



# Radiation-Tolerant FPGA Update

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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

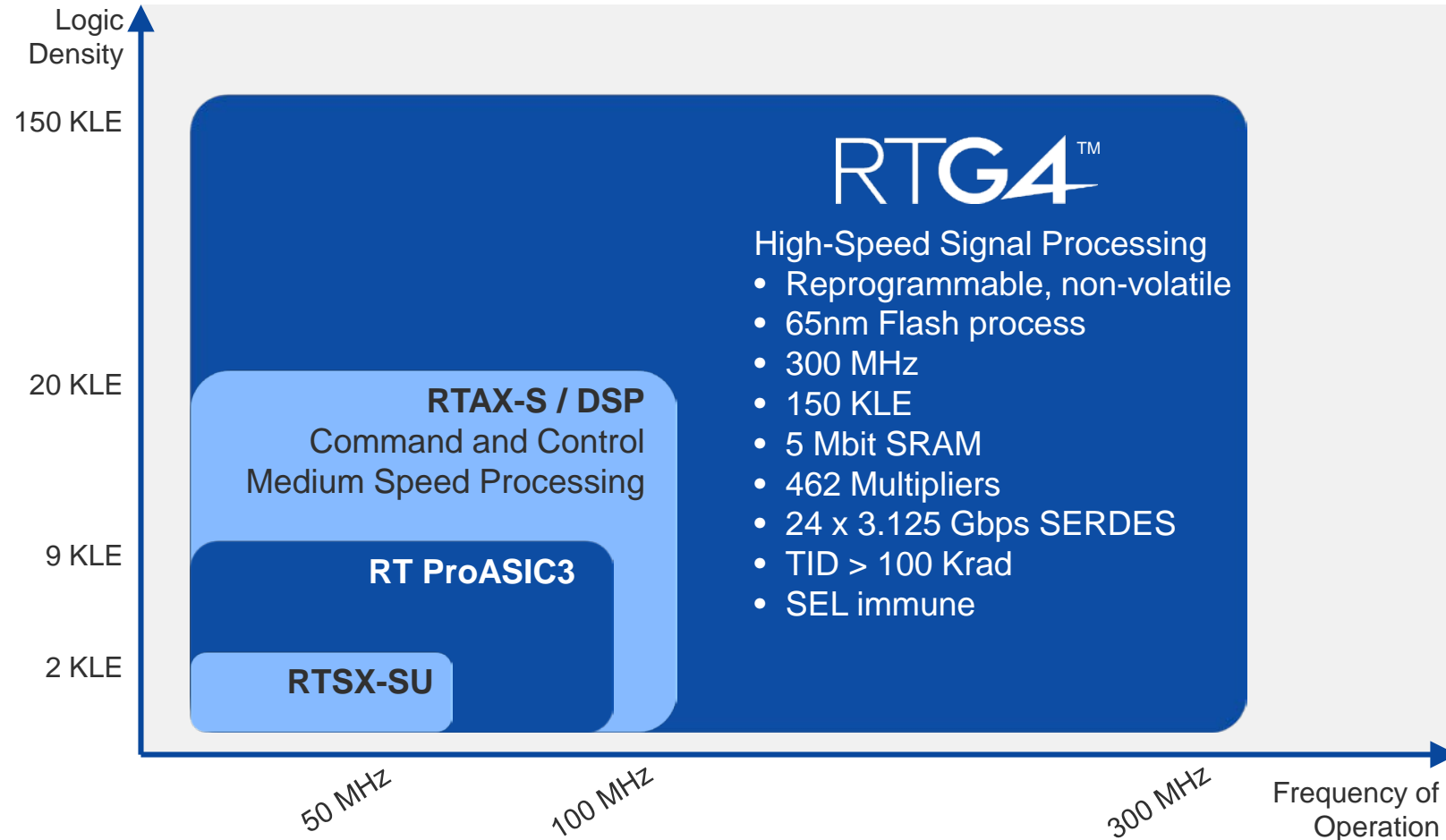
- 60-year space heritage

# Agenda

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- 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

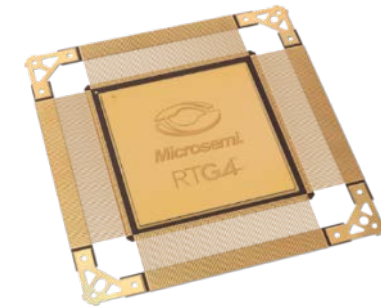
# RTG4 High-Speed RT FPGAs



**RTG4 mitigates the risks of ASICs and SRAM FPGAs, and has 20x improvement in signal processing throughput**

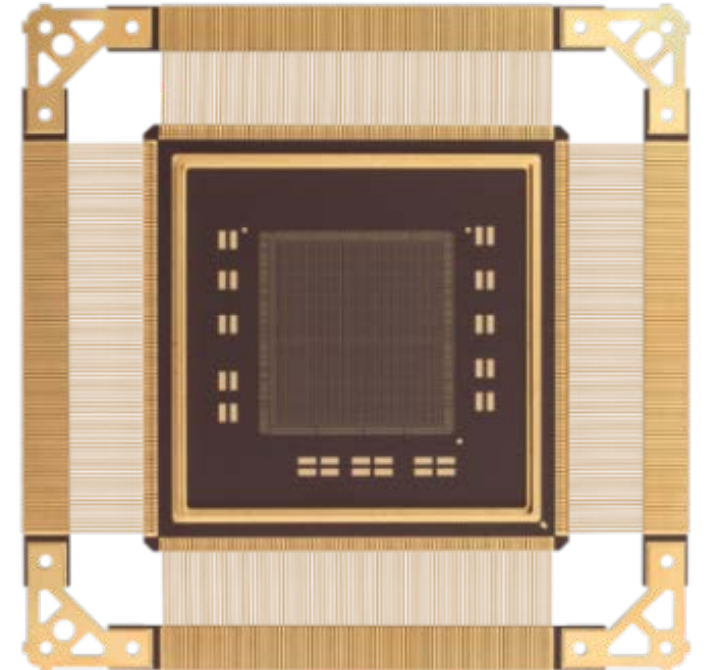
# RTG4 Product Overview

| Resources  | RT4G150              |  |
|--|----------------------|--|
| Logic Elements (TMR Register + 4-Input C Logic)  | 151,824              | 151,824  |
| 18x18 Multiply-Accumulate Blocks   | 462                  | 462  |
| RAM Mbits (1.5 Kbit and 24 Kbit Blocks, with ECC)  | 5.2                  | 5.2  |
| UPROM Kbits  | 381                  | 381  |
| DDR2/3 SDRAM Controller (with ECC)   | 2 x 32               | 0  |
| PCI Express Endpoints  | 2                    | 1  |
| Globals  | 24                   | 24   |
| PLLs (Rad Tolerant)  | 8                    | 8  |
| SpaceWire Clock and Data Recovery Circuits   | 16                   | 4  |
| User IO (excluding SERDES)   | 720                  | 166  |
| SERDES lanes (3.125 Gbps)  | 24                   | 4  |
| <b>Hermetic, Ceramic Packages</b>  |                      |  |
| CG1657 (Ceramic Column Grid Array, Six Sigma Columns)<br>LG1657 (Ceramic Land Grid Array, No Solder Termination)<br>CB1657 (Ceramic Ball Grid Array, For Prototyping Only) | <b>Available Now</b> |  |
| CQ352 (Ceramic Quad Flat Pack)   |                      | <b>Samples Now</b><br>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



# RTG4 Qualification Status – QML Class Q Completed!

- 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, 5962-16208xxyyy part number
  - SMD numbers on Microsemi web site in [DLA Cross Reference Guide](#)

|         |           |                  |                 |
|---------|-----------|------------------|-----------------|
| RT4G150 | 1657-CCGA | RT4G150-CG1657B  | 5962-1620801QXF |
|         |           | RT4G150-1CG1657B | 5962-1620802QXF |
|         |           | RT4G150-CG1657E  | 5962-1620805QXF |
|         |           | RT4G150-1CG1657E | 5962-1620806QXF |
|         | 1657-LGA  | RT4G150-LG1657B  | 5962-1620803QZC |
|         |           | RT4G150-1LG1657B | 5962-1620804QZC |
|         |           | RT4G150-LG1657E  | 5962-1620807QZC |
|         |           | RT4G150-1LG1657E | 5962-1620808QZC |

- 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

The drawing form includes a revision history table with columns for revision number (REV), date, and description. It also features a QR code and a table for approval signatures with columns for name, title, and date. The technical specifications section includes the part number (5962-16208), manufacturer (Microsemi), and a detailed description of the microcircuit: MICROCIRCUIT, MEMORY, DIGITAL CMOS, LOW POWER REPROGRAMMABLE 151,524 LOGIC ELEMENT FLASH FIELD PROGRAMMABLE GATE ARRAY WITH DECOUPLING CAPACITORS, MULTIPLE SUPPLY.



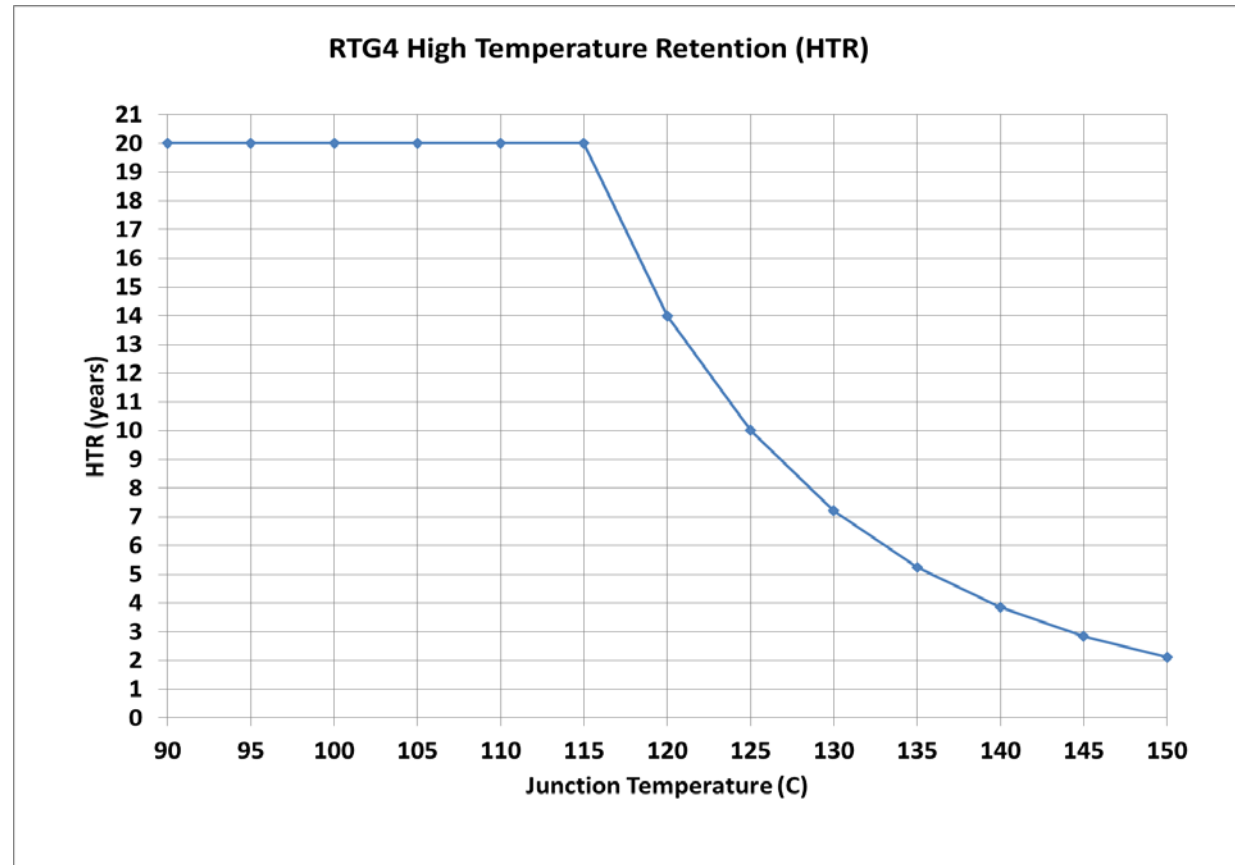
# RTG4 Reliability Testing Highlights

- 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  $T_j \geq 125 \text{ }^\circ\text{C}$
  - All units continued additional life test exceeding MIL-STD-883B requirements: 54 units were functional during and after 4,000-hour life test at  $T_j \geq 125 \text{ }^\circ\text{C}$
- 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  $T_j \leq 115^\circ \text{C}$ , or 10 years at  $T_j \leq 125^\circ \text{C}$
- 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

| $T_j$ (C) | HTR (Years) |
|-----------|-------------|
| 90        | 20          |
| 95        | 20          |
| 100       | 20          |
| 105       | 20          |
| 110       | 20          |
| 115       | 20          |
| 120       | 14          |
| 125       | 10          |
| 130       | 7.2         |
| 135       | 5.3         |
| 140       | 3.9         |
| 145       | 2.8         |
| 150       | 2.1         |



# 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

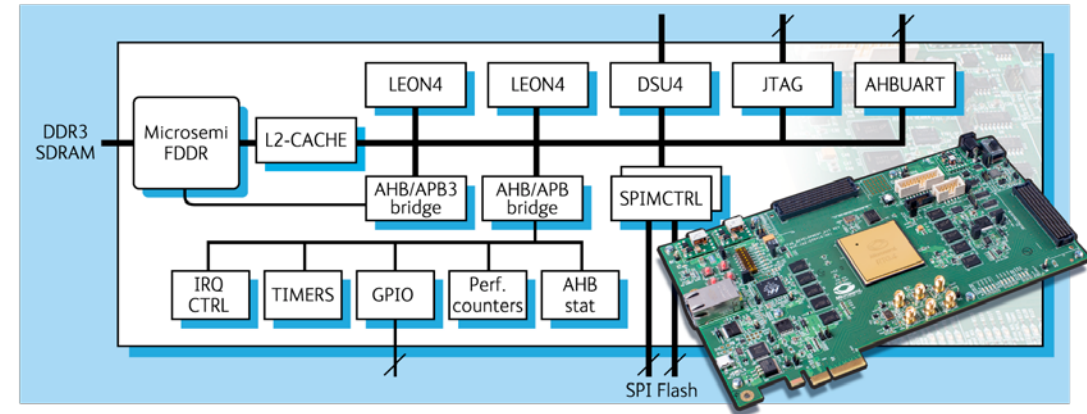
- ARM Cortex M1
  - 32-bit RISC microcontroller
  - Supported by ecosystem from ARM and third-party vendors
- IP available now on MSCC [website](#): [End User Licensing Agreement \(EULA\)](#) must be completed in order to download IP
  - Uses DDR controller, SPI, UART, AHB to SRAM, and timer peripherals
  - Performance targeting RT4G150, Dash-1 speed grade



| Design        | RTG4 LUT      | RTG4 DFF     | RTG4 LSRAM Blocks | RTG4 uSRAM Blocks | MHz |
|---------------|---------------|--------------|-------------------|-------------------|-----|
| ARM Cortex M1 | 11,600 (7.7%) | 6,900 (4.5%) | 2 (1.0%)          | 128 (61%)         | 50  |

# 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](http://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
- Validated in radiation tests. More to come during 2018.



| Design                          | RTG4 4LUT                | RTG4 DFF | RTG4 LSRAM | MHz |
|---------------------------------|--------------------------|----------|------------|-----|
| LEON3 tiny, 2 windows, no cache | < 2% of device resources |          | 0          | 80  |
| LEON3FT                         | 14.9k                    | 5.9k     | 39         | 50  |
| LEON4FT                         | 16.2k                    | 6.4k     | 38         | 50  |
| LEON3FT with FPU                | 23.8k                    | 8.0k     | 39         | 50  |
| LEON4FT with FPU                | 25.1k                    | 8.4k     | 38         | 50  |

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



***COBHAM***

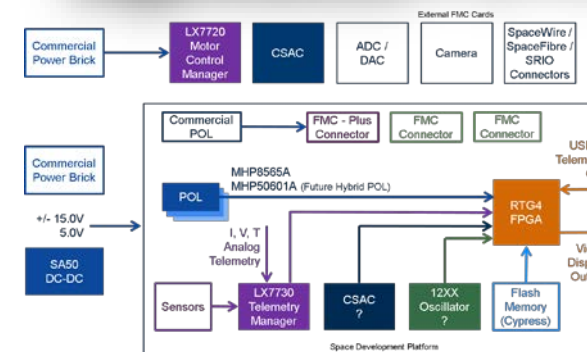
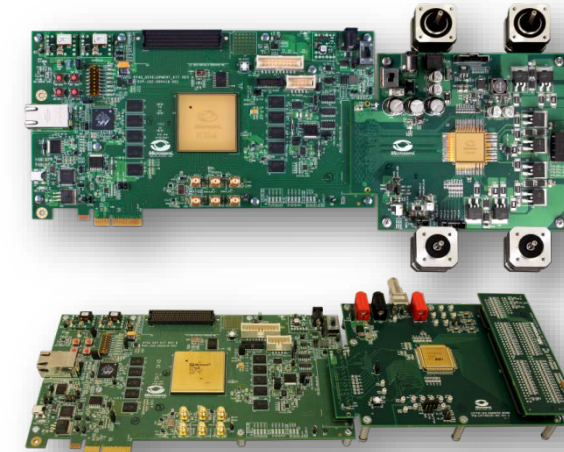
**Cobham Gaisler AB**



# Demo Platforms, Ref Designs, Eval Kits

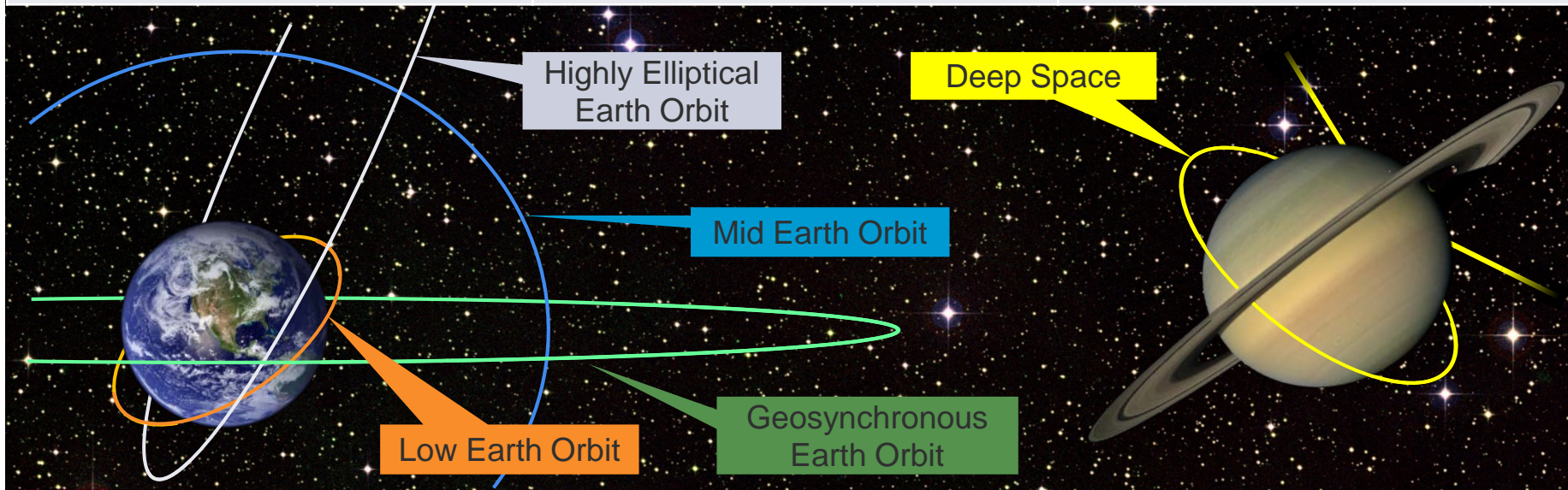
- Microsemi Demos
  - LX7720 plus RTG4 – motor control demo
  - LX7730 plus RTG4 – telemetry demo
  - SA50 DC-DC Module for RTG4 – Power supply demo
  - RTG4 with camera – video processing demo
  - RTG4 in-flight reconfiguration demo w/ RISC-V
  - Space Development Platform
- Partner Demos
  - 3D-Plus 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

|                              |   |  |
|------------------------------|---|--|
| Total Ionizing Dose          | Stays within parametric limits > 125 Krad (Si)                      |  |
| Single Event Latch-Up        | No failure at facility limit of 103 MeV-cm <sup>2</sup> /mg, 100 °C |  |
| Configuration Upset          | No failure at facility limit of 103 MeV-cm <sup>2</sup> /mg, 100 °C |  |
| Flip-Flop Single Event Upset | 2.6E-12 errors/bit-day, GEO solar minimum, 1 MHz                    |  |
| LSRAM Single Event Upset     | 2.0E-7 errors/bit-day,<br>GEO solar min (no EDAC)                   | 1.1E-11 errors/bit-day,<br>GEO solar min (with EDAC) |
| uSRAM Single Event Upset     | 3.1E-8 errors/bit-day,<br>GEO solar min (no EDAC)                   | 2.7E-13 errors/bit-day,<br>GEO solar min (with EDAC) |



# RTG4 Radiation Effects Update

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

- Contact Microsemi for reports

# Programs Baselineing RTG4

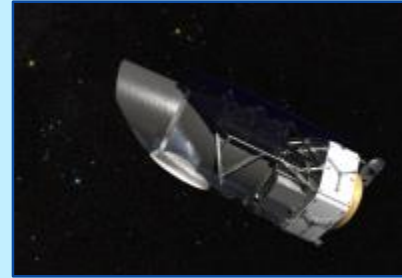
Mission  
Extension  
Vehicle



Orion  
(NASA)



WFIRST  
(NASA)



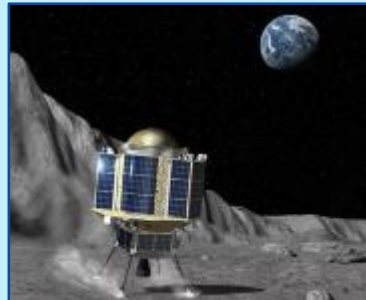
SBC  
(LANL)



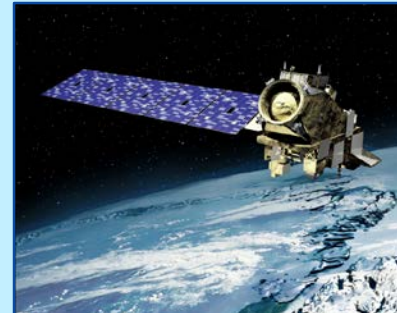
AIDA  
(ESA, DLR, NASA)



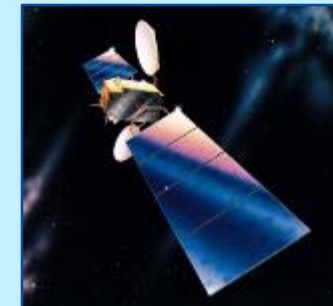
SLIM  
(JAXA)



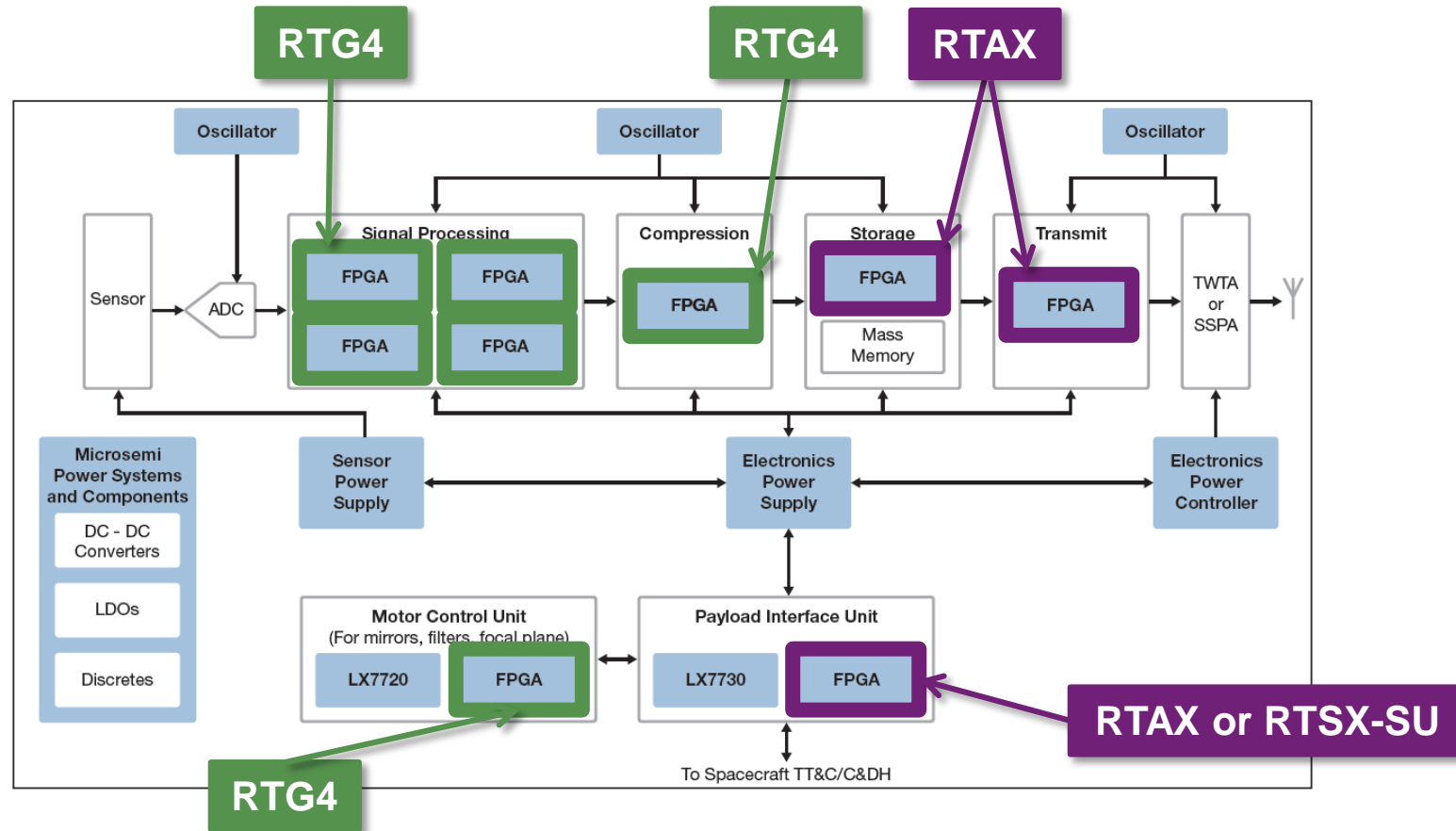
JPSS-2  
(NOAA)



Reconfigurable  
Processor  
(Commercial)



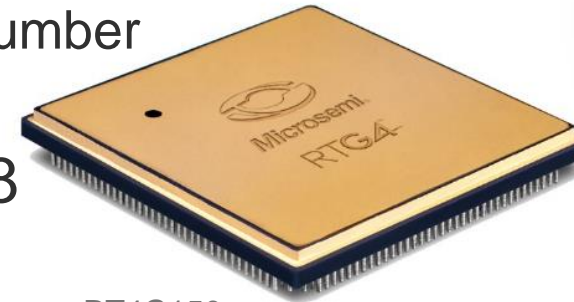
# RT FPGA Examples in Remote Sensing Payload



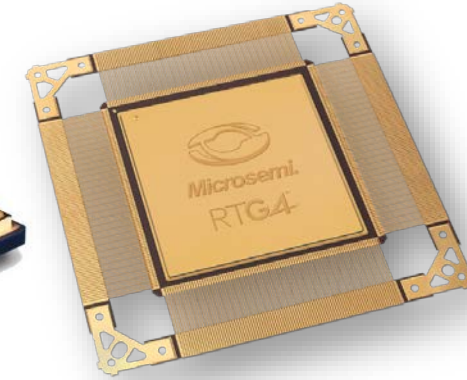
- RTG4 complements existing Microsemi Radiation Tolerant FPGAs
- Expected availability of RTSX-SU and RTAX FPGAs exceeds 10 years

# RTG4 Availability and Qualification Schedule

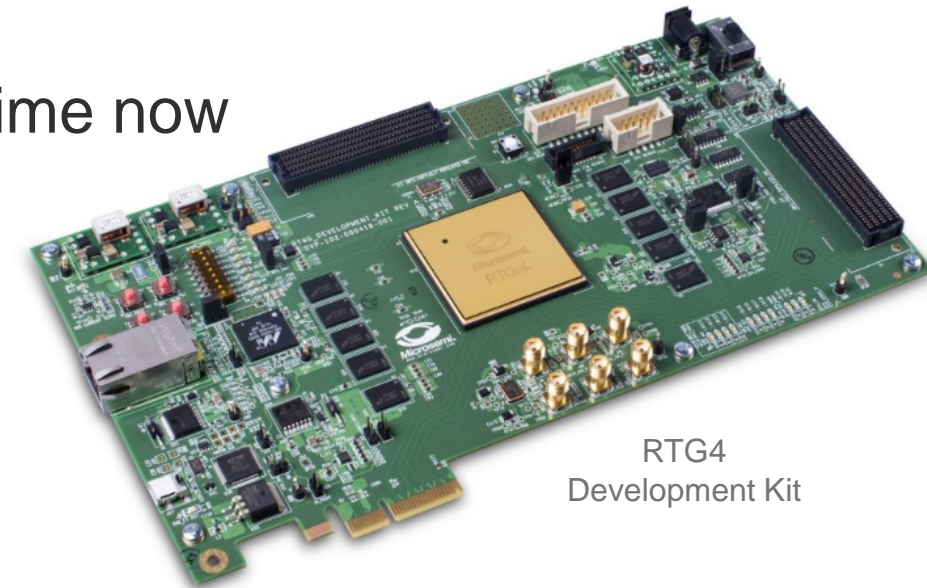
- QML class Q qualification: **Completed!**
  - RTG4 B- and E-flow can be ordered to DLA SMD part number
  - DLA SMD part numbers on [Microsemi web site](#)
- QML class V qualification: expected August 2018
- MIL-STD-883 Class B Qualification: Completed
- RT4G150 PROTO FPGAs: Now
- RT4G150 development 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



RT4G150-  
CG1657

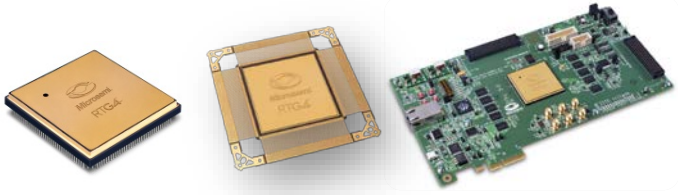
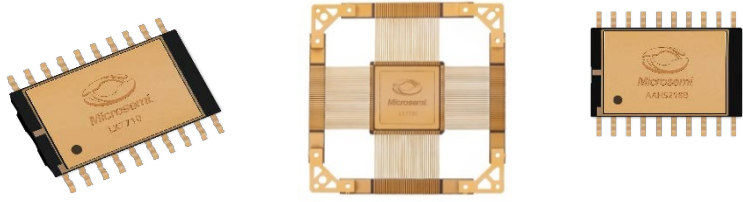

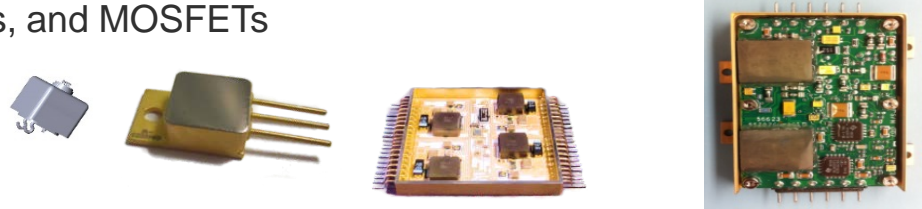



RT4G150-  
CQ352

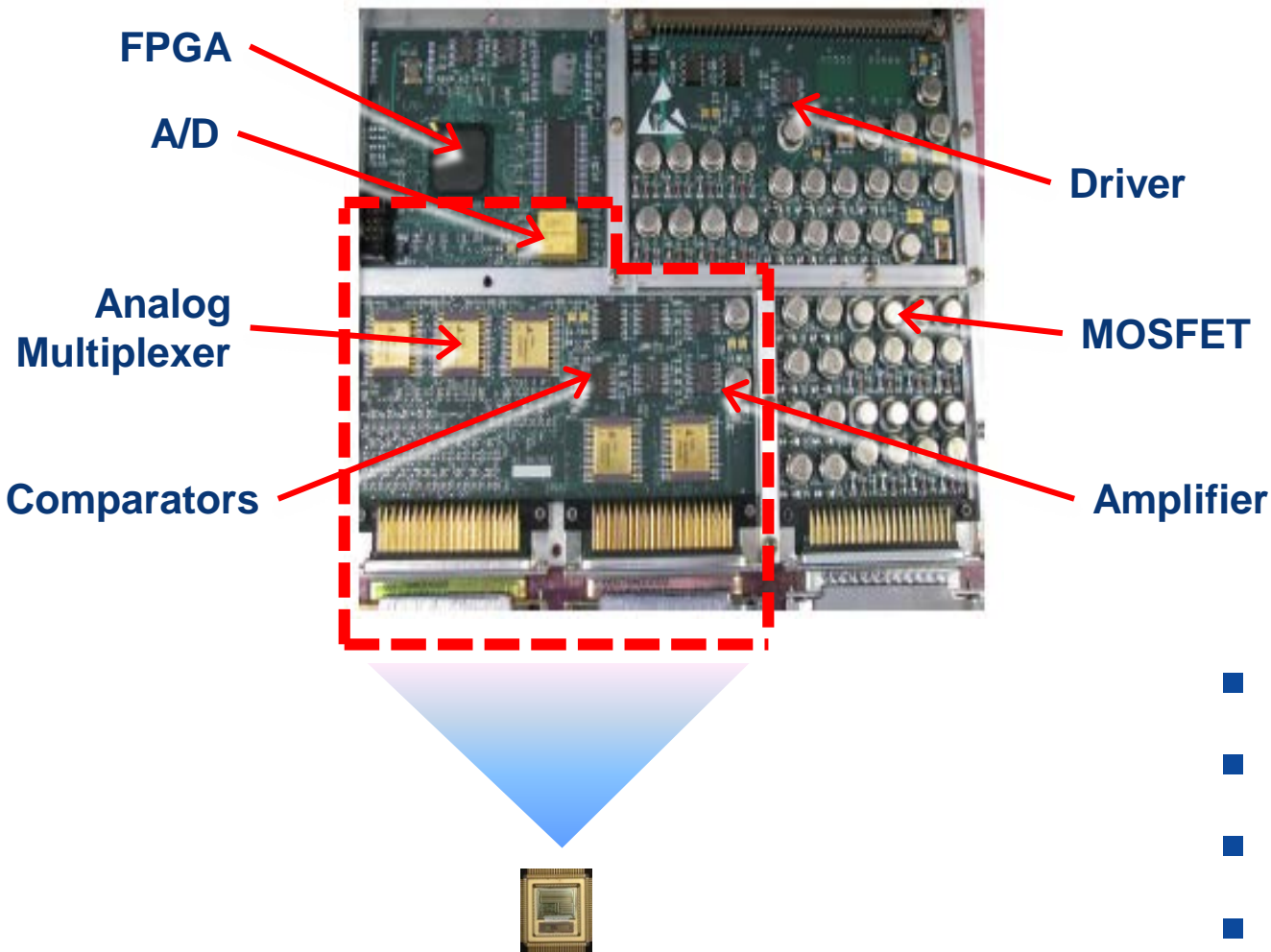


RTG4  
Development Kit

# Delivering A Comprehensive Space Portfolio

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

# Mixed Signal ICs: Weight and Board Space Reduction



↓ Reduced Board Space  
• 50-75%

↓ Reduced Weight

↑ Increased Reliability

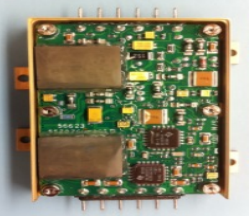



- LX7730 Telemetry Controller
- LX7720 Motor / Position Controller
- AAHS298B High Side Drivers
- LX7710 Diode Arrays
- Custom Mixed Signal Integrated Circuits

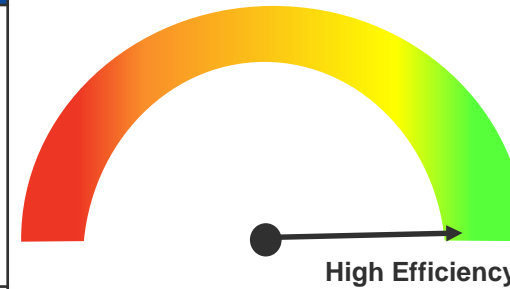


# Microsemi Analog Mixed Signal ICs for Space Applications

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

# Space Power Products

| Product Family   | Key Differentiation   |
|--|---|
| <p><b>Radiation-Hardened Isolated DC-DC Converters</b></p>                                        | <ul style="list-style-type: none"> <li>• Highest output power and efficiency</li> <li>• Shortest lead times</li> </ul>                            |
| <p><b>Radiation-Hardened Power Discretes:</b><br/>JANS Diodes, Bi-Polar Transistors, MOSFETs</p>  | <ul style="list-style-type: none"> <li>• Broadest JANS QPL portfolio</li> <li>• Low Dose Rate guaranteed bipolar transistors</li> </ul>           |
| <p><b>Radiation-Hardened Hybrids:</b><br/>Linear and Switching</p>                               | <ul style="list-style-type: none"> <li>• DLA MIL-PRF-38534-certified facility</li> <li>• Highly integrated for optimal power footprint</li> </ul> |
| <p><b>High-Voltage Electromechanical Relays</b></p>   | <ul style="list-style-type: none"> <li>• Highest reliability</li> <li>• Extensive heritage in space</li> </ul>                                    |



 Broadest Portfolio

 Shortest Lead Times

 Highly Integrated

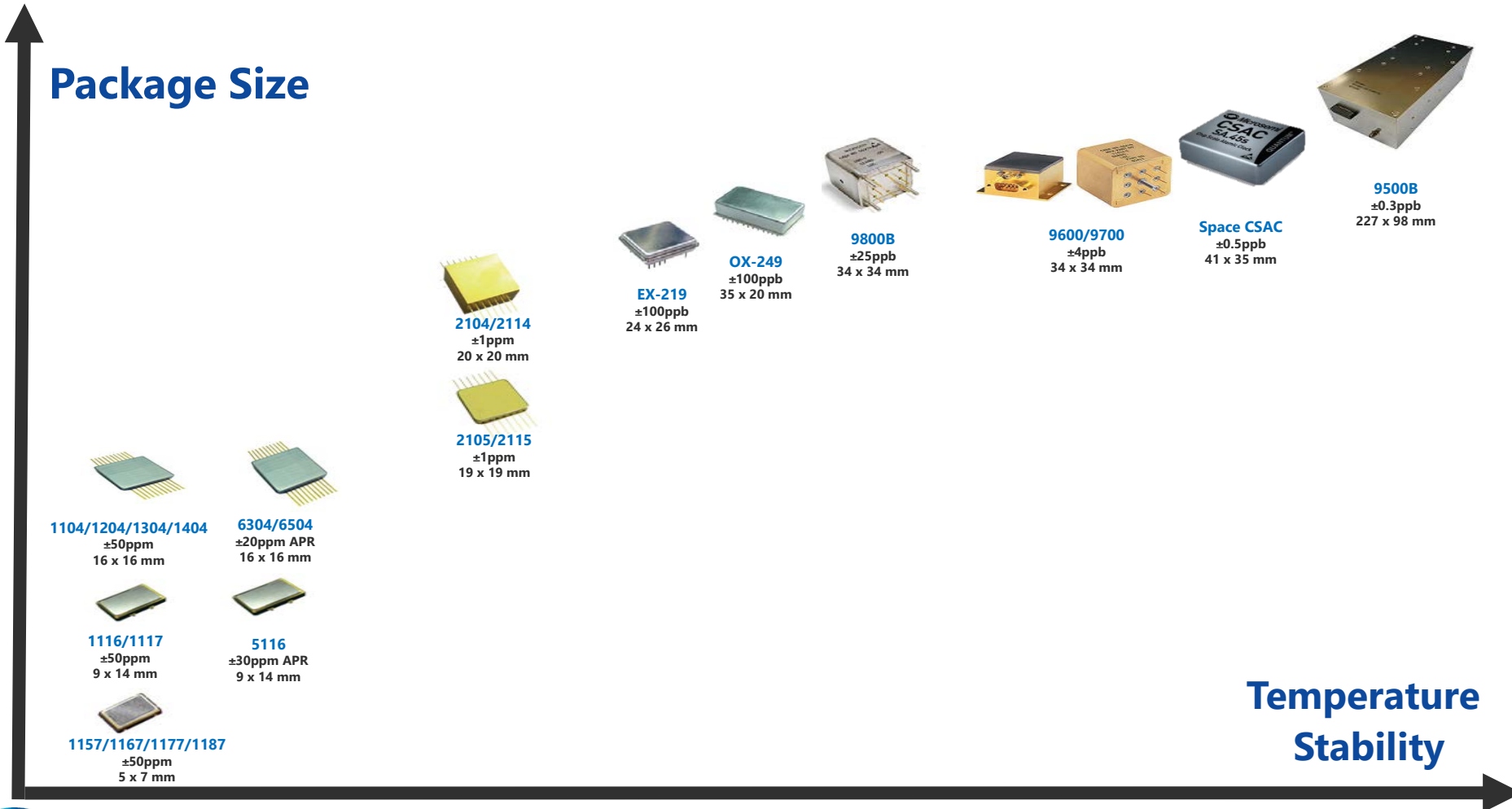
 DLA Certified Facility

 Highest Reliability

 Extensive Heritage

# Space Oscillators and Atomic Clocks

- Eliminate the need for SCD Creation
- Use Microsemi's Hi-Rel Standard documentation for Space Applications



- ↑ Highest Reliability
- ↑ Standard Documentation
- ↑ Broadest portfolio

# Space CSAC (released March 2018)

- Radiation Tolerance: 20krad(Si) TID, no SEL to 64 MeVcm<sup>2</sup>/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 @ +25C
- Volume: <17 cc
- Temp Stability:  $\pm 5.0E-10$
- Operating Temp Range: -10 to +70C
- 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!



**Microsemi**  
Power Matters.™



**LEADING SPACE INNOVATION SINCE 1957**  
Microsemi technology has been used in many major U.S. and international space initiatives since 1957. A selection of programs that have chosen Microsemi products is presented here.



**Atlas**  
NASA



**Mars Science Lab**  
NASA



**International Space Station**  
NASA



**Cassini-Huygens**  
NASA



**Juno**  
NASA



**Cygnus**  
NASA



**Mars Rovers**  
NASA



**Gaia**  
ESA



**Mars Recon. Orbiter**  
NASA



**GOCE**  
ESA



**GOES-R**  
NASA

|             |
|-------------|
| Apollo      |
| Atlas       |
| Centaur     |
| Delta       |
| Mercury     |
| NST-2       |
| Termination |
| Polaris     |
| Poseidon    |
| Surveyor    |
| Titan       |

|               |
|---------------|
| FLTSATCOM     |
| GPS I & II/IA |
| Landsat-D     |
| Leasat        |
| Mission 34    |
| Telstar 4     |

|                             |
|-----------------------------|
| Cassini                     |
| Envisat                     |
| GPS Block IIF               |
| Intelsat 8                  |
| International Space Station |
| ORBCOMM                     |
| QuickBird 1 & 2             |
| SBIRS HIGH                  |
| SBIRS LOW                   |

|                         |
|-------------------------|
| CloudSat                |
| Envisat                 |
| GOCE                    |
| Hayabusa                |
| Lunar Recon. Orbiter    |
| Mars Exploration Rovers |
| Mars Express            |
| Mars Recon. Orbiter     |

|                |
|----------------|
| MESSENGER      |
| MUOS           |
| Rosetta        |
| SAOCOM 1A & 1B |
| SAR-2000       |
| SBIRS          |
| STEREO         |
| Venus Express  |

|                      |
|----------------------|
| AEHF                 |
| ALOS                 |
| Astro-F (IRIS/Akari) |
| CHIRP                |
| Columbus             |
| Cosmo IV             |
| GOSAT/IBUKI          |
| GPS III              |
| INTELSAT             |
| KOMPSAT              |

|                  |
|------------------|
| MetOp            |
| MUOS FS3-5       |
| New Horizons     |
| PAN              |
| SBIRS HIGH 3 & 4 |
| SDS-1            |
| SELENE           |
| WINDS/KIZUNA     |
| WorldView II     |

|                   |
|-------------------|
| ALOS 2 (DAICHI-2) |
| ASNARO            |
| ATV               |
| Chandrayaan I     |
| CLIO (PAN II)     |
| Cygnus            |
| DSAC              |
| Gaia              |
| Galileo           |
| GCOM-W (SHIZUKU)  |

|                  |
|------------------|
| GOES-R           |
| Hayabusa 2       |
| Himawari 8       |
| Iridium Next     |
| IRNSS Series     |
| Juno             |
| JPSS-1           |
| Mangalyaan       |
| Mars Science Lab |
| MetOp SG         |

|                     |
|---------------------|
| Orbcomm Gen 2       |
| PAN 2               |
| SBIRS 5 & 6         |
| Sentinel 1, 2, 3, 4 |
| Skyfox              |
| Terrasar & Tandem X |
| WorldView III       |

1957-1970

1971-1990

1991-2000

2001-2005

2006-2010

2011-2020

# Your Partner for Space Technology



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



# Thank You



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