin connection

The primary clock gating unit **GRCLKGATE** described in section 26 is used to enable/disable the SPI to AHB bridge The unit **GRCLKGATE** can also be used to perform reset of the SPI to AHB bridge. Software must enable clock and release reset described in section 26 before configuration and transmission can start.

External IO selection and configuration is made in the system IO configuration registers (**GRGPREG**) in the address range from 0x8000D000 to 0x8000D03F. See section 7.1 for further information.

The system can be configured to protect and restrict access to the SPI to AHB bridge in the **MEMPROT** unit. See section 47 for more information.

43.1 Overview

The SPI to AHB bridge is an SPI slave that provides a link between a SPI bus (that consists of two data signals, one clock signal and one select signal) and AMBA AHB. On the SPI bus the slave acts as an SPI memory device where accesses to the slave are translated to AMBA accesses. The core can translate SPI accesses to AMBA byte, half-word or word accesses. The access size to use is configurable via the SPI bus.

The core synchronizes the incoming clock and can operate in systems where other SPI devices are driven by asynchronous clocks.

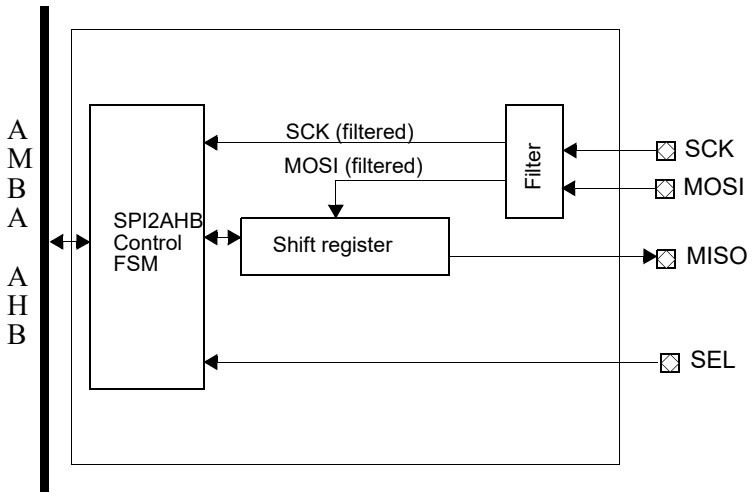


Figure 79. SPI to AHB bridge block diagram

43.2 Transmission protocol

The SPI bus is a full-duplex synchronous serial bus. Transmission starts when a master selects a slave through the slave's Slave Select (SEL) signal and the clock line SCK transitions from its idle state. Data is transferred from the master through the Master-Output-Slave-Input (MOSI) signal and from the slave through the Master-Input-Slave-Output (MISO) signal. In some systems with only one master and one slave, the Slave Select input of the slave may be always active and the master does not need to have a slave select output. This does not apply to this SPI to AHB bridge, the slave select signal must be used to mark the start and end of an operation.

During a transmission on the SPI bus data is either changed or read at a transition of SCK. If data has been read at edge n, data is changed at edge n+1. If data is read at the first transition of SCK the bus is said to have clock phase 0, and if data is changed at the first transition of SCK the bus has clock phase 1. The idle state of SCK may be either high or low. If the idle state of SCK is low, the bus has clock polarity 0 and if the idle state is high the clock polarity is 1. The combined values of clock polarity (CPOL) and clock phase (CPHA) determine the mode of the SPI bus. Figure 80 shows one byte (0x55) being transferred MSb first over the SPI bus under the four different modes. Note that the idle state of the MOSI line is '1' and that CPHA = 0 means that the devices must have data ready before the first transition of SCK. The figure does not include the MISO signal, the behavior of this line is the same as for the MOSI signal. However, due to synchronization the MISO signal will be delayed for a period of time that depends on the system clock frequency.

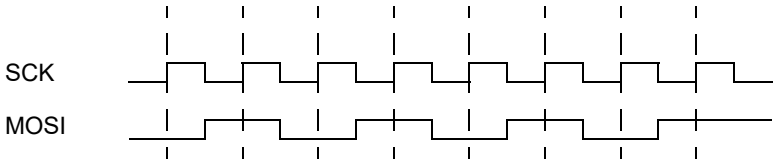


Figure 80. SPI transfer of byte 0x55 in all modes

The SPI to AHB bridge makes use of a protocol commonly used by SPI Flash memory devices. A master first selects the slave via the slave select signal and then issues a one-byte instruction. The instruction is then followed by additional bytes that contain address or data values. All instructions, addresses and data are transmitted with the most significant bit first. All AMBA accesses are done in big endian format. The first byte sent to or from the slave is the most significant byte.

43.3 System clock requirements and sampling

The core samples the incoming SPI SCK clock and does not introduce any additional clock domains into the system. Both the SCK and MOSI lines first pass through two stage synchronizers and are then filtered with a low pass filter.

The synchronizers and filters constrain the minimum system frequency. The core requires the SCK signal to be stable for at least two system clock cycles before the core accepts the SCK value as the new clock value. The core's reaction to transitions will be additionally delayed since both lines are taken through two-stage synchronizers before they are filtered. In order for the slave to be able to output data on the SCK 'change' transition and for this data to reach the master before the next edge the SCK frequency should not be higher than one tenth of the system frequency of core.

The slave select input should be asserted at least two system clock cycles before the SCK line starts transitioning.

43.4 SPI instructions

43.4.1 Overview

The core is controlled from the SPI bus by sending SPI instructions. Some commands require additional bytes in the form of address or data. The core makes use of the same instructions as commonly available SPI Flash devices. Table 577 summarizes the available instructions.

*Table 577.*SPI instructions

Instruction	Description	Instruction code	Additional bytes
RDSR	Read status/control register	0x05	Core responds with register value
WRSR	Write status/control register	0x01	New register value
READ	AHB read access	0x03	Four address bytes, after which core responds with data.
READD	AHB read access with dummy byte	0x0B	Four address butes and one dummy byte, after which core responds with data
WRITE	AHB write access	0x02	Four address bytes followed by data to be written

All instructions, addresses and data are transmitted with the most significant bit first. All AMBA accesses are done in big endian format. The first byte sent to or from the slave is the most significant byte.

43.4.2 SPI status/control register accesses (RDSR/WRSR)

The RDSR and WRSR instructions access the core's SPI status/control register. The register is accessed by issuing the wanted instruction followed by the data byte to be written (WRSR) or any value on the byte in order to shift out the current value of the status/control register (RDSR). The fields available in the SPI status/control register are shown in table 578.

*Table 578.*SPI2AHB SPI status/control register

7	6	5	4	3	2	1	0
Reserved	RAHEAD	PROT	MEXC	DMAACT	MALF	HSIZE	

7 Reserved, always zero (read only)

6 Read ahead (RAHEAD) - When this bit is set the core will make a new access to fetch data as soon as the last current data bit has been moved. Otherwise the core will not attempt the new access until the 'change' transition on SCK. Setting this bit to '1' allows higher SCK frequencies to be used but will also result in a data fetch as soon as the current data has been read out. This means that RAHEAD may not be suitable when accessing FIFO interfaces. (read/write)

Table 578. SPI2AHB SPI status/control register

5	Memory protection triggered (PROT) - '1' if last AHB access was outside the allowed memory area. Updated after each AMBA access (read only). Note that since this bit is updated after each access the RAHEAD = '1' setting may hide errors.
4	Memory exception (MEXC) - '1' if core receives AMBA ERROR response. Updated after each AMBA access (read only). Note that since this bit is updated after each access the RAHEAD = '1' setting may hide errors.
3	DMA active (DMAACT) - '1' if core is currently performing a DMA operation.
2	Malfunction (MALF): This bit is set to one by the core is DMA is not finished when a new byte starts getting shifted. If this bit is set to '1' then the last AHB access was not successful.
1:0	AMBA access size (HSIZE) - Controls the access size that the core will use for AMBA accesses. 0: byte, 1: half-word, 2: word. HSIZE = "11" is illegal.

Reset value: 0x42

43.4.3 Read and write instructions (WRITE and READ/READD)

The READD is the same as the READ instruction with an additional dummy byte inserted after the four address bytes. To perform a read operation on AHB via the SPI bus the following sequence should be performed:

1. Assert slave select
2. Send READ instruction
3. Send four byte AMBA address, the most significant byte is transferred first

3a. Send dummy byte (if READD is used)

4. Read the wanted number of data bytes
5. De-assert slave select

To perform a write access on AHB via the SPI bus, use the following sequence:

1. Assert slave select
2. Send WRITE instruction
3. Send four byte AMBA address, the most significant byte is transferred first
4. Send the wanted number of data bytes
5. De-assert slave select

During consecutive read or write operations, the core will automatically increment the address. The access size (byte, halfword or word) used on AHB is set via the HSIZE field in the SPI status/control register.

The core always respects the access size specified via the HSIZE field. If a write operation writes fewer bytes than what is required to do an access of the specified HSIZE then the write data will be dropped, no access will be made on AHB. If a read operation reads fewer bytes than what is specified by HSIZE then the remaining read data will be dropped when slave select is de-asserted.

The core will not mask any address bits. Therefore it is important that the SPI master respects AMBA rules when performing half-word and word accesses. A half-word access must be aligned on a two byte address boundary (least significant bit of address must be zero) and a word access must be aligned on a four byte boundary (two least significant address bits must be zero).

43.4.4 Memory protection

Default configuration allows full access to the complete AHB address range. The access range can be restricted via configuration registers.

The registers PADDR and PMASK are used to assign the memory protection area's address and mask in the following way:

Protection address, bits 31:16 (PADDR*[31:16]*): ahbaddrh
Protection address, bits 15:0 (PADDR*[15:0]*): ahbaddrl

Protection mask, bits 31:16 (PMASK*[31:16]*): ahbmaskh
Protection mask, bits 15:0 (PMASK*[15:0]*): ahbmaskl

Before the core performs an AMBA access it will perform the check:

(((incoming address) xor (protaddr)) and protmask) /= 0x00000000

If the above expression is true (one or several bits in the incoming address differ from the protection address, and the corresponding mask bits are set to '1') then the access is inhibited. As an example, assume that *protaddr* is 0xA0000000 and *protmask* is 0xF0000000. Since *protmask* only has ones in the most significant nibble, the check above can only be triggered for these bits. The address range of allowed accessed will thus be 0xA0000000 - 0xAFFFFFFF..

The core will set the configuration register bit PROT if an access is attempted outside the allowed address range. This bit is updated on each AHB access and will be cleared by an access inside the allowed range.

43.5 Registers

The core is programmed through registers mapped into APB address space.

*Table 579.*APB registers

APB address offset	Register
0x00	Control register
0x04	Status register
0x08	Protection address register
0x0C	Protection mask register

43.5.1 Control Register

*Table 580.*0x00 - CTRL - Control register

31 2	1	0
RESERVED	IRQEN	EN
0	0	1
r	rw	rw

31 : 2 RESERVED

1 Interrupt enable (IRQEN) - When this bit is set to '1' the core will generate an interrupt each time the DMA field in the status register transitions from '0' to '1'.

0 Core enable (EN) - When this bit is set to '1' the core is enabled and will respond to SPI accesses. Otherwise the core will not react to SPI traffic.

43.5.2 Status Register

*Table 581.*0x04 - STAT - Status register

31 3	2	1	0
RESERVED	PROT	WR	DMA
0	0	0	0
r	wc	r	wc

31 : 3 RESERVED

2 Protection triggered (PROT) - Set to '1' if an access has triggered the memory protection. This bit will remain set until cleared by writing '1' to this position. Note that the other fields in this register will be updated on each AHB access while the PROT bit will remain at '1' once set.

1 Write access (WR) - Last AHB access performed was a write access. This bit is read only.

0 Direct Memory Access (DMA) - This bit gets set to '1' each time the core attempts to perform an AHB access. By setting the IRQEN field in the control register this condition can generate an interrupt. This bit can be cleared by software by writing '1' to this position.

43.5.3 Protection Address Register

*Table 582.*0x08 - PADDR - Protection address register

31 0
PROTADDR
0x0
rw

31 : 0 Protection address (PROTADDR) - Defines the base address for the memory area where the core is allowed to make accesses.

43.5.4 Protection Mask Register

*Table 583.*0x0C - PMASK - Protection mask register

31 0
PROTMASK
0x0
rw

31 : 0 Protection mask (PROTMASK) - Selects which bits in the Protection address register that are used to define the protected memory area.

44 SPI Controller

The GR716 microcontroller comprises two separate SPI controller (SPICTRL) units. Each SPI controller unit controls its own external pins and has a unique AMBA address described in chapter 2.11.

Each SPI controller unit control and status registers are located on the APB bus in the address range from 0x80390000 to 0x803AFFFF. See SPICTRL units connections in the next drawing. The figure shows memory locations and functions used for SPICTRL configuration and control.

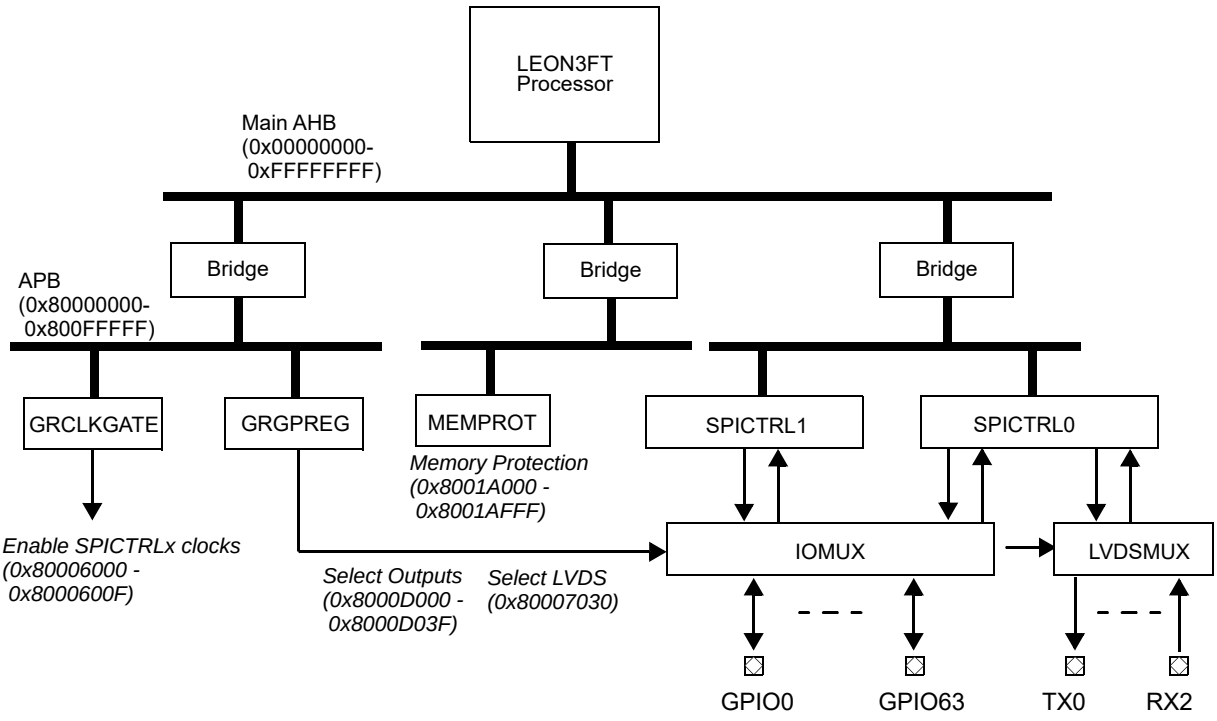


Figure 81. GR716 SPICTRLx bus and pin

The primary clock gating unit **GRCLKGATE** described in section 26 is used to enable/disable SPI controller units. The unit **GRCLKGATE** can also be used to perform reset of individual SPI controller units. Software must enable clock and release reset described in section 26 before SPI configuration and transmission can start.

External IO selection per SPI controller unit is made in the system IO and LVDS configuration register (**GRGPREG**) in the address range from 0x8000D000 to 0x8000D03F and 0x80007030. See section 7.1 for further information.

Each **SPICTRLx** unit controls its own external pins and has a unique AMBA address described in chapter 2.11. SPICTRL unit 0 and 1 has identical configuration and status registers. Configuration and status registers are described in this section 44.3

System can be configured to protect and restrict access to individual SPICTRL unit in the **MEMPROT** unit. See section 47 for more information.

44.1 Overview

The core provides a link between the AMBA APB bus and the Serial Peripheral Interface (SPI) bus and can be dynamically configured to function either as a SPI master or a slave. The SPI bus parameters are highly configurable via registers. Core features also include configurable word length, bit

ordering, clock gap insertion, automatic slave select and automatic periodic transfers of a specified length. All SPI modes are supported and also a 3-wire mode where one bidirectional data line is used. In slave mode the core synchronizes the incoming clock and can operate in systems where other SPI devices are driven by asynchronous clocks.

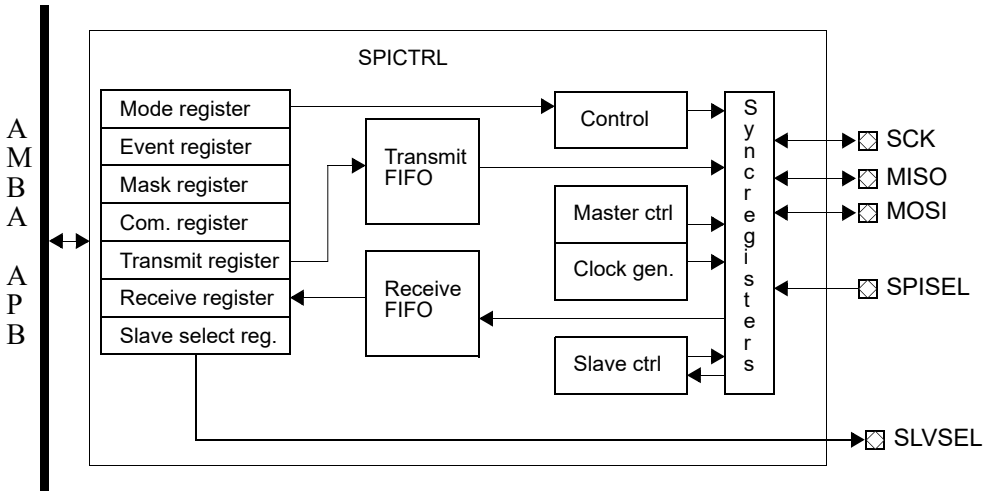


Figure 82. Block diagram

44.2 Operation

44.2.1 SPI transmission protocol

The SPI bus is a full-duplex synchronous serial bus. Transmission starts when a master selects a slave through the slave's Slave Select (SLVSEL) signal and the clock line SCK transitions from its idle state. Data is transferred from the master through the Master-Output-Slave-Input (MOSI) signal and from the slave through the Master-Input-Slave-Output (MISO) signal. In a system with only one master and one slave, the Slave Select input of the slave may be always active and the master does not need to have a slave select output. If the core is configured as a master it will monitor the SPISEL signal to detect collisions with other masters, if SPISEL is activated the master will be disabled.

During a transmission on the SPI bus data is either changed or read at a transition of SCK. If data has been read at edge n, data is changed at edge n+1. If data is read at the first transition of SCK the bus is said to have clock phase 0, and if data is changed at the first transition of SCK the bus has clock phase 1. The idle state of SCK may be either high or low. If the idle state of SCK is low, the bus has clock polarity 0 and if the idle state is high the clock polarity is 1. The combined values of clock polarity (CPOL) and clock phase (CPHA) determine the mode of the SPI bus. Figure 83 shows one byte (0x55) being transferred MSb first over the SPI bus under the four different modes. Note that the idle state of the MOSI line is '1' and that CPHA = 0 means that the devices must have data ready before the first transition of SCK. The figure does not include the MISO signal, the behavior of this line is the same as for the MOSI signal. However, due to synchronization issues the MISO signal will be delayed when the core is operating in slave mode, please see section 44.2.5 for details.

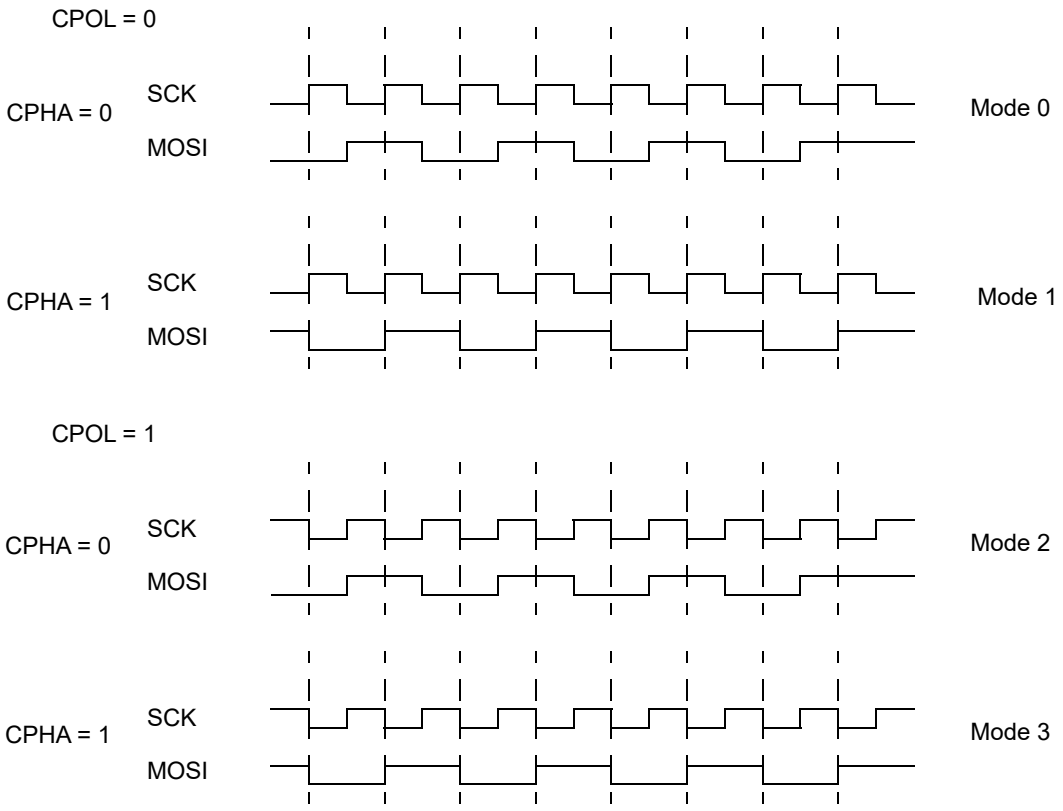


Figure 83. SPI transfer of byte 0x55 in all modes

44.2.2 3-wire transmission protocol

The core can be configured to operate in 3-wire mode, if the TWEN field in the core's Capability register is set to '1', where the controller uses a bidirectional dataline instead of separate data lines for input and output data. In 3-wire mode the bus is thus a half-duplex synchronous serial bus. Transmission starts when a master selects a slave through the slave's Slave Select (SLVSEL) signal and the clock line SCK transitions from its idle state. Only the Master-Output-Slave-Input (MOSI) signal is used for data transfer in 3-wire mode. The MISO signal is not used.

The direction of the first data transfer is determined by the value of the 3-wire Transfer Order (TTO) field in the core's Mode register. If TTO is '0', data is first transferred from the master (through the MOSI signal). After a word has been transferred, the slave uses the same data line to transfer a word back to the master. If TTO is '1' data is first transferred from the slave to the master. After a word has been transferred, the master uses the MOSI line to transfer a word back to the slave.

The data line transitions depending on the clock polarity and clock phase in the same manner as in SPI mode. The aforementioned slave delay of the MISO signal in SPI mode will affect the MOSI signal in 3-wire mode, when the core operates as a slave.

44.2.3 Receive and transmit queues

The core's transmit queue consists of the transmit register and the transmit FIFO. The receive queue consists of the receive register and the receive FIFO. The total number of words that can exist in each queue is thus the FIFO depth plus one. When the core has one or more free slots in the transmit queue it will assert the Not full (NF) bit in the event register. Software may only write to the transmit register when this bit is asserted. When the core has received a word, as defined by word length (LEN) in the Mode register, it will place the data in the receive queue. When the receive queue has one or more elements stored the Event register bit Not empty (NE) will be asserted. The receive register will only contain valid data if the Not empty bit is asserted and software should not access the receive register

unless this bit is set. If the receive queue is full and the core receives a new word, an overrun condition will occur. The received data will be discarded and the Overrun (OV) bit in the Event register will be set.

The core will also detect underrun conditions. An underrun condition occurs when the core is selected, via SPISEL, and the SCK clock transitions while the transmit queue is empty. In this scenario the core will respond with all bits set to '1' and set the Underrun (UN) bit in the Event register. An underrun condition will never occur in master mode. When the master has an empty transmit queue the bus will go into an idle state.

44.2.4 Clock generation

The core only generates the clock in master mode, the generated frequency depends on the system clock frequency and the Mode register fields DIV16, FACT, and PM. Without DIV16 the SCK frequency is:

$$SCKFrequency = \frac{AMBAclockfrequency}{(4 - (2 \cdot FACT)) \cdot (PM + 1)}$$

With DIV16 enabled the frequency of SCK is derived through:

$$SCKFrequency = \frac{AMBAclockfrequency}{16 \cdot (4 - (2 \cdot FACT)) \cdot (PM + 1)}$$

Note that the fields of the Mode register, which includes DIV16, FACT and PM, should not be changed when the core is enabled. If the FACT field is set to 0 the core's register interface is compatible with the register interface found in MPC83xx SoCs. If the FACT field is set to 1, the core can generate an SCK clock with higher frequency.

44.2.5 Slave operation

When the core is configured for slave operation it does not drive any SPI signal until the core is selected, via the SPISEL input, by a master. If the core operates in SPI mode when SPISEL goes low the core configures MISO as an output and drives the value of the first bit scheduled for transfer. If the core is configured into 3-wire mode the core will first listen to the MOSI line and when a word has been transferred drive the response on the MOSI line. If the core is selected when the transmit queue is empty it will transfer a word with all bits set to '1' and the core will report an underflow.

Since the core synchronizes the incoming clock it will not react to transitions on SCK until two system clock cycles have passed. This leads to a delay of three system clock cycles when the data output line should change as the result of a SCK transition. This constrains the maximum input SCK frequency of the slave to (system clock) / 8 or less. The controlling master must also allow the decreased setup time on the slave data out line.

The core can also filter the SCK input. The value of the PM field in the Mode register defines for how many system clock cycles the SCK input must be stable before the core accepts the new value. If the PM field is set to zero, then the maximum SCK frequency of the slave is, as stated above, (system clock) / 8 or less. For each increment of the PM field the clock period of SCK must be prolonged by two times the system clock period as the core will require longer time discover and respond to SCK transitions.

44.2.6 Master operation

When the core is configured for master operation it will transmit a word when there is data available in the transmit queue. When the transmit queue is empty the core will drive SCK to its idle state. If the

SPISEL input goes low during master operation the core will abort any active transmission and the Multiple-master error (MME) bit will be asserted in the Event register. If a Multiple-master error occurs the core will be disabled. Note that the core will react to changes on SPISEL even if the core is operating in loop mode and that the core can be configured to ignore SPISEL by setting the IGSEL field in the Mode register.

44.3 Registers

The core is programmed through registers mapped into APB address space.

*Table 584.*SPI controller registers

APB address offset	Register
0x00	Capability register
0x04-0x1C	Reserved
0x20	Mode register
0x24	Event register
0x28	Mask register
0x2C	Command register
0x30	Transmit register
0x34	Receive register
0x38	Slave Select register
0x3C	Automatic slave select register

44.3.1 SPI Controller Capability Register

*Table 585.*0x00 - CAP - SPI controller Capability register

31	24	23	20	19	18	17	16
SSSZ		MAXWLEN		TWEN	R	ASELA	SSEN
4		0x0		1	0	1	1
r		r		r	r	r	r

15	8	7	6	5	4	0
FDEPTH		SR	FT		REV	
0x10		0	0x0		5	
r		r	r		r	

31 : 24 Slave Select register size (SSSZ) - Number of slave select signals supported.

23 : 20 Maximum word Length (MAXWLEN) - The maximum word length supported is 32-bits

19 Three-wire mode Enable (TWEN)

18 Reserved

17 Automatic slave select available (ASELA)

16 Slave Select Enable (SSEN) - Multiple slave selects

15 : 8 FIFO depth (FDEPTH) - This field contains the depth of the core's internal FIFOs.

7 SYNCRAM (SR) - Core has buffers implemented with SYNCRAM components.

6 : 5 Fault-tolerance (FT) - Not used

4 : 0 Core revision (REV) - This manual applies to core revision 5.

44.3.2 SPI Controller Mode Register

*Table 586.*0x20 - MODE - SPI controller Mode register

31	30	29	28	27	26	25	24	23	20	19	16
R	LOOP	CPOL	CPHA	DIV16	REV	MS	EN	LEN		PM	
0	0	0	0	0	0	0	0	0		0	
r	rw	rw	rw	rw	rw	rw	rw	rw		rw	

15	14	13	12	11	7	6	5	4	3	2	1	0
TWEN	ASEL	FACT	OD	CG		ASELDEL		TAC	TTO	IGSEL	CITE	R
0	0	0	0	0		0		0	0	0	*	0
rw*	rw*	rw	rw*	rw		rw*		rw	rw	rw	rw	r

31 Reserved

30 Loop mode (LOOP) - When this bit is set, and the core is enabled, the core's transmitter and receiver are interconnected and the core will operate in loopback mode. The core will still detect, and will be disabled, on Multiple-master errors.

29 Clock polarity (CPOL) - Determines the polarity (idle state) of the SCK clock.

28 Clock phase (CPHA) - When CPHA is '0' data will be read on the first transition of SCK. When CPHA is '1' data will be read on the second transition of SCK.

27 Divide by 16 (DIV16) - Divide system clock by 16, see description of PM field below and see section 44.2.4 on clock generation. This bit has no significance in slave mode.

26 Reverse data (REV) - When this bit is '0' data is transmitted LSB first, when this bit is '1' data is transmitted MSB first. This bit affects the layout of the transmit and receive registers.

25 Master/Slave (MS) - When this bit is set to '1' the core will act as a master, when this bit is set to '0' the core will operate in slave mode.

24 Enable core (EN) - When this bit is set to '1' the core is enabled. No fields in the mode register should be changed while the core is enabled. This can bit can be set to '0' by software, or by the core if a multiple-master error occurs.

*Table 586.*0x20 - MODE - SPI controller Mode register

23 : 20	Word length (LEN) - The value of this field determines the length in bits of a transfer on the SPI bus. Values are interpreted as: 0b0000 - 32-bit word length 0b0001-0b0010 - Illegal values 0b0011-0b1111 - Word length is LEN+1, allows words of length 4-16 bits. The value of this field must never specify a word length that is greater than the maximum allowed word length specified by the MAXWLEN field in the Capability register.
19 : 16	Prescale modulus (PM) - This value is used in master mode to divide the system clock and generate the SPI SCK clock. The value in this field depends on the value of the FACT bit. If bit 13 (FACT) is '0':The system clock is divided by 4*(PM+1) if the DIV16 field is '0' and 16*4*(PM+1) if the DIV16 field is set to '1'. The highest SCK frequency is attained when PM is set to 0b0000 and DIV16 to '0', this configuration will give a SCK frequency that is (system clock)/4. With this setting the core is compatible with the SPI register interface found in MPC83xx SoCs. If bit 13 (FACT) is '1': The system clock is divided by 2*(PM+1) if the DIV16 field is '0' and 16*2*(PM+1) if the DIV16 field is set to '1'. The highest SCK frequency is attained when PM is set to 0b0000 and DIV16 to '0', this configuration will give a SCK frequency that is (system clock)/2. In slave mode the value of this field defines the number of system clock cycles that the SCK input must be stable for the core to accept the state of the signal. See section 44.2.5.
15	Three-wire mode (TW) - If this bit is set to '1' the core will operate in 3-wire mode. This bit can only be set if the TWEN field of the Capability register is set to '1'.
14	Automatic slave select (ASEL) - If this bit is set to '1' the core will swap the contents in the Slave select register with the contents of the Automatic slave select register when a transfer is started and the core is in master mode. When the transmit queue is empty, the slave select register will be swapped back. Note that if the core is disabled (by writing to the core enable bit or due to a multiple-master-error (MME)) when a transfer is in progress, the registers may still be swapped when the core goes idle. This bit can only be set if the ASELA field of the Capability register is set to '1'. Also see the ASELDEL field which can be set to insert a delay between the slave select register swap and the start of a transfer.
13	PM factor (FACT) - If this bit is 1 the core's register interface is no longer compatible with the MPC83xx register interface. The value of this bit affects how the PM field is utilized to scale the SPI clock. See the description of the PM field.
12	Open drain mode (OD) - If this bit is set to '0', all pins are configured for operation in normal mode. If this bit is set to '1' all pins are set to open drain mode. The implementation of the core may or may not support open drain mode. If this bit can be set to '1' by writing to this location, the core supports open drain mode. The pins driven from the slave select register are not affected by the value of this bit.
11 : 7	Clock gap (CG) - The value of this field is only significant in master mode. The core will insert CG SCK clock cycles between each consecutive word. This only applies when the transmit queue is kept non-empty. After the last word of the transmit queue has been sent the core will go into an idle state and will continue to transmit data as soon as a new word is written to the transmit register, regardless of the value in CG. A value of 0b00000 in this field enables back-to-back transfers.
6 : 5	Automatic Slave Select Delay (ASELDEL) - If the core is configured to use automatic slave select (ASEL field set to '1') the core will insert a delay corresponding to ASELDEL*(SPI SCK cycle time)/2 between the swap of the slave select registers and the first toggle of the SCK clock. As an example, if this field is set to "10" the core will insert a delay corresponding to one SCK cycle between assigning the Automatic slave select register to the Slave select register and toggling SCK for the first time in the transfer. This field can only be set if the ASELA field of the Capability register is set to '1'.
4	Toggle Automatic slave select during Clock Gap (TAC) - If this bit is set, and the ASEL field is set, the core will perform the swap of the slave select registers at the start and end of each clock gap. The clock gap is defined by the CG field and must be set to a value >= 2 if this field is set. This field can only be set if the ASELA field of the Capability register is set to '1'.
3	3-wire Transfer Order (TTO) - This bit controls if the master or slave transmits a word first in 3-wire mode.If this bit is '0', data is first transferred from the master to the slave. If this bit is '1', data is first transferred from the slave to the master. This bit can only be set if the TWEN field of the Capability register is set to '1'.
2	Ignore SPISEL input (IGSEL) - If this bit is set to '1' then the core will ignore the value of the SPISEL input.

*Table 586.*0x20 - MODE - SPI controller Mode register

1	Require Clock Idle for Transfer End (CITE) - If this bit is ‘0’ the core will regard the transfer of a word as completed when the last bit has been sampled. If this bit is set to ‘1’ the core will wait until it has set the SCK clock to its idle level (see CI field) before regarding a transfer as completed. This setting only affects the behavior of the TIP status bit, and automatic slave select toggling at the end of a transfer, when the clock phase (CP field) is ‘0’.
0	RESERVED (R) - Read as zero and should be written as zero to ensure forward compatibility.

44.3.3 SPI Controller Event Register

*Table 587.*0x24 - EVENT - SPI controller Event register

31	30 16	15	14	13	12	11	10	9	8	7 0
TIP	R	AT	LT	R	OV	UN	MME	NE	NF	R
0	0	0	0	0	0	0	0	0	1	0
r	r	r	wc	r	wc	wc	wc	r	r	r

31 Transfer in progress (TIP) - This bit is ‘1’ when the core has a transfer in progress. Writes have no effect. This bit is set when the core starts a transfer and is reset to ‘0’ once the core considers the transfer to be finished. Behavior affected by setting of CITE field in Mode register.

30 : 16 RESERVED (R) - Read as zero and should be written to zero to ensure forward compatibility.

15 Automated transfers (AT) - Not used

14 Last character (LT) - This bit is set when a transfer completes if the transmit queue is empty and the LST bit in the Command register has been written. This bit is cleared by writing ‘1’, writes of ‘0’ have no effect.

13 RESERVED (R) - Read as zero and should be written to zero to ensure forward compatibility.

12 Overrun (OV) - This bit gets set when the receive queue is full and the core receives new data. The core continues communicating over the SPI bus but discards the new data. This bit is cleared by writing ‘1’, writes of ‘0’ have no effect.

11 Underrun (UN) - This bit is only set when the core is operating in slave mode. The bit is set if the core’s transmit queue is empty when a master initiates a transfer. When this happens the core will respond with a word where all bits are set to ‘1’. This bit is cleared by writing ‘1’, writes of ‘0’ have no effect.

10 Multiple-master error (MME) - This bit is set when the core is operating in master mode and the SPISEL input goes active. In addition to setting this bit the core will be disabled. This bit is cleared by writing ‘1’, writes of ‘0’ have no effect.

9 Not empty (NE) - This bit is set when the receive queue contains one or more elements. It is cleared automatically by the core, writes have no effect.

8 Not full (NF) - This bit is set when the transmit queue has room for one or more words. It is cleared automatically by the core when the queue is full, writes have no effect.

7 : 0 RESERVED (R) - Read as zero and should be written to zero to ensure forward compatibility.

44.3.4 SPI Controller Mask Register

*Table 588.*0x28 - MASK - SPI controller Mask register

31	30 16	15	14	13	12	11	10	9	8	7 0
TIPE	R	AT	LTE	R	OVE	UNE	MMEE	NEE	NFE	R
0	0	0	0	0	0	0	0	0	0	0
rw	r	rw	rw	rw	rw	rw	rw	rw	rw	r

31 Transfer in progress enable (TIPE) - When this bit is set the core will generate an interrupt when the TIP bit in the Event register transitions from ‘0’ to ‘1’.

30 : 16 RESERVED (R) - Read as zero and should be written to zero to ensure forward compatibility.

15 Automated transfers (AT) - Not used and should be always be set to ’0’

14 Last character enable (LTE) - When this bit is set the core will generate an interrupt when the LT bit in the Event register transitions from ‘0’ to ‘1’.

13 RESERVED (R) - Read as zero and should be written to zero to ensure forward compatibility.

12 Overrun enable (OVE) - When this bit is set the core will generate an interrupt when the OV bit in the Event register transitions from ‘0’ to ‘1’.

11 Underrun enable (UNE) - When this bit is set the core will generate an interrupt when the UN bit in the Event register transitions from ‘0’ to ‘1’.

10 Multiple-master error enable (MMEE) - When this bit is set the core will generate an interrupt when the MME bit in the Event register transitions from ‘0’ to ‘1’.

9 Not empty enable (NEE) - When this bit is set the core will generate an interrupt when the NE bit in the Event register transitions from ‘0’ to ‘1’.

8 Not full enable (NFE) - When this bit is set the core will generate an interrupt when the NF bit in the Event register transitions from ‘0’ to ‘1’.

7 : 0 RESERVED (R) - Read as zero and should be written to zero to ensure forward compatibility.

44.3.5 SPI Controller Command Register

*Table 589.*0x2C - CMD - SPI controller Command register

31 23	22	21 0
R	LST	R
0	0	0
r	rw	r

31 : 23 RESERVED (R) - Read as zero and should be written to zero to ensure forward compatibility.

22 Last (LST) - After this bit has been written to ‘1’ the core will set the Event register bit LT when a character has been transmitted and the transmit queue is empty. If the core is operating in 3-wire mode the Event register bit is set when the whole transfer has completed. This bit is automatically cleared when the Event register bit has been set and is always read as zero.

21 : 0 RESERVED (R) - Read as zero and should be written to zero to ensure forward compatibility.

44.3.6 SPI Controller Transmit Register

*Table 590.*0x30 - TX - SPI controller Transmit register

31 0
TDATA
0
w

31 : 0 Transmit data (TDATA) - Writing a word into this register places the word in the transmit queue. This register will only react to writes if the Not full (NF) bit in the Event register is set.

44.3.7 SPI Controller Receive Register

*Table 591.*0x34 - RXC - SPI controller Receive register

31	0
RDATA	
0	
r	

31 : 0 Receive data (RDATA) - This register contains valid receive data when the Not empty (NE) bit of the Event register is set. The placement of the received word depends on the Mode register fields LEN and REV:

For LEN = 0b0000 - The data is placed with its MSb in bit 31 and its LSb in bit 0.

For other lengths and REV = '0' - The data is placed with its MSB in bit 15.

For other lengths and REV = '1' - The data is placed with its LSB in bit 16.

To illustrate this, a transfer of a word with eight bits (LEN = 7) that are all set to one will have the following placement:

REV = '0' - 0x0000FF00

REV = '1' - 0x00FF0000

44.3.8 SPI Slave Select Register

*Table 592.*0x38 - SLVSEL - SPI Slave select register (optional)

31	4	3	0
R		SLVSEL	
0		0xF	
r		rw	

31 : 4 RESERVED (R) - Not used

3 : 0 Slave select (SLVSEL) - Slave select signals are mapped to this register on bits 3:0. Software is solely responsible for activating the correct slave select signals, the core does not assert or deassert any slave select signal automatically.

44.3.9 SPI Controller Automatic Slave Select Register

*Table 593.*0x3C - ASLVSEL - SPI controller Automatic slave select register

31	4	3	0
R		ASLVSEL	
0		0	
r		rw	

31 : 4 RESERVED (R)

3 : 0 Automatic Slave select (ASLVSEL) - If SSEN and ASELA in the Capability register are both '1' the core's slave select signals are assigned from this register when the core is about to perform a transfer and the ASEL field in the Mode register is set to '1'. After a transfer has been completed the core's slave select signals are assigned the original value in the slave select register.

45 SPI for Space Slave Controller

The GR716 microcontroller comprises an SPI for Space Slave controller (SPI4S). The SPI for Space Slave controller controls its own external pins and has a unique AMBA address described in chapter 2.11. The nominal SPI for Space Slave interface is connected via LVDS transceivers to external pins and the redundant interface is connected to external pins via the IOMUX.

The control and status register are located on APB bus in the address range from 0x8040E000 to 0x8040EFFF. See SPI for Space Slave controller connections in the next drawing. The figure shows memory locations and functions used for SPI4S configuration and control.

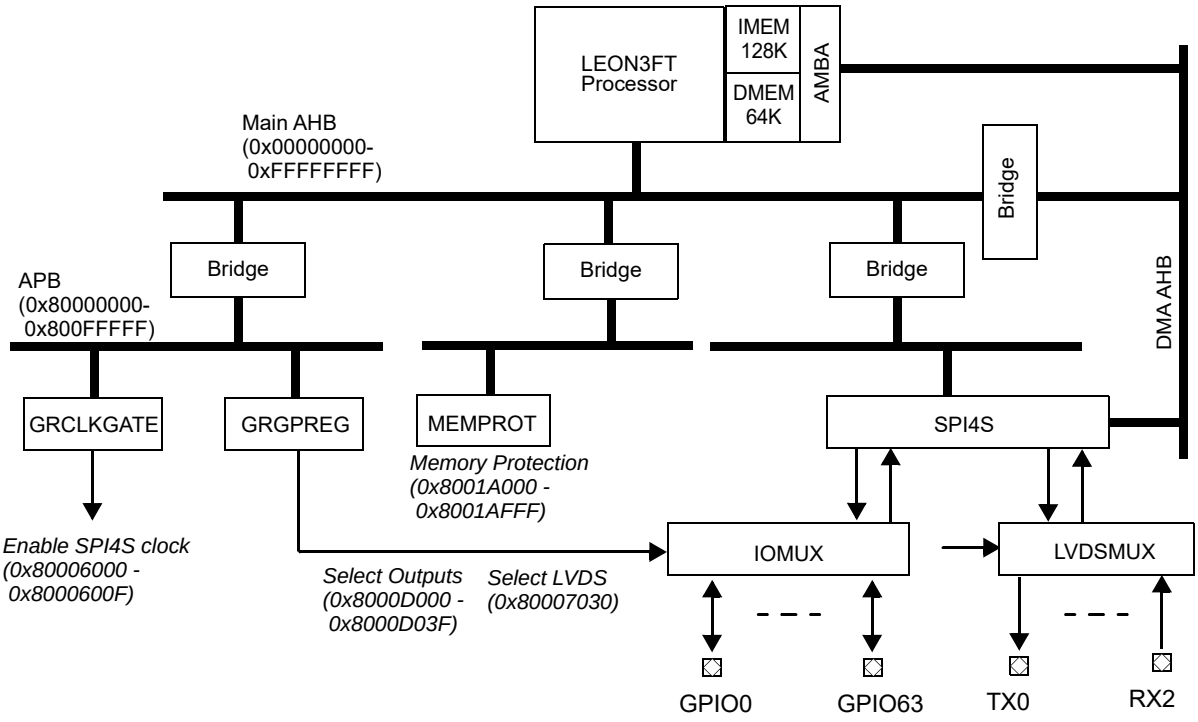


Figure 84. GR716 SPI4S bus and pin connection

The primary clock gating unit **GRCLKGATE** described in section 26 is used to enable/disable the SPI for Space Slave controller. The unit **GRCLKGATE** can also be used to perform reset of the SPI for Space Slave controller. Software must enable clock and release reset described in section 26 before configuration and transmission can start.

External IO selection and configuration is made in the system IO and LVDS configuration registers (**GRGPREG**) in the address range from 0x8000D000 to 0x8000D03F and 0x80007030. See section 7.1 for further information.

The system can be configured to protect and restrict access to the SPI for Space Slave controller in the **MEMPROT** unit. See section 47 for more information.

45.1 Overview

This core is a Dual Port SPI Slave device that provides link between SPI and AMBA AHB and APB ports. Core features include configurable word length (4, 5, 6 ... 32 bits), bit ordering and all four SPI modes are supported. This core also has redundant SPI ports which can be interfaced using two different masters. The slave takes two sets of SPI interfaces (nominal and redundant each consists of two data signals, one clock signal and one chip select signal).

45.2 Implementation of SPI protocols

In order to support the SPI 0 protocol the slave provides configurable word length of 4, 5, 6 ... 32 bits transmission and reception. The Word bit ordering can be MSB first or LSB first transferred.

For SPI 1 protocol the word length of the transfer can be 8, 16 or 24 bits. The word bit ordering MSB transferred first and LSB transferred last is supported. The parity bit can be appended at the end of every word, the parity bit is not included by the SPI slave device, since the implementation supports 9, 17 and 25 bits of word transfer the parity bit can be appended by the software.

All control and data transfer for SPI protocol 0 and 1 are supported only through the APB registers.

The SPI protocol 2 uses a fixed word length of 16 bits. The word bit ordering is MSB transferred first and LSB transferred last. Also this core implements the network layer of the SPI protocol 2, the slave hardware itself can process the SPI protocol 2 commands and provide responses. The APB interface is only for control and status, all the data transfer to the AMBA is performed using the AHB Master.

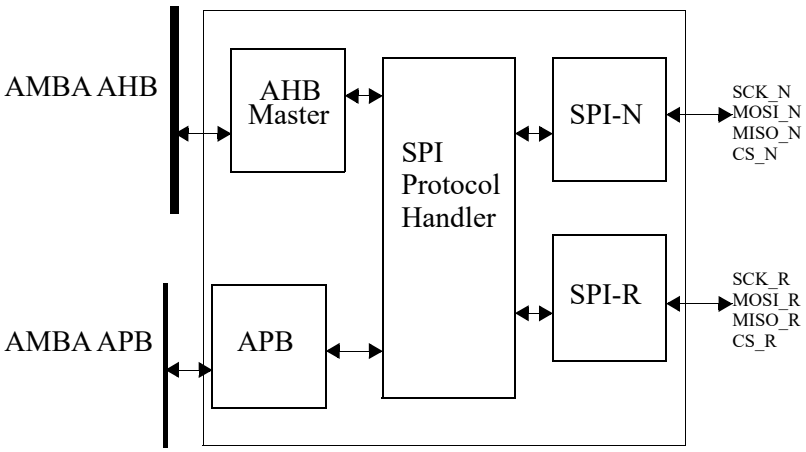


Figure 85. Block diagram

45.3 Transmission

The SPI bus is a full-duplex synchronous serial bus. Transmission starts when a master selects a slave through the slave's Slave Select (CS) signal and the clock line SCK transitions from its idle state. Data is transferred from the master through the Master-Output-Slave-Input (MOSI) signal and from the slave through the Master-Input-Slave-Output (MISO) signal. In some systems with only one master and one slave, the Slave Select input of the slave may be always active and the master does not need to have a slave select output. This does not apply to this device, the slave select signal must be used to mark the start and end of an operation.

During a transmission on the SPI bus data is either changed or read at a transition of SCK. If data has been read at edge n, data is changed at edge n+1. If data is read at the first transition of SCK the bus is said to have clock phase 0, and if data is changed at the first transition of SCK the bus has clock phase 1. The idle state of SCK may be either high or low. If the idle state of SCK is low, the bus has clock polarity 0 and if the idle state is high the clock polarity is 1. The combined values of clock polarity (CPOL) and clock phase (CPHA) determine the mode of the SPI bus. Figure below shows one byte (0x55) being transferred MSb first over the SPI bus under the four different modes. Note that the idle state of the MOSI line is '1' and that CPHA = 0 means that the devices must have data ready before

the first transition of SCK. The figure does not include the MISO signal, the behavior of this line is the same as for the MOSI signal.

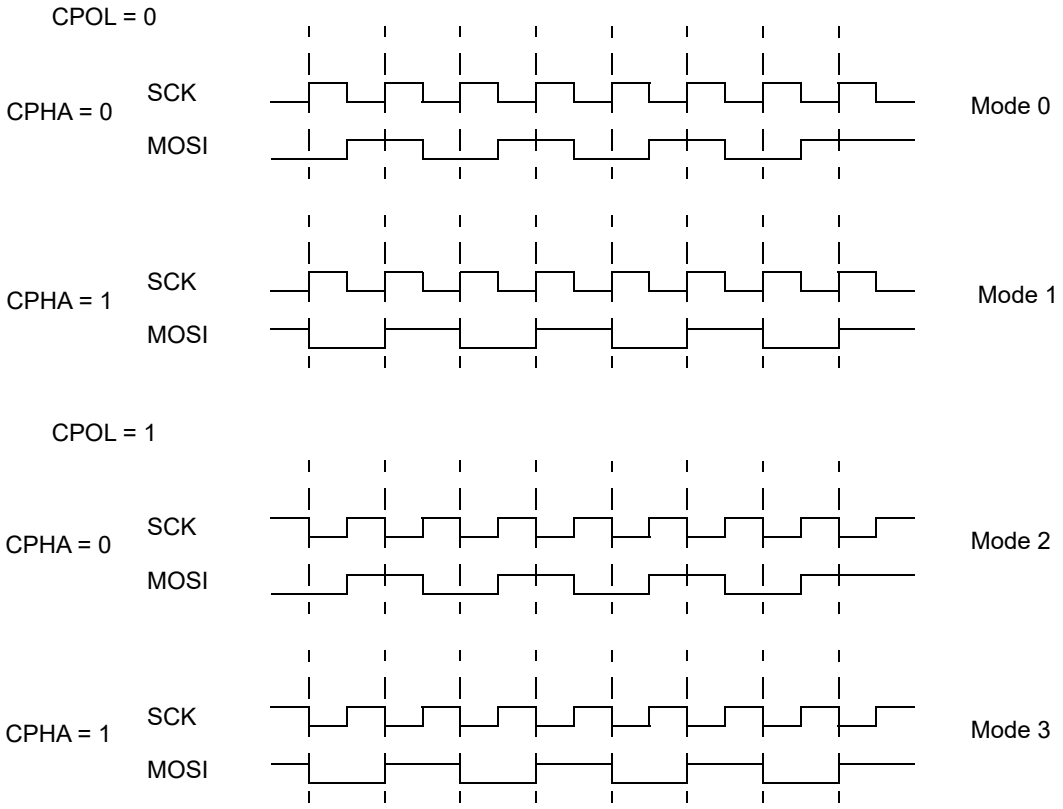


Figure 86. SPI transfer of byte 0x55 in all modes

45.4 Operation

The data transfer between the master and the slave is through APB registers or through command transfer from a master is determined by the EN bit in the SPI2 control register. When APB registers are used the data transferred by a master is available at receive registers (NRDATA or RRDATA depending on the port used) while during the same reception period the contents of the transmit registers (TDATA) are transferred to the master. When appropriate commands are transferred by a master SPI device and EN bit in the SPI2 control register is enabled then the commands are processed by the SPI 2 protocol handler available in this core. The SPI protocol 2 implementation is explained in detail in the following section.

45.5 SPI 2 Protocol Handler

The core is capable of handling the commands (based on SPI protocol 2) transferred by a SPI master and provide response. The message format transferred between a SPI master and SPI slave device is defined below.

Table 594. Example message format (write data)

Signal	Message Header		Payload	Payload CRC
MOSI	Command #1	Command #2	Data	CRC-16
MISO	Response #1	Response #2	0x0000	0x0000

Table 595. Example message format (read data)

Signal	Message Header		Payload	Payload CRC
MOSI	Command #1	Command #2	0x0000	0x0000
MISO	Response #1	Response #2	Data	CRC-16

The message header is composed of a Command token from the master and a Response token from the slave. The message also contains optional data words and CRC checksum appended at the end that are calculated for the data words transferred. The CRC is mandatory, if the message contains payload data then the message is always appended with one word of CRC. The received messages are processed by the SPI slave device and response and data are transferred as per the received command. Also note some of the status bits inplatform

the response token are status for the previously received command.

45.6 Message Header - Command Token

The master transmits a message header that specifies the action need to be performed in slave. The command token sent by the master device consist of two 16 bit words. The message header content details are explained below.

Table 596. Command word 1

MSB	**Command Token Word #1**														**LSB**
Prefix		**Command Code**						**Spare**		**Message Length**					
15	**14**	**13**	**12**	**11**	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
’0’	’1’	C5	C4	C3	C2	C1	C0	’1’	’1’	L5	L4	L3	L2	L1	L0

Table 597. Command word 2

MSB	**Command Token Word #1**														**LSB**
Prefix		**Sub-Address**								**Spare**		**CRC-4**			
31	**30**	**29**	**28**	**27**	**26**	**25**	**24**	**23**	**22**	**21**	**20**	**19**	**18**	**17**	**16**
’0’	’1’	SA7	SA6	SA5	SA4	SA3	SA2	SA1	SA0	’1’	’1’	C3	C2	C1	C0

Prefix and spare

The prefix bits are transmitted initially. In the command word#1 and #2 the prefix and spare bits have fixed value in the current implementation, these are reserved bits. The spislave receives them and use it for validating the token. If an invalid prefix and spare bits are received then Status illegal command (SIC) status bit is enabled and also transmitted to master as part of the next response token.

Message Length

The number of payload words that will be transmitted in the current message. The number should not include the command token and the CRC checksum appended at the end of the message.

Sub-address

This field provide additional sub-address location for write and read commands.

CRC-4

The final four bits of the command token consist of a checksum for all the previous command token bits transmitted in this message. The CRC-4 should be computed for the following 28 bits, Command word #1 (16bits, MSB first sent to the CRC generator) and Command word #2 (excluding this CRC-4 field) (12bits, MSB first sent to the CRC generator). The Prefix and Spare fields are included in the CRC calculation. The generator polynomial used is X4 + X + 1. In this SPI slave receiving end the CRC-4 is calculated internally for the received command token, if the calculated CRC-4 does not match the expected value (this field) the corresponding command token is discarded and message error status is enabled and transmitted to master as part of the next response token.

Payload data

The payload consist of the data need to be transferred from the master to slave. Depending on the command executed the master must include valid data or dummy information in the form of string of zeros. For example the write command have the data to be written as the payload but the read command have dummy information in the form of string of zeros.

Payload CRC

When a valid payload is delivered in the payload data section of the message a Payload CRC (CRC-16) must be included at the end of the message. The generator polynomial used is x16+ x15+ x2+ 1. When dummy information in the form of string of zeros is included then no Payload CRC need to be attached then the payload CRC field must be all zero (0X0000). In the SPI slave receiving end the CRC-16 is calculated internally for the received payload data, if the calculated CRC-16 does not match the expected value (this field) the corresponding operation with respect to the command is not performed and message error status is enabled and transmitted to master as part of the next response token.

45.6.1 Command Code

The command code specify the operating instruction for the receiving slave. The detailed explanation of each command code and its implementation are explained in the table below.

Table 598. Reset Command

Code	Command	Length	Sub-Address	Payload	Description
0x00	RESET_SPI	0x00	0x00	None	This command will reset all the spi slave device registers to the default value except the time registers (TIME1, TIME2) and core enable registers (ENN and ENR)

The RESET_SPI command resets the SPI slave device to a power up initialized state. The SPI slave resets the system only if it received a valid command. If the prefix and spare bits does not match or if the calculated CRC-4 does not match the expected value then the RESET_SPI command is discarded.

Time synchronization command

Table 599. Time synchronization command

Code	Command	Length	Sub-Address	Payload	Description
0x07	SYNCH	0x04	0x00	MOSI: <SYNC1> <SYNC2> <SYNC3> <SYNC4> <CRC-16> MISO: <all zeros>	The master must transmit the SYNC command token followed by payload words containing synchronization information for it. These words are copied inside dedicated registers implemented in the SPI slave device after validation.

The time register is of 64 bit in width, the most significant time is transferred first in SYNC1 followed by SYNC2, SYNC3 and SYNC4. The time register roll over when its maximum count is reached. The time is synchronised only when all the words are received and also the command token CRC-4 and data CRC-16 must be valid. All bits are zero at reset. The RESET_SPI does not reset the time register.

Table 600. Time increment command

Code	Command	Length	Sub-Address	Payload	Description
0x08	TICK	0x00	Used as index for increment.	None	This command is used to advance the timing synchronization register available in the SPI slave device (same register used for the SYNC command)

A valid command increments the implemented time register. The sub address field specify from which bit the time register must increment.

Table 601. Read back sent command

Code	Command	Length	Sub-Address	Payload	Description
0x0A	READBACK	0x02	0x00	MOSI: <all zeros> MISO: <CMDTOKEN> < CRC-16>	The command can be used to verify the correct reception of the previous command. Upon reception of the command the slave respond with the previous command token

The SPI slave device after receiving the READBACK_CMD send the previous command token transmitted by the SPI master. This command is useful only when some other command (other than

RESET_SPI) was previously transmitted. If the previous command is RESET_SPI, the SPI master only receives zeros in the payload section of this command.

Table 602. Write Command

Code	Command	Length	Sub-Address	Payload	Description
0x0D	WRITE_SA	Number of words to be written, N	SA	MOSI: <DW1> <DW2> …<DWN> <CRC-16> MISO: <all zeros>	he command is used to write a certain number of data words into a slave specific Sub Address. Dedicated field of the command token select the payload length and the target SA.

When a valid WRITE_SA command is received the payload data is stored at the address specified. The address for writing the data is calculated by using the write address register (CONFIG_WRITE), and sub-address. The CRC-16 is calculated for received words and compared with the received payload CRC, if a data CRC error is detected then message error status is enabled and transmitted to master as part of the next response token.

Table 603. Read command

Code	Command	Length	Sub-Address	Payload	Description
0x0E	READ_SA	Number of words to be read, N	SA	MOSI: <all zeros> MISO: <DW1> <DW2> …<DWN> <CRC-16>	The command is used to read a certain number of data words into a slave specific Sub Address. Dedicated field of the command token select the payload length and the target SA

When a valid READ_SA command is received the payload data is transferred from the address specified. The address for reading the data is calculated by using the read address register (CONFIG_READ), and sub-address. The CRC-16 is calculated for transmitted words and sent as payload CRC by the slave device.

Table 604. Configure address commands

Code	Command	Length	Sub-Address	Payload	Description
0x20	CONFIG-WRITE_ADDR	0x02	0x00	MOSI: <CW1> <CW2> <CRC-16> MISO: <all zeros>	The command can be used to notify the slave about the address to which the data from the master is written, used for WRITE_SA command.
0x21	CONFIG READ_ADDR	0x02	0x00	MOSI: <CR1> <CR2> <CRC-16> MISO: <all zeros>	The command can be used to notify the slave about the address from which the data to the master is read, used for READ_SA command.

Dedicated registers for write address and read address is implemented, these registers takes value from this command. The purpose of this register is to access up to 32 bits of address space. The most significant word CW1 (or CR1) contains the most significant bytes of the target address.

Redundancy commands

Table 605. Redundancy commands

Code	Command	Length	Sub-Address	Payload	Description
0x24	ACTIVATE	0x00	0x00	None	The command is used to activate the other slave interface. This command cannot activate the interface in which it is receiving this command.
0x25	DEACTIVATE	0x00	0x00	None	The command is used to deactivate the other slave interface. This command cannot deactivate the interface in which it is receiving this command.

The SPI Slave device has two dedicated interfaces for two masters. The masters can send to its corresponding slave interface to activate or deactivate the other SPI interface. The master device cannot activate or deactivate the same ports on which it is connected, it can only activate or deactivate the other ports.

Initially both the SPI port interfaces are enabled to receive commands, when the communication between the nominal master and slave interface fails then the redundant master can deactivate the nominal interface using its dedicated redundant interface. The redundant master can also activate the nominal interface.

An example switchover scenario from nominal to redundant interface is described in the following text.

The nominal master communicates with its dedicated interface to a slave device, a fault occurred can be detected by the master using several options,

The status received by the master have invalid values (using the response token),

The Read back command sent does not provide appropriate values in the received payload,

Error bits are enabled in the status received by the master (using the response token),

Based on any of the above mentioned fault detection methods the master can send deactivate command in the redundant interface to deactivate the nominal interface of the slave. The master can send Read back sent commands (using redundant) to check if the previous deactivate command was received by the slave and can check the status of the response token as well. After conforming a proper communication has been established the master can use the redundant interface to perform its normal operations.

Any other commands which are not implemented is received then the command token is discarded and Status illegal command (SIC) bit is enabled and also transmitted to master as part of the next response token.

45.6.2 Message Header -Response Token

The slave transmits a message header which consist of status of module and details of error occurred. The message header sent by SPI slave device is called response token which consist of two 16 bit words. The message header content details are explained below..

Table 606. Response Token Word #1

MSB	Response Token Word #2														LSB
Prefix		Command Code					Spare					Module State			
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
’0’	’1’	SFT	ME	AR	IC	’0’	’0’	’0’	’0’	’0’	’0’	MS3	MS2	MS1	MS0

Table 607. Response Token Word #3

MSB	Response Token Word #2														LSB
Prefix		DATA	Spare									CRC-4			
31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
’0’	’1’	SA7	’0’	’0’	’1’	’1’	’1’	’0’	’0’	’0’	’0’	C3	C2	C1	C0

Table 608. Response Status bit

Bit	Identifier	Type	Value	Description	Clear Condition	Comment
13	TERMINAL_FAULT	Error	’0’ = no fault ‘1’ = fault	The bit flag a SPI terminal fault condition.	According to the module current state.	In SPI slave device this bit is enabled or disabled by SPI2 control register (STF) using APB.
12	MESSAGE_ERROR	Error	’0’ = no fault ‘1’ = fault	This bit is utilized to indicate that the previous message received from the bus master has failed to pass the validity tests.	Always related to the previous command. Reception of a valid command will clear it (with a delay of one command).	This status bit is enabled when the received message fails to pass the command token and payload data CRC checks. The next valid command clears this status bit.
11	ADDRESS_ERROR	Error	’0’ = no fault ‘1’ = fault	This bit flag an AMBA error occurred while performing the previous command.	Always related to the previous command. Reception of a valid command will clear it (with a delay of one command)	The SPI slave device uses an AHB master to perform the memory read and write, this bit is enabled when an AHB error is reported.

Table 608. Response Status bit

Bit	Identifier	Type	Value	Description	Clear Condition	Comment
10	ILLEGAL_CMD	Error	’0’ = no fault ‘1’ = fault	This bit flag that the previous received command was not compatible with the SPI slave device.	Always related to the previous command. Reception of a valid command will clear it (with a delay of one command)	When the prefix and spare bits in the received command token do not match the intended value or an unimplemented command is received this status bit is enabled. The next valid command clears this status bit

Table 609. Response Module State bits

Bit	Description
3	In the SPI slave device these bits are enabled or disabled by SPI2 control register (MODSTAT) using APB. These bits can be used by Software controlling the slave device to provide additional status to the master.
2	
1	
0	

45.7 Redundancy

The SPI slave has a two SPI ports which can be interfaced using two different masters. The slave takes two sets of SPI interfaces (nominal and redundant). The configuration registers available in the device is used to enable which interface to communicate and it is possible to use dedicated commands (using SPI 2 protocol) to activate and deactivate ports. While using configuration registers to activate or deactivate ports, the complete control of activation and deactivation must be performed by the external unit, only one port is active at any time. When commands are used to control the ports, the device can receive commands from both the interfaces. By receiving from both the interfaces the slave device can deactivate a non-working interface. The intention is to keep only one bus active for normal operation but using the redundant bus to achieve switchover. The SPI protocol 2 implementation supports dedicated commands to achieve the activation and deactivation of interfaces.

45.8 Registers

The core is programmed through registers mapped into APB address space.

*Table 610.*APB registers

APB address offset	Register
0x00	Control register
0x04	Status register
0x08	Transmit register
0x0C	Nominal receive register
0x10	Redundant receive register
0x14	Interrupt enable register
0x18	Interrupt register
0x1C	Reserved
0x20	SPI2 control register
0x24	SPI2 time1 register
0x28	SPI2 time2 register
0x2C	SPI2 config address write register
0x30	SPI2 config address read register

45.8.1 Control Register

*Table 611.*0x00 - CTRL - Control register

31 24	23 13	12 8	7	6	5	4	3	2	1	0
Key	R	WLEN	IAMBA	CPHA	CPOL	REV	R	RESET	ENR	ENN
0	0	0x0F	0	0	0	1	0	0	1	1
w	r	rw	rw	rw	rw	rw	r	rw	rw	rw

31 Safety code (KEY) - Must be 0x68 when writing, otherwise register write is ignored

23 : 13 RESERVED (R) - Read as zero and should be written to zero to ensure forward compatibility.

12 : 8 Word length (WLEN) - The value of this field determines the length in bits of a transfer on the SPI bus. Valid values are 0x03 to 0x1F

Word length is WLEN+1, allows words of length 4-32 bits.

7 AMBA Interrupt enable (IAMBA) - If set, AMBA interrupt generation is enabled for the events that are individually maskable by the Interrupt enable (INTE) register

6 Clock phase (CPHA) - When CPHA is ‘0’ data will be read on the first transition of SCK. When CPHA is ‘1’ data will be read on the second transition of SCK.

5 Clock polarity (CPOL) - Determines the polarity (idle state) of the SCK clock.

4 Reverse data (REV) - When this bit is ‘0’ data is transmitted LSB first, when this bit is ‘1’ data is transmitted MSB first.

3 RESERVED (R) - Read as zero and should be written to zero to ensure forward compatibility.

2 Reset (RESET) - Resets all the registers in the core except time registers (TIME1, TIME2) and core enable registers (ENN and ENR).

1 Enable redundant port transfer (ENR) - Enable bit for redundant port transfer.

0 Enable nominal port transfer (ENN)- Enable bit for nominal port transfer.

45.8.2 Status Register

*Table 612.*0x04 - STAT - Status register

31 8	7	6	5	4	3 2	1	0
RESERVED	ATR	ATN	SAR	SIC	R	RR	RN
0	0	1	0	0	0	0	0
r	r	r	r	r	r	r	r

31 : 3 RESERVED

7 Active transmission in redundant port (ATR) - This bit provides the status of the redundant transmission port. Set based on the incoming activate and deactivate commands (active '1' else '0'). Valid only for SPI protocol 2 implementation.

6 Active transmission in nominal port (ATN) - This bit provides the status of the nominal transmission port. Set based on the incoming activate and deactivate commands (active '1' else '0'). Valid only for SPI protocol 2 implementation.

5 Status address error (SAR) - This bit gets set to '1' when an AMBA write or read access resulted in a error. A valid new command clears this status bit. Valid only for SPI protocol 2 implementation.

4 Status illegal command (SIC) - This bit gets set to '1' when an illegal command is received. A valid new command clears this status bit. Valid only for SPI protocol 2 implementation.

3 : 2 RESERVED (R) - Read as zero and should be written to zero to ensure forward compatibility.

1 Received data redundant (RR) - This bit gets set to '1' each time a data is received in the redundant port. The bit gets set to '0' when the Redundant receive register is read.

0 Received data nominal (RN) - This bit gets set to '1' each time a data is received in the nominal port. The bit gets set to '0' when the Nominal receive register is read.

45.8.3 Transmit Register

*Table 613.*0x08 - TDATA - Transmit register

31 0
TDATA
0
rw

31 : 0 Transmit data (TDATA) - The written data is transferred to the master device when appropriate conditions for CS and SCK are satisfied. The word to transmit should be written with its least significant bit at bit 0. Also note that only the number of bits need to be transferred from this register should match the word length register (WLEN). Valid only for SPI protocol 0 and 1.

45.8.4 Nominal Receive Register

*Table 614.*0x0C - NRDATA - Nominal receive register

31 0
NRDATA
0
r

31 : 0 Nominal Receive data (NRDATA) - This register contains received data from the nominal port. Valid only for SPI protocol 0 and 1.

45.8.5 Redundant Receive Register

*Table 615.*0x10 - RRDATA - Redundant receive register

31 0
RRDATA
0

*Table 615.*0x10 - RRDATA - Redundant receive register

r

31 : 0 Redundant Receive data (RRDATA) - This register contains received data from the redundant port. Valid only for SPI protocol 0 and 1.

45.8.6 Interrupt Enable Register

*Table 616.*0x14 - INTE- Interrupt enable register

31 24	23 8	7	6	5	4	3	2	1	0
Key	RESERVED	WDE	AE	CRE	CWE	TICKE	SYNCE	RXRE	RXNE
0	0	0	0	0	0	0	0	0	0
w	r	rw	rw	rw	rw	rw	rw	rw	rw

31 : 24 Safety code (KEY) - Must be 0x68 when writing, otherwise register write is ignored.

23 : 8 RESERVED (R) - Read as zero and should be written to zero to ensure forward compatibility.

7 Write data interrupt enable (WDE). Valid only for SPI protocol 2.

6 AMBA access error interrupt enable (AE). Valid only for SPI protocol 2.

5 Change in config read address interrupt enable (CRE). Valid only for SPI protocol 2.

4 Change in config write address interrupt enable (CWE). Valid only for SPI protocol 2.

3 Tick command received interrupt enable (TICKE). Valid only for SPI protocol 2.

2 Sync command received interrupt enable (SYNCE). Valid only for SPI protocol 2.

1 Data received in redundant port interrupt enable (RXRE).Valid only for SPI protocol 0 and 1.

0 Data received in nominal port interrupt enable (RXNE). Valid only for SPI protocol 0 and 1.

45.8.7 Interrupt Register

*Table 617.*0x18- INT- Interrupt register

31 24	23 8	7	6	5	4	3	2	1	0
Key	RESERVED	WD	AI	CR	CW	TICK	SYNC	RXR	RXN
0	0	0	0	0	0	0	0	0	0
w	r	wc	wc	wc	wc	wc	wc	wc	wc

31 : 24 Safety code (KEY) - Must be 0x68 when writing, otherwise register write is ignored.

23 : 8 RESERVED (R) - Read as zero and should be written to zero to ensure forward compatibility.

7 Write data interrupt (WD). Valid only for SPI protocol 2.

6 AMBA access error interrupt (AI). Valid only for SPI protocol 2.

5 Change in config read address interrupt (CR). Valid only for SPI protocol 2.

4 Change in config write address interrupt (CW). Valid only for SPI protocol 2.

3 Tick command received interrupt (TICK). Valid only for SPI protocol 2.

2 Sync command received interrupt (SYNC). Valid only for SPI protocol 2.

1 Data received in redundant port interrupt (RXR).Valid only for SPI protocol 0 and 1.

0 Data received in nominal port interrupt (RXN). Valid only for SPI protocol 0 and 1.

45.8.8 SPI2 Control Register

*Table 618.*0x20- SPI2C- SPI2 control register

31 24	23 8	7	6	5	4	3	2	1	0
Key	RESERVED	MODSTAT				RESERVED		STF	EN
0	0	0	0	0	0	0	0	0	1
w	r	rw	rw	rw	rw	r	r	rw	rw

31 : 24 Safety code (KEY) - Must be 0x68 when writing, otherwise register write is ignored.

23 : 8 RESERVED (R) - Read as zero and should be written to zero to ensure forward compatibility.

7: 4 Module state (MODSTAT). The values in these bits are sent to the master via the response token. These are user configurable registers which can be set to ‘1’ or ‘0’. Valid only for SPI protocol 2.

3: 2 RESERVED (R) - Read as zero and should be written to zero to ensure forward compatibility.

1 SPI terminal failure (STF). This value in this bit is sent to the master via the response token. In order to intimate a terminal failure this bit can be written to ‘1’ through software. Valid only for SPI protocol 2.

0 Enable (EN). SPI protocol 2 enable bit. If set to ‘1’ the commands received from master are handled by the SPI 2 protocol handler in the core. If set to ‘0’ the data received and transfered are using the APB registers.

45.8.9 SPI2 Time1 Register

*Table 619.*0x24 - TIME1 - SPI2 time1 register

31 0
TIME1
0x00000000
r

31 : 0 Time 1 register (TIME1) - Provides the most significant 32 bits of the time register. This is a status (read only) register, the contents of this register is a reflection of the time modified/incremented using the sync and tick command respectively.

45.8.10 SPI2 Time2 Register

*Table 620.*0x28 - TIME2 - SPI2 time2 register

31	0
TIME2	
0x00000000	
r	

31 : 0 Time 2 register (TIME2) - Provides the lower 32 bits of the time register. This is a status (read only) register, the contents of this register is a reflection of the time modified/incremented using the sync and tick command respectively.

45.8.11 SPI2 Config Address Write Register

*Table 621.*0x2C - CONFW - SPI2 config address write register

31	0
CONFW	
0x40000000	
r	

31 : 0 Configuration write address (CONFW) - Defines the base address for the memory area where the core is allowed to make accesses. This is a status (read only) register, the contents of this register can be modified by the configuration write address command.

45.8.12 SPI2 Config Address Read Register

*Table 622.*0x30 - CONFR - SPI2 config address read register

31	0
CONFR	
0x40000000	
r	

31 : 0 Configuration read address (CONFR) - Defines the base address for the memory area where the core is allowed to make accesses. This is a status (read only) register, the contents of this register can be modified by the configuration read address command.

46 SPI Memory Controller

The GR716 microcontroller comprises 2 separate SPI memory controller units (SPIMCTRLx). Each SPI memory controller unit controls its own external pins and has a unique AMBA address described in chapter 2.11. SPI memory controller unit 0 (SPIMCTRL0) has dedicated external signals, while SPI memory controller unit 1 (SPIMCTRL1) has access to external signals via IO switch matrix described in section 2.5.

Each SPI memory controller unit control and status register are located on main AHB bus in the address range from 0xFFFF0000 to 0xFFFF02FFF. See SPIMCTRL units connections in the next drawing. The figure shows memory locations and functions used for SPIMCTRL configuration and control.

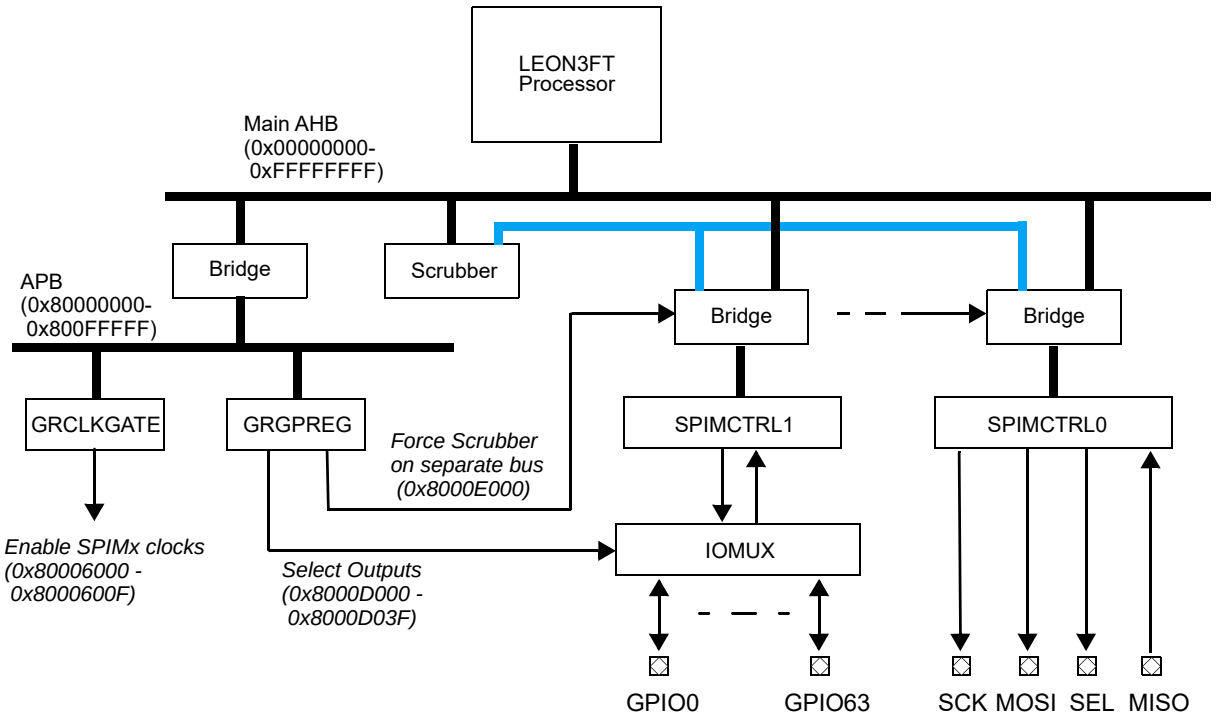


Figure 87. GR716 SPIMx bus and pin connection

The primary clock gating unit **GRCLKGATE** described in section 26 is used to enable/disable individual SPI memory controller units (SPIMCTRLx). The unit **GRCLKGATE** can also be used to perform reset of individual SPI memory controller units (SPIMCTRLx). Software must enable clock and release reset described in section 26 before SPI memory controller units (SPIMCTRLx) configuration and transfers can start.

External IO selection for SPI memory controller unit 1 (SPIMCTRL1) is made in the system IO configuration register (**GRGPREG**) in the address range from 0x8000D000 to 0x8000D03F. See section 7.1 for further information.

Each **SPIMCTRLx** unit controls its own external pins and has a unique AMBA address described in chapter 2.11. SPIMCTRL unit 0 and 1 has identical configuration and status registers. Configuration and status registers are described in this section 46.3

System can be configured to scrub memory contents of individual SPIMCTRL units in the **SCRUBBER** unit. See section 42 for more information.

46.1 Overview

The core maps a memory device connected via the Serial Peripheral Interface (SPI) into AMBA address space. Read accesses are performed by performing normal AMBA read operations in the mapped memory area. Other operations, such as writes, are performed by directly sending SPI commands to the memory device via the core's register interface. The core is highly configurable and supports most SPI Flash memory devices.

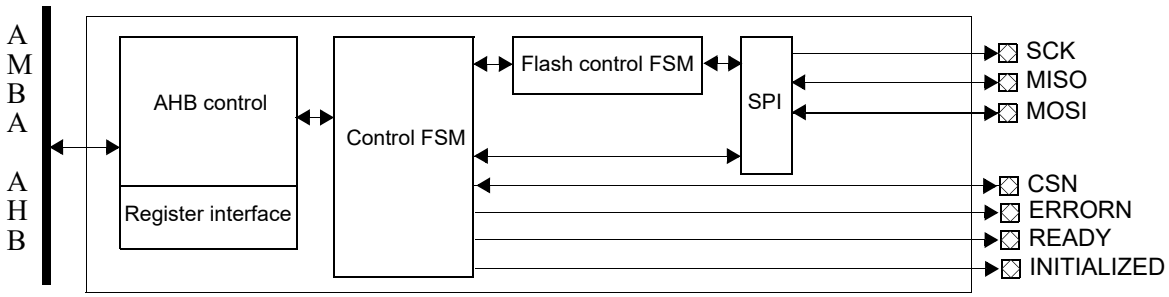


Figure 88. Block diagram

46.2 Operation

46.2.1 Operational model

The core has two memory areas that can be accessed via the AMBA bus; the I/O area and the ROM area. The ROM area maps the memory device into AMBA address space and the I/O area is utilized for status reporting and to issue user commands to the memory device.

When transmitting SPI commands directly to the device the ROM area should be left untouched. The core will issue an AMBA ERROR response if the ROM area is accessed when the core is busy performing an operation initiated via I/O registers.

Depending on the type of device attached the core may need to perform an initialization sequence. Accesses to the ROM area during the initialization sequence receive AMBA error responses. The core has successfully performed all necessary initialization when the Initialized bit in the core's status register is set.

46.2.2 I/O area

The I/O area contains registers that are used when issuing commands directly to the memory device. By default, the core operates in System mode where it will perform read operations on the memory device when the core's ROM area is accessed. Before attempting to issue commands directly to the memory device, the core must be put into User mode. This is done by setting the User Control (USRC) bit in the core's Control register. Care should be taken to not enter User mode while the core is busy, as indicated by the bits in the Status register. The core should also have performed a successful initialization sequence before User mode accesses (INIT bit in the Status register should be set).

Note that a memory device may need to be clocked when there has been a change in the state of the chip select signal. It is recommended that software transmits a byte with the memory device deselected after entering and before leaving User mode.

The following steps are performed to issue a command to the memory device after the core has been put into User mode:

1. Check Status register and verify that the BUSY and DONE bits are cleared. Also verify that the core is initialized and not in error mode.
2. Optionally enable DONE interrupt by setting the Control register bit IEN.
3. Write command to Transmit register.

4. Wait for interrupt (if enabled) or poll DONE bit in Status register.
5. When the DONE bit is set the core has transferred the command and will have new data available in the Receive register.
6. Clear the Status register's DONE bit by writing one to its position.

The core should not be brought out of User mode until the transfer completes. Accesses to ROM address space will receive an AMBA ERROR response when the core is in User mode and when an operation initiated under User mode is active.

46.2.3 ROM area

The ROM area only supports AMBA read operations. Write or locked access operations will receive AMBA ERROR responses. When a read access is made to the ROM area the core will perform a read operation on the memory device. The system has support for AMBA SPLIT responses and the core will issue command SPLIT the master until the read operation on the memory device has finished.

The AMBA read operation is transfered onto the external SPI interface using the parameters set in the configuration register. The read command bit field determines if normal or fast read is used. The additional bit fields determine the length of address and dummy state. The length of address and dummy bit fields are defined number of bytes.

Next is an example of using normal read. To enable normal read user should use the read command 0x3 and set number of dummy bytes to 0x0.

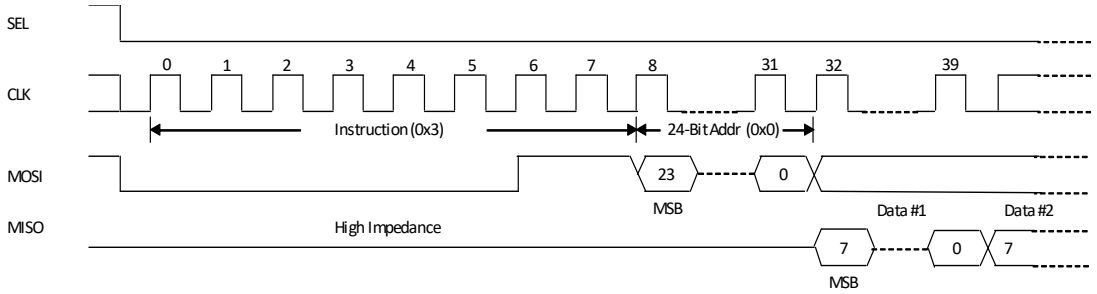


Figure 89. Read Data Bytes (READ) Instruction sequence and Data-Out sequence

Next is an example of using fast read. To enable normal read user should use the read command 0xB and set number of dummy bytes to 0x0 or greater. Note that the dummy byte bit field is set to 0x1 in the example but is set to 0x0 as default. The reason for this is that external SPI PROM might require additional dummy states at 50 MHz to return correct data.

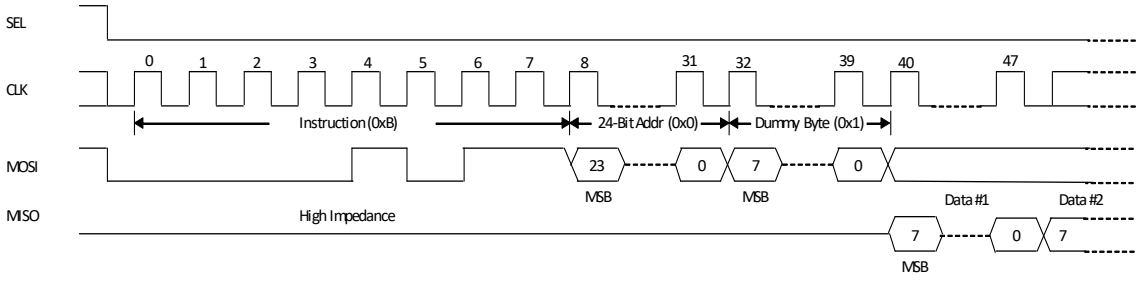


Figure 90. Read Data Bytes at higher speed (FAST_READ) Instruction sequence and Data-Out sequence

The expected read performance is determined by the following factors:

- Scaler mode (CTRL.EAS)

- Number of address bytes used (CONF.ADDRBYTES)
- Fast or normal read mode i.e. number of dummy bytes required (CONF.DUMMYBYTES)
- Number of Data bytes read (AMBA transaction length. Valid length 1,2 or 4 bytes)
- EDAC Enabled (ECONF.EE)
- Internal system delay (approximately 3 SPI clock cycles)

The number of system clocks required for a SPI READ operation can estimated using the formula:

$SPIOP_{ClkCycles}$ = (4 - CONF.ADDRBYTES + CONF.DUMMYBYTES + <NbrOfBytes>) x 8 x (8 - 6 x CTRL.EAS) x (1 + ECONF.EE)

For an 32 bit instruction fetch using normal scaler this would result in approximately 540 system clocks.

BCH EDAC protection requires two consecutive reads from two non-consecutive address i.e. a SPI READ operation with EDAC enabled will require twice as many system clocks to be completed.

46.2.4 BCH EDAC

The SPIMCTRL is provided with an BCH EDAC that can correct one error and detect two errors in a 32-bit word. For each word, a 7-bit checksum is generated according to the equations below. A correctable error will be handled transparently by the memory controller, but adding one waitstate to the access. If an un-correctable error (double-error) is detected, the current AHB cycle will end with an error response. The EDAC can be used during access to SPI Memories areas by setting the EDAC enable bits in the EDAC configuration register. The equations below show how the EDAC checkbits are generated:

```
CB0 = D0 ^ D4 ^ D6 ^ D7 ^ D8 ^ D9 ^ D11 ^ D14 ^ D17 ^ D18 ^ D19 ^ D21 ^ D26 ^ D28 ^ D29 ^ D31
CB1 = D0 ^ D1 ^ D2 ^ D4 ^ D6 ^ D8 ^ D10 ^ D12 ^ D16 ^ D17 ^ D18 ^ D20 ^ D22 ^ D24 ^ D26 ^ D28
CB2 = D0 ^ D3 ^ D4 ^ D7 ^ D9 ^ D10 ^ D13 ^ D15 ^ D16 ^ D19 ^ D20 ^ D23 ^ D25 ^ D26 ^ D29 ^ D31
CB3 = D0 ^ D1 ^ D5 ^ D6 ^ D7 ^ D11 ^ D12 ^ D13 ^ D16 ^ D17 ^ D21 ^ D22 ^ D23 ^ D27 ^ D28 ^ D29
CB4 = D2 ^ D3 ^ D4 ^ D5 ^ D6 ^ D7 ^ D14 ^ D15 ^ D18 ^ D19 ^ D20 ^ D21 ^ D22 ^ D23 ^ D30 ^ D31
CB5 = D8 ^ D9 ^ D10 ^ D11 ^ D12 ^ D13 ^ D14 ^ D15 ^ D24 ^ D25 ^ D26 ^ D27 ^ D28 ^ D29 ^ D30 ^ D31
CB6 = D0 ^ D1 ^ D2 ^ D3 ^ D4 ^ D5 ^ D6 ^ D7 ^ D24 ^ D25 ^ D26 ^ D27 ^ D28 ^ D29 ^ D30 ^ D31
```

Data is always accessed as words (4 bytes at a time) and the corresponding checkbits are located at the address acquired by inverting the word address using it as a byte address. The chip-select is kept active. A word written as four bytes to addresses 0, 1, 2, 3 will have its checkbits at address 0xFFFFFFF, addresses 4, 5, 6, 7 at 0xFFFFFFE and so on. All the bits up to the maximum bank size will be inverted while the same chip-select is always asserted. This way all the bank sizes can be supported and no memory will be unused (except for a maximum of 4 byte in the gap between the data and checkbit area). A read access will automatically read the four data bytes individually from the nominal addresses and the EDAC checkbit byte from the top part of the bank.

Write accesses are not being handled automatically. Instead, write accesses must only be performed as individual word accesses by the software, writing one word at a time, and the corresponding checkbit byte must be calculated and be written to the correct location by the software.

If a correctable EDAC error is detected during a memory read, the ERR bit in the EDAC Status Register is set and. If an uncorrectable EDAC error is detected during a read operation, the MERR bit in the EDAC Status Register will be set and an error response will be generated on the AHB access.

46.3 Registers

The core is programmed through registers mapped into AHB address space.

*Table 623.*SPIMCTRL registers

AHB address offset	Register
0x00	Configuration register
0x04	Control register
0x08	Status register
0x0C	Receive register
0x10	Transmit register
0x14	EDAC configuration register
0x18	EDAC status register

46.3.1 Configuration Register

*Table 624.*0x00 - CONF - Configuration register

31 12	11 10	9 8	7 0
RESERVED	DUMMYBYTES	ADDRBYTES	READCMD
0	0x0	0x0	0x3
r	rw	rw	rw

31 :12 RESERVED

11:10 Use Dummy Byte (DUMMYBYTES) - Insert dummy bytes after last address bytes for higher speed rates i.e. when read instruction bit is set to use FAST read mode. The bit field DUMMYBYTES is the number of dummy bytes that is inserted after the last address byte.

9:8 Reduce number of address bytes (ADDRBYTES) - Default number of address bytes is set to 3.

"00" Use 3 address bytes (Default)

"01" Use 2 address bytes

"10" Use 1 address byte

"11" Use 3 address bytes. Bit field ADDRBYTES will automatically reset back to "00".

7:0 Read instruction (READCMD) - Read instruction that the core will use for reading from the memory device.

46.3.2 Control Register

*Table 625.*0x04 - CTRL - Control register

31 5	4	3	2	1	0
RESERVED	RST	CSN	EAS	IEN	USRC
	0	1	0	0	0
	rw	rw	rw	rw	rw

31 :5 RESERVED

4 Reset core (RST) - By writing ‘1’ to this bit the user can reset the core. This bit is automatically cleared when the core has been reset. Reset core should be used with care. Writing this bit has the same effect as system reset. Any ongoing transactions, both on AMBA and to the SPI device will be aborted.

3 Chip select (CSN) - Controls core chip select signal. This field always shows the level of the core’s internal chip select signal. This bit is always automatically set to ‘1’ when leaving User mode by writing USRC to ‘0’.

2 Enable Alternate Scaler (EAS) - When this bit is set the SPI clock is divided by using the alternate scaler. Set scaler to system clock frequency divided by 4. Default scaler is system clock divided by 16.

1 Interrupt Enable (IEN) - When this bit is set the core will generate an interrupt when a User mode transfer completes.

0 User control (USRC) - When this bit is set to ‘1’ the core will accept SPI data via the transmit register. Accesses to the memory mapped device area will return AMBA ERROR responses.

46.3.3 Status Register

*Table 626.*0x08 - STAT - Status register

31 3	2	1	0
RESERVED	INIT	BUSY	DONE
0	0	0	0
r	r	r	wc

31:3 RESERVED

2 Initialized (INIT) - This read only bit is set to ‘1’ when the SPI memory device has been initialized. Accesses to the ROM area should only be performed when this bit is set to ‘1’.

1 Core busy (BUSY) - This bit is set to ‘1’ when the core is performing an SPI operation.

*Table 626.*0x08 - STAT - Status register

0 Operation done (DONE) - This bit is set to '1' when the core has transferred an SPI command in user mode.

Reset value: 0x00000000

46.3.4 Receive Register

*Table 627.*0x0C - RX - Receive register

31 8	7 0
RESERVED	RDATA
0	nr
R	rw

31 :8 RESERVED

7:0 Receive data (RDATA) : Contains received data byte

Reset value: 0x000000UU, where U is undefined

46.3.5 Transmit Register

*Table 628.*0x10 - TX - Transmit register

31 8	7 0
RESERVED	TDATA
0	0
r	rw

31 :8 RESERVED

7:0 Transmit data (TDATA) - Data byte to transmit

46.3.6 EDAC Configuration Register

*Table 629.*0x14 - ECONF - EDAC Configuration register

31 1	0
RESERVED	EE
0	0x0
r	rw

31 :1 RESERVED

0 Enable EDAC BCH Protection (EE) - Enables BCH protection and correction

46.3.7 EDAC Status Register

*Table 630.*0x18 - ESTAT - EDAC Status register

31 2	1	0
RESERVED	MERR	ERR
0	0x0	0x0
r	rw	rw

31 :2 RESERVED

1 Data word with multiple bit errors has been detected

0 Correctable Errors has been detected

47 AMBA Protection Unit

The GR716 microcontroller comprises two separate AMBA memory protection units (MEMPROT). The MEMPROT units described in this section have the capability to detect and protect memory areas from write accesses.

The first AMBA memory protection units (MEMPROT0) is connected to Main AHB bus and the second AMBA memory protection units (MEMPROT1) is connected to the DMA AMBA bus. Each AMBA memory protection unit has a unique AMBA address described in chapter 2.11 for configuration and status.

The control and status registers for the AMBA memory protection units are located on the APB bus in the address range from 0x80005000 to 0x80005FFF and in the range from 0x8010A000 to 0x8010AFFF. See AMBA memory protection units connections in the next drawing. The figure shows memory locations and functions used for AMBA memory protection units configuration and control.

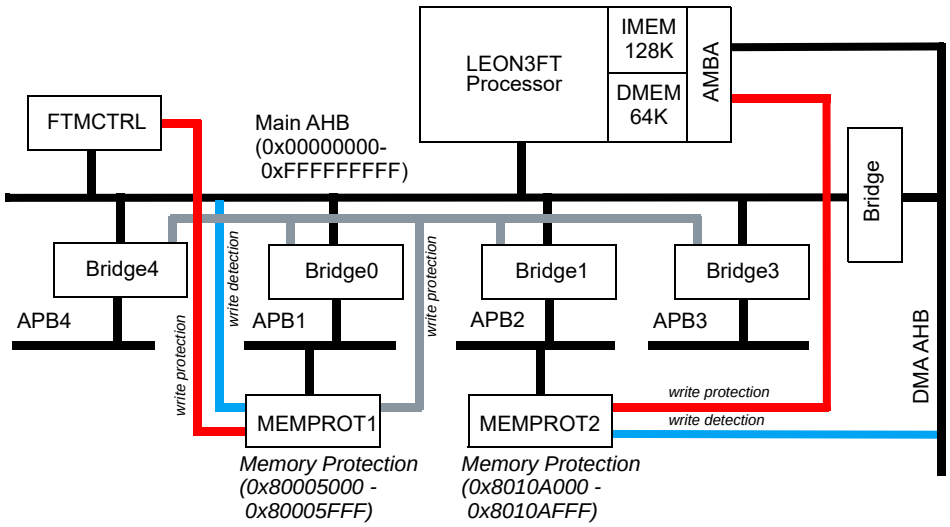


Figure 91. GR716 MEMPROTx bus connection

The primary clock gating unit **GRCLKGATE** described in section 26 is used to enable/disable the AMBA memory protection units. The unit **GRCLKGATE** can also be used to perform reset of individual AMBA memory protection units. Software must enable clock and release reset described in section 26 before configuration.

The system can be configured to protect and restrict access to the AMBA memory protection units.

47.1 Overview

The AMBA Protection unit allows user to define memory segments for protection, memory segments are defined by an start and stop address, to which write permissions can be set. The AMBA protection unit supports up to four individual segments for the system bus and four segments for the dma bus.

The memory protection unit can also restrict write access to individual APB slave interface for specific AHB masters. The restriction needs to be enabled by the user or software. It should be noted that write access to registers in the memory protection can not be restricted to prevent situation where the system can't control APB accesses.

The LEON3FT microcontroller includes 2 separate memory protection units hence register map is split into separate chapters for system and dma bus. The first protection unit monitors masters accesses on the system bus and the second protection unit monitors masters accesses on the DMA bus.

47.2 Operation

The External memory controller, On-chip memory controller and APB controller allows the software to define write protected memory segments, memory segments are defined by a start address and end address, to which write permissions for specific bus masters can be granted or denied. Four segments can be identified with a segment ID between 0 to 3. A segment with a low ID has precedence over one with a high ID, but only if the segment with lower ID is enabled. The precedence or segment ID are only of interests when specified memory area overlaps or bus masters are the same.

Each segment can be configured to grant or deny a write access individually for each AMBA master on the bus. This is done by setting the Enable bits in the relevant Configuration register for the segment.

The protection unit on the main bus provides also access control registers, to manage grants for each master to write in APB slaves on the main bus. They restricts write access to selected APB slaves for each master when the corresponding bit in the corresponding register is set high.

47.3 Registers

The core is programmed through registers mapped into APB address space.

*Table 631.*AHB system and DMA protection configuration and status registers

APB address offset	Registers
Memory Protection Unit for system bus (0x80005000)	
0x80005000	Protection Configuration register
0x80005004	Protection Segment 0 Start Address register
0x80005008	Protection Segment 0 End Address register
0x8000500C	Protection Segment 0 Configuration register
0x80005010	Not used
0x80005014	Protection Segment 1 Start Address register
0x80005018	Protection Segment 1 End Address register
0x8000501C	Protection Segment 1 Configuration register
0x80005020	Not used
0x80005024	Protection Segment 2 Start Address register
0x80005028	Protection Segment 2 End Address register
0x8000502C	Protection Segment 2 Configuration register
0x80005030	Not used
0x80005034	Protection Segment 3 Start Address register
0x80005038	Protection Segment 3 End Address register
0x8000503C	Protection Segment 3 Configuration register
0x80005040 - 0x800050FF	Not used
0x80005100	Access control for CPU and BRIDGE on APB bus 0
0x80005104	Access control for Scrubber on APB bus 0
0x80005108 - 0x8000510F	Not used
0x80005110	Access control for DMA controller #0 and # 1 on APB bus 0
0x80005114	Access control for DMA controller #2 and # 3 on APB bus 0
0x80005118 - 0x8000513F	Not used
0x80005140	Access control for CPU and BRIDGE on APB bus 1
0x80005144	Access control for Scrubber on APB bus 1
0x80005148 - 0x8000514F	Not used
0x80005150	Access control for DMA controller #0 and # 1 on APB bus 1

*Table 631.*AHB system and DMA protection configuration and status registers

APB address offset	Registers
0x80005154	Access control for DMA controller #2 and # 3 on APB bus 1
0x80005158 - 0x8000517F	Not used
0x80005180	Access control for CPU and BRIDGE on APB bus 3
0x80005184	Access control for Scrubber on APB bus 3
0x80005188 - 0x8000518F	Not used
0x80005190	Access control for DMA controller #0 and # 1 on APB bus 3
0x80005194	Access control for DMA controller #2 and # 3 on APB bus 3
0x80005198 - 0x800051BF	Not used
0x800051C0	Access control for CPU and BRIDGE on APB bus 4
0x800051C4	Access control for Scrubber on APB bus 4.
0x800051C8 - 0x800051DF	Not used
0x800051E0	Access control for DMA controller #0 and # 1 on APB bus 4
0x800051E4	Access control for DMA controller #2 and # 3 on APB bus 4
0x800051E8 - 0x80005FFF	Not used
Memory Protection Unit for DMA bus (0x8010A000)	
0x8010A000	Protection Configuration register
0x8010A004	Protection Segment 0 Start Address register
0x8010A008	Protection Segment 0 End Address register
0x8010A00C	Protection Segment 0 Configuration register
0x8010A010	Not used
0x8010A014	Protection Segment 1 Start Address register
0x8010A018	Protection Segment 1 End Address register
0x8010A01C	Protection Segment 1 Configuration register
0x8010A020	Not used
0x8010A024	Protection Segment 2 Start Address register
0x8010A028	Protection Segment 2 End Address register
0x8010A02C	Protection Segment 2 Configuration register
0x8010A030	Not used
0x8010A034	Protection Segment 3 Start Address register
0x8010A038	Protection Segment 3 End Address register
0x8010A03C	Protection Segment 3 Configuration register
0x8010A040 - 0x8010AFFF	Not used

47.3.1 System Protection register description

This chapter specifies access control registers for peripherals and registers accessible 0x40000000 to 0x4FFFFFFF and the range 0x80000000 to 0x8041FFFF.

Table 632. 0x80005000 - PCR - Protection Configuration register

31 24	23 4	3 1	0
NSEG	Reserved	PROT	EN
0x4	0x0	0x0	0
r	r	rw	rw

31: 24 NSEG - Number of segments supported.

23: 4 Reserved

3: 1 PROT - Protection of memory control access. This bit field needs to be set to 101b in order to be able to change any register configuration of the memory protection.

0 EN - Enable Memory Protection of specified memory segments. This is bit is used to enable and disable all protected segments at the same-time.

Table 633. 0x80005004 + segment*0x10 - PSA - Protection Segment Start Address register

31 0
SADDR
0x0
rw

31: 0 SADDR - Start address of segment. Start address should be in the range 0x40000000 to 0x4FFFFFFF and the range 0x80000000 to 0x8041FFFF.

Table 634. 0x80005008 + segment*0x10 - PEA - Protection Segment End Address register

31 0
EADDR
0x0
rw

31: 0 EADDR - End address of segment. End address should be in the range 0x40000000 to 0x4FFFFFFF and the range 0x80000000 to 0x8041FFFF.

Table 635. 0x8000500C + segmant*0x10 - PSC - Protection Segment Control register

31 30 29 28 27 26 25 24 23 22 21 20 19	18	17	16	15 1	0
Reserved	G2	G1	G0	Reserved	EN
0	0	0	0	0	0
r	rw	rw	rw	r	rw

31: 19 RESERVED

18 G2 - Grant SCRUBBER on the main bus exclusive write permission

17 G1 - Grant DMA bus masters exclusive write permission. DMA bus masters can be any master performing accesses on the DMA bus i.e. SpaceWire, CAN, MIL-1553, UART, I2C, PacketWire and/or DMA

16 G0 - Grant LEON3FT processor exclusive write permission

15: 1 RESERVED

0 EN - Enable Memory Protection for specified memory segments. This bit will grant exclusive write permission to specified masters within protected memory segment

47.3.2 Protection register for AMBA APB 0

This chapter specifies access control registers for peripherals and registers accessible 0x80000000 to 0x8000FFFF.

Table 636. 0x80005100 - APB0PROT0 - APB Control 0 Protection register 0

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
C15	C14	C13	C12	C11	C10	C9	C8	C7	C6	C5	C4	C3	C2	C1	C0	B15	B14	B13	B12	B11	B10	B9	B8	B7	B6	B5	B4	B3	B2	B1	B0
0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

31		Memory controller with EDAC (C15)
30		Multi-processor Interrupt Ctrl. (C14)
29	C	Modular Timer Unit 0 (C13)
28	P	Modular Timer Unit 1 (C12)
27	U	Memory Protection Unit for system bus (C11)
26		Clock gating configuration register unit 0 (C10)
25	C	Clock gating configuration register unit 1 (C9)
23	O	Configuration and test registers (C8)
24	N	LEON3 Statistics Unit (C7)
22	T	AHB Status Register (C6)
21	R	On-chip Instruction memory control registers (C5)
20	O	CCSDS TDP / SpaceWire I/F (C4)
19	L	IO Mux configuration register (C3)
18		CCSDS TDP / SpaceWire I/F (C2)
17		Test register used for test purpose (C1)
16		Slave UART configuration (C0)
15		Memory controller with EDAC (B15)
14	B	Multi-processor Interrupt Ctrl. (B14)
13	R	Modular Timer Unit 0 (B13)
12	I	Modular Timer Unit 1 (B12)
11	D	Memory Protection Unit for system bus (B11)
10	G	Clock gating configuration register unit 0 (B10)
9	E	Clock gating configuration register unit 1 (B9)
8		Configuration and test registers (B8)
7	C	LEON3 Statistics Unit (B7)
6	O	AHB Status Register (B6)
5	N	On-chip Instruction memory control registers (B5)
4	T	CCSDS TDP / SpaceWire I/F (B4)
3	R	IO Mux configuration register (B3)
2	L	CCSDS TDP / SpaceWire I/F (B2)
1		Test register used for test purpose (B1)
0		Slave UART configuration (B0)

Table 637. 0x0x80005104 - APB0PROT1 - APB Control 0 Protection register 1

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RESERVED																B15	B14	B13	B12	B11	B10	B9	B8	B7	B6	B5	B4	B3	B2	B1	B0
0x0																0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0
r																rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Table 637. 0x0x80005104 - APB0PROT1 - APB Control 0 Protection register 1

31: 16		Not Used
15		Memory controller with EDAC (B15)
14		Multi-processor Interrupt Ctrl. (B14)
13	S	Modular Timer Unit 0 (B13)
12	C	Modular Timer Unit 1 (B12)
11	R	Memory Protection Unit for system bus (B11)
10	U	Clock gating configuration register unit 0 (B10)
9	B	Clock gating configuration register unit 1 (B9)
8		Configuration and test registers (B8)
7	C	LEON3 Statistics Unit (B7)
6	O	AHB Status Register (B6)
5	N	On-chip Instruction memory control registers (B5)
4	T	CCSDS TDP / SpaceWire I/F (B4)
3	R	IO Mux configuration register (B3)
2	L	CCSDS TDP / SpaceWire I/F (B2)
1		Test register used for test purpose (B1)
0		Slave UART configuration (B0)

Table 638. 0x0x80005110 - APB0PROT2 - APB Control 0 Protection register 2

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
A15	A14	A13	A12	A11	A10	A9	A8	A7	A6	A5	A4	A3	A2	A1	A0	B15	B14	B13	B12	B11	B10	B9	B8	B7	B6	B5	B4	B3	B2	B1	B0
0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

31		Memory controller with EDAC (A15)
30	D	Multi-processor Interrupt Ctrl. (A14)
29	M	Modular Timer Unit 0 (A13)
28	A	Modular Timer Unit 1 (A12)
27	0	Memory Protection Unit for system bus (A11)
26		Clock gating configuration register unit 0 (A10)
25	C	Clock gating configuration register unit 1 (A9)
23	O	Configuration and test registers (A8)
24	N	LEON3 Statistics Unit (A7)
22	T	AHB Status Register (A6)
21	R	On-chip Instruction memory control registers (A5)
20	O	CCSDS TDP / SpaceWire I/F (A4)
19	L	IO Mux configuration register (A3)
18		CCSDS TDP / SpaceWire I/F (A2)
17		Test register used for test purpose (A1)
16		Slave UART configuration (A0)
15		Memory controller with EDAC (B15)
14	D	Multi-processor Interrupt Ctrl. (B14)
13	M	Modular Timer Unit 0 (B13)
12	A	Modular Timer Unit 1 (B12)
11	1	Memory Protection Unit for system bus (B11)
10		Clock gating configuration register unit 0 (B10)
9	C	Clock gating configuration register unit 1 (B9)
8	O	Configuration and test registers (B8)

Table 638. 0x0x80005110 - APB0PROT2 - APB Control 0 Protection register 2

7	N	LEON3 Statistics Unit (B7)
6	T	AHB Status Register (B6)
5	R	On-chip Instruction memory control registers (B5)
4	O	CCSDS TDP / SpaceWire I/F (B4)
3	L	IO Mux configuration register (B3)
2		CCSDS TDP / SpaceWire I/F (B2)
1		Test register used for test purpose (B1)
0		Slave UART configuration (B0)

Table 639. 0x0x80005114 - APB0PROT3 - APB Control 0 Protection register 3

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
A15	A14	A13	A12	A11	A10	A9	A8	A7	A6	A5	A4	A3	A2	A1	A0	B15	B14	B13	B12	B11	B10	B9	B8	B7	B6	B5	B4	B3	B2	B1	B0
0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

31		Memory controller with EDAC (A15)
30	D	Multi-processor Interrupt Ctrl. (A14)
29	M	Modular Timer Unit 0 (A13)
28	A	Modular Timer Unit 1 (A12)
27	2	Memory Protection Unit for system bus (A11)
26		Clock gating configuration register unit 0 (A10)
25	C	Clock gating configuration register unit 1 (A9)
23	O	Configuration and test registers (A8)
24	N	LEON3 Statistics Unit (A7)
22	T	AHB Status Register (A6)
21	R	On-chip Instruction memory control registers (A5)
20	O	CCSDS TDP / SpaceWire I/F (A4)
19	L	IO Mux configuration register (A3)
18		CCSDS TDP / SpaceWire I/F (A2)
17		Test register used for test purpose (A1)
16		Slave UART configuration (A0)
15		Memory controller with EDAC (B15)
14	D	Multi-processor Interrupt Ctrl. (B14)
13	M	Modular Timer Unit 0 (B13)
12	A	Modular Timer Unit 1 (B12)
11	3	Memory Protection Unit for system bus (B11)
10		Clock gating configuration register unit 0 (B10)
9	C	Clock gating configuration register unit 1 (B9)
8	O	Configuration and test registers (B8)
7	N	LEON3 Statistics Unit (B7)
6	T	AHB Status Register (B6)
5	R	On-chip Instruction memory control registers (B5)
4	O	CCSDS TDP / SpaceWire I/F (B4)
3	L	IO Mux configuration register (B3)
2		CCSDS TDP / SpaceWire I/F (B2)
1		Test register used for test purpose (B1)
0		Slave UART configuration (B0)

47.3.3 Protection register for AMBA APB 1

This chapter specifies access control registers for peripherals and registers accessible 0x80100000 to 0x8010FFFF.

Table 640. 0x0x80005140 - APB1PROT0 - APB Control 1 Protection register 0

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
C15	C14	C13	C12	C11	C10	C9	C8	C7	C6	C5	C4	C3	C2	C1	C0	B15	B14	B13	B12	B11	B10	B9	B8	B7	B6	B5	B4	B3	B2	B1	B0
0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

31		GRSPW2 SpaceWire Serial Link (C15)
30		MIL-STD-1553B Interface. (C14)
29	C	CAN Controller with DMA (C13)
28	P	CAN Controller with DMA (C12)
27	U	SPI to AHB Bridge (C11)
26		I2C to AHB Bridge (C10)
25	C	Stand alone DMA unit 0 (C9)
23	O	Stand alone DMA unit 1 (C8)
24	N	Stand alone DMA unit 2 (C7)
22	T	Stand alone DMA unit 3 (C6)
21	R	On-chip Instruction memory control registers (C5)
20	O	Memory protection for DMA bus (C4)
19	L	IO Mux configuration register (C3)
18		PLL control registers (C2)
17		PacketWire Receiver with DMA (C1)
16		PacketWire Transmitter with DMA (C0)
15		GRSPW2 SpaceWire Serial Link (B15)
14	B	MIL-STD-1553B Interface (B14)
13	R	CAN Controller with DMA (B13)
12	I	CAN Controller with DMA (B12)
11	D	SPI to AHB Bridge (B11)
10	G	I2C to AHB Bridge (B10)
9	E	Stand alone DMA unit 0 (B9)
8		Stand alone DMA unit 1 (B8)
7	C	Stand alone DMA unit 2 (B7)
6	O	Stand alone DMA unit 3 (B6)
5	N	Memory protection for DMA bus (B5)
4	T	CCSDS TDP / SpaceWire I/F (B4)
3	R	Brown-Out detection control registers (B3)
2	L	PLL control registers (B2)
1		PacketWire Receiver with DMA (B1)
0		PacketWire Transmitter with DMA (B0)

Table 641. 0x0x80005144 - APB1PROT1 - APB Control 1 Protection register 1

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RESERVED																B15	B14	B13	B12	B11	B10	B9	B8	B7	B6	B5	B4	B3	B2	B1	B0
0x0																0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0
r																rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

Table 641. 0x0x80005144 - APB1PROT1 - APB Control 1 Protection register 1

31: 16		Not Used
15		GRSPW2 SpaceWire Serial Link (B15)
14		MIL-STD-1553B Interface (B14)
13	S	CAN Controller with DMA (B13)
12	C	CAN Controller with DMA (B12)
11	R	SPI to AHB Bridge (B11)
10	U	I2C to AHB Bridge (B10)
9	B	Stand alone DMA unit 0 (B9)
8		Stand alone DMA unit 1 (B8)
7	C	Stand alone DMA unit 2 (B7)
6	O	Stand alone DMA unit 3 (B6)
5	N	Memory protection for DMA bus (B5)
4	T	CCSDS TDP / SpaceWire I/F (B4)
3	R	Brown-Out detection control registers (B3)
2	L	PLL control registers (B2)
1		PacketWire Receiver with DMA (B1)
0		PacketWire Transmitter with DMA (B0)

Table 642. 0x0x80005150 - APB1PROT2 - APB Control 1 Protection register 2

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
A15	A14	A13	A12	A11	A10	A9	A8	A7	A6	A5	A4	A3	A2	A1	A0	B15	B14	B13	B12	B11	B10	B9	B8	B7	B6	B5	B4	B3	B2	B1	B0
0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

31		GRSPW2 SpaceWire Serial Link (C15)
30	D	MIL-STD-1553B Interface. (C14)
29	M	CAN Controller with DMA (C13)
28	A	CAN Controller with DMA (C12)
27	0	SPI to AHB Bridge (C11)
26		I2C to AHB Bridge (C10)
25	C	Stand alone DMA unit 0 (C9)
23	O	Stand alone DMA unit 1 (C8)
24	N	Stand alone DMA unit 2 (C7)
22	T	Stand alone DMA unit 3 (C6)
21	R	On-chip Instruction memory control registers (C5)
20	O	Memory protection for DMA bus (C4)
19	L	IO Mux configuration register (C3)
18		PLL control registers (C2)
17		PacketWire Receiver with DMA (C1)
16		PacketWire Transmitter with DMA (C0)
15		GRSPW2 SpaceWire Serial Link (B15)
14	D	MIL-STD-1553B Interface (B14)
13	M	CAN Controller with DMA (B13)
12	A	CAN Controller with DMA (B12)
11	1	SPI to AHB Bridge (B11)
10		I2C to AHB Bridge (B10)
9	C	Stand alone DMA unit 0 (B9)
8	O	Stand alone DMA unit 1 (B8)

Table 642. 0x0x80005150 - APB1PROT2 - APB Control 1 Protection register 2

7	N	Stand alone DMA unit 2 (B7)
6	T	Stand alone DMA unit 3 (B6)
5	R	Memory protection for DMA bus (B5)
4	O	CCSDS TDP / SpaceWire I/F (B4)
3	L	Brown-Out detection control registers (B3)
2		PLL control registers (B2)
1		PacketWire Receiver with DMA (B1)
0		PacketWire Transmitter with DMA (B0)

Table 643. 0x0x80005154 - APB1PROT3 - APB Control 1 Protection register 3

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
A15	A14	A13	A12	A11	A10	A9	A8	A7	A6	A5	A4	A3	A2	A1	A0	B15	B14	B13	B12	B11	B10	B9	B8	B7	B6	B5	B4	B3	B2	B1	B0
0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

31		GRSPW2 SpaceWire Serial Link (C15)
30	D	MIL-STD-1553B Interface. (C14)
29	M	CAN Controller with DMA (C13)
28	A	CAN Controller with DMA (C12)
27	2	SPI to AHB Bridge (C11)
26		I2C to AHB Bridge (C10)
25	C	Stand alone DMA unit 0 (C9)
23	O	Stand alone DMA unit 1 (C8)
24	N	Stand alone DMA unit 2 (C7)
22	T	Stand alone DMA unit 3 (C6)
21	R	On-chip Instruction memory control registers (C5)
20	O	Memory protection for DMA bus (C4)
19	L	IO Mux configuration register (C3)
18		PLL control registers (C2)
17		PacketWire Receiver with DMA (C1)
16		PacketWire Transmitter with DMA (C0)
15		GRSPW2 SpaceWire Serial Link (B15)
14	D	MIL-STD-1553B Interface (B14)
13	M	CAN Controller with DMA (B13)
12	A	CAN Controller with DMA (B12)
11	3	SPI to AHB Bridge (B11)
10		I2C to AHB Bridge (B10)
9	C	Stand alone DMA unit 0 (B9)
8	O	Stand alone DMA unit 1 (B8)
7	N	Stand alone DMA unit 2 (B7)
6	T	Stand alone DMA unit 3 (B6)
5	R	Memory protection for DMA bus (B5)
4	O	CCSDS TDP / SpaceWire I/F (B4)
3	L	Brown-Out detection control registers (B3)
2		PLL control registers (B2)
1		PacketWire Receiver with DMA (B1)
0		PacketWire Transmitter with DMA (B0)

47.3.4 Protection register for AMBA APB 3

This subsection specifies access control registers for peripherals and registers accessible 0x80000 to 0x8030FFFF.

Table 644. 0x0x80005180 - APB3PROT0 - APB Control 3 Protection register 0

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
C15	C14	C13	C12	C11	C10	R	R	C7	C6	C5	C4	C3	C2	C1	C0	B15	B14	B13	B12	B11	B10	R	R	B7	B6	B5	B4	B3	B2	B1	B0
0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0
rw	rw	rw	rw	rw	rw	r	r	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	r	r	rw	rw	rw	rw	rw	rw	rw	rw

31		Generic UART 0 (C15)
30		Generic UART 1 (C14)
29	C	Generic UART 2 (C13)
28	P	Generic UART 3(C12)
27	U	Generic UART 4 (C11)
26		Generic UART 5 (C10)
25	C	unused
24	O	unused
23	N	External ADC / DAC Interface (C7)
22	T	SPI Controller 0 (C6)
21	R	SPI Controller 1 (C5)
20	O	PWM generator (C4)
19	L	General Purpose I/O port 0 to 31(C3)
18		General Purpose I/O port 32 to 64 (C2)
17		I2C-master 0 (C1)
16		I2C-master 1 (C0)
15		Generic UART 0 (B15)
14	B	Generic UART 1 (B14)
13	R	Generic UART 2 (B13)
12	I	Generic UART 3(B12)
11	D	Generic UART 4 (B11)
10	G	Generic UART 5 (B10)
9	E	unused
8		unused
7	C	External ADC / DAC Interface (B7)
6	O	SPI Controller 0 (B6)
5	N	SPI Controller 1 (B5)
4	T	PWM generator (B4)
3	R	General Purpose I/O port 0 to 31(B3)
2	L	General Purpose I/O port 32 to 64 (B2)
1		I2C-master 0 (B1)
0		I2C-master 1 (B0)

Table 645. 0x0x80005184 - APB3PROT1 - APB Control 3 Protection register 1

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RESERVED																B15	B14	B13	B12	B11	B10	R	R	B7	B6	B5	B4	B3	B2	B1	B0
0x0																0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0
r																rw	rw	rw	rw	rw	rw	r	r	rw	rw	rw	rw	rw	rw	rw	rw

Table 645. 0x0x80005184 - APB3PROT1 - APB Control 3 Protection register 1

31: 16		Not Used
15		Generic UART 0 (B15)
14		Generic UART 1 (B14)
13	S	Generic UART 2 (B13)
12	C	Generic UART 3(B12)
11	R	Generic UART 4 (B11)
10	U	Generic UART 5 (B10)
9	B	unused
8		unused
7	C	External ADC / DAC Interface (B7)
6	O	SPI Controller 0 (B6)
5	N	SPI Controller 1 (B5)
4	T	PWM generator (B4)
3	R	General Purpose I/O port 0 to 31(B3)
2	L	General Purpose I/O port 32 to 64 (B2)
1		I2C-master 0 (B1)
0		I2C-master 1 (B0)

Table 646. 0x0x80005190 - APB3PROT2 - APB Control 3 Protection register 2

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
A15	A14	A13	A12	A11	A10	R	R	A7	A6	A5	A4	A3	A2	A1	A0	B15	B14	B13	B12	B11	B10	R	R	B7	B6	B5	B4	B3	B2	B1	B0
0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0
rw	rw	rw	rw	rw	rw	r	r	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	r	r	rw	rw	rw	rw	rw	rw	rw	rw

31		Generic UART 0 (A15)
30	D	Generic UART 1 (A14)
29	M	Generic UART 2 (A13)
28	A	Generic UART 3 (A12)
27	0	Generic UART 4 (A11)
26		Generic UART 5 (A10)
25	C	unused
23	O	unused
24	N	External ADC / DAC Interface (A7)
22	T	SPI Controller 0 (A6)
21	R	SPI Controller 1 (A5)
20	O	PWM generator (A4)
19	L	General Purpose I/O port 0 to 31 (A3)
18		General Purpose I/O port 32 to 64 (A2)
17		I2C-master 0 (A1)
16		I2C-master 1 (A0)
15		Generic UART 0 (B15)
14	D	Generic UART 1 (B14)
13	M	Generic UART 2 (B13)
12	A	Generic UART 3(B12)
11	1	Generic UART 4 (B11)
10		Generic UART 5 (B10)
9	C	unused
8	O	unused

Table 646. 0x0x80005190 - APB3PROT2 - APB Control 3 Protection register 2

7	N	External ADC / DAC Interface (B7)
6	T	SPI Controller 0 (B6)
5	R	SPI Controller 1 (B5)
4	O	PWM generator (B4)
3	L	General Purpose I/O port 0 to 31(B3)
2		General Purpose I/O port 32 to 64 (B2)
1		I2C-master 0 (B1)
0		I2C-master 1 (B0)

Table 647. 0x0x80005194 - APB3PROT3 - APB Control 3 Protection register 3

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
A15	A14	A13	A12	A11	A10	R	R	A7	A6	A5	A4	A3	A2	A1	A0	B15	B14	B13	B12	B11	B10	R	R	B7	B6	B5	B4	B3	B2	B1	B0
0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0
rw	rw	rw	rw	rw	rw	r	r	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	r	r	rw	rw	rw	rw	rw	rw	rw	rw

31		Generic UART 0 (A15)
30	D	Generic UART 1 (A14)
29	M	Generic UART 2 (A13)
28	A	Generic UART 3 (A12)
27	2	Generic UART 4 (A11)
26		Generic UART 5 (A10)
25	C	unused
23	O	unused
24	N	External ADC / DAC Interface (A7)
22	T	SPI Controller 0 (A6)
21	R	SPI Controller 1 (A5)
20	O	PWM generator (A4)
19	L	General Purpose I/O port 0 to 31 (A3)
18		General Purpose I/O port 32 to 64 (A2)
17		I2C-master 0 (A1)
16		I2C-master 1 (A0)
15		Generic UART 0 (B15)
14	D	Generic UART 1 (B14)
13	M	Generic UART 2 (B13)
12	A	Generic UART 3(B12)
11	3	Generic UART 4 (B11)
10		Generic UART 5 (B10)
9	C	unused
8	O	unused
7	N	External ADC / DAC Interface (B7)
6	T	SPI Controller 0 (B6)
5	R	SPI Controller 1 (B5)
4	O	PWM generator (B4)
3	L	General Purpose I/O port 0 to 31(B3)
2		General Purpose I/O port 32 to 64 (B2)
1		I2C-master 0 (B1)
0		I2C-master 1 (B0)

47.3.5 Protection register for AMBA APB 4

This subsection specifies access control registers for peripherals and registers accessible 0x80400000 to 0x8040FFFF.

Table 648. 0x0x800051C0 - APB4PROT0 - APB Control 4 Protection register 0

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
C15	C14	C13	C12	C11	C10	C9	C8	C7	C6	C5	C4	C3	C2	C1	C0	B15	B14	B13	B12	B11	B10	B9	B8	B7	B6	B5	B4	B3	B2	B1	B0
0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

31		ADC0 (C15)
30		ADC1 (C14)
29	C	ADC2 (C13)
28	P	ADC3 (C12)
27	U	ADC4 (C11)
26		ADC5 (C10)
25	C	ADC6 (C9)
24	O	ADC7 (C8)
23	N	DAC0 (C7)
22	T	DAC1 (C6)
21	R	DAC2 (C5)
20	O	DAC3 (C4)
19	L	I2C-slave 0 (C3)
18		I2C-slave 1 (C2)
17		PWM generator 1 (C1)
16		SPI for Space slave (C0)
15		ADC0 (B15)
14	B	ADC1 (B14)
13	R	ADC2 (B13)
12	I	ADC3 (B12)
11	D	ADC4 (B11)
10	G	ADC5 (B10)
9	E	ADC6 (B9)
8		ADC7 (B8)
7	C	DAC0 (B7)
6	O	DAC1 (B6)
5	N	DAC2 (B5)
4	T	DAC3 (B4)
3	R	I2C-slave 0 (B3)
2	L	I2C-slave 1 (B2)
1		PWM generator 1 (B1)
0		SPI for Space slave (B0)

Table 649. 0x0x800051C4 - APB4PROT1 - APB Control 3 Protection register 1

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
RESERVED																B15	B14	B13	B12	B11	B10	B9	B8	B7	B6	B5	B4	B3	B2	B1	B0
0x0																0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0
r																rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

31: 16	Not Used

Table 649. 0x0x800051C4 - APB4PROT1 - APB Control 3 Protection register 1

15		ADC0 (B15)
14		ADC1 (B14)
13	S	ADC2 (B13)
12	C	ADC3 (B12)
11	R	ADC4 (B11)
10	U	ADC5 (B10)
9	B	ADC6 (B9)
8		ADC7 (B8)
7	C	DAC0 (B7)
6	O	DAC1 (B6)
5	N	DAC2 (B5)
4	T	DAC3 (B4)
3	R	I2C-slave 0 (B3)
2	L	I2C-slave 1 (B2)
1		PWM generator 1 (B1)
0		SPI for Space slave (B0)

Table 650. 0x0x800051E0 - APB4PROT2 - APB Control 4 Protection register 2

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
A15	A14	A13	A12	A11	A10	A9	A8	A7	A6	A5	A4	A3	A2	A1	A0	B15	B14	B13	B12	B11	B10	B9	B8	B7	B6	B5	B4	B3	B2	B1	B0
0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

31		ADC0 (B15)
30	D	ADC1 (B14)
29	M	ADC2 (B13)
28	A	ADC3 (B12)
27	0	ADC4 (B11)
26		ADC5 (B10)
25	C	ADC6 (B9)
23	O	ADC7 (B8)
24	N	DAC0 (B7)
22	T	DAC1 (B6)
21	R	DAC2 (B5)
20	O	DAC3 (B4)
19	L	I2C-slave 0 (B3)
18		I2C-slave 1 (B2)
17		PWM generator 1 (B1)
16		SPI for Space slave (B0)
15		ADC0 (B15)
14	D	ADC1 (B14)
13	M	ADC2 (B13)
12	A	ADC3 (B12)
11	1	ADC4 (B11)
10		ADC5 (B10)
9	C	ADC6 (B9)
8	O	ADC7 (B8)
7	N	DAC0 (B7)
6	T	DAC1 (B6)

Table 650. 0x0x800051E0 - APB4PROT2 - APB Control 4 Protection register 2

5	R	DAC2 (B5)
4	O	DAC3 (B4)
3	L	I2C-slave 0 (B3)
2		I2C-slave 1 (B2)
1		PWM generator 1 (B1)
0		SPI for Space slave (B0)

Table 651. 0x0x800051E4 - APB4PROT3 - APB Control 4 Protection register 3

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
A15	A14	A13	A12	A11	A10	A9	A8	A7	A6	A5	A4	A3	A2	A1	A0	B15	B14	B13	B12	B11	B10	B9	B8	B7	B6	B5	B4	B3	B2	B1	B0
0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0	0x0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

31		ADC0 (B15)
30	D	ADC1 (B14)
29	M	ADC2 (B13)
28	A	ADC3 (B12)
27	2	ADC4 (B11)
26		ADC5 (B10)
25	C	ADC6 (B9)
23	O	ADC7 (B8)
24	N	DAC0 (B7)
22	T	DAC1 (B6)
21	R	DAC2 (B5)
20	O	DAC3 (B4)
19	L	I2C-slave 0 (B3)
18		I2C-slave 1 (B2)
17		PWM generator 1 (B1)
16		SPI for Space slave (B0)
15		ADC0 (B15)
14	D	ADC1 (B14)
13	M	ADC2 (B13)
12	A	ADC3 (B12)
11	3	ADC4 (B11)
10		ADC5 (B10)
9	C	ADC6 (B9)
8	O	ADC7 (B8)
7	N	DAC0 (B7)
6	T	DAC1 (B6)
5	R	DAC2 (B5)
4	O	DAC3 (B4)
3	L	I2C-slave 0 (B3)
2		I2C-slave 1 (B2)
1		PWM generator 1 (B1)
0		SPI for Space slave (B0)

47.3.6 DMA protection register description

This chapter specifies access control registers for peripherals and registers accessible 0x30000000 to 0x31FFFFFF.

Table 652. 0x8010A000 - PCR - Protection Configuration register

31 24	23 4	3 1	0
NSEG	Reserved	PROT	EN
0x4	0x0	0x0	1
r	r	rw	rw

31: 24 NSEG - Number of segments supported.

23: 4 Reserved

3: 1 PROT - Protection of memory control access. This bit field needs to be set to 101b in order to be able to change any register configuration of the memory protection.

0 EN - Enable Memory Protection of specified memory segments. This is bit can be used to enable and disable all protected segments at the same-time. This bit is enabled at startup and individual segment can be controlled via separate segment control registers

Table 653. 0x8010A004 + segment*0x10 - PSA - Protection Segment Start Address register

31 0
SADDR
0x0
rw

31: 0 SADDR - Start address of segment. Start address should be in the range 0x30000000 to 0x31FFFFFF.

Table 654. 0x8010A5008 + segment*0x10 - PEA - Protection Segment End Address register

31 0
EADDR
0x0
rw

31: 0 EADDR - End address of segment. End address should be in the range 0x30000000 to 0x31FFFFFF.

Table 655. 0x8010A00C + segmant*0x10 - PSC - Protection Segment Control register

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15 ... 1	0
G15	G14	G13	G12	G11	G10	G9	G8	G7	G6	G5	G4	G3	G2	G1	G0	Reserved	EN
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	r	rw

31	G15 - Grant SPI4S on the DMA bus exclusive write permission
30	G14 - Grant DMA controller #3 on the DMA bus exclusive write permission
29	G13 - Grant DMA controller #2 on the DMA bus exclusive write permission
28	G12 - Grant DMA controller #1 on the DMA bus exclusive write permission
27	G11 - Grant DMA controller #0 on the DMA bus exclusive write permission
26	G10 - Grant PacketWire transmitter on the DMA bus exclusive write permission
25	G9 - Grant PacketWire receiver on the DMA bus exclusive write permission
24	G8 - Grant Bridge from System bus exclusive write permission.
23	G7 - Grant UART on the DMA bus exclusive write permission
22	G6 - Grant CAN on the DMA bus exclusive write permission
21	G5 - Grant CAN on the DMA bus exclusive write permission
20	G4 - Grant I2C on the DMA bus exclusive write permission
19	G3 - Grant SPI on the DMA bus exclusive write permission
18	G2 - Grant SpaceWire on the DMA bus exclusive write permission
17	G1 - Grant MIL-1553 on the DMA bus exclusive write permission.
16	G0 - Grant Bridge from Debug bus exclusive write permission.
15: 1	RESERVED
0	EN - Enable Memory Protection for specified memory segments. This bit will grant exclusive write permission to specified masters within protected memory segment

47.4 Example of configure and use the Memory protection

This chapter gives examples how of the memory protection unit can be used

47.4.1 Protect local instruction memory

To protect the local instruction memory from any erroneously writes during normal operation the protected area start and stop address should be specified and the master given access to the protected area: (For this example we use segment number #0 but any segment can be used for protection)

PSA0.SADDR = 0x31000000
PSA0.SADDR = 0x3100FFFF
PSAC0.GRANT = 0x0000
PSAC0.EN = 0x1
PCR.EN = 0x1

This example defines the protected area, grants no master access to the area and enable segment end global protection.

47.4.2 Protect external SRAM memory

To protect an area in the external SRAM memory from any erroneously writes during normal operation the protected area start and stop address should be specified and the master given access to the protected area: (For this example we use segment number #0 but any segment can be used for protection)

PSA0.SADDR = 0x40100000

PSA0.SADDR = 0x401FFFFF
PSAC0.GRANT = 0x0000
PSAC0.EN = 0x1
PCR.EN = 0x1

This example defines the protected area, grants no master access to the area and enable segment end global protection.

To give a AMBA master access to the protected area change the value in the register PSAC0.GRANT to e.g. 0x0002 to give access to masters accessing the system AMBA bus via the AHB2AHB bridge from the DMA AMBA bus.

47.4.3 Protect clock gating unit from erroneous accesses

To protect the clock gating from erroneous access the APB bridge can be programmed to deny all write accesses or to grant privilege access to specific AMBA bus masters.

The clock gating unit 1 and 2 are located on APB bus 1 and access to clock gating unit 1 and 2 are controlled via register APB0PROT0, APB1PROT1, APBPROT2 and APBPROT3.

To deny all DMA controllers access:

APB1PROT2.A9 = 0x1
APB1PROT2.A10 = 0x1
APB1PROT2.B9 = 0x1
APB1PROT2.B10 = 0x1
APB1PROT3.A9 = 0x1
APB1PROT3.A10 = 0x1
APB1PROT3.B9 = 0x1
APB1PROT3.B10 = 0x1

48 Serial Debug and remote access Interface

The GR716 microcontroller comprises two Debug UART units. The UART units described in this section have the capability to respond on external UART singling and act as a master on the internal bus without software support. The capability to respond to external access without software support differentiates the two debug UART units from the regular UART units described in chapter 18.

The first serial debug unit (AHBUART0) is directly connected to AMBA debug bus and the second serial debug unit (AHBUART1) is connected to the DMA AMBA bus. Each Serial Debug unit have a unique AMBA address described in chapter 2.11 for configuration and status.

The first unit is the main debug interface during software development and have direct access to the internal state of the processor and trace buffers. This interface can be disabled during mission via external pin configuration i.e. tie DSU_EN to low.

The second serial debug interface unit is to be used for remote access of the GR716 microcontroller in mission mode i.e. when DSU_EN is low. The second unit is available via the IO switch matrix described in chapter 2.5. The second UART debug unit is setup via boot straps.

The control and status register for the serial debug interface units are located on APB bus in the address range from 0x8000F000 to 0x8000FFFF and in the range from 0x94000000 to 0x9400FFF. See serial debug interface units connections in the next drawing. The figure shows memory locations and functions used for serial debug interface units configuration and control.

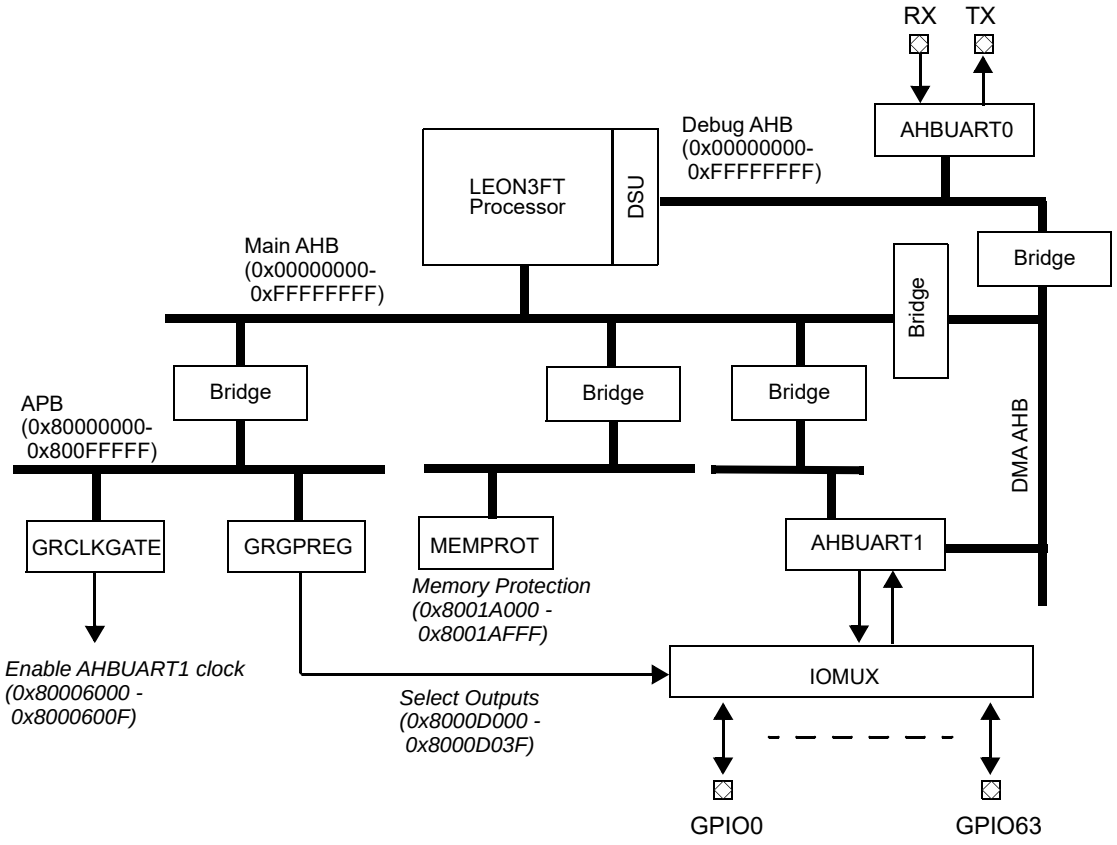


Figure 92. GR716 AHBUARTx bus and pin connection

The primary clock gating unit **GRCLKGATE** described in section 26 is used to enable/disable the AHBUART1. The unit **GRCLKGATE** can also be used to perform reset of the AHBUART1 unit. Software must enable clock and release reset described in section 26 before configuration and transmission can start.

External IO selection and configuration is made in the system IO configuration registers (**GRG-PREG**) in the address range from 0x8000D000 to 0x8000D03F. See section 7.1

The system can be configured to protect and restrict access to the AHBUART1 unit in the **MEM-PROT** unit. For more information See section 47 for more information.

48.1 Overview

Each UART debug interface consists of a UART connected to the AMBA AHB bus as a master. A simple communication protocol is supported to transmit access parameters and data. Through the communication link, a read or write transfer can be generated to any address on the AMBA AHB bus.

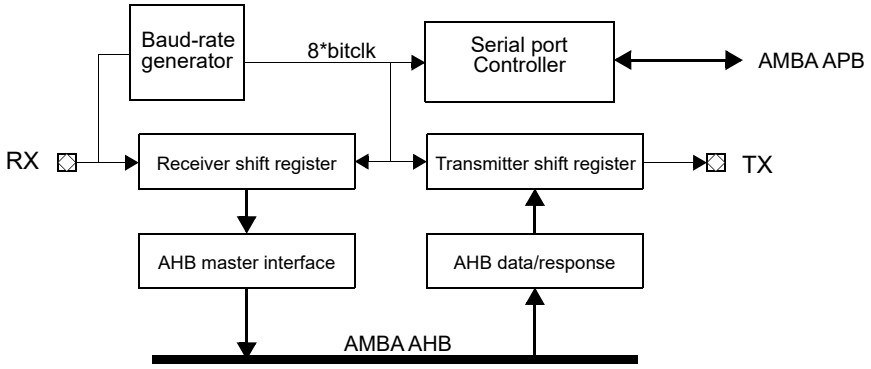


Figure 93. Block diagram

48.2 Operation

48.2.1 Transmission protocol

The interface supports a simple protocol where commands consist of a control byte, followed by a 32-bit address, followed by optional write data. Write access does not return any response, while a read access only returns the read data. Data is sent on 8-bit basis as shown below.

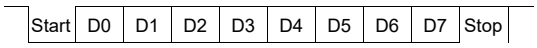


Figure 94. Data frame

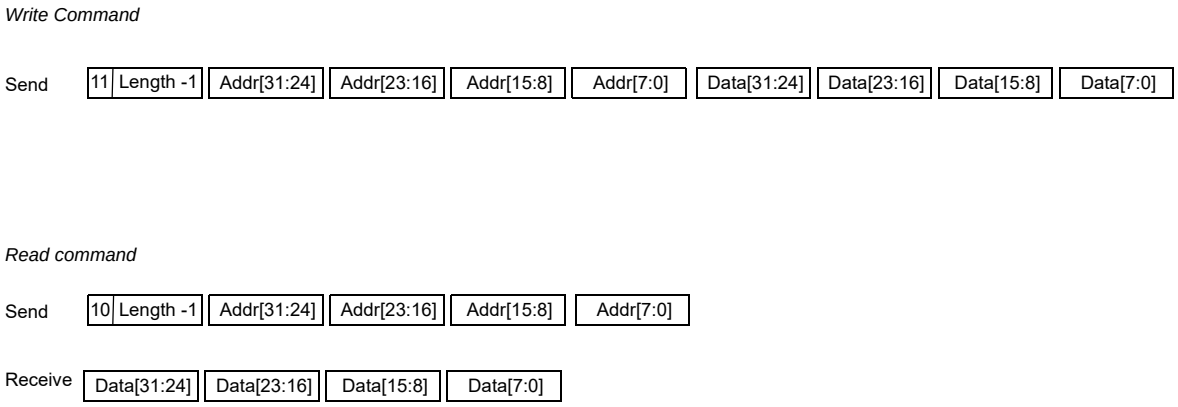


Figure 95. Commands

Block transfers can be performed be setting the length field to n-1, where n denotes the number of transferred words. For write accesses, the control byte and address is sent once, followed by the number of data words to be written. The address is automatically incremented after each data word. For read accesses, the control byte and address is sent once and the corresponding number of data words is returned.

48.2.2 Baud rate generation

The UART contains a 18-bit down-counting scaler to generate the desired baud-rate. The scaler is clocked by the system clock and generates a UART tick each time it underflows. The scaler is reloaded with the value of the UART scaler reload register after each underflow. The resulting UART tick frequency should be 8 times the desired baud-rate.

If not programmed by software, the baud rate will be automatically discovered. This is done by searching for the shortest period between two falling edges of the received data (corresponding to two bit periods). When three identical two-bit periods has been found, the corresponding scaler reload value is latched into the reload register, and the BL bit is set in the UART control register. If the BL bit is reset by software, the baud rate discovery process is restarted. The baud-rate discovery is also restarted when a 'break' or framing error is detected by the receiver, allowing to change to baudrate from the external transmitter. For proper baudrate detection, the value 0x55 should be transmitted to the receiver after reset or after sending break.

The best scaler value for manually programming the baudrate can be calculated as follows:

```
scaler = (((system_clk*10)/(baudrate*8))-5)/10
```

48.3 Registers

The core is programmed through registers mapped into APB address space.

*Table 656.*AHB UART registers

APB address offset	Register
0x4	AHB UART status register
0x8	AHB UART control register
0xC	AHB UART scaler register

48.3.1 AHB UART control register

*Table 657.*0x08 - CTRL - AHB UART control register

31 … 2	1	2
RESERVED	BL	EN
0	0	0
r	r	rw

0: Receiver enable (EN) - if set, enables both the transmitter and receiver. Reset value: ‘0’.

1: Baud rate locked (BL) - is automatically set when the baud rate is locked. Reset value: ‘0’.

48.3.2 AHB UART status register

*Table 658.*0x04 - STAT - AHB UART status register

31 … 10	9 … 8	7	6	5	4	3	2	1	0
RESERVED	TCNT	RX	FE	R	OV	BR	TH	TS	DR
0	0	MR	0	0	0	0	1	1	0
r	r	r	rw	r	rw	rw	r	r	r

0: Data ready (DR) - indicates that new data has been received by the AMBA AHB master interface. Read only. Reset value: ‘0’.

1: Transmitter shift register empty (TS) - indicates that the transmitter shift register is empty. Read only. Reset value: ‘1’

2: Transmitter hold register empty (TH) - indicates that the transmitter hold register is empty. Read only. Reset value: ‘1

3: Break (BR) - indicates that a BREAKE has been received. Reset value: ‘0’

4: Overflow (OV) - indicates that one or more character have been lost due to receiver overflow. Reset value: ‘0’

6: Frame error (FE) - indicates that a framing error was detected. Reset value: ‘0’

7: Input state (RX) - Filtered input state

9: 8 Counter State (TCNT) - Internal Counter state

48.3.3 AHB UART scaler register

*Table 659.*0x0C - SCALER - AHB UART scaler register

31 … 18	17 … 0
RESERVED	SCALER RELOAD VALUE
0	0x3FFFB
r	rw

17: 0 Baudrate scaler reload value = (((system_clk*10)/(baudrate*8))-5)/10. Reset value: “3FFFF“.

49 AHB Status Registers

The GR716 microcontroller have 2 separate AHB Status Register units (AHBSTAT).

The 2 separate AHB Status Register units AHBSTAT0 and AHBSTAT1 monitors the DMA bus and the system bus respectively for accesses triggering an error response.

Each AHB Status Register unit (AHBSTATx) have a unique AMBA address described in chapter 2.11 for configuration and status.

The AHB Status Register units are located on APB bus in the address range from 0x8000A000 to 0x8000AFFF and 0x80306000 to 0x80306FFF.

See units connections in the next drawing. The drawing picture memory locations and functions used for configuration and control.

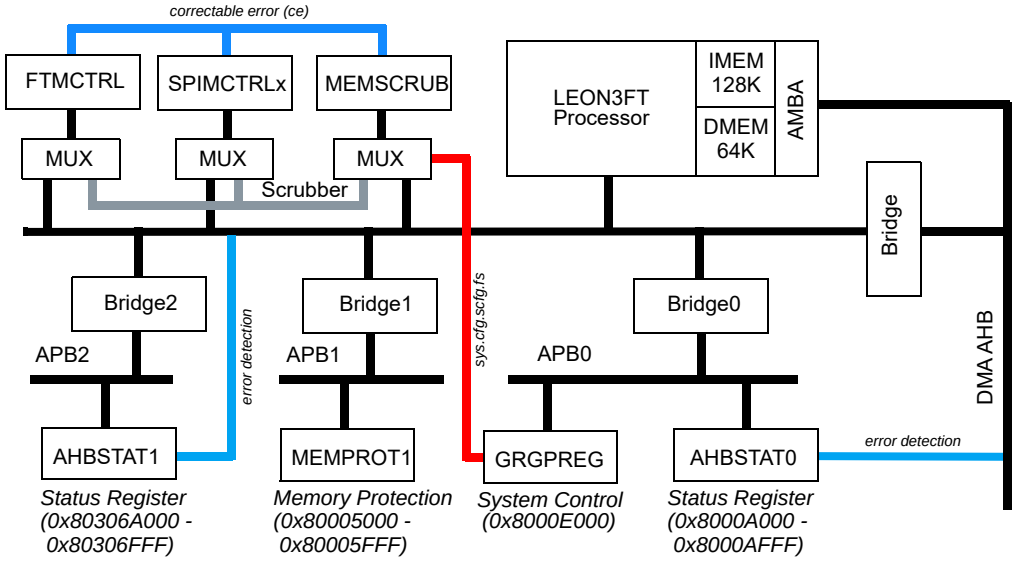


Figure 96. GR716 Status Register bus connection

AHBSTAT unit 0 and 1 has identical configuration and status register. Configuration and status registers are describe in this section 49.3.

System can be configured to protect and restrict access to individual AHBSTAT units in the **MEMPROT** unit. See section 47 for more information.

49.1 Overview

The status registers store information about AMBA AHB accesses triggering an error response. There is a status register and a failing address register capturing the control and address signal values of a failing AMBA bus transaction, or the occurrence of a correctable error being signaled from a fault tolerant core.

49.2 Operation

49.2.1 Errors

The registers monitor AMBA AHB bus transactions and store the current HADDR, HWRITE, HMASTER and HSIZE internally. The monitoring are always active after startup and reset until an error response (HRESP = “01”) is detected. When the error is detected, the status and address register

contents are frozen and the New Error (NE) bit is set to one. At the same time an interrupt is generated, as described hereunder.

Note that many of the fault tolerant units containing EDAC signal an un-correctable error as an AMBA error response, so that it can be detected by the processor as described above.

49.2.2 Correctable errors

Not only error responses on the AHB bus can be detected. Many of the fault tolerant units containing EDAC have a correctable error signal which is asserted each time a correctable error is detected. When such an error is detected, the effect will be the same as for an AHB error response. The only difference is that the Correctable Error (CE) bit in the status register is set to one when a correctable error is detected.

When the CE bit is set the interrupt routine can acquire the address containing the correctable error from the failing address register and correct it. When it is finished it resets the NE bit and the monitoring becomes active again. Interrupt handling is described in detail hereunder.

49.2.3 Interrupts

The interrupt is connected to the interrupt controller to inform the processor of the error condition. The normal procedure is that an interrupt routine handles the error with the aid of the information in the status registers. When it is finished it resets the NE bit and the monitoring becomes active again. Interrupts are generated for both AMBA error responses and correctable errors as described above.

49.3 Registers

The core is programmed through registers mapped into APB address space.

*Table 660.*AHB Status registers

APB address offset	Registers
AHB Status Register unit #1 (AHBSTAT1)	
0x8000A000	AHB Status register
0x8000A004	AHB Failing address register
AHB Status Register unit #1 (AHBSTAT2)	
0x80306000	AHB Status register
0x80306004	AHB Failing address register

49.3.1 AHB Status register

Table 661. 0x00 - AHBS - AHB Status register

31 10	9	8	7 6	3	2 0
RESERVED	CE	NE	HWRITE	HMASTER	HSIZE
0	0	0	NR	NR	NR
r	rn	rn	r	r	r

31: 10	RESERVED
9	CE: Correctable Error. Set if the detected error was caused by a correctable error and zero otherwise.
8	NE: New Error. Deasserted at start-up and after reset. Asserted when an error is detected. Reset by writing a zero to it.
7	The HWRITE signal of the AHB transaction that caused the error.
6: 3	The HMASTER signal of the AHB transaction that caused the error.
2: 0	The HSIZE signal of the AHB transaction that caused the error

49.3.2 AHB Failing address register

*Table 662.*0x04 - AHBFAR - AHB Failing address register

31 0
AHB FAILING ADDRESS
NR
t

31: 0	The HADDR signal of the AHB transaction that caused the error.

50 Trace buffer

The GR716 microcontroller have 2 separate AMBA trace buffer (AHBTRACE) units. The AHB-TRACE units described in this section have the capability to trace all transactions on the main AHB bus and Debug AHB bus.

The first AMBA trace buffer (AHBTRACE0) is tracing the Main AHB bus and the second AMBA trace buffer (AHBTRACE1) is tracing the DMA AMBA bus. Each AMBA trace buffer (AHB-TRACE) unit have a unique AMBA address described in chapter 2.11 for configuration and status.

The control and status register for the AMBA trace buffer units are located on AHB bus in the address range from 0x90000000 to 0x907FFFFF and in the range from 0x9FF20000 to 0x9FF3FFFF. See AMBA memory protection units connections in the next drawing. The drawing picture memory locations and functions used for AMBA memory protection units configuration and control.

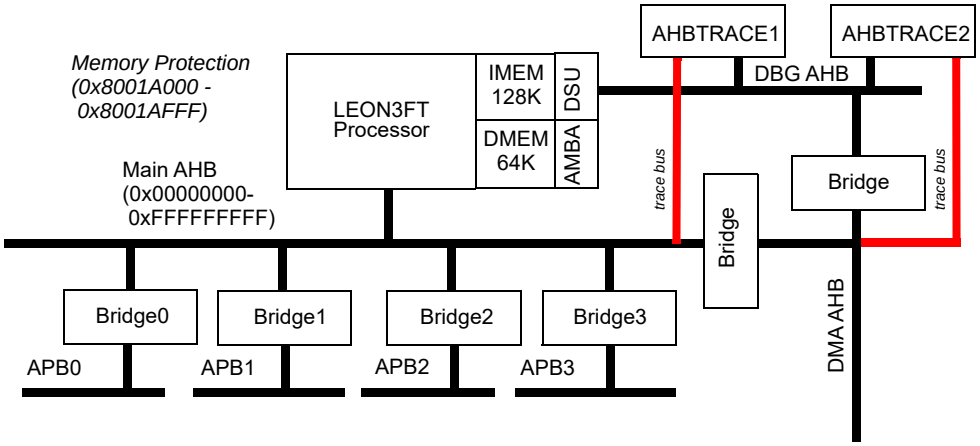


Figure 97. GR716 AHBTRACEx bus and pin connection

AHBTRACE unit 0 and 1 has identical configuration and status register. Configuration and status registers for AHBTRACE1 are describe in this section 50.4 and register for AHBTRACE0 is embedded into DSU3 described in section 19.7.

50.1 Overview

The trace buffer consists of a circular buffer that stores AMBA AHB data transfers. The user can select to trace the main bus, DMA bus, Debug bus or Scrubber bus. The address, data and various control signals of the selected AHB bus are stored and can be read out for later analysis.

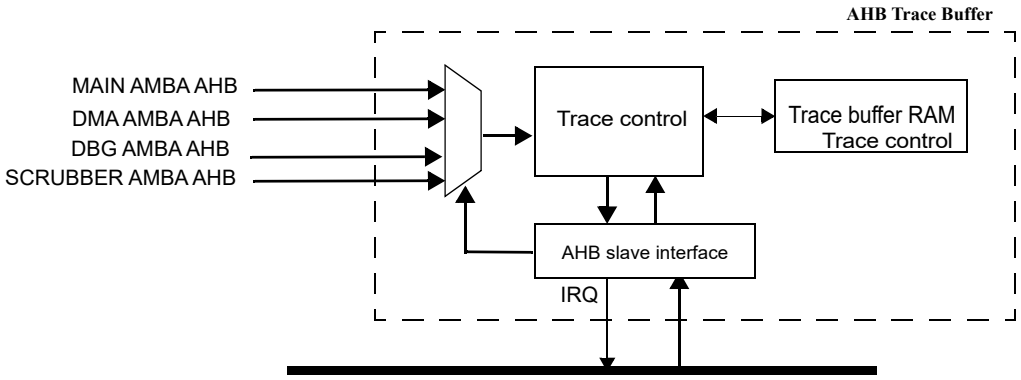


Figure 98. Block diagram

When the trace buffer is configured to store the information as indicated in the table below:

*Table 663.*AHB Trace buffer data allocation

Bits	Name	Definition
127:96	Time tag	The value of the time tag counter
95	AHB breakpoint hit	Set to '1' if a DSU AHB breakpoint hit occurred.
94:80	-	Not used
79	Hwrite	AHB HWRITE
78:77	Htrans	AHB HTRANS
76:74	Hsize	AHB HSIZE
73:71	Hburst	AHB HBURST
70:67	Hmaster	AHB HMASTER
66	Hmastlock	AHB HMASTLOCK
65:64	Hresp	AHB HRESP
63:32	Load/Store data	AHB HRDATA[31:0] or HWDATA[31:0]
31:0	Load/Store address	AHB HADDR

In addition to the AHB signals, a 32-bit counter is also stored in the trace as time tag.

50.2 Operation

50.2.1 Overview

The trace buffer is enabled by setting the enable bit (EN) in the trace control register. Each AMBA AHB transfer is then stored in the buffer in a circular manner. The address to which the next transfer is written is held in the trace buffer index register, and is automatically incremented after each transfer. Tracing is stopped when the EN bit is reset, or when a AHB breakpoint is hit. An interrupt is generated when a breakpoint is hit.

50.2.2 AHB statistics

The trace module generates statistics from the traced AHB bus. Statistics is collected and output to LEON statistics unit (L3STAT). The statistical outputs can be filtered by the AHB trace buffer filters, this is controlled by the Performance counter Filter bit (PF) in the AHB trace buffer control register. The core can collect data for the events listed in table 664 below.

*Table 664.*AHB events

Event	Description	Note
idle	HTRANS=IDLE	Active when HTRANS IDLE is driven on the AHB slave inputs and slave has asserted HREADY.
busy	HTRANS=BUSY	Active when HTRANS BUSY is driven on the AHB slave inputs and slave has asserted HREADY.
nseq	HTRANS=NONSEQ	Active when HTRANS NONSEQ is driven on the AHB slave inputs and slave has asserted HREADY.
seq	HTRANS=SEQ	Active when HTRANS SEQUENTIAL is driven on the AHB slave inputs and slave has asserted HREADY.
read	Read access	Active when HTRANS is SEQUENTIAL or NON-SEQUENTIAL, slave has asserted HREADY and the HWRITE input is low.
write	Write access	Active when HTRANS is SEQUENTIAL or NON-SEQUENTIAL, slave has asserted HREADY and the HWRITE input is high.

*Table 664.*AHB events

Event	Description	Note
hsize[5:0]	Transfer size	Active when HTRANS is SEQUENTIAL or NON-SEQUENTIAL, slave has asserted HREADY and HSIZE is BYTE (hsize[0]), HWORD (HSIZE[1]), WORD (hsize[2]), DWORD (hsize[3]), 4WORD hsize[4], or 8WORD (hsize[5]).
ws	Wait state	Active when HREADY input to AHB slaves is low and AMBA response is OKAY.
retry	RETRY response	Active when master receives RETRY response
split	SPLIT response	Active when master receives SPLIT response
spdel	SPLIT delay	Active during the time a master waits to be granted access to the bus after reception of a SPLIT response. The core will only keep track of one master at a time. This means that when a SPLIT response is detected, the core will save the master index. This event will then be active until the same master is re-allowed into bus arbitration and is granted access to the bus. This also means that the delay measured will include the time for re-arbitration, delays from other ongoing transfers and delays resulting from other masters being granted access to the bus before the SPLIT:ed master is granted again after receiving SPLIT complete. If another master receives a SPLIT response while this event is active, the SPLIT delay for the second master will not be measured.
locked	Locked access	Active while the HMASTLOCK signal is asserted on the AHB slave inputs. (Currently not used by L3STATand L4STAT)

50.3 Using the AHB trace buffer

The debug monitor GRMON3 has build-in support for using AHB trace buffer. For more information see chapter for using the trace buffer in the GRMON3 User's Manual [GRMON3].

50.4 Registers

50.4.1 Register address map

The trace buffer occupies 128 KiB of address space in the AHB I/O area.The following register addresses are decoded:

*Table 665.*Trace buffer address space

Address	Register
0x000000	Trace buffer control register
0x000004	Trace buffer index register
0x000008	Time tag counter
0x00000C	Trace buffer master/slave filter register
0x000010	AHB break address 1
0x000014	AHB mask 1
0x000018	AHB break address 2
0x00001C	AHB mask 2
0x010000 - 0x020000	Trace buffer
...0	Trace bits 127 - 96
...4	Trace bits 95 - 64
...8	Trace bits 63 - 32
...C	Trace bits 31 - 0

50.4.2 Trace buffer control register

The trace buffer is controlled by the trace buffer control register:

*Table 666.*0x000000 - CTRL - Trace buffer control register

31 23	22 16	15	14 12	11 9	8	7 6	5	4	3	2	1	0
RESERVED	DCNT	BA	BSEL	RESERVED	PF	BW	RF	AF	FR	FW	DM	EN
0	0	1	0	0	0	*	0	0	0	0	0	*
r	rw	r	rw	r	rw	r	rw	rw	rw	rw	r	rw

31: 23 RESERVED

22: 16 Trace buffer delay counter (DCNT)

15 Bus select Available (BA) - Set to ‘1’ to indicate that the core has several buses connected. The bus to trace is selected via the BSEL field.

14: 12 Bus select (BSEL)
"000" - Main AHB Bus
"001" - DMA AHB bus
"010" - Debug AHB bus
"011" - Scrubber AHB bus

11: 9 RESERVED

8 Performance counter Filter (PF) - If this bit is set to ‘1’, the cores performance counter (statistical) outputs will be filtered using the same filter settings as used for the trace buffer. If a filter inhibits a write to the trace buffer, setting this bit to ‘1’ will cause the same filter setting to inhibit the pulse on the statistical output.

7: 6 Bus width (BW) - This value corresponds to log2(Supported bus width / 32)

5 Retry filter (RF) - If this bit is set to ‘1’, AHB retry responses will not be included in the trace buffer.

4 Address Filter (AF) - If this bit is set to ‘1’, only the address range defined by AHB trace buffer breakpoint 2’s address and mask will be included in the trace buffer.

3 Filter Reads (FR) - If this bit is set to ‘1’, read accesses will not be included in the trace buffer.

2 Filter Writes (FW) - If this bit is set to ‘1’, write accesses will not be included in the trace buffer.

*Table 666.*0x000000 - CTRL - Trace buffer control register

1	Delay counter mode (DM) - Indicates that the trace buffer is in delay counter mode.
0	Trace enable (EN) - Enables the trace buffer

50.4.3 Trace buffer index register

The trace buffer index register indicates the address of the next 128-bit line to be written.

*Table 667.*0x000004 - INDEX - Trace buffer index register

31 11	10 4	3 0
RESERVED	INDEX	0x0
0	NR	0
r	rw	r

31: 11	RESERVED
10: 4	Trace buffer index counter (INDEX).
3: 0	Read as 0x0

50.4.4 Trace buffer time tag register

The time tag register contains a 32-bit counter that increments each clock when the trace buffer is enabled. The value of the counter is stored in the trace to provide a time tag.

*Table 668.*0x000008 - TIMETAG - Trace buffer time tag counter

31 0
TIME TAG VALUE
0
r

50.4.5 Trace buffer master/slave filter register

The master/slave filter register allows filtering out specified master and slaves from the trace.

*Table 669.*Trace buffer master/slave filter register

31 16	15 0
SMASK[15:0]	MMASK[15:0]
0	0
rw	rw

31: 16	Slave Mask (SMASK) - If SMASK[n] is set to ‘1’, the trace buffer will not save accesses performed to slave n.
15: 0	Master Mask (MMASK) - If MMASK[n] is set to ‘1’, the trace buffer will not save accesses performed by master n.

50.4.6 Trace buffer breakpoint registers

The DSU contains two breakpoint registers for matching AHB addresses. A breakpoint hit is used to freeze the trace buffer by clearing the enable bit. Freezing can be delayed by programming the DCNT field in the trace buffer control register to a non-zero value. In this case, the DCNT value will be decremented for each additional trace until it reaches zero and after two additional entries, the trace buffer is frozen. A mask register is associated with each breakpoint, allowing breaking on a block of addresses. Only address bits with the corresponding mask bit set to '1' are compared during breakpoint detection. To break on AHB load or store accesses, the LD and/or ST bits should be set.

Table 670. Trace buffer AHB breakpoint address register

31	2	1	0
BADDR[31:2]		0b00	
NR		0	
rw		r	

31: 2 Breakpoint address (BADDR) - Bits 31:2 of breakpoint address

1: 0 Reserved, read as 0

Table 671. Trace buffer AHB breakpoint mask register

31	2	1	0
BMASK[31:2]		LD	ST
NR		0	0
rw		rw	rw

31: 2 Breakpoint mask (BMASK) - Bits 31:2 of breakpoint mask

1 Load (LD) - Break on data load address

0 Store (ST) - Break on data store address

51 Boot ROM

51.1 Overview

The GR716 microcontroller contains a on-chip Boot ROM for low-level initialization and optional self-testing, standby and application loading. The Boot ROM contains instructions executed by the CPU. The Boot ROM may be configured via bootstraps signals controlled by the user at reset.

The Boot ROM prepares an execution environment suitable for an Application Software (ASW) to take over the system. This reduces the system initialization normally required by the application to perform.

It is possible to disable the Boot ROM via bootstraps signals, see section 7.1. When the Boot ROM is disabled, the reset address is determined by bootstrap signals. Note that in this case boot ing from I2C PROM is not supported.

51.2 ROM Architecture

51.2.1 Logical division of Boot ROM

This section describes the top-level structure of the Boot ROM. The design is logically divided in three main parts:

- Processor module initialization
- Standby mode
- Load sequence

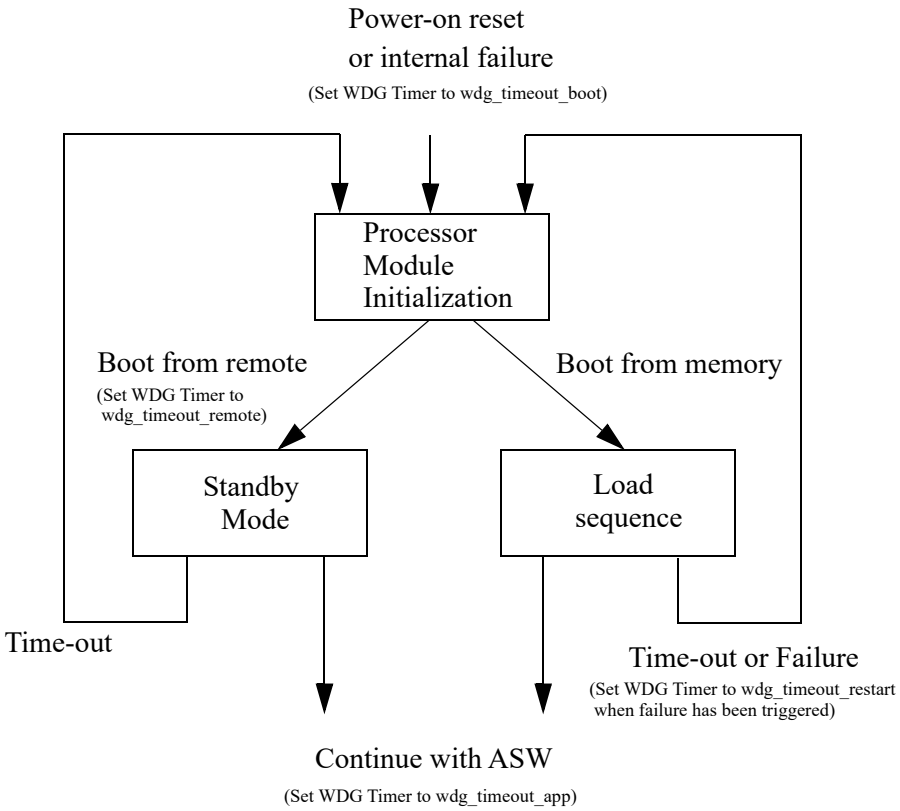


Figure 99. Boot ROM to-level architecture

The *Processor Module Initialization* sequence is triggered by reset condition. It is responsible for initializing and self-testing of on-chip instruction and data memory, writing the boot report. Processor module initialization has a mostly linear execution path, meaning that a minimum number of branch decisions which depend on system external factors are made. Initialization sequence is directly followed by the standby mode or load sequence.

The *Standby mode* is entered when the GR716 microcontroller is configured via bootstraps to be configured remotely via external interface, for example SpW, SPI, UART, etc. The watchdog timer is initialized.

The *Loading sequence* is responsible for validating, loading and executing an ASW image residing in application storage memory (ASM) or RAM. After the ASW load the ASW will be executed.

51.2.2 Properties of the Boot ROM

The table below gives an overview of certain properties of the Boot ROM. Some parameters are given in seconds based on a 50MHz system clock, however they must be scaler to the actual system clock to get the correct number of seconds.

*Table 672.*Run-time properties

Name	Value	Description
gptimer_prescaler	50000	Initialization value for GPTIMER prescaler reload. This value shall be set to generate a 1 second timer tick frequency. (At 50MHz system clock)
wdg_timeout_boot	360	Timeout, in seconds, for the watchdog timer during start of internal boot. (At 50MHz system clock)
wdg_timeout_restart	1	Timeout, in seconds, for the watchdog timer when an internal error has occurred. (At 50MHz system clock)
wdg_timeout_app	600	Timeout, in seconds, set prior to application hand over from Boot ROM. (At 50MHz system clock)
wdg_timeout_remote	5*3600	Timeout, in seconds, waiting for remote access. (At 50MHz system clock)
i2c_prescaler	-	Precscaler set for 100KHz transfer for 50MHz system clock
i2c_deviceid	0x50	I2C device ID is locked to 0x50
mcfg1, mcfg2, mcfg3 - Initialization value for external memory controller		
mcfg1_r_ws	0xF	max read PROM wait states
mcfg1_bsize	0x6	Prom banks size of 512KiB
mcfg2_r_ws	0x4	max read SRAM wait states
mcfg2_bsize	0x6	Sram banks size of 512KiB
%psr, %wim and %tbr settings for applications and remote boot mode		
PSR_SUPER	0x1	Enable Supervisor mode
PSR_CWP	0x0	Default CWP
PSR_PIL	0x0	Processor interrupt level for application and remote access
PIL_EF	0x0	FPU disabled
fp_start	0x3000FF00	Frame pointer
sp_start	0x3000FEA6	Stack pointer
boot_image_header	0x3000FF48	Boot image header start
boot_report	0x3000FFF8	Boot report start

51.2.3 Clock configuration

This section specifies the clocks registers used and enabled after boot depending upon the boostraps.

Table 673: Clock configuration

Mode	PLL Config	Clock Unit	Description
External SPI ROM	N/a	CLKEN0.S0 CLKEN0.S1 1)	Boot from external SPI PROM with or without redundant source
External SRAM		CLKEN0.MC	Boot from external SRAM with or without redundant source
External ROM/PROM		CLKEN0.MC	Boot from external SRAM with or without redundant source
External NVRAM		CLKEN0.MC	Boot from external NVRAM with or without redundant source
External I2C PROM		CLKEN0.IM0 CLKEN0.IM1 1)	Boot from external I2C PROM with or without redundant source
SpaceWire	PLLREF.CFG 3)	CLKEN0.TD	Remote boot via SpaceWire
SPI4S		CLKEN0.SP	Remote boot via SPI4S
I2C		CLKEN0.IA	Remote boot via I2C
UART		CLKEN0.SA	Remote boot via UART

Note 1: Only enabled if boot from primary option fails

Note 2: Table only specify bits enabled by boot. All other bits will remain as is after reset.

Note 3: SpaceWire PLL option is configured by is determined by GPIO[63] and DUART_TX. For more information see table 30 in section 3.1.

51.2.4 Memory Layout

The Boot PROM usage of the memory resources in table 674.

*Table 674.*Boot software usage of the memory resources

Memory	**Properties**	**Context**
Boot memory	Read-only	Boot software executable and constant data
On-chip RAM	Volatile R/W	Boot software volatile runtime data and stack. Used by processor module initialization, load sequence and standby mode. Boot report will be written into the on-chip RAM above the stack.
External PROM/SRAM (FTMCTRL)	Non-Volatile R/W Volatile R/W	Application software, runtime and stack.
External SPI Memory (SPIMCTRL)	Non-Volatile R/W	Application software to be copied into the on-chip RAM and executed from on-chip RAM (Application software can be available at two different areas for dual module redundancy check)
External I2C Memory (I2CMST)	Non-Volatile R/W	Application software to be copied into the on-chip RAM and executed from on-chip RAM (Application software can be available at two different areas for dual module redundancy check)

51.2.5 Boot report

Boot report entries are written by the Boot SW. The boot report in combination with the image header located in the local data ram contains the following information:

- Boot software version
- Internal Instruction and Data RAM test status
- ASW loaded and integrity status
- Start of execution (entry point)
- Application software id

The total size of the boot report allocated in the data memory is 8 bytes. The boot address always allocates the last 2 words in the local data memory. The boot report format:

Table 675. 0x30000FF8 - BOOTRPT0 - Boot Rom Report

31 10	9 7	6 5	4 2	1	0
Reserved	CPY	EXT	RMT	I	D
0	*	*	*	*	*
rw	rw	rw	rw	rw	rw

31: 10 Reserved.

9: 7 ASW source copy (CPY) - Status field for ASW source selected:

0x0 - None
0x1 - SRAM chip select 0 and 1
0x2 - PROM chip select 0 and 1
0x3 - SPI memory using dedicated external SPI memory interface
0x4 - SPI redundant memory interface
0x5 - I2C master interface 0
0x6 - I2C master interface 1

6: 5 External boot source (EXT) - Status field for external boot source:

0x0 - None
0x1 - External SRAM/MRAM using SRAM chip select 0
0x2 - External PROM using PROM chip select 0
0x3 - External SPI memory

4: 2 Remote access (RMT) - Status field for remote access:

0x0 - None
0x1 - SpaceWire remote access enabled
0x2 - UART remote access enabled
0x3 - I2C remote access enabled
0x4 - SPI remote access enabled

1 Onchip instruction memory test (I) - 1: memory failure detected,, 0: test passed.

0 Onchip data memory test (D) - 1: memory failure detected,, 0: test passed.

Table 676. 0x30000FFC - BOOTRPT1 - Boot Rom Report

31 0
Reserved
0
rw

31: 0 Reserved

In case of using the ASW container the application can read and check the latest ASW header located in the data memory on address specified in table 672 and ASW header format in table 677.

51.2.6 Application software image format

Application software image files are located in ASM from where they are loaded by the Boot software Application loader. An image consists of an image header, a number of image section headers, and a variable number of data blocks. All addresses (entry point and data destination addresses) must be aligned to 32-bit words.

*Table 677.*Image header

Field	Type	Description
id	32-bit word	User defined section. The values does not affect Boot software execution.
ep [1)]	32-bit word	Application software entry point
stp	32-bit word	Application stack pointer
sections 0 [1)]	image section header	Section layout defined in table below.
sections [1 ..7]	image section header	Section layout defined in table below.
cksum	16 -bit word	16-bit ISO checksum as defined in [ECSS-E7041], annex A. Calculated over all fields of the image header.
Reserved	16-bit word	Reserved, set to zero

Note 1: See errata for details about entry point located in section0

*Table 678.*Image section header

Field	Type	Description
flags	32-bit word	Bit 0: ENABLE - This section shall be copied to RAM. Bit 31..1: RESERVED - Must be 0
source	32-bit word	Location of source data block, expressed as number of 32-bit words relative to image header. (Note: Offset is not relative to section header.)
dest	32-bit word	Absolute destination address
length	32-bit word	Length of section data block in 32-bit words.
datacksum	16-bit word	Data block checksum over data[0]..data[length-1]. 16-bit ISO checksum as defined in [ECSS-E7041], annex A.
Reserved	16-bit word	Reserved

*Table 679.*Image section data block

Field	Type	Description
data[0]	32-bit word	Data word 0
data[1]	32-bit word	Data word 1
...	...	...
data[length-1]	32-bit word	Data word length-1

When the application software is loaded the image header read is always stored in top of memory. The application software can determine its origin by reading the stored header in the local data memory. The image header start is always set to *'boot_image_header'* from the end of the last address in the local data memory.

51.3 Loader description

Load sequence is the summing-up of Boot software components executing after standby mode. The component includes enable clocks and pins, image loading and application software boot.

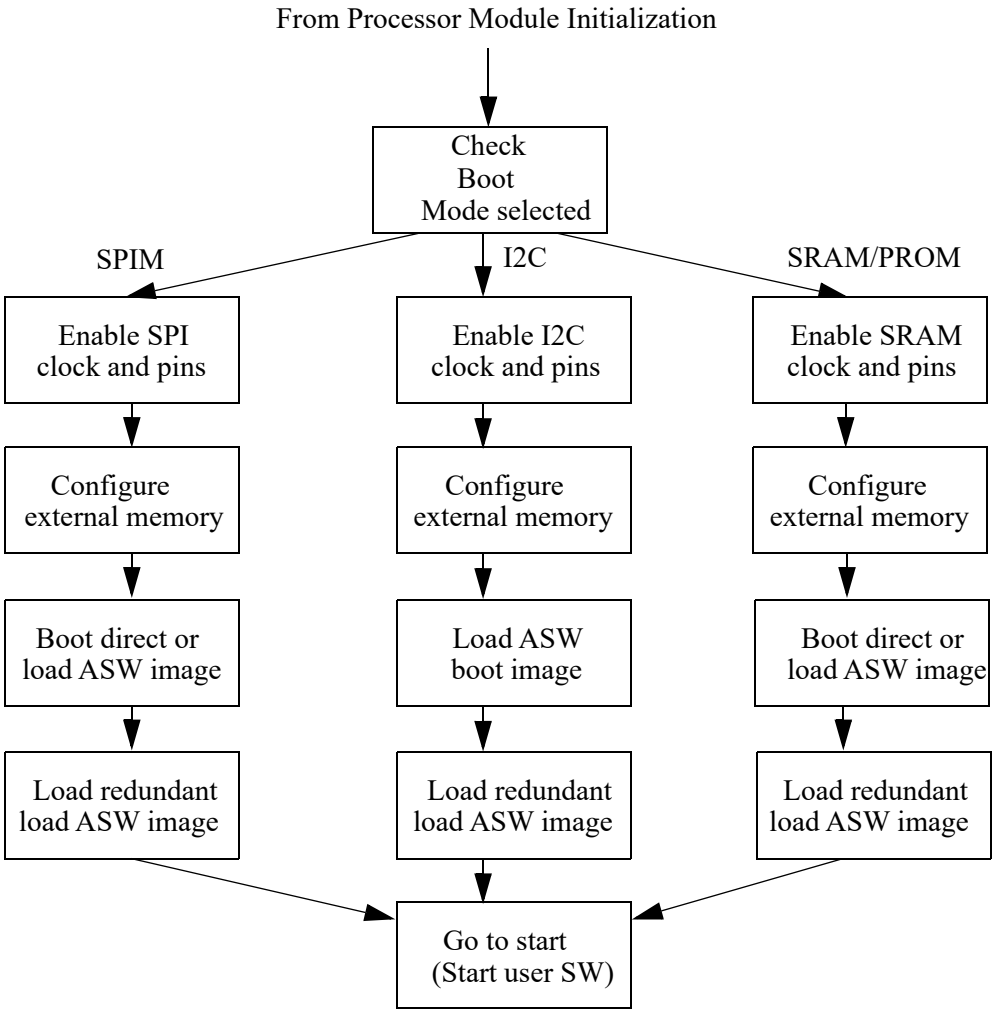


Figure 100. Load sequence detailed description

For more information see Table 672.

51.4 Standby description

After processor initialization has completed the Standby mode is started if selected by the bootstrap signals. The bootstrap configures which interface is used for the remote control. For each of the remote access options the boot software enable interface clock and pins. See sections below for more information about which pins are used for respective interface.

Full access is granted to the unit accessing the GR716 Microcontroller via the selected remote control and access interface. When remote control unit upload new software to the GR716 Microcontroller the remote unit can reset and re-start the processor via the interrupt controller unit, see chapter 40 for more information. The remote unit needs to instruct the GR716 Microcontroller to restart and start executing the uploaded software.

While in standby mode the processor is in power-down mode. The watchdog timer is activated during Standby mode.

51.4.1 I2C2AHB

A remote host can access the AHB DMA bus via the I2CAHB interface described in chapter 37.

Information on which pins used to connect to the external I2C bus is described in Table 31.

51.4.2 SpaceWire - RMAP

A remote host can access the AHB DMA bus via the SpaceWire RMAP interface described in chapter 33.

Information on which pins used to connect to the external SpaceWire bus is described in Table 31.

51.4.3 SPI2AHB

A remote host can access the AHB DMA bus via the SPI2AHB interface described in chapter 43.

Information on which pins used to connect to the external SPI bus is described in Table 31.

51.4.4 UART

There are two AHBUART interfaces on the GR716, only the AHBUART connected directly to the AHB DMA bus is used for the remote control in Standby mode.

A remote host can access the AHB DMA bus via the AHBUART interface described in chapter 48.

Information on which pins used to connect to the external UART bus is described in Table 31.

51.5 State at handover to application software

After the boot sequence has finished the following general state applies:

- GPTIMER prescaler is set to gptimer_prescaler
- Watchdog timer value is set to wdg_timeout_app or wdg_timeout_reomte and is kicked in less than 100 clock cycles from entry to ASW.
- Boot report is located at address boot_report
- ASW header is located at the address boot_image_header.
- All interfaces are disabled except for the interface requested to be enabled via bootstraps
- The clock-gate unit is configured according to the bootstrap configuration
- Frame pointer (register %fp) is set to the start before the boot report
- Stack pointer (register %sp) is set to frame pointer minus 96.
- PSR.S=1, PSR.ET=0, PSR.CWP=0, PSR.EF=0
- WIM=0x2
- Single vector trapping is disabled

For more information see Table 672.

51.6 Boot source requirements

This chapter specifies limitations to external interface or components during boot.

51.6.1 SpaceWire Remote access

Remote access via SpaceWire (without software support) requires the SpaceWire input frequency to be 5 MHz, 10 MHz, 20 MHz or 25 MHz.

51.6.2 External SPI Memory

External SPI memories will be clocked with system clock divided by 8 during the boot sequence. The external SPI memory is assumed to support read command 0x3 and have 3 address bytes as default.

51.6.3 External I2C Memory

No direct boot from I2C memory. The Boot ROM only supports 10 bit device addressing on the I2C bus. The external I2C memory is assumed to have 2 address bytes.

51.6.4 External PROM/SRAM memory

The access time for external PROM shall be equal or less than 16 system clock cycles and for external SRAM the access time shall be equal or less than 4 system clock cycles.

51.6.5 NVRAM

Booting using the NVRAM memory controller is also supported by the ASIC design, please contact support@gaisler.com for more information about options for bare die.

51.7 Protection schemes

The boot image has a number of protection schemes build in to check for erroneous boot software, hardware malfunction:

SRAM/PROM:

- BCH EDAC protection
- Scrubber (SRAM only)
- ASW load image protection with CRC protection
- Redundant ASW load image
- Watchdog timer

SPI Memory:

- BCH EDAC protection
- ASW load image protection
- Redundant ASW load image with CRC protection
- Watchdog timer

I2C Memory:

- ASW load image protection
- Redundant ASW load image with CRC protection
- Watchdog timer

Remote Access:

- Watchdog timer

Internal Memories startup test (Instruction, Data and Register Window):

- Scrubber (Instruction and Data)
- Memory test at startup.

Boot ROM startup and access:

- Protection of unwanted access or start of boot due to erroneous trap handler
- Watchdog timer

51.7.1 BCH EDAC Protection

When the memory controller with EDAC enabled (SPIMCTRL/FTMCTRL) detects a correctable error, the data will be temporarily corrected and delivered onto the on-chip bus.

A uncorrectable error detected during a load of a ASW will force the boot ROM software to enter error state and wait for re-boot or try to load a redundant ASW image.

51.7.2 Hardware Scrubber

The scrubber is used by the Boot ROM to clear internal instruction and data ram.

51.7.3 ASW load image

Application software load image correctness can be checked using 16-bit cyclic redundant code defined in [ECSS-E7041]. The load image also provides features to automatically copy instruction and data sections before executing ASW.

51.7.4 Redundant ASW load image

All externally memory boot options have the capability to boot from redundant memory in case of bad CRC is detected on first boot image. An error on the second will force the GR716 microcontroller to reboot and retry the first image.

PROM primary boot uses external ROM chip select signal 0 and redundant PROM uses ROM chip signal 1.

SRAM primary boot uses external ram chip select signal 0 and redundant SRAM uses RAM chip signal 1.

SPI memory boot automatically selects SPI memory controller 0 as primary boot and SPI memory controller 1 as redundant boot option.

I2C memory boot automatically selects I2C master controller 0 as primary boot and I2C master controller 1 as redundant boot option.

51.7.5 Watchdog Timer

A watchdog timer will be enabled to detect erroneous behavior during boot sequence. The Watchdog Timer is reloaded at reset and during start of the boot ROM and at the end of boot ROM to make sure the ASW or accesses from the external interface can be executed or received.

The watchdog have different settings and reload value depending boot software executed and boot option selected by user.

Watchdog timeout value and state:

- During initialization of boot software and memory test the watchdog is set to a value ’*wdg_timeout_boot*’ long enough to cope with memory and register test. The watchdog is always enabled at boot program start because the boot software might have been called from an unwanted trap.

- For application booting from external memory the watchdog is set to a value ’*wdg_timeout_app*’ long enough to cope with starting or loading an application from an external memory.
- For application booting via remote access the watchdog is set to a value ’*wdg_timeout_remote*’. The value is set to a ’extrem’ long value to be able to cope with slow transfers or interfaces. The watchdog timer reload register is accessible via remote interface and in case where software upload is extremely slow the remote software should be able to extend or reload the watchdog counter by writing to the watchdog timers registers.
- When a failure is encountered during initialization of the microcontroller which can’t be resolved the boot software requests a system reboot by setting the watchdog timer to a ’*wdg_timeout_restart*’.

51.7.6 Memory test

The memory test write a predefined pattern consecutively to the whole memory. It reads the data back and verifies for equality. The same procedure is repeated with an inverted pattern. This tests the integrity of the memory device it self i.e. test that every bit in the memory is capable of holding both 0 and 1.

In case memory test passes, the memory area is cleared. In case of failure a flag will be raised in the boot report.

52 Electrical description

All electrical specifications are defined at package solder point level, unless otherwise stated.

All the figures provided in this section have been derived from post-layout simulations or prototype validation of the GR716 microcontroller. The GR716 microcontroller has not yet been fully characterized in production test.

52.1 Absolute maximum ratings

Table 680. Absolute maximum ratings [1) 2) 3)]

Symbol	Parameter	Rating		Units
		Min.	Max.	
	Voltage between any supply domain grounds	-0.3	0.3	V
V_{DDIO} [5)]	DC Supply Voltage for I/O	-0.3	4.0	V
V_{DD} [5)]	DC Supply Voltage for Core	-0.3	2.2	V
V_{DDA} [5)]	Analog Supply Voltage, except for PLL	-0.3	4.0	V
V_{DD_LDO} [5)]	LDO Supply Voltage	-0.3	4.0	V
V_{DDAPLL} [5) 7)]	Analog Supply Voltage for PLL	-0.3	2.2	V
V_{GPIO}	Voltage between GPIO pin and ground	-0.3	V_{DDIO} + 0.3 [8)]	V
V_{DIO_IN} [5)]	Digital input Voltage	-0.3	V_{DDIO} + 0.3 [8)]	V
V_{DIO_OUT} [5)]	Digital Output Voltage	-0.3	V_{DDIO} + 0.3 [8)]	V
I_{GPIO_IN}	GPIO current, when configured as Input or HiZ	-10	10	mA
I_{GPIO_OUT}	GPIO current, when configured as output. ESD-diode current max 10mA	-10	10	mA
I_{DIO_IN}	Digital input current	-10	10	mA
I_{DIO_OUT}	Digital output current when configured as HiZ	-10	10	mA
I_{DIO_OUT}	Digital output current, when configured as output. ESD-diode current max 10mA	-10	10	mA
Vref	Bandgap reference decoupling capacitor	-0.3	V_{DDA} + 0.3 [8)]	V
Rref [9)]	Reference current resistor	-0.3	V_{DDA} + 0.3 [8)]	V
V_{XO_IN}	Crystal input	-0.3	V_{DD} + 0.3	V
T_{store}	Storage Temperature	-65	+150	°C
T_{solder}	Lead Temperature (Soldering 10 sec.)		+250	°C
T_j	Junction Temperature		+150	°C
Θ_{JC} (ceramic)[4)]	Thermal Resistance, Junction to Case		6	°C/W
P_D	Power Dissipation		4	W
V_{HBM}	ESD level [6)]		2000	V

Note 1: Extended operation at the maximum levels may degrade the performance and affect the reliability of the device. Exceeding the maximum input levels may permanently damage the device.

Note 2: All GND pins must be connected to the same GND plane on PCB. Any externally applied voltage difference between GND pins can create harmful circulating ground currents inside the package

Note 3: The thermal resistance, Θ_{JC}, sets the maximum power dissipation, P_D, assuming that the package is mounted on PCB with main heat flowing through the main heat-sinking path for the package. Otherwise, maximum power dissipation limit will be significantly lower.

Table 680. Absolute maximum ratings [1) 2) 3)]

Symbol	Parameter	Rating		Units
		Min.	Max.	

Note 4: Case means bottom surface of package, which is the main heat-sinking path out of this package.

Note 5: Supply values are relative its dedicated supply ground.

Note 6: Electrostatic discharge level is given for individual I/O cells in terms of the Human Body Model.

Note 7: V_{DDAPLL} shall not be connected except for external decoupling to ground

Note 8: Voltage may not exceed 4.0V

Note 9: 5.11kΩ ±3.5% (EOL). The tolerance of the reference resistor will directly affect the accuracy of the DAC output. For application with requirement for high precision DAC outputs selection of reference resistors with better tolerance should be considered.

52.2 Recommended operating conditions

Table 681. Recommended operating conditions [1)]

Symbol	Parameter	Rating			Units
		Min.	Typ.	Max.	
	Voltage between any supply domain grounds	-0.1	0.0	0.1	V
V_{DDIO} [3)]	DC Supply Voltage for I/O	3.0	3.3	3.6	V
V_{DD} [3)]	DC Supply Voltage for Core	1.65	1.8	1.95	V
V_{DDA} [3) 8)]	Analog Supply Voltage, except for PLL	3.0	3.3	3.6	V
V_{LDO} [3)]	DC Supply Voltage for LDO	3.0	3.3	3.6	V
V_{DDAPLL} [3) 7)]	Analog Supply Voltage for PLL		1.8		V
V_{DIO_IN} [3)]	Digital input Voltage	- 0.1		V_{DDIO} + 0.1	V
Vref [5)]	Bandgap reference decoupling capacitor		4.7		nF
Rref [6)]	Reference current resistor		5.11 [6)]		kΩ
f_{XO_IN}	Crystal input frequency	5		25	MHz
$\|V_{ID}\|$	Magnitude of LVDS differential input voltage	0.1 [4)]		0.6	V
T_{case} [2)]	Case Temperature	-55		+125	°C
SL_{IN_LVTTL}	Slew rate of all LVTTL inputs	1.0			V/ns
SL_{IN_LVDS}	Slew rate of all LVDS inputs	1.5			V/ns

Note 1: Within recommended operating conditions, all functionality and performance parameters in this data-sheet are valid, and device long-term reliability is maintained.

Note 2: Full functionality is guaranteed within -55 to +145°C (tested within -55 to +125°C). Analog-performance specifications are guaranteed within -40 to +115°C.

Note 3: Supply values are relative its dedicated supply ground.

Note 4: Failure to comply with the differential input thresholds will make the receiver logic condition unknown. For noisy environment or protection from various failures such as open inputs, floating inputs or shorted inputs an external fail-safe function should be considered

Note 5: Decoupled to ground via 4.7nF capacitor

Note 6: 5.11kΩ ±1% tolerance, 10ppm/°C

Note 7: Analog supply voltage for PLL is generated from internal voltage regulator.

Note 8: An analogue supply VDDA can be non-supplied. Then the supply must be grounded via maximum 200 ohm impedance.

52.3 Power supplies characteristics

Table 682. DC characteristics [1)]

Symbol	Parameter	Condition	Rating			Units
			Min.	Typ.	Max.	
I_{DD}	Core Supply Current	F_{CLK} = 25Mhz and internal SpaceWire clock at 100MHz [2)]		75	100	mA
I_{DDS}	Core Standby Current	No clocks		5		mA
I_{DDE}	Core Disable Current	Core supplied via internal LDO		5		mA
I_{DDLDO}	LDO Supply Current	F_{CLK} = 25Mhz and internal SpaceWire clock at 100MHz [2) 4)]		100		mA
I_{DDLDOS}	LDO Standby Current	No clocks		15		mA
I_{DDLDOE}	LDO Disable Current	Power supply via separate core and IO supply		1		mA
I_{DDA}	Analog Supply Current, sum for all V_{DDA}	F_{CLK} = 50Mhz and internal SpaceWire clock at 100MHz [3)]		20	50	mA
I_{DDPLL}	PLL Supply Current	F_{CLK} = 50Mhz and internal SpaceWire clock at 100MHz [2)]		5	15	mA
I_{DDIO}	I/O Supply Current	[2) 4)]		100		mA
I_{DDIOE}	I/O Disable Current	IO supplied via LDO		10		mA
$I_{DDIOS_LVDS_E}$	I/O Supply Current	[5) 4)]		30		mA
$I_{DDIOS_LVDS_D}$	I/O Supply Current	[6) 4)]		1	10	mA
I_{DDXO}	XO Supply Current	F_{XO} = 25Mhz		5		mA
I_{DDXO_D}	XO Supply Current	no clock signal		25		uA

Note 1: Recommended operating conditions, see chapter 52.2

Note 2: Digital user scenario with SpaceWire running at full data rate.

Note 3: Analog user scenario with ADC sampling at 200ksps and DAC running at 3Msps

Note 4: All LVDS output terminals are terminated with 100Ω and no external load on the LVTTL outputs and $|V_{ID}| > 100$ mV

Note 5: IDDIO with all LVDS receivers and transmitters enabled and no clock signals

Note 6: IDDIO with all LVDS receivers and transmitters disabled and no clock signals.

Note: There is no direct ESD protection between V_{DD} and $V_{DDIO,}$ so they can be powered up independently. However, it is recommended to power up V_{DDIO} before V_{DD} in order to minimize toggling, and hence reduce the rush-in currents.

52.4 Input voltages, leakage currents and capacitances

Table 683. DC characteristics for LVTTL inputs [1)]

Symbol	Parameter	Condition	Rating			Units
			Min.	Typ.	Max.	
V_{IH}	Input High Voltage		2.0			V
V_{IL}	Input Low Voltage				0.8	V
I_{ILEAK_1} [2)]	Input Leakage Current GPIO	$V_{IN} = V_{DDIO}$			10	uA
		$V_{IN} = 0V$	-10			uA
I_{ILEAK_2} [2)]	Input Leakage Current GPIO (Internal pull down)	$V_{IN} = V_{DDIO}$			160	uA
		$V_{IN} = 0V$	-10			uA
I_{ILEAK_3} [2)]	Input Leakage Current GPIO (Internal pull up)	$V_{IN} = V_{DDIO}$			10	uA
		$V_{IN} = 0V$	-160			uA
I_{ILEAK_4} [3)]	Input Leakage Current (Internal pull down)	$V_{IN} = V_{DDIO}$			160	uA
		$V_{IN} = 0V$	-10			uA
I_{ILEAK_5} [4)]	Input Leakage Current	$V_{IN} = V_{DDIO}$			10	uA
		$V_{IN} = 0V$	-10			uA
I_{ILEAK_6} [5)]	Input Leakage Current	$V_{IN} = V_{DDIO}$			10	uA
		$V_{IN} = 0V$	-10			uA
C_{I_LVTTL}	LVTTL Input capacitance				5	pF

Note 1: Recommended operating conditions, see chapter 52.2

Note 2: Digtial GPIO[x] input signals

Note 3: TESTEN, DSU_ENA and DSU_BREAK input signals only.

Note 4: CLK, SPWCLK, DUART_RX, SPIM_SEL, SPIM_SCK and SPIM_MOSI input signals only.

Note 5: RESET_IN_N input signals only.

Table 684. DC characteristics for LVDS inputs [1)]

Symbol	Parameter	Condition	Rating			Units
			Min.	Typ.	Max.	
V_{CM} [5)]	Common mode input voltage	$\|V_{ID}\|$ = 100mV	0.05		2.35	V
		$\|V_{ID}\|$ = 600mV	0.3		2.1	V
$\|V_{ID}\|$	Magnitude of differential input voltage	V_{CM} = +0.3V to +2.1V	0.1 [4)]		0.6	V
V_{TH}	Differential input high threshold		100 [4)]			mV
V_{TL}	Differential input low threshold				-100 [4)]	mV
I_I [5)]	Input current		-20		20	uA
I_{IB}	Input balance current		-6		6	uA
C_{I_LVDS}	LVDS Input capacitance				5	pF

Note 1: Recommended operating conditions, see chapter 52.2

Note 2: LVDS receivers fully compliant to ANSI TIA/EIA-644 “Low Voltage Differential Signaling”

Note 3: LVDS receivers are designed with no differential input voltage hysteresis

Note 4: Failure to comply with the differential input thresholds will make the receiver logic condition unknown. For noisy environment or protection from various failures such as open inputs, floating inputs or shorted inputs a external fail-safe function should be considered.

Note 5: All on-chip LVDS receivers are non-cold-spare ports. The LVDS input pin voltage must be between GND V_{DDIO}, otherwise the input current limits for I_I are not valid due to the on-chip ESD protection diodes will conduct current.

This is planned to be updated in the next revision of the silicon. See section 56.

52.5 Output voltages, leakage currents and capacitances

Table 685. DC characteristics for LVTTL outputs [1)]

Symbol	Parameter	Condition	Rating			Units
			Min.	Typ.	Max.	
V_{OH}	Output High Voltage	I_{OH} = -2 mA [2)]	2.4			V
V_{OL}	Output Low Voltage	I_{OL} = 2 mA [2)]			0.4	V
I_{OLEAK}	Output Leakage Current	Outputs at tri-state. V_{OUT} = V_{DDIO} and V_{OUT}=0V	-10		10	uA
C_{O_LVTTL}	LVTTL Output capacitance				5	pF

Note 1: Recommended operating conditions, see chapter 52.2

Note 2: All outputs defined with 2mA drive capability in Table 715

Table 686. DC characteristics for LVDS outputs [1) 3)]

Symbol	Parameter	Condition	Rating			Units
			Min.	Typ.	Max.	
V_{OS}	Offset voltage	2)	1.125	1.250	1.375	V
ΔV_{OS}	Change in magnitude of V_{OS} for complementary output states	2)	-50		50	mV
$\|V_{OD}\|$	Absolute differential Output voltage	2)	250	350	450	mV
$\Delta\|V_{OD}\|$	Change in magnitude of $\|V_{OD}\|$ for complementary output states	2)	-50		50	mV
I_{OZ} [5)]	Output leakage current when disabled	4)	-2		2	uA
I_{OS}	Short-circuit Output current				24	mA
I_{ODS}	Differential short-circuit Output current				12	mA
C_{O_LVDS}	LVDS Output capacitance				5	pF

Note 1: Recommended operating conditions, see chapter 52.2

Note 2: LVDS outputs are terminated with 100 Ohm.

Note 3: LVDS drivers fully compliant to ANSI TIA/EIA-644 “Low Voltage Differential Signaling”

Note 4: Each LVDS pair is internally connected with a resistor (>1kΩ). The given output leakage current values only apply with the opposite LVDS output terminal floating.

Note 5: All on-chip LVDS transmitters are non-cold-spare ports. The LVDS output pin voltage must be between GND V_{DDIO}, otherwise the output current limits for I_{OZ} are not valid due to the on-chip ESD protection diodes will conduct current.

This is planned to be updated in the next revision of the silicon. See section 56.

52.6 Simplified IO buffer schematics

Simplified input and output buffer schematics presented in this chapter is applicable within absolute maximum rating conditions, see chapter 52.1

52.6.1 Simplified Bidir buffer with analog capability schematic

Figure 101. Simplified bidir buffer with analog capability schematic

52.6.2 Simplified LVDS input buffer schematic

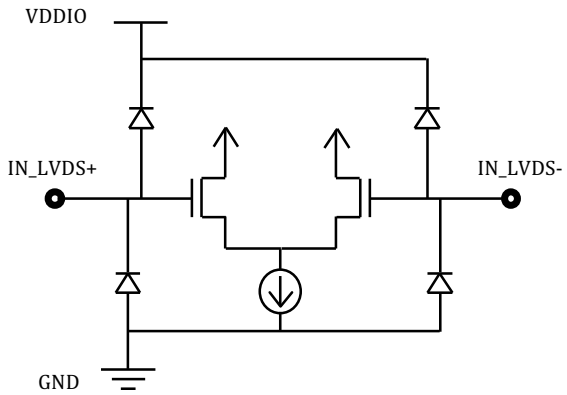


Figure 102. Simplified LVDS input buffer schematic

52.6.3 Simplified LVDS output buffer schematic

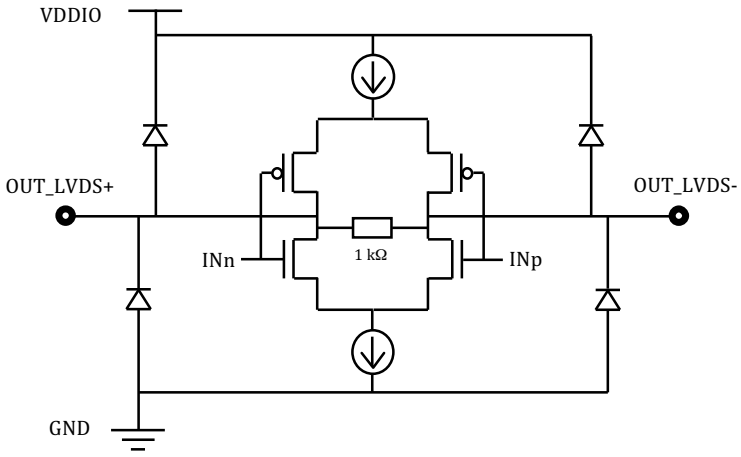


Figure 103. Simplified LVDS output buffer schematic

52.7 DAC Electrical Characteristics

All the figures provided in this section have been derived from post-layout simulations or prototype validation of the GR716 microcontroller. The GR716 microcontroller has not yet been fully characterized in production test.

Table 687. Electrical characteristics for internal DAC outputs [1)]

Symbol	Parameter	Condition	Rating			Units
			Min.	Typ.	Max.	
	Resolution			12		Bit
FS	Full-scale	I_{Rref}=1V/5.11kohm	TBD	4.0	TBD	mA
f_S	Sampling rate	Without DEM	-		3	MSps
		With DEM (transparent cal.)	-		50	kSps
t_D	Clock delay	Number of DAC clock cycles from digital code update		2	TBD	
t_{SETL}	Settling time [2)]	10% residual		TBD	TBD	ns
		0.1% residual		TBD	TBD	
$\|I_{OFFS}\|$	Offset current			1	TBD	LSB
	Gain error				TBD	%
INL	Integral non-linearity	Without DEM, virt. gnd load			2 3)	LSB
		With DEM, virt. gnd load			1.3 3)	
		Without DEM, R_{load} (0-2.5V)			3 3)	
		With DEM, R_{load} (0-2.5V)			2.3 3)	
DNL	Differential non-linearity	Without DEM			1 3)	LSB
		With DEM			0.8 3)	
PSRR	Power-supply rejection ratio	V_{sup}= $VDDA_{DAC}$ - $VSSA_{DAC}$, $VSSA_{DAC}$ ideally grounded.				uA_{pp}
		V_{sup}=3.3V_{DC} ±0.3V_{DC}		TBD	TBD	
		V_{sup}=20mV_{pp}, 100kHz		TBD	TBD	
$\|I_{OUT_SD}\|$	Output leakage current	Shutdown		1	TBD	nA
I_{VDDA_DAC}	Current consumption per DAC	I_{Rref}=1V/5.11kohm				mA
		Operating at $f_{S,max}$			6	
		Operating at $f_{S,min}$		TBD	TBD	
$I_{VDDA_DAC_SD}$	Current consumption per DAC, when brown out is powered down	Shutdown		100		uA
$VDDA_{DAC}$	Supply voltage		3.0		3.6	V

Note 1: $VDDA_{DAC}$-$VSSA_{DAC}$=3.0-3.6V, typical values are at 25C, min/max values are at full temperature range.

Note 2: To be added to t_D.

Note 3: The values are derived from block-level simulations and have not yet been verified with bench measurements.

52.8 ADC Electrical Characteristics

All the figures provided in this section have been derived from post-layout simulations or prototype validation of the GR716 microcontroller. The GR716 microcontroller has not yet been fully characterized in production test.

Table 688. Electrical characteristics for internal ADC inputs [1)]

Symbol	Parameter	Condition	Rating			Units
			Min.	Typ.	Max.	
	Resolution	Single-ended mode		11		Bit
		Differential mode		11		
f_S	Sampling rate	Equal to $f_{adc,clk}$/20. One MUX channel at a time.	5		200	kSps
$f_{adc,clk}$	Clock input frequency	User programmable clock source and divider.	0.1		4	MHz
t_D	Clock delay	From divider input to analog sample taken.		TBD	TBD	ns
$VDDA_{ADC}$	Supply voltage		3.0		3.6	V
Single-ended analog input						
FS	Full-scale	With reference to $VSSA_{ADC}$. Vref=1.000V.	TBD	2.5	TBD	V
	Gain error	With reference to $VSSA_{ADC}$. Vref=1.000V.			2 [2)]	%
$\|V_{INOFFS}\|$	Offset voltage				2 [2)]	LSB
INL	Integral non-linearity	TBD			1 [2)]	LSB
		TBD			2 [2)]	
DNL	Differential non-linearity	TBD			1 [2)]	LSB
		TBD			1 [2)]	
$\|I_{IN,LEAK}\|$	Input leakage current			TBD	TBD	nA
C_{IN}	Input capacitance	Per pin to ground when channel is unselected		2	TBD	pF
		Per pin to ground when channel is selected		20	TBD	pF
PSRR	Power-supply rejection ratio	V_{sup}= $VDDA_{ADC}$ - $VSSA_{ADC}$, $VSSA_{ADC}$ ideally grounded.				LSB
		V_{sup}=3.3V_{DC} ±0.3V_{DC}		TBD	TBD	
		V_{sup}=20mV_{pp}, 100kHz		TBD	TBD	
I_{VDDA_ADC}	Current consumption per ADC including the pre-amplifier	Operating at $f_{S,max}$		10	30	mA
		Operating at $f_{S,min}$		TBD	TBD	
		Shutdown		TBD	TBD	
Differential analog input, without pre-amplifier						
FS_{diff}	Full-scale	With reference to $VSSA_{ADC}$. Vref=1.000V.	TBD	±2	TBD	V
	Gain error	With reference to $VSSA_{ADC}$. Vref=1.000V.			2 [2)]	%

Table 688. Electrical characteristics for internal ADC inputs [1)]

Symbol	Parameter	Condition	Rating			Units
			Min.	Typ.	Max.	
$\|V_{INOFFS}\|$	Offset voltage				1 [2)]	LSB
INL	Integral non-linearity	TBD			1 [2)]	LSB
		TBD			2 [2)]	
DNL	Differential non-linearity	TBD			1 [2)]	LSB
		TBD			1 [2)]	
$\|I_{IN,LEAK}\|$	Input leakage current			TBD	TBD	nA
C_{IN}	Input capacitance	Per pin to ground when channel is unselected		2	TBD	pF
		Per pin to ground when channel is selected		20	TBD	pF
PSRR	Power-supply rejection ratio	V_{sup}= $VDDA_{ADC}$ - $VSSA_{ADC}$, $VSSA_{ADC}$ ideally grounded.				LSB
		V_{sup}=3.3V_{DC} ±0.3V_{DC}		TBD	TBD	
		V_{sup}=20mV_{pp}, 100kHz		TBD	TBD	
I_{VDDA_ADC}	Current consumption per ADC including the pre-amplifier	Operating at $f_{S,max}$		10	30	mA
		Operating at $f_{S,min}$		TBD	TBD	
		Shutdown		TBD	TBD	
Differential analog input, with pre-amplifier						
FS_{PreAmp}	Full-scale at pre-amp input, differential input	Vref=1.00V				V
		Gain x1	TBD	±2	TBD	
		Gain x2	TBD	±1	TBD	
		Gain x4	TBD	±0.5	TBD	
G_{PreAmp}	Gain of pre-amp	Gain x1		1 [2)]		
		Gain x2		2 [2)]		
		Gain x4		4 [2)]		
	Gain error of ADC				TBD	%
$\|VP_A,OFFS\|$	Input offset voltage of pre-amp (excluding ADC offset)	Gain x1			TBD	mV
		Gain x2			TBD	
		Gain x4			TBD	
$\|V_{ADC,OFFS}\|$	Offset voltage of ADC				1 [2)]	LSB
INL	Integral non-linearity	TBD			1 [2)]	LSB
		TBD			2 [2)]	
DNL	Differential non-linearity	TBD			1 [2)]	LSB
		TBD			1 [2)]	
$R_{IN,DM}$	Input resistance, differential mode	Gain x1		22		kΩ
		Gain x2		15		
		Gain x4		9		
$R_{IN,CM}$	Input resistance, common mode [3)]	Gain x1		20		kΩ
		Gain x2		20		
		Gain x4		20		

Table 688. Electrical characteristics for internal ADC inputs [1)]

Symbol	Parameter	Condition	Rating			Units
			Min.	Typ.	Max.	
$\|I_{IN}\|$	Input current	Per input pin. VIN: $VSSA_{ADC}$ to $VDDA_{ADC}$			TBD	uA
C_{IN}	Input capacitance	Per input pin to ground		2	TBD	pF
CMR	Input common-mode voltage range	Gain x1	0		V_{DDA}	V
		Gain x2	(1/8) * V_{DDA}		(7/8) * V_{DDA}	
		Gain x4	(3/16) * V_{DDA}		(13/16) * V_{DDA}	
CMRR	Input common-mode rejection ratio	V_{sup}= $VDDA_{ADC}$ - $VSSA_{ADC}$, $VSSA_{ADC}$ ideally grounded.				LSB
		V_{sup}=3.3V_{DC} ±0.3V_{DC}		TBD	TBD	
		V_{sup}=20mV_{pp}, 100kHz		TBD	TBD	
PSRR	Power-supply rejection ratio	V_{sup}= $VDDA_{ADC}$ - $VSSA_{ADC}$, $VSSA_{ADC}$ ideally grounded.				LSB
		V_{sup}=3.3V_{DC} ±0.3V_{DC}		TBD	TBD	
		V_{sup}=20mV_{pp}, 100kHz		TBD	TBD	
I_{VDDA_ADC}	Current consumption per ADC including the pre-amplifier	Operating at $f_{S,max}$		10	30	mA
		Operating at $f_{S,min}$		TBD	TBD	
		Shutdown		TBD	TBD	

Note 1: $VDDA_{ADC}$-$VSSA_{ADC}$=3.0-3.6V, typical values are at 25C, min/max values are at full temperature range.

Note 2: The values are derived from block-level simulations and have not yet been verified with bench measurements.

Note 3: CM impedance is defined as small-signal current per input pin, when applying only CM small-signal voltage. The internal CM termination DC voltage is about 1.6V.

52.9 Reference Voltages and Currents Electrical Characteristics

Table 689. Reference Voltages and Currents Electrical characteristics [1)]

Symbol	Parameter	Condition	Rating			Units
			Min.	Typ.	Max.	
$Vref_{DC}$	Reference voltage	Internal bandgap reference used		1.0		V
$Vref_{Noise}$	Reference noise	White noise 1KHz - 100MHz		TBD		nV/ SQR(Hz)
		1/f noise 0.1 - 1000 Hz		TBD		uV_{RMS}
$PSRR_{Vref}$	Power-supply rejection ratio of Vref	V_{sup}= VDDAREF - $VSSA_{REF}$, $VSSA_{REF}$ ideally grounded.				mV_{pp}
		V_{sup}=3.3V_{DC} ±0.3V_{DC}		TBD	TBD	
		V_{sup}=20mV_{pp}, 100kHz		TBD	TBD	
I_{Rref}	Reference current	External resistor to $VSSA_{REF}$	2)	2)	2)	uA_{DC}
I_{VDDA_REF}	Current consumption	Excluding Vref_buf output current.		2		mA
$VDDA_{REF}$	Supply voltage		3.0		3.6	

Note 1: Unless otherwise noted: $VDDA_{REF}$-$VSSA_{REF}$=3.0 - 3.6V, typical values are at 25C, min/max values are at full temperature range.

Note 2: Determined as I_{Rref}=V_{Rref}/R_{ref}, where R_{ref} is an external resistance connected to $VSSA_{REF}$. The tolerance spread of I_{Rref} is, hence, set by the tolerance spreads of V_{Rref} and R_{ref}.

52.10 Reset and Brownout-Detector Electrical Characteristics

Table 690. Reset Electrical Characteristics [1)]

Symbol	Parameter	Condition	Rating			Units
			Min.	Typ.	Max.	
V_{TH}	Threshold	Worst-case hysteresis.	TBD		TBD	V
V_{HYST}	Hysteresis		30		TBD	mV
V_{DIFF_BO-RST}	Difference between Brownout and Reset threshold	Worst-case hysteresis for both. Brownout setting:				mV
		<lowest>	100			
		<next lowest>	TBD			
		|	|			
		<highest>	TBD			
t_{RLS}	Release delay [2)]	C_RST=0	TBD	0.03	TBD	ms
		C_RST=47nF	TBD	35	TBD	
		C_RST=1uF	TBD	750	TBD	
t_{RSP}	Response time	Including t_{REJ_RSP}	TBD		10	us
I_{VDD_CORE}	Current consumption	No shutdown mode available.		TBD	TBD	uA
VDD_{CORE}	Supply voltage		-0.1		2.0	V

Note 1: Unless otherwise noted: VDD_{CORE}-GND_{CORE}=-0.1 - 2.0V, typical values are at 25C, min/max values are at full temperature range.

Note 2: Prerequisite for release delay limit is that VDDCORE is discharged below threshold Vth. For delay see note 3 for table 715

Table 691. Brownout-Detector for 1.8V Characteristics [1)]

Symbol	Parameter	Condition	Rating			Units
			Min.	Typ.	Max.	
V_{TH}	Threshold	Worst-case hysteresis for both. Programmable setting:				V
		<lowest>		1.55		
		|		|		
		<highest>		1.75		
t_{RSP}	Response time	Including t_{REJ_BO}	TBD		10	us
t_{REJ}	Glitch rejection time		TBD			us
V_{DD_BO}	Supply voltage		-0.1		2.0	V
I_{VDD_BO}	Current consumption	Operation mode		100	TBD	uA
		Shutdown		TBD	TBD	uA

Note 1: Unless otherwise noted: VDD_{CORE}-GND_{CORE}=-0.1 - 2.0V, typical values are at 25C, min/max values are at full temperature range.

Table 692. Brownout-Detector for 3.3V Characteristics [1)]

Symbol	Parameter	Condition	Rating			Units
			Min.	Typ.	Max.	
V_{TH}	Threshold	Worst-case hysteresis for both. Programmable setting:				V
		<lowest>		2.80		
		|		|		
		<highest>		3.10		
t_{RSP}	Response time	Including t_{REJ_BO}	TBD		10	us
t_{REJ}	Glitch rejection time		TBD			us
V_{DD_BO}	Supply voltage		-0.1		3.6	V
I_{VDDA_BO}	Current consumption	Operation mode		100	TBD	uA
		Shutdown		TBD	TBD	uA

Note 1: Unless otherwise noted: VDD_{CORE}-GND_{CORE}=-0.1 - 2.0V, $VDDA_{BO}$-$VSSA_{BO}$=-0.1 - 3.6V, typical values are at 25C, min/max values are at full temperature range.

52.11 AC characteristics

All the timing figures provided in this section have been derived from pre-layout simulations. Timing has not yet been measured or characterized in production test.

All measured AC parameters will be tested with no capacitive load (<5pF) on the outputs. Timing measurements will be performed using a voltage level equivalent to $V_{DDIO}/2$.

AC characteristics presented in this chapter is applicable within recommended operating conditions, see section 52.2

52.11.1 System clock timing

The timing waveforms are shown in figure 104, and the timing parameters are defined in table 693.

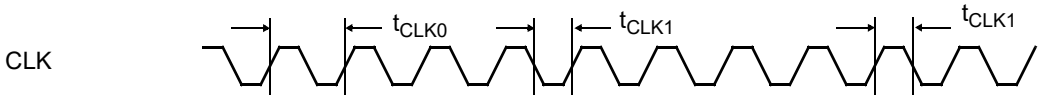


Figure 104. System clock timing waveforms

Table 693. System clock timing parameters

Name	Parameter	Reference edge	Min	Max	Unit
t_{CLK0}	Clock period	-	20	1)	ns
	Clock period 3) 4)		20 5)	200	ns
t_{CLK1}	Clock high/low pulse length	-	0.40 x t_{CLK0}	0.60 x t_{CLK0}	ns
t_{CLK2}	Clock cycle jitter 2)	-	-	2	ns

Note 1: Max value can not be larger than 8 x clock period of internal SpaceWire clock when SpaceWire is used.

Note 2: Only applicable when system clock is not used as input to the PLL

Note 3: Only applicable when PLL use CLK to generate internal SpaceWire clock (see section 4)

Note 4: When SpaceWire clock is used as source to the PLL the internal SpaceWire clock shall not exceed 100MHz

Note 5: The current revision of the silicon does not support 20 ns period time, see errata in section 55.

52.11.2 External SpaceWire clock timing

The timing waveforms are shown in figure 105, and the timing parameters are defined in table 694.

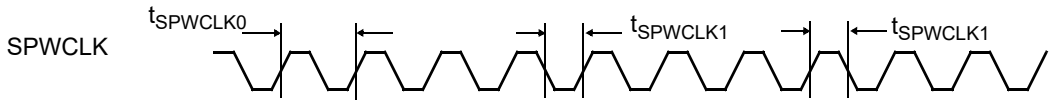


Figure 105. External SpaceWire clock timing waveforms

Table 694. External SpaceWire clock timing parameters

Name	Parameter	Reference edge	Min	Max	Unit
$t_{SPWCLK0}$	Clock period [1)]	-	10	-	ns
	Clock period [2) 3)]	-	40	200	ns
$t_{SPWCLK1}$	Clock high/low pulse length [1)]	-	0.45 x $t_{SPWCLK0}$	0.55 x $t_{SPWCLK0}$	ns
	Clock high/low pulse length [2)]	-	0.40 x $t_{SPWCLK0}$	0.60 x $t_{SPWCLK0}$	ns
$t_{SPWCLK2}$	Clock cycle jitter [1)]	-	-100	100	ps
	Clock cycle jitter [2)]	-	-	2	ns

Note 1: Only applicable when PLL is bypassed (see section 4).

Note 2: Only applicable when PLL use SPWCLK to generate internal SpaceWire clock (see section 4)

Note 3: When SpaceWire clock is used as source to the PLL the internal SpaceWire clock shall not exceed 100MHz

52.11.3 External 1553B clock timing

The timing waveforms are shown in figure 105, and the timing parameters are defined in table 694.

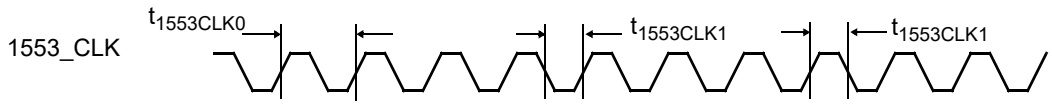


Figure 106. External 1553B clock timing waveforms

Table 695. External 1553B clock timing parameters

Name	Parameter	Reference edge	Min	Max	Unit
$t_{1553CLK0}$	Clock period	-	50	50	ns
$t_{1553CLK1}$	Clock high/low pulse length	-	25	25	ns

Note 1: External MIL-1553B clock is only available via IO mux, see chapter 2.5

52.11.4 External PWM Clock

The timing waveforms are shown in figure 105, and the timing parameters are defined in table 694.

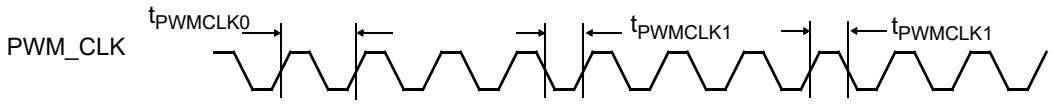


Figure 107. External PWM clock timing waveforms

Table 696. External PWM clock timing parameters

Name	Parameter	Reference edge	Min	Max	Unit
$t_{PWMCLK0}$	Clock period	-	5		ns
$t_{PWMCLK1}$	Clock high/low pulse length	-	2.5	2.5	ns
$t_{PWMCLK2}$	Clock cycle jitter	-	-100	100	ps

Note 1: External PWM clock is only available via IO mux, see chapter 2.5

52.11.5 External PacketWire Clock

The timing waveforms are shown in figure 105, and the timing parameters are defined in table 694.

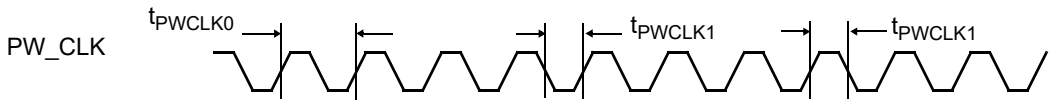


Figure 108. External PacketWire clock timing waveforms

Table 697. External PacketWire clock timing parameters

Name	Parameter	Reference edge	Min	Max	Unit
t_{PWCLK0}	Clock period	-	100		ns
t_{PWCLK1}	Clock high/low pulse length	-	50	50	ns
t_{PWCLK2}	Clock cycle jitter	-	-100	100	ps

Note 1: External PacketWire clock is only available via IO mux, see chapter 2.5

52.11.6 External SPI4S clock

The timing waveforms are shown in figure 105, and the timing parameters are defined in table 694.

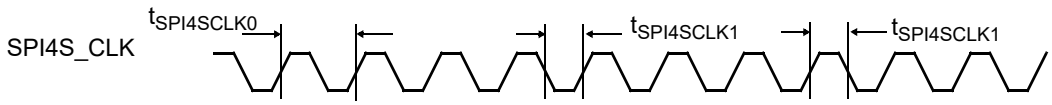


Figure 109. External SPI4S clock timing waveforms

Table 698. External PacketWire clock timing parameters

Name	Parameter	Reference edge	Min	Max	Unit
$t_{SPI4SCLK0}$	Clock period	-	40		ns
$t_{SPI4SCLK1}$	Clock high/low pulse length	-	20	20	ns
$t_{SPI4SCLK2}$	Clock cycle jitter	-	-100	100	ps

Note 1: External SPI4S clock is only available via IO mux, see chapter 2.5

52.11.7 Reset in timing

The timing waveforms are shown in figure 110, and the timing parameters are defined in table 699.

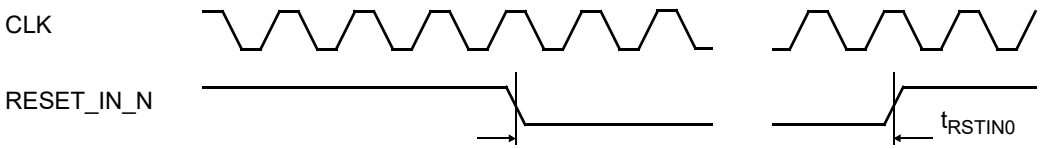


Figure 110. Reset timing waveforms

*Table 699.*Reset timing parameters

Name	Parameter	Reference edge	Min	Max	Unit
t_{RSTIN0}	Asserted period	-	10 x t_{CLK0}	-	ns
Note 1:	The RESET_IN_N input is re-synchronized internally, and does not have to meet any setup or hold requirements.				
Note 2:	V_{DD} must reach at least minimum operating voltage before start for t_{RSTIN0} before RESET_IN_N is de-asserted.				
Note 3:	The internal reset for the system clock domain is released 5 x t_{CLK0} after RESET_IN_N is de-asserted. The internal reset for the SpaceWire clock domain is released 5 x internal SpaceWire clock cycles after RESET_IN_N is de-asserted and PLL has acquired lock.				

52.11.8 SPI Master and Memory interface timing

The timing waveforms are shown in figure 111, and the timing parameters are defined in table 700.

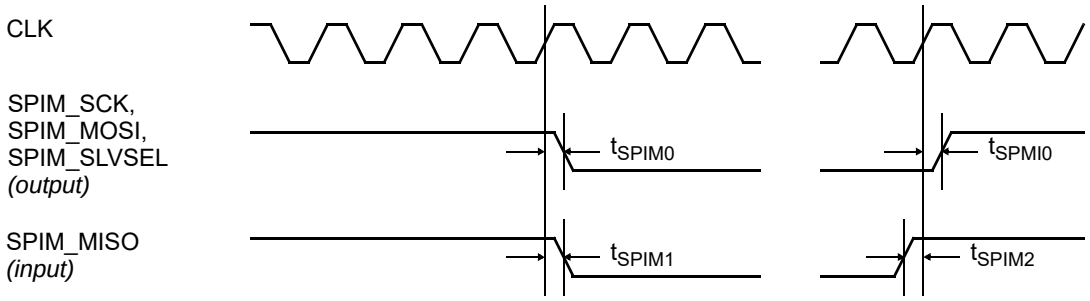


Figure 111. SPI interface timing waveforms

*Table 700.*SPI interface timing parameters

Name	**Parameter**	**Reference edge**	**Min**	**Max**	**Unit**
t_{SPIM0}	Clock to output delay	Rising CLK edge	0	15	ns
t_{SPIM1}	Input to clock hold	Rising CLK edge	-	4	ns
t_{SPIM2}	Input to clock setup	Rising CLK edge	-	4	ns
Note:	The SPI_MISO input is re-synchronized internally, and does not have to meet any setup or hold requirements.				

52.11.9 SPI Slave interface timing

The timing waveforms are shown in figure 111, and the timing parameters are defined in table 700.

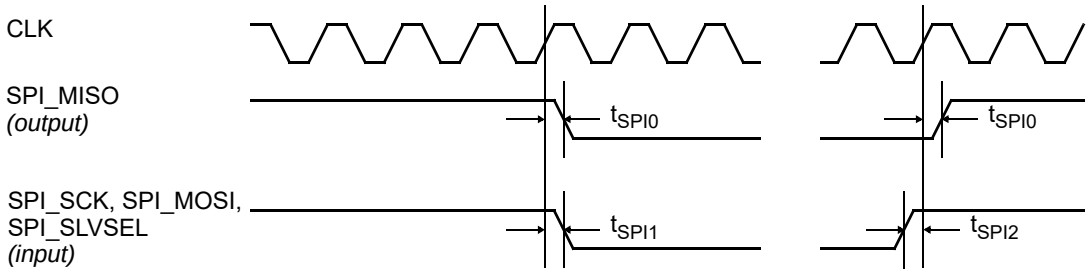


Figure 112. SPI interface timing waveforms

*Table 701.*SPI interface timing parameters

Name	Parameter	Reference edge	Min	Max	Unit
t_{SPI0}	Clock to output delay	Rising CLK edge	0	15	ns
t_{SPI1}	Input to clock hold	Rising CLK edge	-	4	ns
t_{SPI2}	Input to clock setup	Rising CLK edge	-	4	ns
Note:	The SPI_SCK, SPI_MOSI and SPI_SLVSEL inputs are re-synchronized internally, and does not have to meet any setup or hold requirements.				

52.11.10 SPI4S Slave interface LVTTL timing

The timing waveforms are shown in figure 111, and the timing parameters are defined in table 700.

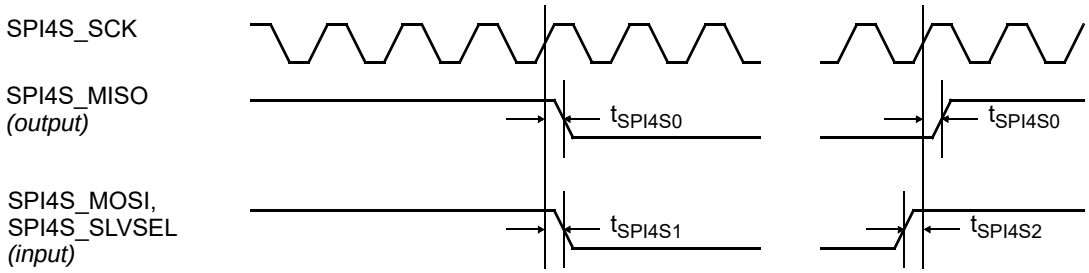


Figure 113. SPI interface timing waveforms

*Table 702.*SPI interface timing parameters

Name	Parameter	Reference edge	Min	Max	Unit
t_{SPI4S0}	Clock to output delay	Rising SPI4S_CLK edge	0	15	ns
t_{SPI4S1}	Input to clock hold	Rising SPI4S_CLK edge	-	4	ns
t_{SPI4S2}	Input to clock setup	Rising SPI4S_CLK edge	-	4	ns

52.11.11 SPI4S Slave interface LVDS timing

The timing waveforms are shown in figure 111, and the timing parameters are defined in table 700.

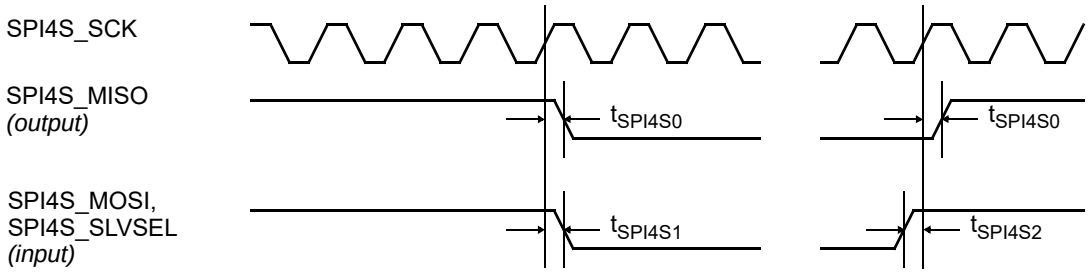


Figure 114. SPI interface timing waveforms

*Table 703.*SPI interface timing parameters

Name	Parameter	Reference edge	Min	Max	Unit
t_{SPI4S0_LVDS}	Clock to output delay	Rising SPI4S_CLK edge	0	15	ns
t_{SPI4S1_LVDS}	Input to clock hold	Rising SPI4S_CLK edge	-	4	ns
t_{SPI4S2_LVDS}	Input to clock setup	Rising SPI4S_CLK edge	-	4	ns

52.11.12 SpaceWire interface LVTTL timing

The timing waveforms are shown in figure 115, and the timing parameters are defined in table 704.

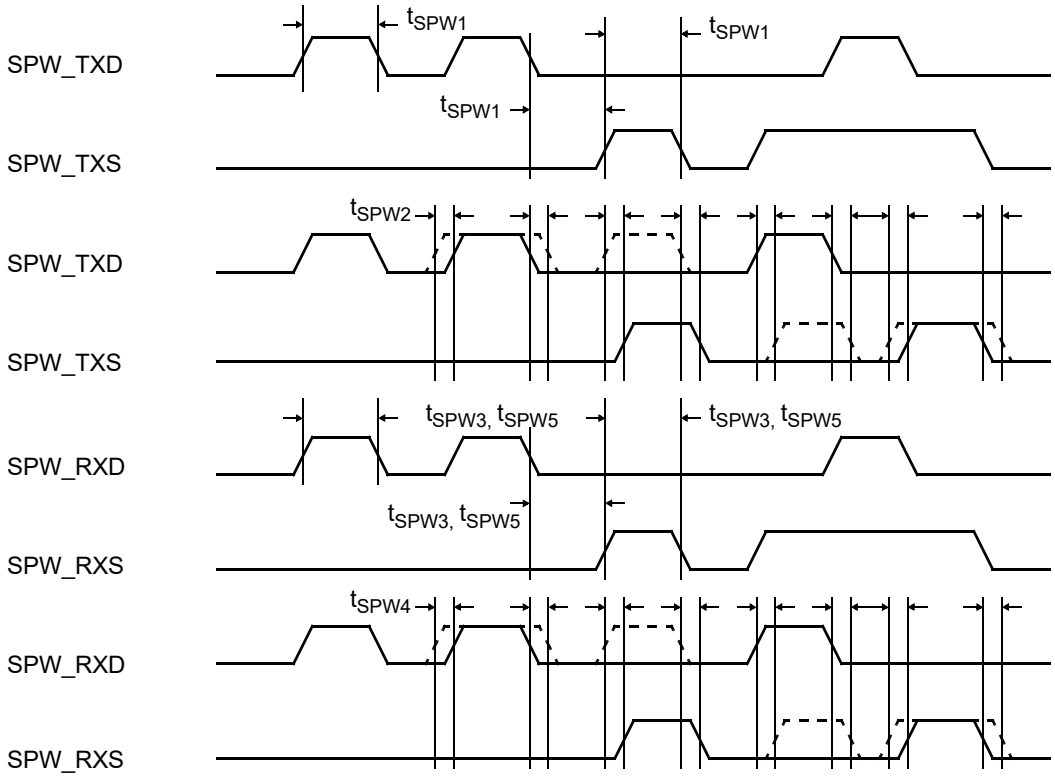


Figure 115. SpaceWire LVTTL interface timing waveforms

*Table 704.*SpaceWire interface timing parameters

Name	Parameter	Reference edge	Min	Max	Unit
t_{SPW1}	Output data bit period	-	10	500	ns
t_{SPW2}	Data & strobe output skew & jitter	-	0	150	ps
t_{SPW3}	Input data bit period	-	10	500	ns
t_{SPW4}	Data & strobe input skew, jitter & hold	-	-	500	ps
t_{SPW5}	Data & strobe edge separation	-	5	-	ns

52.11.13 SpaceWire LVDS interface timing

The timing waveforms are shown in figure 116, and the timing parameters are defined in table 705.

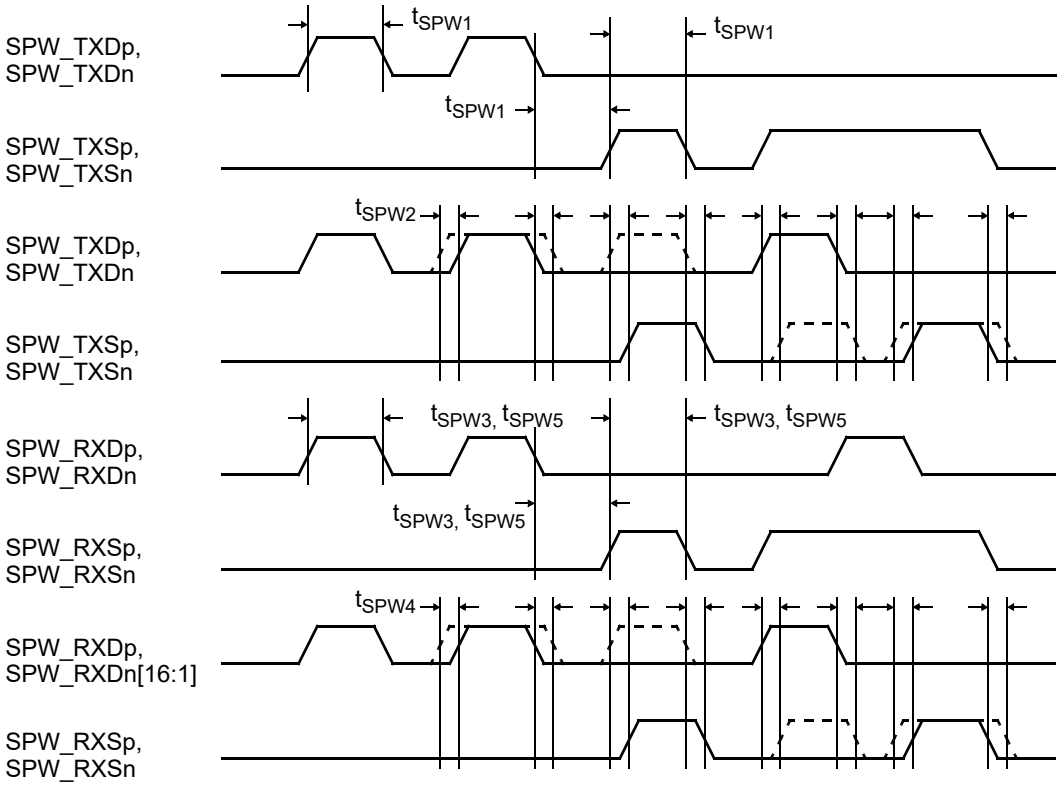


Figure 116. SpaceWire LVDS interface timing waveforms

*Table 705.*SpaceWire LVDS interface timing parameters (V_{DD} = 1.8 V +/- 0.15 V, V_{DDIO} = 3.3 V +/- 0.3 V, T_{case} = -55°C to +125°C)

Name	Parameter	Reference edge	Min	Max	Unit
t_{SPW1_LVDS}	Output data bit period	-	10	500	ns
t_{SPW2_LVDS}	Data & strobe output skew & jitter	-	0	150	ps
t_{SPW3_LVDS}	Input data bit period	-	10	500	ns
t_{SPW4_LVDS}	Data & strobe input skew, jitter & hold	-	-	500	ps
t_{SPW5_LVDS}	Data & strobe edge separation	-	5	-	ns

52.11.14 CAN LVTTL interface timing

The timing waveforms and timing parameters are shown in figure 117 and are defined in table 706.

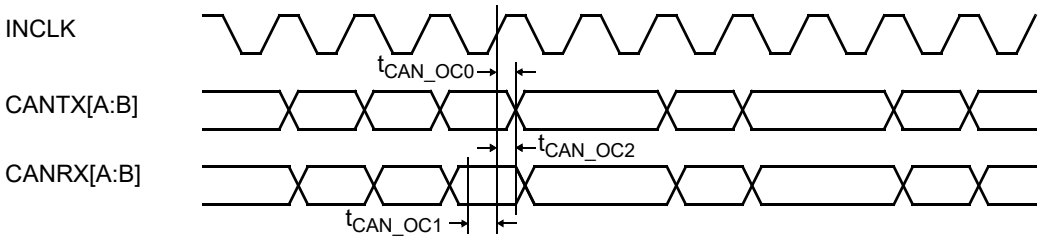


Figure 117. Timing waveforms

*Table 706.*Timing parameters (V_{DD} = 1.8V +/- 0.15V, V_{DDIO} = 3.3V +/- 0.3V, T_{case} = -55°C to +125°C)

Name	Parameter	Reference edge	Min	Max	Unit
t_{CAN_OC0}	clock to data output delay	rising SYS_CLK edge	2 1)	20 2)	ns
t_{CAN_OC1}	data input to clock setup	rising SYS_CLK edge	-	-	ns 3)
t_{CAN_OC2}	data input from clock hold	rising SYS_CLK edge	-	-	ns 3)

Note 1: Guaranteed by design, not tested.

Note 2: Verified by static timing analysis, not tested

Note 3: The CAN inputs are re-synchronized to the internal system clock with a t_{CLK0} period. The signals do not have to meet any setup or hold requirements.

52.11.15 MIL-1553B interface timing

The timing waveforms and timing parameters are shown in figure 118 and are defined in table 707.

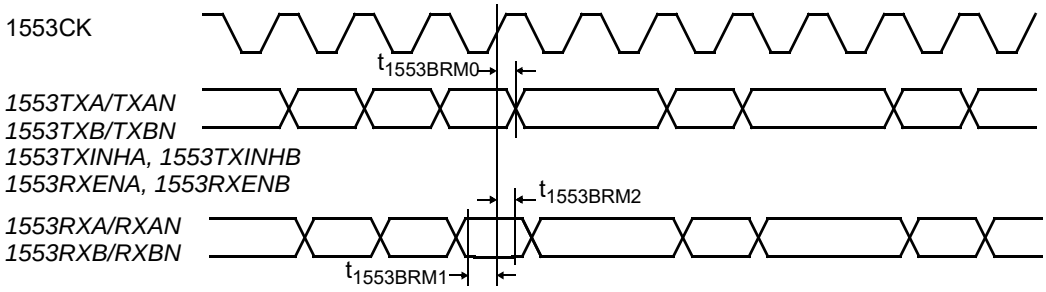


Figure 118. Timing waveforms

*Table 707.*Timing parameters (V_{DD} = 1.8V +/- 0.15V, V_{DDIO} = 3.3V +/- 0.3V, T_{case} = -55°C to +125°C)

Name	Parameter	Reference edge	Min	Max	Unit
$t_{1553BRM0}$	clock to data output delay	rising 1553CK edge	2 1)	21 1)	ns
$t_{1553BRM1}$	data input to clock setup	rising 1553CK edge	-	-	ns 2)
$t_{1553BRM2}$	data input from clock hold	rising 1553CK edge	-	-	ns 2)
$t_{1553BRM3}$	clock frequency	1553CK	20		MHz 3)

Note 1: Parameter not measured during production test.

Note 2: The 1553RXA, 1553RXAN, 1553RXB and 1553RXBN inputs are re-synchronized internally.

Note 3: The core frequency must be lower than the internal system frequency: $t_{1553BRM3} < F_{CLK}$

52.11.16 I2C-master

The timing waveforms and timing parameters are shown in figure 119 and are defined in table 708.

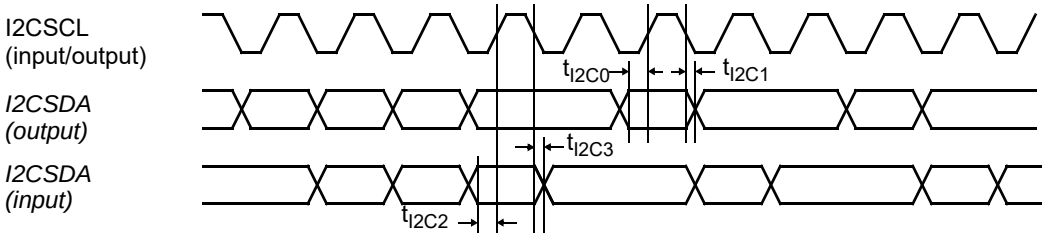


Figure 119. Timing waveforms

*Table 708.*Timing parameters (V_{DD} = 1.8V +/- 0.15V, V_{DDIO} = 3.3V +/- 0.3V, T_{case} = -55°C to +125°C)

Name	Parameter	Reference edge	Min	Max	Unit
t_{I2C0}	data output valid before clock	rising I2CSCL edge	-	scaler [1)]	t_{CLK0} periods
t_{I2C1}	data output valid after clock	falling I2CSCL edge	scaler [1)]	-	t_{CLK0} periods
t_{I2C2}	data input setup to clock	rising I2CSCL edge	2 [2)]	-	t_{CLK0} periods
t_{I2C3}	data input hold from clock	falling I2CSCL edge	0 [2)]	-	t_{CLK0} periods

Note 1: The core's I2C bus functional timing depends on the core's scaler value and the internal system clock t_{CLK0} period. When the scaler is set for the core to operate in Fast- or Standard-Mode, the timing characteristics in the I2C-bus specification apply. The maximum t_{CLK0} period for proper operation is 50 ns.

Note 2: The I2CSCL and I2CSDA inputs are re-synchronized to the internal system clock with a t_{CLK0} period.

Note 3: I2CSCL and I2CSDA are open-drain outputs, driving a logical 0 level or tri-state.

Note 4: For correct operation, the signals should be pulled-up externally with 10 kOhm.

52.11.17 PacketWire RX interface timing

The timing waveforms and timing parameters are shown in figure 120 and are defined in table 709.

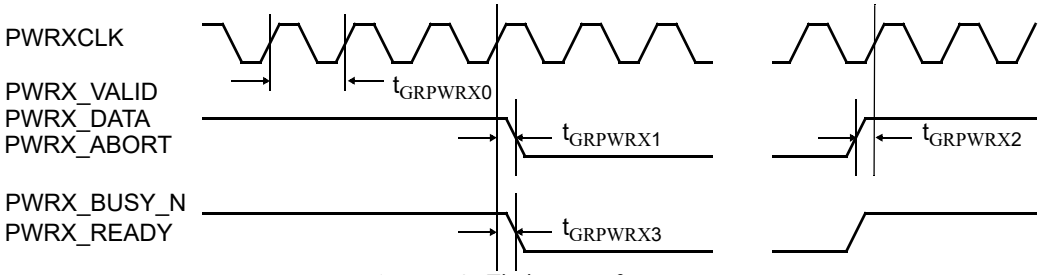


Figure 120. Timing waveforms

*Table 709.*Timing parameters (V_{DD} = 1.8V +/- 0.15V, V_{DDIO} = 3.3V +/- 0.3V, T_{case} = -55°C to +125°C)

Name	Parameter	Reference edge	Min	Max	Unit
$t_{GRPWRX0}$	bit period	rising PWRXCLK edge	100	-	ns
$t_{GRPWRX1}$	data/active/abort input to clock hold	rising PWRXCLK edge	5	-	ns
$t_{GRPWRX2}$	data/active/abort input to clock setup	rising PWRXCLK edge	5	-	ns
$t_{GRPWRX3}$	clock to output delay	rising PWRXCLK edge		20	ns

Note 1: Verified by static timing analysis, not tested

52.11.18 PacketWire TX interface timing

The timing waveforms and timing parameters are shown in figure 120 and are defined in table 709.

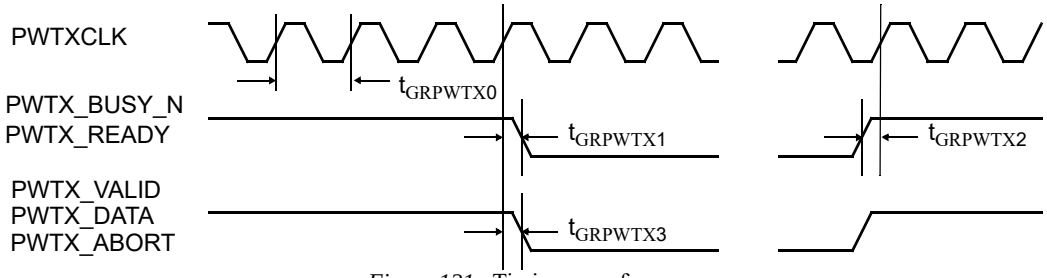


Figure 121. Timing waveforms

*Table 710.*Timing parameters (V_{DD} = 1.8V +/- 0.15V, V_{DDIO} = 3.3V +/- 0.3V, T_{case} = -55°C to +125°C)

Name	Parameter	Reference edge	Min	Max	Unit
$t_{GRPWTX0}$	bit period	rising SYS_CLK edge	100	-	ns
$t_{GRPWTX1}$	data/active/abort input to clock hold	rising SYS_CLK edge	5	-	ns
$t_{GRPWTX2}$	data/active/abort input to clock setup	rising SYS_CLK edge	5	-	ns
$t_{GRPWTX3}$	clock to output delay	rising SYS_CLK edge	-	20	ns

52.11.19 Fault-tolerant 8-bit PROM/IO memory interface timing

The timing waveforms and timing parameters are shown in figures 122, and are defined in table 711.

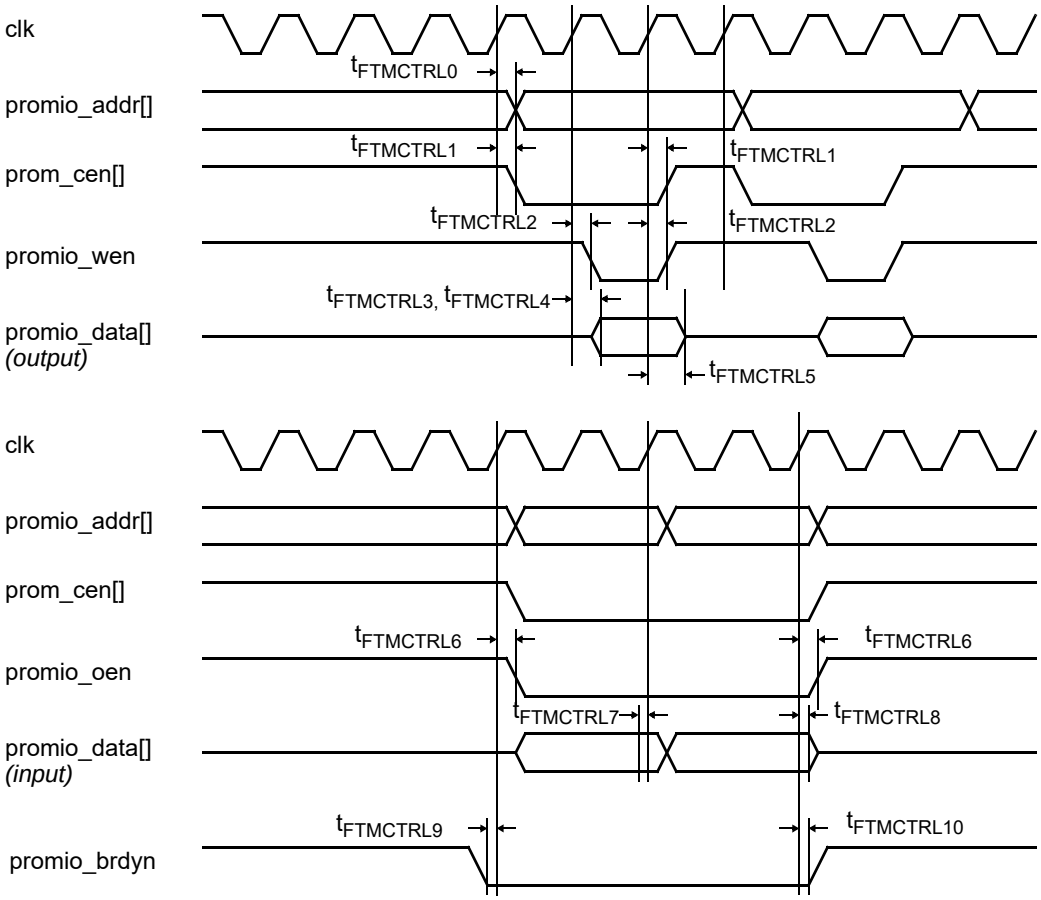


Figure 122. Timing waveforms - SRAM and PROM accesses

*Table 711.*Timing parameters - PROM and I/O accesses

Name	Parameter	Reference edge	Min	Max	Unit
$t_{FTMCTRL0}$	address clock to output delay	rising clk edge [1]	0 [2]	20 [3]	ns
$t_{FTMCTRL1}$	clock to output delay	rising clk edge [1]	0 [2]	20 [3]	ns
$t_{FTMCTRL2}$	clock to output delay	rising clk edge [1]	0 [2]	20 [3]	ns
$t_{FTMCTRL3}$	clock to data output delay	rising clk edge [1]	0 [2]	20 [3]	ns
$t_{FTMCTRL4}$	clock to data non-tri-state delay	rising clk edge [1]	0 [2]	20 [3]	ns
$t_{FTMCTRL5}$	clock to data tri-state delay	rising clk edge [1]	5 [3]	20 [3]	ns
$t_{FTMCTRL6}$	clock to output delay	rising clk edge [1]	0 [2]	20 [3]	ns
$t_{FTMCTRL7}$	data input to clock setup	rising clk edge [1]	5 [3]	-	ns
$t_{FTMCTRL8}$	data input from clock hold	rising clk edge [1]	-	-	ns
$t_{FTMCTRL9}$	input to clock setup	rising clk edge [1]	5 [3]	-	ns
$t_{FTMCTRL10}$	input from clock hold	rising clk edge [1]	-	-	ns

[1] Timing values are relative to the internal clock for the PROM/SRAM memory controller.

2) Guaranteed by design, not tested

3) Verified by static timing analysis, not tested

52.11.20 UART interface timing

The timing waveforms and timing parameters are shown in figure 123 and are defined in table 712.

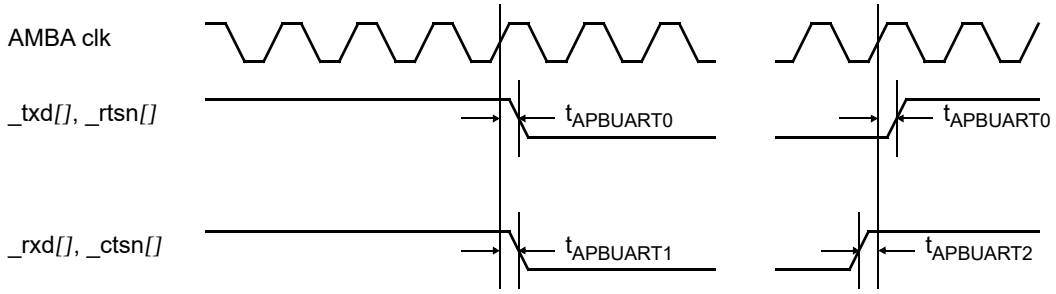


Figure 123. Timing waveforms

*Table 712.*Timing parameters

Name	Parameter	Reference edge	Min	Max	Unit
$t_{APBUART0}$	clock to output delay	rising clk edge	0 [1)]	20 [2)]	ns
$t_{APBUART1}$	input to clock hold	rising clk edge [3)]	-	-	ns
$t_{APBUART2}$	input to clock setup	rising clk edge [3)]	-	-	ns

[1)] Guaranteed by design, not tested.

[2)] Verified by static timing analysis, not tested

[3)] The *_cstn* and *_rxd* inputs are re-synchronized internally. These signals to not have to meet any setup or hold requirements.

52.11.21 DSU signals timing

The timing waveforms and timing parameters are shown in figure 124 and are defined in table 713.

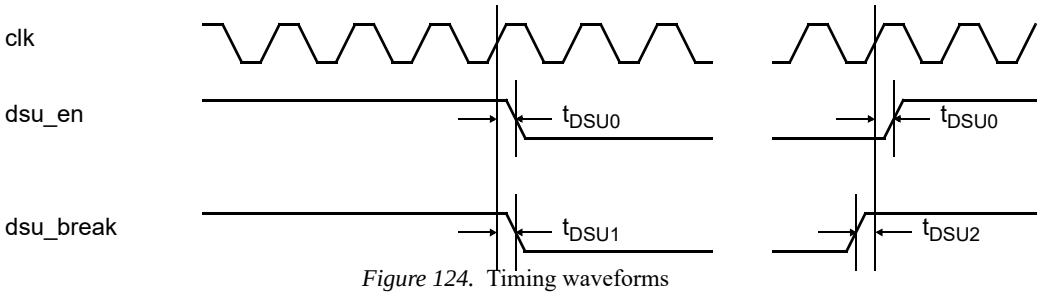


Figure 124. Timing waveforms

*Table 713.*Timing parameters

Name	Parameter	Reference edge	Min	Max	Unit
t_{DSU0}	clock to output delay	rising clk edge	0 [1)]	30 [1)]	ns
t_{DSU1}	input to clock hold	rising clk edge	- [3)]	- [3)]	ns
t_{DSU2}	input to clock setup	rising clk edge	- [3)]	- [3)]	ns

Notes:

1) This parameter is guaranteed by design and is not tested

2) This parameter is determined by static timing analysis and is not tested

3) The break and dsu_en signals are re-synchronized internally. These signals do not have to meet any setup or hold requirements. As the *dsu_en* signal controls clock gating for the Debug AHB bus the signal's value should be kept constant from power-up.

52.11.22 General purpose I/O timing

The timing waveforms are shown in figure 125, and the timing parameters are defined in table 714.

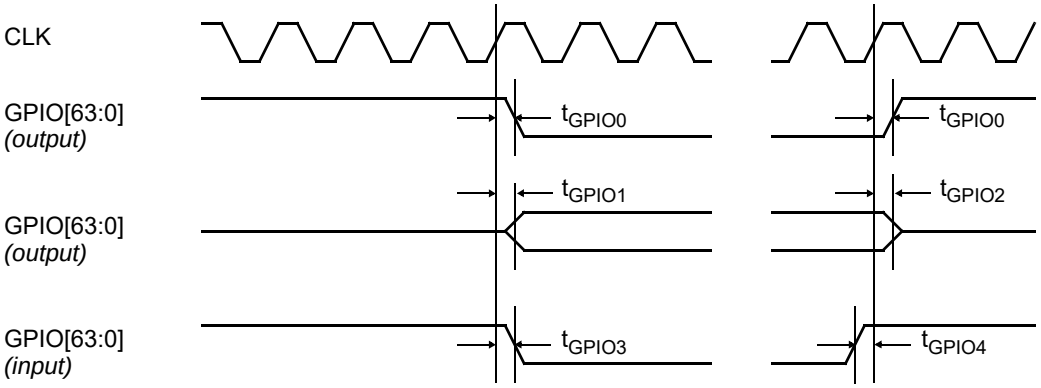


Figure 125. General purpose I/O timing waveforms

*Table 714.*General purpose I/O timing parameters

Name	Parameter	Reference edge	Min	Max	Unit
t_{GPIO0}	Clock to output delay	Rising CLK edge	0	20	ns
t_{GPIO1}	Clock to non-tri-state delay	Rising CLK edge	0	20	ns
t_{GPIO2}	Clock to tri-state delay	Rising CLK edge	0	20	ns
t_{GPIO3}	Input to clock hold	Rising CLK edge	5		ns
t_{GPIO4}	Input to clock setup	Rising CLK edge	5		ns
Note 1:	The GPIO[...] inputs are re-synchronized to the internal system clock				
Note 2:	Parameter is determined by static timing analysis and is not tested				

53 Mechanical description

53.1 Component and package

The GR716 microcontroller is provided in a 132-lead CQFP package.

53.2 Pin assignment

The pin assignment in table 715 shows the implementation characteristics of each signal indicating how each pin has been configured in terms of electrical levels, drive capability and internal pull-up or pull-down.

*Table 715.*Pin assignment

Name	I/O	Pin	Level	Drive [mA]	Pull	Active	Note
C_RST [3)]	-	18	-			-	Reset capacitor
RESET_IN_N	in	17	LVTTL			Low	System input reset. Bypass of the power-on-reset functionality.
XO_OUT	out	58	LVTTL	2		High	System clock out from oscillator
XO_X1	in	59	LVTTL			-	Crystal oscillator positive input
XO_X2	in	60	LVTTL			-	Crystal oscillator negative input
VREFBUF	out	30	-	2		-	External analog precision voltage reference
VREF [4)]	out	31	-			-	External BandGap reference. Connect to external capacitor.
RREF [5)]	out	32	-			-	External BandGap reference. Connect to external resistor.
RESET_OUT_N [6)]	out	16	LVTLL			Low	Reset signal generated from the Power On Reset or Software controlled reset. This signal will also indicate an error or watchdog event has occurred
TESTEN	in	128	LVTLL		Down	High	Test mode enable
CLK	in [1)]	57	LVTLL			High	System Clock
SPWCLK	in [1)]	54	LVTTL			High	SpaceWire Clock
DSU_EN	in	5	LVTTL		Down	High	DSU enable
DSU_BREAK	in	6	LVTTL		Down	High	DSU Break
DUART_RX	in [1)]	7	LVTTL			High	Debug UART data receive
DUART_TX	out	8	LVTTL	2		High	Debug UART data transmit
SPIM_SEL	inout	9	LVTTL	2		Low	SPI Memory select
SPIM_SCK	inout	10	LVTTL	2		High	SPI Memory data clock
SPIM_MOSI	inout	11	LVTTL	2		High	SPI Memory master out slave in
SPIM_MISO	in	12	LVTTL		Up	High	SPI Memory master input slave out

*Table 715.*Pin assignment

Name	I/O	Pin	Level	Drive [mA]	Pull	Active	Note
LVDS_RX[0]p	in	48	LVDS[2)]			High	LVDS receivers and transmitters. See section 3.3 pin definition and functionality.
LVDS_RX[0]n	in	49	LVDS[2)]			Low	
LVDS_RX[1]p	in	50	LVDS[2)]			High	
LVDS_RX[1]n	in	51	LVDS[2)]			Low	
LVDS_RX[2]p	in	52	LVDS[2)]			High	
LVDS_RX[2]n	in	53	LVDS[2)]			Low	
LVDS_TX[0]p	out	42	LVDS[2)]			High	
LVDS_TX[0]n	out	43	LVDS[2)]			Low	
LVDS_TX[1]p	out	44	LVDS[2)]			High	
LVDS_TX[1]n	out	45	LVDS[2)]			Low	
LVDS_TX[2]p	out	46	LVDS[2)]			High	
LVDS_TX[2]n	out	47	LVDS[2)]			Low	
GPIO[37]	inout	21	LVTTL [7)]	2 [7)]	[8)]	[8)]	General purpose IO with analog ADC input capabilities. See section 2.5 for functionality
GPIO[38]	inout	22	LVTTL [7)]	2 [7)]	[8)]	[8)]	
GPIO[39]	inout	23	LVTTL [7)]	2 [7)]	[8)]	[8)]	
GPIO[40]	inout	24	LVTTL [7)]	2 [7)]	[8)]	[8)]	
GPIO[41]	inout	25	LVTTL [7)]	2 [7)]	[8)]	[8)]	
GPIO[42]	inout	26	LVTTL [7)]	2 [7)]	[8)]	[8)]	
GPIO[43]	inout	27	LVTTL [7)]	2 [7)]	[8)]	[8)]	
GPIO[44]	inout	28	LVTTL [7)]	2 [7)]	[8)]	[8)]	
GPIO[45]	inout	34	LVTTL [7)]	2 [7)]	[8)]	[8)]	General purpose IO with analog DAC output capabilities. See section 2.5 for functionality
GPIO[46]	inout	35	LVTTL [7)]	2 [7)]	[8)]	[8)]	
GPIO[47]	inout	36	LVTTL [7)]	2 [7)]	[8)]	[8)]	
GPIO[48]	inout	37	LVTTL [7)]	2 [7)]	[8)]	[8)]	
GPIO[0]	inout	82	LVTTL	2	[8)]	[8)]	
GPIO[1]	inout	83	LVTTL	2	[8)]	[8)]	
GPIO[2]	inout	84	LVTTL	2	[8)]	[8)]	
GPIO[3]	inout	85	LVTTL	2	[8)]	[8)]	
GPIO[4]	inout	86	LVTTL	2	[8)]	[8)]	
GPIO[5]	inout	90	LVTTL	2	[8)]	[8)]	
GPIO[6]	inout	91	LVTTL	2	[8)]	[8)]	
GPIO[7]	inout	92	LVTTL	2	[8)]	[8)]	
GPIO[8]	inout	93	LVTTL	2	[8)]	[8)]	
GPIO[9]	inout	94	LVTTL	2	[8)]	[8)]	
GPIO[10]	inout	95	LVTTL	2	[8)]	[8)]	
GPIO[11]	inout	96	LVTTL	2	[8)]	[8)]	
GPIO[12]	inout	97	LVTTL	2	[8)]	[8)]	
GPIO[13]	inout	98	LVTTL	2	[8)]	[8)]	
GPIO[14]	inout	99	LVTTL	2	[8)]	[8)]	
GPIO[15]	inout	100	LVTTL	2	[8)]	[8)]	
GPIO[16]	inout	104	LVTTL	2	[8)]	[8)]	
GPIO[17]	inout	105	LVTTL	2	[8)]	[8)]	
GPIO[18]	inout	106	LVTTL	2	[8)]	[8)]	

*Table 715.*Pin assignment

Name	I/O	Pin	Level	Drive [mA]	Pull	Active	Note
GPIO[19]	inout	107	LVTTL	2	8)	8)	
GPIO[20]	inout	108	LVTTL	2	8)	8)	
GPIO[21]	inout	109	LVTTL	2	8)	8)	
GPIO[22]	inout	110	LVTTL	2	8)	8)	
GPIO[23]	inout	111	LVTTL	2	8)	8)	
GPIO[24]	inout	112	LVTTL	2	8)	8)	
GPIO[25]	inout	113	LVTTL	2	8)	8)	
GPIO[26]	inout	114	LVTTL	2	8)	8)	
GPIO[27]	inout	118	LVTTL	2	8)	8)	
GPIO[28]	inout	119	LVTTL	2	8)	8)	
GPIO[29]	inout	120	LVTTL	2	8)	8)	
GPIO[30]	inout	121	LVTTL	2	8)	8)	
GPIO[31]	inout	122	LVTTL	2	8)	8)	
GPIO[32]	inout	123	LVTTL	2	8)	8)	
GPIO[33]	inout	124	LVTTL	2	8)	8)	
GPIO[34]	inout	125	LVTTL	2	8)	8)	
GPIO[35]	inout	126	LVTTL	2	8)	8)	
GPIO[36]	inout	127	LVTTL	2	8)	8)	
GPIO[49]	inout	64	LVTTL	2	8)	8)	
GPIO[50]	inout	65	LVTTL	2	8)	8)	
GPIO[51]	inout	66	LVTTL	2	8)	8)	
GPIO[52]	inout	67	LVTTL	2	8)	8)	
GPIO[53]	inout	68	LVTTL	2	8)	8)	
GPIO[54]	inout	69	LVTTL	2	8)	8)	
GPIO[55]	inout	70	LVTTL	2	8)	8)	
GPIO[56]	inout	71	LVTTL	2	8)	8)	
GPIO[57]	inout	72	LVTTL	2	8)	8)	
GPIO[58]	inout	73	LVTTL	2	8)	8)	
GPIO[59]	inout	77	LVTTL	2	8)	8)	
GPIO[60]	inout	78	LVTTL	2	8)	8)	
GPIO[61]	inout	79	LVTTL	2	8)	8)	
GPIO[62]	inout	80	LVTTL	2	8)	8)	
GPIO[63]	inout	81	LVTTL	2	8)	8)	
VDD_CORE	-	1, 15, 61, 76, 89, 103, 117, 132					1.8V supply 9) 10) 13)
VDD_IO	-	4, 13, 63, 74, 87, 101, 115, 129					3.3V supply 10)
GND	-	3, 14, 41, 62, 75, 88, 102, 116, 130					Ground 10)
VDDA_ADC	-	19					Analog ADC supply 10) 12)
VSSA_ADC	-	20					Analog ADC ground 10) 12)
VDDA_REF	-	29					Analog reference supply 10) 12)
VSSA_REF	-	33					Analog reference ground. 10) 12)
VDDA_DAC	-	39					Analog DAC supply 10) 12)

*Table 715.*Pin assignment

Name	I/O	Pin	Level	Drive [mA]	Pull	Active	Note
VSSA_DAC	-	38					Analog DAC ground [10) 12)]
VDDA_LVDS	-	40					Analog LVDS supply [10) 12)]
VDDA_PLL	-	55					Analog PLL supply [11)]
VSSA_PLL	-	56					Analog PLL ground [11)]
LDO_IN	-	2, 131					LDO Supply pins [10)]

Note 1: Input is protected by schmitt trigger

Note 2: LVDS inputs and outputs pins, no on-chip support for cold spare or fail safe

Note 3: Reset capacitor must be large enough to keep the device in reset until power and system clock is stable. Capacitor (C_{rst}) is recommend to be at least 47nF and must be greater or equal to 5nF. Start-up reset pulse width (T_{pw}) can be estimated using the formula: $T_{pw} = 755000*C_{rst}$. For example $T_{pw_15nF} = 755000*47nF$=~35ms.

Note 4: Connect to ground via 4.7nF decoupling capacitor.

Note 5: Connect to ground via resistance of 5.11 Kohm.

Note 6: Connect to ground via resistance of 10 Kohm resistor.

Note 7: Applies only for digital functionality

Note 8: Parameter is programmable when digital functionality is selected for pin

Note 9: In single voltage supply mode no external 1.8V supply should be connected

Note 10: External decoupling should be added in all supply modes and as close as possible to the supply pins.

Note 11: The PLL is supplied by 1.8V from an internal LDO, which should have an external 2.2uF ceramic decoupling capacitor (typically X7R), rated 6V or higher on the PLL supply pin VDDA_PLL to VSSA_PLL. The VDDA_PLL supply pin shall be left open, with exception of this decoupling capacitor to VSSA_PLL.

Note 12: It is recommended to use separate power supplies for analog supply or to insert local LP filters, such that supply noise becomes lower than TBD V_rms between analog supply and ground.

Note 13: VDD_CORE shall not be supplied when LDO_IN is supplied.

53.3 Mechanical package drawings

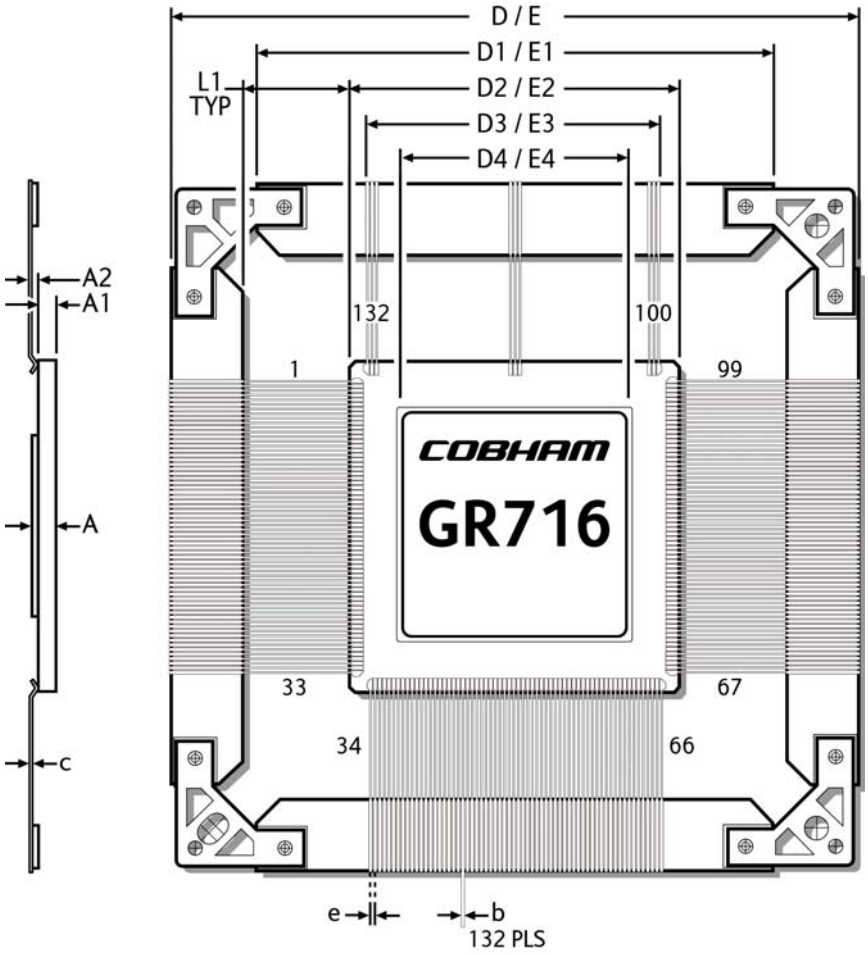


Figure 126. 132 CQFP package top view

Table 716. Package dimensions[1)2)]

Name	Parameter	Min	TYP	Max	Unit
A			3.05	3.5	mm
A1		1.84		2.26	mm
A2		0.27		0.53	mm
b1	Width of lead when closest to case	0.23		0.329	mm
b2	Width of lead when closest to ceramic bar	0.15		0.25	mm
c		0.075		0.175	mm
D/E			50.85		mm
D1/E1			30.73		mm
D2/E2		23.88		24.26	mm
D3/E3			20.32		mm
D4/E4			20.2		mm
e			0.635		mm
L1	Length of lead from case to ceramic bar (L2+L3)		8.3		mm
L2	Length of lead with width b1		7.0		mm
L3	Length of lead with width b2		1.3		mm
Note 1:	The lid is connected to ground				
Note 2:	Mass of case, including the lead frames, shall be 7±1 grams.				

54 Ordering information

Please contact Cobham Gaisler AB through sales@gaisler.com. Ordering information is provided in table 717 and a legend is provided in table 718.

*Table 717.*Ordering information, available models and legacy models

Product	Description
GR716A-CP-CQ132	Engineering model (Prototype)
GR716A-MP-CQ132	Electrical Qualified Model
GR716A-MS-CQ132 [1)]	Fight model
GR716A-DD-CQ132 [5)]	Dummy package model
GR716-XX-CQ132-AAAA [2) 3)]	Obsolete prototype, not available for ordering
GR716-XX-CQ132-AAAB [2)]	Obsolete prototype, not available for ordering
GR716-XX-CQ132-AABA [2) 4)]	Engineering model (Prototype)

Note 1: Contact Cobham Gaisler AB through sales@gaisler.com for availability.

Note 2: Not available for new orders.

Note 3: Marked with GR716-XX-CQ132 on the lid.

Note 4: GR716-XX-CQ132-AABA has the same configuration as all -CP, -MP, -MS parts

Note 5: Electrical rejects may be used in lieu of dummy package model

*Table 718.*Ordering legend

Designator	Option	Description
Product	GR716A [2)]	Radiation-Tolerant LEON3 Microcontroller.
Temperature Range	M	-55°C to +125°C (Military range)
	C	0°C to +70°C (Commercial range)
	X	Prototypes, tested at room temperature only
	D	Reserved for Dummy package
Screening level and assembly flow	S	Space grade
	P	Prototype grade
	X	First assembled prototypes
	D	Reserved for Dummy package
Package Type	CQ	Ceramic Quad Flat Pack (CQFP) [1)]
Lead Count	132	Number of leads
Package configuration	A	
Silicon version	A	
Mask version	A	First mask version
	B [3)]	Metal mask version update for Errata, see 55.1
Bonding option	A	Voltage monitor IO direction control enabled
	B	Voltage monitor IO direction control disabled to resolve errata GR716-ERRATA-20190402 for Mask revision A, see 55.1

Note 1: Gold lead finish

Note 2: GR716A is the final product name for the GR716 defined by this datasheet and user manual. Contact for sales for information of next generation of GR716 with product name GR716B that is under development.

Note 3: For silicon and mask change description and list of errata see section 54.1 and 55.1

54.1 Silicon and mask information

This section describes changes and updates for silicon and metal-mask versions.

For more information contact support@gaisler.com.

Table 719 lists silicon and mask change and errata corrected. Errata information is further described in section 55.1.

*Table 719.*Silicon and mask change description and list of errata corrected by update

Silicon [1)]	Mask [2)]	Errata Corrected	Description
A (no change)	B	GR716-ERRATA-20190401	Mask update from first version to version B. Only masks for metal layers were updated.
		GR716-ERRATA-20190402	
		GR716-ERRATA-20190404	
		GR716-ERRATA-20190507	

Note 1: Silicon is a set of masks of dozen or so (varies with process and manufacturer) individual masks that are required to complete a product wafer fabrication from start to finish.

Note 2: Mask defines the geometrical pattern to be used for a single step in the manufacturing process of the product wafer

55 Errata

This chapter describes known issues with current existing silicon.

If not otherwise stated, the items in this section are planned for correction in the next revision of the silicon.

For more information contact support@gaisler.com.

55.1 Overview

Table 720 lists errata that are further described in section 55.2.

*Table 720.*Errata

ID	Device(s) Affected	Name / Description
GR716-ERRATA-20190401	GR716-XX-CQ132-AAAA GR716-XX-CQ132-AAAB	XO doesn't start to oscillate due to low gain
GR716-ERRATA-20190402	GR716-XX-CQ132-AAAA GR716-XX-CQ132-AAAB	VMON erroneous startup state
GR716-ERRATA-20190403	GR716-XX-CQ132-AAAA GR716-XX-CQ132-AAAB GR716-XX-CQ132-AABA	Internal ADC settling time is too short
GR716-ERRATA-20190404	GR716-XX-CQ132-AAAA GR716-XX-CQ132-AAAB	ADC offset error
GR716-ERRATA-20190405	GR716-XX-CQ132-AAAA GR716-XX-CQ132-AAAB GR716-XX-CQ132-AABA	FTMCTRL external PROM chip select anomaly for 8 MiB bank size
GR716-ERRATA-20190406	GR716-XX-CQ132-AAAA GR716-XX-CQ132-AAAB GR716-XX-CQ132-AABA	GRDMAC channels must be in ascending order without spaces
GR716-ERRATA-20190506	GR716-XX-CQ132-AAAA GR716-XX-CQ132-AAAB	PLL does not lock for high frequency input
GR716-ERRATA-20190507	GR716-XX-CQ132-AAAA GR716-XX-CQ132-AAAB	ADC Pre-amplifier Gain non-ideal
GR716-ERRATA-20190801	GR716-XX-CQ132-AAAA GR716-XX-CQ132-AAAB GR716-XX-CQ132-AABA	GRDMAC Conditional descriptor Termination condition type 0 do not terminate
GR716-ERRATA-20200226	GR716-XX-CQ132-AAAA GR716-XX-CQ132-AAAB GR716-XX-CQ132-AABA	XO power-down not supported
GR716-ERRATA-20200309	GR716-XX-CQ132-AABA	XO worst-case gain margin including too low gain
GR716-ERRATA-20200310	GR716-XX-CQ132-AABA	ADC Pre-amplifier Gain non-ideal #2
GR716-ERRATA-20200511	GR716-XX-CQ132-AAAA GR716-XX-CQ132-AAAB GR716-XX-CQ132-AABA	Lower ESD tolerance on supply pins

55.2 Errata description

55.2.1 XO doesn't start to oscillate due to low gain

ID: GR716-ERRATA-20190401

The drive strength of the XO have small gain margin compared to what is needed in-order to start oscillation of a external crystal. The impact is that the crystal and its passive components needs to be chosen carefully to guarantee that the oscillator is starting successfully. Frequency, load capacitance and ESR value needs to be considered. Refer to the XO section for suggested crystals.

Workaround: N/A

This item is planned to be corrected for the next revision of the silicon.

55.2.2 VMON erroneous startup state

ID: GR716-ERRATA-20190402

The Brown out blocks could start in a triggered and latched state after power-on. One feature of the brown out is that it locks the IOs direction when it triggers. This together with the faulty state after power on implies that the supported boot alternatives are limited. IO direction is only locked for GR716-XX-CQ132-AAAA.

Workaround: To get to a known state after power-on toggle the power down signals to each of the brown out blocks. First set the signals to logic high, followed by logic low. After this sequence the brown out is in a known state and will work as intended.

This item is planned to be corrected for the next revision of the silicon.

55.2.3 Internal ADC settling time is too short

ID: GR716-ERRATA-20190403

Sampling can give less correct or accurate value due to internal ADC settling time is too short when switching between ADC control units.

Workaround: Use ADC control unit 0 and 4. ADC control units 0 and 4 have priority over all other ADC control units and use longer settling time by default.

This item is planned to be corrected for the next revision of the silicon.

55.2.4 ADC offset error

ID: GR716-ERRATA-20190404

The ADC has offset error i.e. it will not be possible to detect an external voltage level for single ended input in the range from 0mV to 8mV. The ADC offset error is due to too high impedance in the ground connection between the ADC and the external PAD.

Workaround: N/A

This item is planned to be corrected for the next revision of the silicon.

55.2.5 FTMCTRL external PROM chip select anomaly for 8 MiB bank size

ID: GR716-ERRATA-20190405

PROM bank chip select pins romsn[1:0] does not behave according to the description in section 20.7 when MCFG1.ROMBANKSZ=0xA. When MCFG1.ROMBANKSZ=0xA then romsn[1:0] will never be activated. ROMBANKSZ=0x0..0x09 behave as per the description in section 20.7.

Workaround: Set MCFG1.ROMBANKSZ=0x0. With this value, romsn[0] will be activated for the lower 8MiB and romsn[1] for the upper 8MiB of the PROM bank.

This item is planned to be corrected for the next revision of the silicon.

55.2.6 GRDMAC channels must be in ascending order without spaces

ID: GR716-ERRATA-20190406

The GRDMAC can’t cope with disabled channels between active channels.

Workaround: Enable only used channels in ascending order without space

This item is planned to be corrected for the next revision of the silicon.

55.2.7 PLL does not lock for high frequency input

ID: GR716-ERRATA-20190506

PLL is not locking for the highest input frequencies.

Workaround: It is recommended to use an input frequency to the PLL no higher than 25 MHz.

This item is planned to be corrected for the next revision of the silicon.

55.2.8 ADC Pre-amplifier Gain non-ideal

ID: GR716-ERRATA-20190507

The gain of the ADC pre-amplifiers are too low. Gain values are 0.95-1.0 (gain x1), 1.85-2.0 (gain x2) and 3.5-4.0 (gain x4). The gain can be different for the 8 input channels for both amplifiers. Contact support for more information.

Workaround: n/a.

55.2.9 GRDMAC Conditional descriptor Termination condition type 0 do not terminate

ID: GR716-ERRATA-20190801

DMA transfer will not start due to conditional descriptor type 0 termination condition is erroneous and will not terminate correctly if expected data is low or cleared

This item is planned to be corrected for the next revision of the silicon.

Workaround: Use conditional descriptor type 1 to detect if bit is cleared to start DMA transfer.

55.2.10 XO power-down not supported

ID: GR716-ERRATA-20200226

It is not possible to set the XO in a low-powered mode. This implies that the XO will consume power also in applications where an external clock source is used.

This item is planned to be corrected for the next revision of the silicon.

Workaround: n/a.

55.2.11 XO worst-case gain margin including too low gain

ID: GR716-ERRATA-20200309

The limit drive strength worst-case gain margins requires careful considerations of the crystal oscillator design. Refer to the XO section for suggested crystals and design considerations.

This item is planned to be corrected for the next revision of the silicon.

Workaround: See crystal recommendations in chapter 9.2.3

55.2.12 ADC Pre-amplifier Gain non-ideal #2

ID: GR716-ERRATA-20200310

The gain of the ADC pre-amplifiers are too low. Typical gain values are 0.99 (gain x1), 1.95 (gain x2) and 3.85 (gain x4). Contact support for more information.

Workaround: n/a.

55.2.13 Lower ESD tolerance on supply pins

ID: GR716-ERRATA-20200511

A limited number of supply pins have 500V HBM tolerance. After mounted with decoupling, stated ESD rating in chapter 52.1 is applicable.

Contact support@gaisler.com for more information.

This item is planned to be corrected for the next revision of the silicon.

Workaround: n/a.

56 Planned Features

This chapter describes future features planned for the next revision of the silicon.

Contact support@gaisler.com for more information.

56.1 Overview

Table 721 lists features that are further described in section 56.2.

*Table 721.*Features

ID	Device Release	Name / Description
GR716-FEATURE-20190406	GR716-XX-CQ132-ABAA	ColdSpare and FailSafe for LVDS
GR716-FEATURE-20190407	GR716-XX-CQ132-ABAA	CAN-FD capability
GR716-FEATURE-20190408	GR716-XX-CQ132-ABAA	FPGA scrubber and support unit
GR716-FEATURE-20190409	GR716-XX-CQ132-ABAA	SPI memory controller with support for 4 byte address
GR716-FEATURE-20190410	GR716-XX-CQ132-ABAA	SpaceWire TDP synchronization to PPS 1Hz input
GR716-FEATURE-20190411	GR716-XX-CQ132-ABAA	SpaceWire router capability
GR716-FEATURE-20200308	GR716-XX-CQ132-ABAA	ADC 13-bit resolution mode and increase of sampling rate for ADC 11-bit mode
GR716-FEATURE-20200309	GR716-XX-CQ132-ABAA	Additional ADC sample hold circuits for simultaneously sampling up to 3 sources
GR716-FEATURE-20200310	GR716-XX-CQ132-ABAA	Analog comparator capability

56.2 Feature description

56.2.1 ColdSpare and FailSafe for LVDS

ID: GR716-FEATURE-20190406

Contact support@gaisler.com for more information.

56.2.2 FPGA scrubber and support unit

ID: GR716-FEATURE-20190407

Contact support@gaisler.com for more information.

56.2.3 CAN-FD capability

ID: GR716-FEATURE-20190408

Contact support@gaisler.com for more information.

56.2.4 SPI memory controller with support for 4 byte address

ID: GR716-FEATURE-20190409

Contact support@gaisler.com for more information.

56.2.5 SpaceWire TDP synchronization to PPS 1Hz input

ID: GR716-FEATURE-20190410

Contact support@gaisler.com for more information.

56.2.6 SpaceWire router capability

ID: GR716-FEATURE-20190411

Contact support@gaisler.com for more information.

56.2.7 ADC 13-bit resolution mode and increase of sampling speed

ID: GR716-FEATURE-20200308

Contact support@gaisler.com for more information.

56.2.8 Additional ADC sample hold circuits for simultaneously sampling up to 3 sources

ID: GR716-FEATURE-20200309

Contact support@gaisler.com for more information.

56.2.9 Analog comparator capability

ID: GR716-FEATURE-20200310

Contact support@gaisler.com for more information.

Cobham Gaisler AB
Kungsgatan 12
411 19 Göteborg
Sweden
www.cobham.com/gaisler
sales@gaisler.com
T: +46 31 7758650
F: +46 31 421407

Cobham Gaisler AB, reserves the right to make changes to any products and services described herein at any time without notice. Consult Cobham or an authorized sales representative to verify that the information in this document is current before using this product. Cobham does not assume any responsibility or liability arising out of the application or use of any product or service described herein, except as expressly agreed to in writing by Cobham; nor does the purchGR716-DS-UMase, lease, or use of a product or service from Cobham convey a license under any patent rights, copyrights, trademark rights, or any other of the intellectual rights of Cobham or of third parties. All information is provided as is. There is no warranty that it is correct or suitable for any purpose, neither implicit nor explicit.

Copyright © 2020 Cobham Gaisler AB