Radiation-Tolerant FPGA Update

Ken O’Neill
Director of Marketing, Space and Aviation
Company Overview

- Leading-edge semiconductor solutions differentiated by:
  - Performance
  - Reliability
  - Security
  - Power

- Solid financial foundation
  - FY2017 revenue: $1.8B
  - 4800 employees today

- Major focus products
  - FPGAs and ASIC
  - Timing and OTN
  - Mixed-signal and RF
  - Switches and PHYs
  - Storage controllers
  - Discretes and integrated power solutions
Microsemi's Space Pedigree

Extensive Space Heritage
• Developing space solutions for six decades
• Proven track record of innovation, quality, and reliability

Broad Solutions Portfolio
• Power, mixed-signal, and digital for bus and payload applications

Expanding our Product Portfolio through Continuous Innovation

A Partner for the Long Run
• 60-year space heritage
Agenda

- RTG4 radiation tolerant FPGAs
  - Product overview
  - CQ352 package
  - Qualification and reliability update
  - Software, IP and solutions
  - Radiation testing, results and schedule

- Mixed Signal
- Clocks and Oscillators
- Power Products
RTG4 High-Speed RT FPGAs

RTG4 mitigates the risks of ASICs and SRAM FPGAs, and has 20x improvement in signal processing throughput.
# RTG4 Product Overview

<table>
<thead>
<tr>
<th>Resources</th>
<th>RT4G150</th>
</tr>
</thead>
<tbody>
<tr>
<td>Logic Elements (TMR Register + 4-Input C Logic)</td>
<td>151,824</td>
</tr>
<tr>
<td>18x18 Multiply-Accumulate Blocks</td>
<td>462</td>
</tr>
<tr>
<td>RAM Mbits (1.5 Kbit and 24 Kbit Blocks, with ECC)</td>
<td>5.2</td>
</tr>
<tr>
<td>UPROM Kbits</td>
<td>381</td>
</tr>
<tr>
<td>DDR2/3 SDRAM Controller (with ECC)</td>
<td>2 x 32</td>
</tr>
<tr>
<td>PCI Express Endpoints</td>
<td>2</td>
</tr>
<tr>
<td>Globals</td>
<td>24</td>
</tr>
<tr>
<td>PLLs (Rad Tolerant)</td>
<td>8</td>
</tr>
<tr>
<td>SpaceWire Clock and Data Recovery Circuits</td>
<td>16</td>
</tr>
<tr>
<td>User IO (excluding SERDES)</td>
<td>720</td>
</tr>
<tr>
<td>SERDES lanes (3.125 Gbps)</td>
<td>24</td>
</tr>
</tbody>
</table>

## Hermetic, Ceramic Packages

<table>
<thead>
<tr>
<th>Packages</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>CG1657 (Ceramic Column Grid Array, Six Sigma Columns)</td>
<td>Available Now</td>
</tr>
<tr>
<td>LG1657 (Ceramic Land Grid Array, No Solder Termination)</td>
<td></td>
</tr>
<tr>
<td>CB1657 (Ceramic Ball Grid Array, For Prototyping Only)</td>
<td></td>
</tr>
<tr>
<td>CQ352 (Ceramic Quad Flat Pack)</td>
<td>Samples Now</td>
</tr>
</tbody>
</table>

- Flight units in July '18
CQ352 Package Update

- CQ352 package features:
  - 166 MSIO supporting up to 3.3 V
  - 4 SpaceWire ports
  - 4 SerDes transceivers supporting EPCS and PCIE
  - Embedded Presidio Precious Metal Electrode (PME) 0508 decoupling capacitors

- Package size and weight:
  48 mm x 48 mm x 2.25 mm, 32 g

- Pin assignment table and package drawing available on the Microsemi website

- Engineering silicon available today

- Flight units qualified to Mil Std 883B will be available July 2018 (to lead time)

- Software support now available in Libero SoC v11.7 SP3 and later
QML Class Q qualification completed

- Mil Std 883 Class B qualification completed
- SMD has been approved and is posted on DLA web site
- RTG4 FPGAs (B, E flow) can be ordered using, and will be dual marked with, 5962-16208xxxyy part number
- SMD numbers on Microsemi web site in DLA Cross Reference Guide

QML Class V qualification pending

- Completion target: mid 2018
- Qualification uses RT4G150 in 1657-pin LGA / CCGA package
  - 45 units from 1 wafer lot
  - 4,000 hour life test was completed in 2017
  - Qualification data has been submitted to DLA
  - EV-flow flight units are available prior to official QML class V qualification
RTG4 Reliability Testing Highlights

- **Mil Std 883 Class B and QML class Q Qualification:**
  - 3 wafer lots, 54 units successfully completed 1,000-hour group C life test at $T_J \geq 125 \, ^\circ C$
  - All units continued additional life test exceeding MIL-STD-883B requirements:
    - 54 units were functional during and after 4,000-hour life test at $T_J \geq 125 \, ^\circ C$

- **Additional reliability testing**
  - Total 969 RTG4 FPGAs completed > 420,000 device-hours of life testing, 0 failures

- **ESD Class 1A**
  - $V_{DDAIO}$ passed 250 V, other pins passed 2000 V

- **Extensive reliability data collected for commercial 65nm Flash process from UMC**
  - Overall 65nm product FIT rate calculated < 3.11 FIT (60% confidence level, $EA = 0.7eV$)

- **See** RT0001: Microsemi FPGA and SoC Products Reliability Report
RTG4 High Temperature Retention

- Product retention 20 years at $T_J \leq 115^\circ$ C, or 10 years at $T_J \leq 125^\circ$ C
- Zero failures during Non-Volatile Memory Cycling Endurance testing
  - 54 units, from 6 wafer lots
  - 470+ program / erase cycles (exceeds datasheet limits),
  - Followed by 1,000 hour high temp life test

<table>
<thead>
<tr>
<th>$T_J$ (C)</th>
<th>HTR (Years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>90</td>
<td>20</td>
</tr>
<tr>
<td>95</td>
<td>20</td>
</tr>
<tr>
<td>100</td>
<td>20</td>
</tr>
<tr>
<td>105</td>
<td>20</td>
</tr>
<tr>
<td>110</td>
<td>20</td>
</tr>
<tr>
<td>115</td>
<td>20</td>
</tr>
<tr>
<td>120</td>
<td>14</td>
</tr>
<tr>
<td>125</td>
<td>10</td>
</tr>
<tr>
<td>130</td>
<td>7.2</td>
</tr>
<tr>
<td>135</td>
<td>5.3</td>
</tr>
<tr>
<td>140</td>
<td>3.9</td>
</tr>
<tr>
<td>145</td>
<td>2.8</td>
</tr>
<tr>
<td>150</td>
<td>2.1</td>
</tr>
</tbody>
</table>
Libero SoC Software Highlights

- 11.7 SP3 – Released in January 2017
  - CQ352 package support: STD speed grade, advance timing data
- 11.8 – Released in March 2017
  - Include Synplify Pro ME (L2016.09M-2), which does not infer feed-through Write mode
- 11.8 SP1 – Released August 2017
  - DirectC and .DAT file generation for RTG4 inflight programming (DirectC tool is free of charge)
- 11.8 SP2 – Released November 2017
  - Adjustments to LSRAM X9 and X12 modes
- 11.8 SP3 – Released February 2018
  - Bitstream detection of DEVRST_N assertion during programming
  - SRAM ECC simulation enhancements
  - Permanent programming enabled (One-Time Programmable mode)
  - Enhancements to Min Delay Violation repair
- 11.8 SP4 – expect to release July or August 2018
RISC-V Open Instruction Set Architecture

- Free and open Instruction Set Architecture (ISA)
  - 32-bit instructions, optional 16-bit compressed instructions
  - 32-bit, 64-bit, and 128-bit address-space options
  - Quad floating point, virtualization, many cores, heterogeneous computing

- RISC-V is not an on open-source processor: it is an ISA specification
  - Covered under the Berkeley Software Distribution (BSD) open source license
RISC-V for RTG4

- **RISC-V software tools**
  - GNU GCC, binutils, newlib stdc library, gdb JTAG/OpenPCD debug
  - LLVM/Clang
  - Linux and Windows dev environment
  - Verification Suite

- **RTG4 support**
  - Soft RISC-V IP is free of charge
  - Preliminary IP is running at 70 MHz in RT4G150 “-1”
  - Sample RISC-V project for RTG4 dev kit available now on GitHub website
  - For details, refer to RISC-V website

- **See our RTG4 RISC-V demo!**
ARM Cortex M1 in RTG4

- **ARM Cortex M1**
  - 32-bit RISC microcontroller
  - Supported by ecosystem from ARM and third-party vendors

- IP available now on MSCC website: [End User Licensing Agreement (EULA)](#) must be completed in order to download IP
  - Uses DDR controller, SPI, UART, AHB to SRAM, and timer peripherals
  - Performance targeting RT4G150, Dash-1 speed grade

<table>
<thead>
<tr>
<th>Design</th>
<th>RTG4 LUT</th>
<th>RTG4 DFF</th>
<th>RTG4 LSRAM Blocks</th>
<th>RTG4 uSRAM Blocks</th>
<th>MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARM Cortex M1</td>
<td>11,600 (7.7%)</td>
<td>6,900 (4.5%)</td>
<td>2 (1.0%)</td>
<td>128 (61%)</td>
<td>50</td>
</tr>
</tbody>
</table>
Cobham Gaisler LEON3FT and LEON4FT for RTG4

- LEON3FT and LEON4FT are available for RTG4 – also support IGLOO2 and SmartFusion2 for prototyping
- Users select between built-in RTG4 LSRAM ECC or technology-agnostic fault-tolerance
- Bridges to optionally use Microsemi IP such as FDDR memory controller and SerDes IP
- Ready-made template designs, easily adapted. Bitstreams available: www.gaisler.com/LEON-RTG4
- Supported by the same software environment as existing LEON3FT and LEON4FT microprocessor devices
  - GCC and LLVM
  - RTEMS, VxWorks, Linux, Bare-C
  - GRMON3, MKPROM2

<table>
<thead>
<tr>
<th>Design</th>
<th>RTG4 4LUT</th>
<th>RTG4 DFF</th>
<th>RTG4 LSRAM</th>
<th>MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEON3 tiny, 2 windows, no cache</td>
<td>&lt; 2% of device resources</td>
<td>0</td>
<td>0</td>
<td>80</td>
</tr>
<tr>
<td>LEON3FT</td>
<td>14.9k</td>
<td>5.9k</td>
<td>39</td>
<td>50</td>
</tr>
<tr>
<td>LEON4FT</td>
<td>16.2k</td>
<td>6.4k</td>
<td>38</td>
<td>50</td>
</tr>
<tr>
<td>LEON3FT with FPU</td>
<td>23.8k</td>
<td>8.0k</td>
<td>39</td>
<td>50</td>
</tr>
<tr>
<td>LEON4FT with FPU</td>
<td>25.1k</td>
<td>8.4k</td>
<td>38</td>
<td>50</td>
</tr>
</tbody>
</table>

LEON3FT and LEON4FT configurations with 16 KiB D-cache and 16 KiB I-cache, including instruction trace buffer support (High-Performance LEON configuration). Makes use of RTG4 built-in ECC for SRAM.
Other RTG4 IP Cores

- 1553 and PCIF—available now from Microsemi
- TSE and SGMII—available now from Microsemi
- JESD204B TX and RX—available now from Microsemi
- SpaceWire
  - STAR-Dundee IP available now
- SpaceFibre
  - STAR-Dundee IP available now, multi-lane operation at 3.125 Gbps per lane
- LEON3-FT and LEON4-FT
  - Cobham Gaisler IP available now
- Serial RapidIO
  - IP vendor evaluation in progress
  - Contact Microsemi for details
Demo Platforms, Ref Designs, Eval Kits

- **Microsemi Demos**
  - LX7720 plus RTG4 – motor control demo
  - LX7730 plus RTG4 – telemetry demo
  - SA50 DC-DC Module for RTG4 – Power supply demo
  - RTG4 with camera – video processing demo
  - RTG4 in-flight reconfiguration demo w/ RISC-V
  - Space Development Platform

- **Partner Demos**
  - 3D-Plus memory with RTG4
  - Cypress memory with RTG4
  - Star Dundee SpWi and SpFi with RTG4
  - Gaisler Leon3 with RTG4
  - TI ADC with RTG4
  - Blue Pearl CDC analysis tool RT3P and RTG4

- **See our RTG4 / RISC-V / LX7730 Demo**
RTG4 Radiation Summary

<table>
<thead>
<tr>
<th>Radiation Event</th>
<th>Specification Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Ionizing Dose</td>
<td>Stays within parametric limits &gt; 125 Krad (Si)</td>
</tr>
<tr>
<td>Single Event Latch-Up</td>
<td>No failure at facility limit of 103 MeV-cm²/mg, 100 °C</td>
</tr>
<tr>
<td>Configuration Upset</td>
<td>No failure at facility limit of 103 MeV-cm²/mg, 100 °C</td>
</tr>
<tr>
<td>Flip-Flop Single Event Upset</td>
<td>2.6E-12 errors/bit-day, GEO solar minimum, 1 MHz</td>
</tr>
<tr>
<td>LSRAM Single Event Upset</td>
<td>2.0E-7 errors/bit-day, GEO solar min (no EDAC)</td>
</tr>
<tr>
<td></td>
<td>1.1E-11 errors/bit-day, GEO solar min (with EDAC)</td>
</tr>
<tr>
<td>uSRAM Single Event Upset</td>
<td>3.1E-8 errors/bit-day, GEO solar min (no EDAC)</td>
</tr>
<tr>
<td></td>
<td>2.7E-13 errors/bit-day, GEO solar min (with EDAC)</td>
</tr>
</tbody>
</table>
# RTG4 Radiation Effects Update

<table>
<thead>
<tr>
<th>Test</th>
<th>Environment</th>
<th>Test Schedule</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fabric, SRAM and PLL SEE</td>
<td>Proton</td>
<td>Complete</td>
<td>Available on request</td>
</tr>
<tr>
<td>SERDES SEE</td>
<td>Heavy Ion</td>
<td>July 2018</td>
<td>Preliminary data to be presented at SpaceWire 2018; further testing in July 2018</td>
</tr>
<tr>
<td>In-Beam Programming</td>
<td>Heavy Ion</td>
<td>Complete</td>
<td>Presented at RADECS 2017 and SEE Symposium 2017</td>
</tr>
<tr>
<td>PLL SEE</td>
<td>Heavy Ion</td>
<td>July 2018</td>
<td>Preliminary data available; further testing in May 2018</td>
</tr>
<tr>
<td>Fabric DDR Controller SEE</td>
<td>Heavy Ion</td>
<td>July 2018</td>
<td>Testing in July 2018</td>
</tr>
<tr>
<td>MSIO SEE</td>
<td>Heavy Ion</td>
<td>May 2018</td>
<td>Testing in May 2018</td>
</tr>
<tr>
<td>TID (leakage current and propagation effects)</td>
<td>Gamma, X-ray</td>
<td>Complete (X-ray)</td>
<td>Presented at RADECS 2017 and posted on Microsemi web site</td>
</tr>
<tr>
<td>TID (retention effects)</td>
<td>Gamma, HTOL</td>
<td>Complete</td>
<td>Presented at NSREC 2016 and NSREC 2017</td>
</tr>
</tbody>
</table>

| ▪ Contact Microsemi for reports |

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Programs Baselining RTG4

- Mission Extension Vehicle
- Orion (NASA)
- WFIRST (NASA)
- SBC (LANL)
- AIDA (ESA, DLR, NASA)
- SLIM (JAXA)
- JPSS-2 (NOAA)
- Reconfigurable Processor (Commercial)
• RTG4 complements existing Microsemi Radiation Tolerant FPGAs
• Expected availability of RTSX-SU and RTAX FPGAs exceeds 10 years
RTG4 Availability and Qualification Schedule

- **QML class Q qualification:** Completed!
  - RTG4 B- and E-flow can be ordered to DLA SMD part number
  - DLA SMD part numbers on [Microsemi web site](http://www.microsemi.com)
- **QML class V qualification:** expected August 2018
- **MIL-STD-883 Class B Qualification:** Completed
- **RT4G150 PROTO FPGAs:** Now
- **RT4G150 development kit:** Now
- **CG1657 B/E/EV-flow flight units:** Available to lead time now
- **CG1657 daisy chain packages:** Now
- **CQ352 B-flow flight units:** July 2018
- **CQ352 eng models:** Available to lead time now
## Delivering A Comprehensive Space Portfolio

<table>
<thead>
<tr>
<th>Radiation-Tolerant FPGAs</th>
<th>High Performance, High Density, Low Power TID up to 300 Krad, SEL Immune RTG4 FPGAs up to 300 MHz and 150K LE RTProASIC3, RTAX and RTSX-SU QML Qualified</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rad-Hard Mixed Signal Integrated Circuits</td>
<td>Telemetry and Motor Control Space System Managers High Side Drivers Regulators and PWMs Extensive Custom IC Capability</td>
</tr>
<tr>
<td>Space Qualified Oscillators</td>
<td>Ovenized Quartz Oscillators Hybrid Voltage Controlled and Temperature Compensated Crystal Oscillators Cesium Clocks</td>
</tr>
<tr>
<td>Rad-Hard Power Solutions</td>
<td>Rad-hard JANS Diodes, Bi-Polar Small Signal Transistors, and MOSFETs Rad-hard Isolated DC-DC Converter Modules Custom Power Supplies 2 W to &gt; 5 KW Point of Load Hybrid Solutions Electromechanical Relays</td>
</tr>
<tr>
<td>Space Screening capability on RF Products</td>
<td>Surface Acoustic Wave (SAW ) Filters Packaged and Chip Si Diodes Si Bipolar Transistors GaAs pHEMT MMICs</td>
</tr>
</tbody>
</table>
Mixed Signal ICs: Weight and Board Space Reduction

- LX7730 Telemetry Controller
- LX7720 Motor / Position Controller
- AAHS298B High Side Drivers
- LX7710 Diode Arrays
- Custom Mixed Signal Integrated Circuits
## Microsemi Analog Mixed Signal ICs for Space Applications

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Description</th>
<th>Status</th>
<th>SMD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>In Production</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LX7730</td>
<td>RT telemetry controller</td>
<td>QML certified Q &amp; V</td>
<td>5962-1721901QXC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>132 L CQFP</td>
<td></td>
</tr>
<tr>
<td>AAHS298B</td>
<td>RT 8 channel high side driver</td>
<td>QML certified Q &amp; V</td>
<td>5962-1523101QYC , VYC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20 L CSOIC flat leads</td>
<td>5962-1523101QXC , VXC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20 L CSOIC formed leads</td>
<td></td>
</tr>
<tr>
<td>LX7710</td>
<td>RT 8 pair diode array</td>
<td>QML certified Q &amp; V</td>
<td>5962-1621001QXC , VXC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20 L CSOIC formed leads</td>
<td></td>
</tr>
<tr>
<td><strong>Custom</strong></td>
<td>Various</td>
<td>In Flight</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(QML-Q and QML-V screening)</td>
</tr>
<tr>
<td><strong>In Qual</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LX7720</td>
<td>RT motor/position controller</td>
<td>Sampling now Seeking QML V &amp; Q</td>
<td>TBD</td>
</tr>
</tbody>
</table>
# Space Power Products

<table>
<thead>
<tr>
<th>Product Family</th>
<th>Key Differentiation</th>
</tr>
</thead>
</table>
| Radiation-Hardened Isolated DC-DC Converters | • Highest output power and efficiency  
• Shortest lead times                   |
| Radiation-Hardened Power Discretes: JANS Diodes, Bi-Polar Transistors, MOSFETs | • Broadest JANS QPL portfolio  
• Low Dose Rate guaranteed bipolar transistors |
| Radiation-Hardened Hybrids: Linear and Switching | • DLA MIL-PRF-38534-certified facility  
• Highly integrated for optimal power footprint |
| High-Voltage Electromechanical Relays  | • Highest reliability  
• Extensive heritage in space |

## Chart

- **High Efficiency**
- **Output Power**
- **Broasted Portfolio**
- **Shortest Lead Times**
- **Highly Integrated**
- **DLA Certified Facility**
- **Highest Reliability**
- **Extensive Heritage**

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Space Oscillators and Atomic Clocks

- Eliminate the need for SCD Creation
- Use Microsemi’s Hi-Rel Standard documentation for Space Applications
Space CSAC (released March 2018)

- Radiation Tolerance: 20 krad(Si) TID, no SEL to 64 MeV cm$^2$/gm
- Targeting short duration LEO applications (COTS product)
- Low size, weight and power

**Key Specifications:**
- Nominal Frequency: 10 MHz
- Power Consumption: <120 mW steady-state @ +25°C
- Volume: <17 cc
- Temp Stability: ±5.0E-10
- Operating Temp Range: -10 to +70°C
- Aging Rate: <9.0E-10/month (typical)
- Warm-up Time: 3 min
- 1PPS disciplining

Source: NASA/JPL-Caltech
Microsemi Space Legacy – 60 Years, and Counting!
Your Partner for Space Technology

- Leadership in space
- Leveraging our product breadth
- Innovative new products
- Focused on growth applications
Thank You