GR716A / GR716B
GR716 Rad-Hard Microcontroller
For Space Applications

AMICSA 2021

2021-05-27
Fredrik Johansson
Cobham Gaisler AB
GR716

Single-Core LEON3FT Microcontroller
Features

- LEON3FT - Fault-tolerant SPARC V8 32-bit processor, 50 MHz
  - LEON-REX – extension with 16-bit instructions: improved code density
  - Floating Point Unit
  - Memory protection units
  - Non-intrusive advanced on-chip debug support unit
  - Determinism: Multi-bus, fixed interrupt latency, cache-less architecture...
- External EDAC memory: 8-bit PROM/SRAM, SPI, I2C
- SpaceWire interface with time distribution support, 100 Mbps
- MIL-STD-1553B interface
- 2x CAN 2.0B controller interface
- PacketWire with CRC acceleration support
- Programmable PWM interface
- SPI with SPI-for-Space protocols
- Interrupt controller, Status registers, JTAG debug, etc.
- UARTs, I2C, GPIO, Timers with Watchdog
- 2x ADC 11bits resolution @ 200ksps, 4 diff or 8 single channels
- DAC 12bits @ 3Msps, 4 channels
- Mixed General-purpose inputs and outputs
- Power-on-Reset and Brown-out-detection
- Temperature sensor, Integrated PLL
- On-chip regulator for 3.3V single supply
GR716A - LEON3FT Microcontroller

- **On-chip SRAM w/ Dual Port, EDAC and Scrubbing, Radiation Tolerant**
  - 192 KiB Instruction and Data – User defined mix of instruction vs data

- **Integrated Floating Point Unit**
  - IEEE-754 compliant floating-point unit, supporting both single and double precision operands

- **Memory Protection Unit**
  - 8 zones and individual access control of peripherals

- **System Clock frequency: 50MHz**
  - Dynamic reconfiguration of system clock for low power
  - 100 MHz system clock for high performance system under restricted environment conditions

- **System Benchmark**
  - Dryshstone: 1.24 Dhrystone / MHz
  - Whetstone: 0.43 Whetstone / MHz
  - CoreMark: 2.21 CoreMark / MHz
  - EDAC, Scrubbing, DMA transfers and debug are non-intrusive and do not affect performance

<table>
<thead>
<tr>
<th>Processor</th>
<th>Processor core</th>
<th>LEON3FT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Architecture</td>
<td>SPARC V8 w. V8e subset</td>
<td></td>
</tr>
<tr>
<td>RISC type</td>
<td>32bit</td>
<td></td>
</tr>
<tr>
<td>Instruction set</td>
<td>SPARC V8(e), LEON REX</td>
<td></td>
</tr>
<tr>
<td>Pipeline stages</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Tightly coupled memory</td>
<td>192 KiB</td>
<td></td>
</tr>
<tr>
<td>FPU</td>
<td>IEEE-754</td>
<td></td>
</tr>
<tr>
<td>MPU</td>
<td>yes</td>
<td></td>
</tr>
<tr>
<td>Mul/Div</td>
<td>Mul/Div</td>
<td></td>
</tr>
<tr>
<td>Peripheral DMA</td>
<td>multi-channel</td>
<td></td>
</tr>
<tr>
<td>Interrupt handling</td>
<td>deterministic</td>
<td></td>
</tr>
<tr>
<td>Performance counters</td>
<td>yes</td>
<td></td>
</tr>
<tr>
<td>Debug unit</td>
<td>yes</td>
<td></td>
</tr>
<tr>
<td>Embedded trace buffer</td>
<td>yes</td>
<td></td>
</tr>
<tr>
<td>Processor MHz</td>
<td>50</td>
<td></td>
</tr>
</tbody>
</table>

**Performance**

- Dhrystone / MHz: 0.93 / 1.24 / 1.46
- Whetstone / MHz: 0.43
- CoreMark / MHz: 2.21

* Dhrystone Performance: Compiler Versions and Ground Rules application note is available at https://www.gaisler.com/index.php/information/app-tech-notes
• **Standby**
  • Current consumption direct after boot has finished (Waiting remote boot)

• **CoreMark**
  • Highest measured current consumption while running CoreMark (All code is executed from internal memory protected by EDAC)

• **WhetStone**
  • Highest measured current consumption while running WhetStone (All code is executed from internal memory protected by EDAC)

• **MIL-1553 / SRAM / RTEMS**
  • Highest measured current consumption while receiving and transmitting MIL-1553 traffic.
  • RTEMS operating systems and drivers are executed from external SRAM

• **Miscellaneous**
  • LVDS adds 4mA per LVDS
  • ADC adds 2mA per ADC
  • DAC adds 4mA per DAC
  • PLL adds 2mA
  • External voltage reference 2-4mA

---

<table>
<thead>
<tr>
<th>Mode</th>
<th>Supply Mode</th>
<th>Frequency</th>
<th>1.8V Supply</th>
<th>3.3V Supply</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standby</td>
<td>Dual Supply</td>
<td>10MHz</td>
<td>18mA</td>
<td>10mA</td>
</tr>
<tr>
<td></td>
<td>Single Supply</td>
<td>10MHz</td>
<td>-</td>
<td>34mA</td>
</tr>
<tr>
<td></td>
<td>Dual Supply</td>
<td>25MHz</td>
<td>58mA</td>
<td>11mA</td>
</tr>
<tr>
<td></td>
<td>Single Supply</td>
<td>25MHz</td>
<td>-</td>
<td>75mA</td>
</tr>
<tr>
<td>CoreMark</td>
<td>Dual Supply</td>
<td>10MHz</td>
<td>36mA</td>
<td>10mA</td>
</tr>
<tr>
<td></td>
<td>Single Supply</td>
<td>10MHz</td>
<td>-</td>
<td>52mA</td>
</tr>
<tr>
<td></td>
<td>Dual Supply</td>
<td>25MHz</td>
<td>104mA</td>
<td>11mA</td>
</tr>
<tr>
<td></td>
<td>Single Supply</td>
<td>25MHz</td>
<td>-</td>
<td>121mA</td>
</tr>
<tr>
<td>WhetStone</td>
<td>Dual Supply</td>
<td>10MHz</td>
<td>34mA</td>
<td>10mA</td>
</tr>
<tr>
<td></td>
<td>Single Supply</td>
<td>10MHz</td>
<td>-</td>
<td>48mA</td>
</tr>
<tr>
<td></td>
<td>Dual Supply</td>
<td>25MHz</td>
<td>97mA</td>
<td>11mA</td>
</tr>
<tr>
<td></td>
<td>Single Supply</td>
<td>25MHz</td>
<td>-</td>
<td>117mA</td>
</tr>
<tr>
<td>RTEMS/1553</td>
<td>Dual Supply</td>
<td>10MHz</td>
<td>35mA</td>
<td>15mA</td>
</tr>
<tr>
<td></td>
<td>Single Supply</td>
<td>10MHz</td>
<td>-</td>
<td>56mA</td>
</tr>
<tr>
<td></td>
<td>Dual Supply</td>
<td>25MHz</td>
<td>78mA</td>
<td>20mA</td>
</tr>
<tr>
<td></td>
<td>Single Supply</td>
<td>25MHz</td>
<td>-</td>
<td>104mA</td>
</tr>
</tbody>
</table>

* Values represent maximum measured current consumption in mode or test
** Values are an average of 128 sample averaging with 532us between samples
GR716A - LEON3FT Microcontroller

- **BCC2.2.0 Development Environment**
  - GCC-10.2 or LLVM-8.0
  - GR716 BSP and Drivers Support build in
  - Free download from www.gaisler.com

- **GRMON3 Debugger**
  - Graphical User Interface (GUI) based on Eclipse TCF (Target Communication Framework) platform (used by Wind River and Xilinx)
  - GRMON displays HW/SW state in GUI without GDB in-between

- **TSIM3 Software Simulator**
  - Zephyr RTOS support
    - To be released in 2021
• GR716 Evaluation and Development Boards
  (All development boards are available today for GR716A)
  • GR716 Software Evaluation Board
  • GR716 Hardware Engineering board
  • GR716 Interface Development Board

• Board Information and support
  • Boards supported by current BSP
  • Quick start guides and examples

• For more information about boards see

• Evaluation boards can be shipped immediately
  • Loaner agreement for 3 months
  • Compiler, debugger and software available for download
  • Current version is shipped with GR716A
GR716A - LEON3FT Microcontroller

- **Build your application via available interface boards**
- **Compatible boards possible to direct connect and use from Cobham Gaisler:**
  - GR-ACC-6U-6UART
  - GR-ACC-GR740
  - GR-CPCI-CAN
  - GR-TMTC-PW (6U)
  - SPI4S Test Board
  - Analog Front end
- **Use Configuration Board to avoid driver contamination**
  - Possible to fit mezzanine board on the development board to avoid erroneous configuration of the IOs
- **For further information and inquiries**
  - www.caes.com/gaisler
  - sales@gaisler.com
## GR716A - LEON3FT Microcontroller

<table>
<thead>
<tr>
<th>GR716A</th>
<th>Status</th>
<th>Milestone</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prototype level functional test</td>
<td>done</td>
<td>Q4 2018</td>
<td>completed in December</td>
</tr>
<tr>
<td>Prototype level performance test</td>
<td>done</td>
<td>Q2 2019</td>
<td>Completed in April</td>
</tr>
<tr>
<td>Prototype level part delivery</td>
<td>done</td>
<td>Q2 2019</td>
<td>Completed in April</td>
</tr>
<tr>
<td>Evaluation board delivery</td>
<td>done</td>
<td>Q2 2019</td>
<td>Completed in April</td>
</tr>
<tr>
<td>Datasheet and User’s manual released on website</td>
<td>done</td>
<td>Q2 2019</td>
<td>Completed in May</td>
</tr>
<tr>
<td>Prototype Radiation test</td>
<td>done</td>
<td>Q3 2019</td>
<td>Completed in September</td>
</tr>
<tr>
<td>Prototype with improved analogue performance</td>
<td>done</td>
<td>Q3 2019</td>
<td>Available for order</td>
</tr>
<tr>
<td>Qualification lot production</td>
<td></td>
<td>Q2 2021</td>
<td>On-going</td>
</tr>
<tr>
<td>Flight qualification complete GR716A</td>
<td></td>
<td>Q3 2021</td>
<td>On-going</td>
</tr>
</tbody>
</table>
GR716B
Enhanced Single-Core LEON3FT Microcontroller
GR716B - LEON3FT Processor

Features

- LEON3FT - Fault-tolerant SPARC V8 32-bit processor, 100 MHz
  - LEON-REX – extension with 16-bit instructions: improved code density
  - Pipelined Floating Point Unit
  - Memory protection units
  - Non-intrusive advanced on-chip debug support unit
  - Determinism: Multi-bus, fixed interrupt latency, cache-less architecture...

- External EDAC memory: 8-bit PROM/SRAM, SPI (4 Byte address), I2C
- Hardware FPGA programming: Xilinx Virtex5, UltraScale, ...
- 2-Port SpaceWire Router with time distribution support, 200 Mbps
- Robust: MIL-STD-1553B interface
- 2x CAN-FD controller interface with CANopen support for remote boot
- PacketWire with CRC acceleration support
- Programmable Enhanced PWM interface with Digital voltage control loop support
- SPI with SPI-for-Space protocols
- Ethernet, UARTs, I2C, GPIO, Timers with Watchdog
- Programmable Enhanced DMA with AES-256 Encryption support
- Interrupt controller, Status registers, JTAG debug, etc.
- 4x ADC 13bits resolution @ 500Ksps, 8 differential or 16 single ended channels
- DAC 12bits @ 3Msps, 4 channels
- LVDS with ColdSpare and Fail-Safe support, Mixed General-purpose inputs and outputs
- Power-on-Reset and Brown-out-detection
- 20xAnalogoue comparator
- Temperature sensor, Integrated PLL
- On-chip regulator for 3.3V single supply
Application areas required to be supported by the controller
- Up to 4 switching power controllers for Buck, Boost, Full-bridge topologies, etc.
- Overcurrent and overvoltage power-converter protections
- Power system monitoring
- Latch-up detection, to support e.g. space usage of commercial FPGAs and other COTS
- Motor control

Application areas desired to be supported by GR716B
- Magnetorquer control
- High voltage and high current generators
- General application areas for GR716B:
  - Propulsion Unit control
  - Sun-sensor control
  - Reaction-wheel control
  - Mass Memory control
  - Program and scrubber support of COTS FPGA
  - Instrument Control Unit
  - Remote Terminal Unit control
  - Solar panel control
  - Antenna control and tuning
  - Nanosatellite Controller
2x Real-Time Accelerator (RTA)
- Two independent LEON3 subsystems:
  - Speed up response time for time critical applications
  - Fast access to peripheral and interface
  - Up to 16KiB of instructions and data ram
  - 3x Processing power

13b ADC with Fast Analogue Comparator
- 20 Fast Analogue Comparators
  - External or internal reference
  - FIR filter and timestamp support
- 4 ADC with increased resolution up to 13 bits
  - Simultaneously sample up to 4 channels at the same time
  - Interleave 3 channels to reach higher sampling speed
  - Up to 16 single ended sources
GR716B - LEON3FT Microcontroller

- **FPGA supervisor core** (GRSCRUB)
  - Compatible with Xilinx FPGAs
  - SelectMap interface
  - Programming
  - Scrubbing
  - Blind or readback
  - Full or partial
  - CRC, ECC, or Full Frame Check (FFC)

- **GRDMA core** (GRDMAC2)
  - **Simplified** programming model
  - Single descriptor queue
  - **Easier** to manage descriptor table
  - Pause, resume and restart from SW
  - Support for if-else statements
  - Support AES-256 Encryption/Decryption
  - Termination condition based upon combination of register value and interrupt
  - More debug and diagnostic features

- Support for 8b interface for reducing number of pins used will be supported by GR716B

- Support for if-else statement makes it possible to support more complex DMA sequence

The ADA-SDEV-KIT2 is a Development Kit for the Xilinx Kintex Ultrascale XQRKU060 Space-Grade FPGA.
On-Chip DC/DC Controller:

- Switching power converters such as the Buck and Boost topology
- Overcurrent and overvoltage power-converter protections
- Programmable control loop
Motor Control:

- Up to 4 BLDC motors can be controlled.
- Support for PWM-control mode, block-commutation mode, etc.
- Over-current detection.
**Power system monitoring / Latch-Up Detector:**

- Overall system requirement is to detect and shut-down within 12us

- Latch Up detector should have 2 programmable thresholds ("Averaging" and "Fast") Current

- Current TID-Test Setup: Clamp when 9 Detection over last 16 samples (16 Samples = Detection period)
GR716B - LEON3FT Microcontroller

<table>
<thead>
<tr>
<th>GR716B</th>
<th>Status</th>
<th>Milestone</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scrubber interoperability test w Xilinx UltraScale FPGAs</td>
<td>done</td>
<td>Q1 2020</td>
<td>FPGA prototype</td>
</tr>
<tr>
<td>Tape-out of improved LVDS test chip w Cold Spare</td>
<td>done</td>
<td>Q2 2020</td>
<td>Samples back in Q3</td>
</tr>
<tr>
<td>GR716B ESA ARTES* System Requirements Review</td>
<td>done</td>
<td>2nd July 2020</td>
<td></td>
</tr>
<tr>
<td>GR716B ESA ARTES* Preliminary Design Review</td>
<td>done</td>
<td>Dec 2020</td>
<td></td>
</tr>
<tr>
<td>Early GR716B prototype samples</td>
<td></td>
<td>Q3 2022</td>
<td></td>
</tr>
<tr>
<td>GR716B prototypes tested in full temperature range</td>
<td></td>
<td>Q3 2022</td>
<td></td>
</tr>
<tr>
<td>Evaluation board delivery</td>
<td></td>
<td>Q3 2022</td>
<td></td>
</tr>
<tr>
<td>Datasheet and User’s manual release online</td>
<td></td>
<td>Q3 2022</td>
<td>Draft version Q3 2020</td>
</tr>
<tr>
<td>Flight part qualification complete</td>
<td></td>
<td>TBC</td>
<td>To be determined after funding secured</td>
</tr>
</tbody>
</table>

* GR716B ARTES Competitiveness & Growth Full activity aims to develop and test a new generation microcontroller GR716B based on the GR716A microcontroller. GR716B shall enable use of commercial off the shelf (COTS) FPGAs in critical space applications (beneficial not the least for satcom constellations), support switching power applications, enhance analogue functions, increase processing performance and support more advanced interfaces. The proposed activity shall also enrich the software ecosystem by industrialization of state-of-the-art operating systems, development and simulation tools.
## Specification

<table>
<thead>
<tr>
<th>Part nr.</th>
<th>Processor core</th>
<th>Clock frequency</th>
<th>Performance</th>
<th>TID krad (Si)</th>
<th>SEL LET (MeV·cm²/mg)</th>
<th>Power cons.</th>
<th>Package</th>
<th>Qualification status</th>
<th>Availability</th>
<th>Development board</th>
</tr>
</thead>
<tbody>
<tr>
<td>GR716A</td>
<td>Single-Core LEON3FT</td>
<td>50 MHz</td>
<td>&gt;98 DMIPS</td>
<td>100</td>
<td>&lt; 200mW at 40 deg C</td>
<td>132-Pin Ceramic Quad Flat Pack</td>
<td>Screening and qualification tests planned for Q2 2021, Life testing extended into Q3 2021, Qualification tests as per PCA defined by ESCC Basic Specification No. 256700, Screening tests as per ESCC 9000</td>
<td>Flight parts in Q3 2021, GR716 Software Evaluation Board, GR716 Hardware engineering board, GR716 interface development board</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GR716B</td>
<td>Single-Core LEON3FT</td>
<td>100 MHz*</td>
<td>&gt;196 DMIPS*</td>
<td>100*</td>
<td>&lt; 200mW at 40 deg C*</td>
<td>132-Pin Ceramic Quad Flat Pack</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Complete software toolchain and debuggers are available

* Products under development, Values can be changed without notice
For further information and inquiries

www.caes.com/gaisler
sales@gaisler.com

Thank you for listening!