Power Matters.™

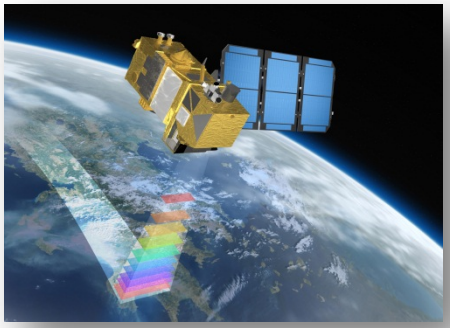
Microsemi

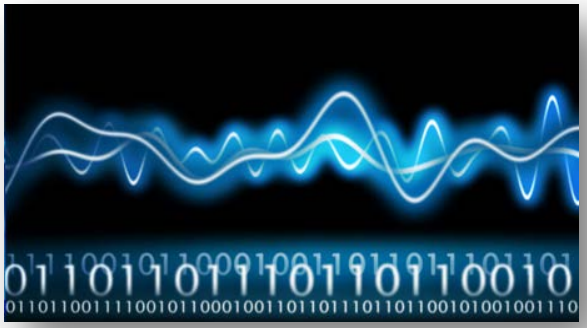
RTG4 High-Speed RT FPGAs and Space System Managers

Ken O'Neill
Director of Marketing, Space and Aviation

Satellite Signal Processing Congestion

- Sensor resolution increasing faster than downlink bandwidth
- Satellites required to perform more on-board processing
- Requires high-density, high-performance payload processing electronics





1. Radiation-Hardened ASICs

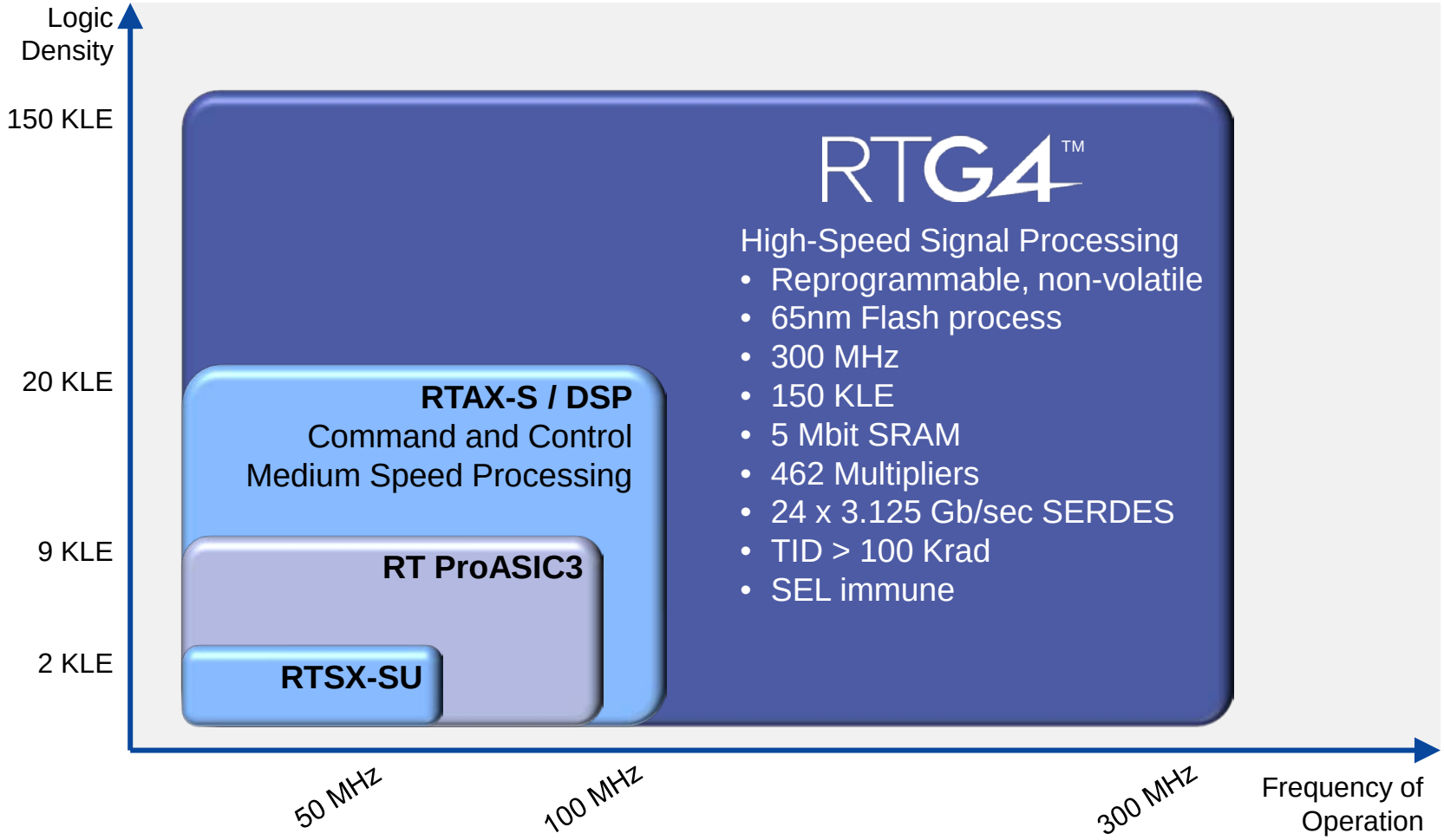
- ☑ High speed, high density, low power
- ☒ Large NRE, relatively low volumes
- ☒ Long development time, long fabrication cycle time
- ☒ High risk of schedule and cost over-runs

2. SRAM FPGAs

- ☑ Easy prototyping, reprogrammable
- ☒ Configuration SEU effects require cumbersome mitigation, increases Size, Weight and Power

Existing solutions for satellite on-board processing have high risks

Introducing RTG4 High-Speed RT FPGAs



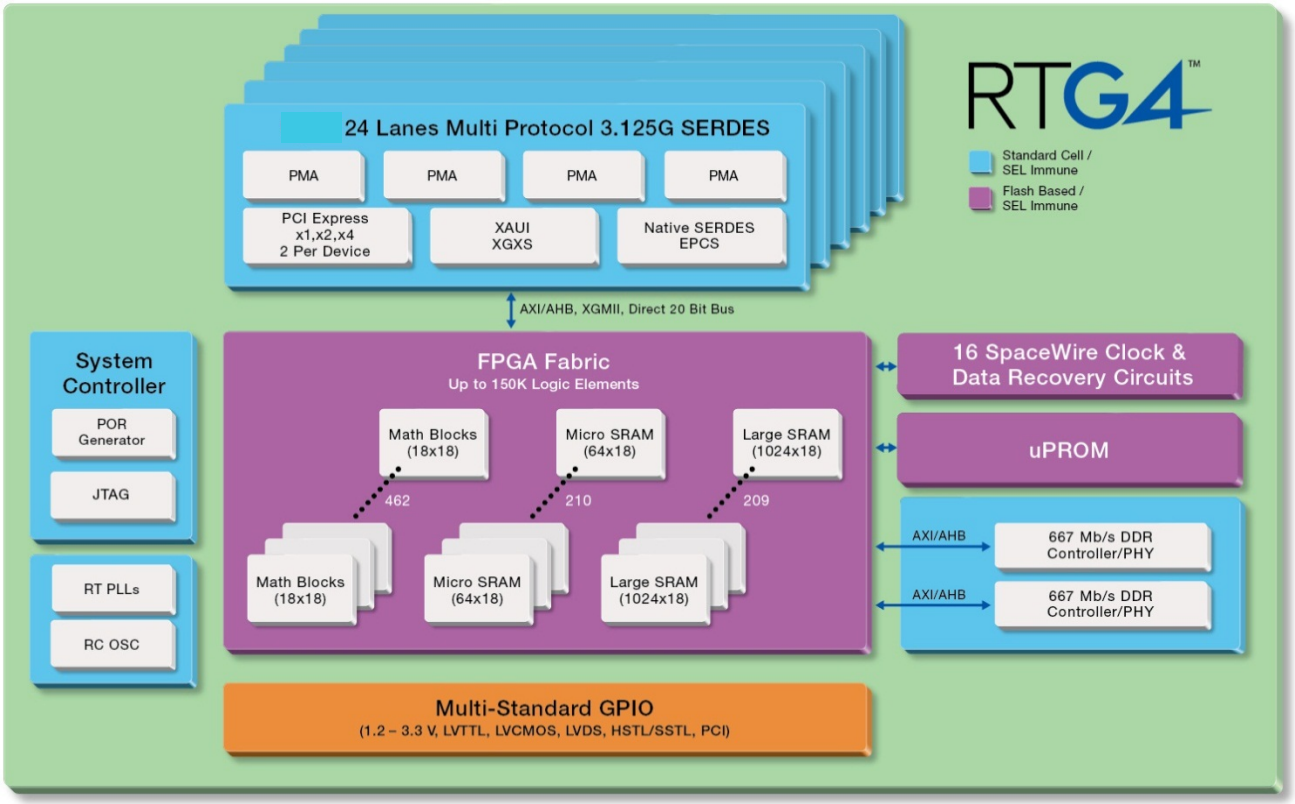
RTG4 mitigates risks of ASICs and SRAM FPGAs, and has 20X improvement in signal processing throughput

Why RTG4 is Compelling

- More flexible than an RH ASIC
  - Reprogrammable, no NRE, no cost and schedule risk
- More signal-processing features than any other RT FPGA
  - More registers, combinatorial logic, multiply blocks, and transceivers
  - Lower power, live at power-up, no external boot memory needed
- Radiation enhanced for Geosynchronous Earth Orbit and deep space
  - RTG4 65nm Flash has complete immunity to configuration upsets (SEU)
  - Total ionizing dose (TID) and single event effects (SEE) hardened by design

RTG4 offers groundbreaking features for satellite applications

RTG4 Radiation-Mitigated Architecture



- Total-dose hardening of Flash cells
- Single-event hardening of registers, SRAM, multipliers, PLLs

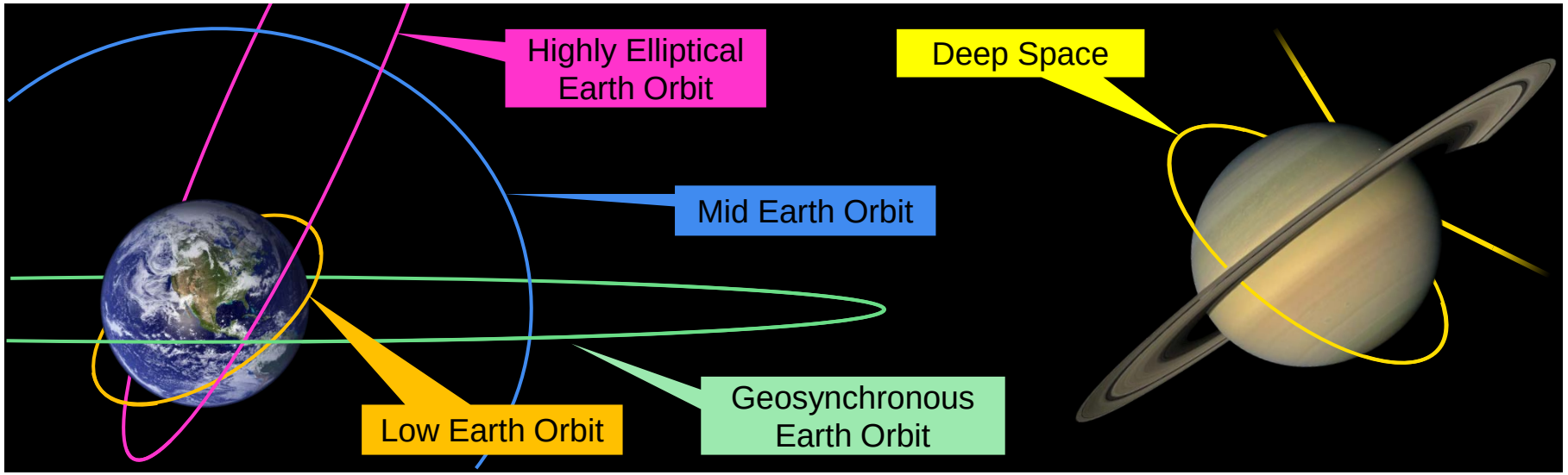
Comprehensive radiation-mitigated architecture for signal processing applications

RTG4 Resources

Resources	RT4G150
Logic Elements (TMR Register + 4-Input C Logic)	151,824
18x18 Multiply-Accumulate Blocks	462
RAM Mbits (1.5 Kbit and 24 Kbit Blocks, with ECC)	5.2
UPROM Kbits	381
DDR2/3 SDRAM Controller (with ECC)	2x32
PCI Express Endpoints	2
Globals	24
PLLs (Rad Tolerant)	8
SpaceWire Clock & Data Recovery Circuits	16
User IO (excluding SERDES)	720
SERDES lanes (3.125 Gbit/sec)	24
Hermetic, Ceramic Packages	
CG1657 (Column Grid Array, Six Sigma Columns)	**Available Now**
CQ352 (Ceramic Quad Flat Pack)	TBD

RTG4 Radiation Mitigation

- Total ionizing dose (TID) immune to > 125 kRAD
- Single event latch-up (SEL) and configuration upset (SEU) immune
  - Tested to 103 MeV-cm^2/mg (facility limit) at 100°C
- SEU in FPGA flip-flops < 1x10^{-11} errors/bit/day (GEO solar min)
- SEU in non-EDAC LSRAM < 4 x10^{-8} errors/bit/day (GEO solar min)
  - No multi-bit upset (MBU) was observed
  - LSRAM with EDAC will be tested

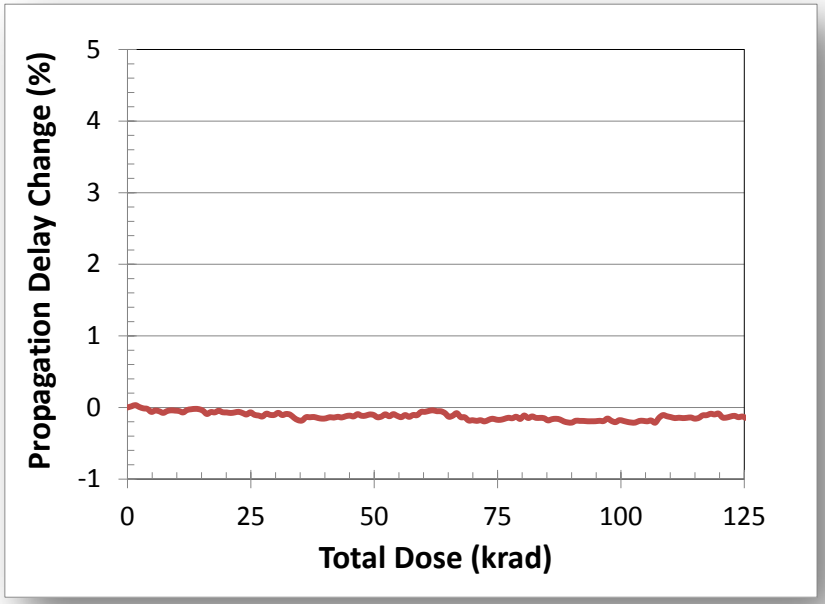


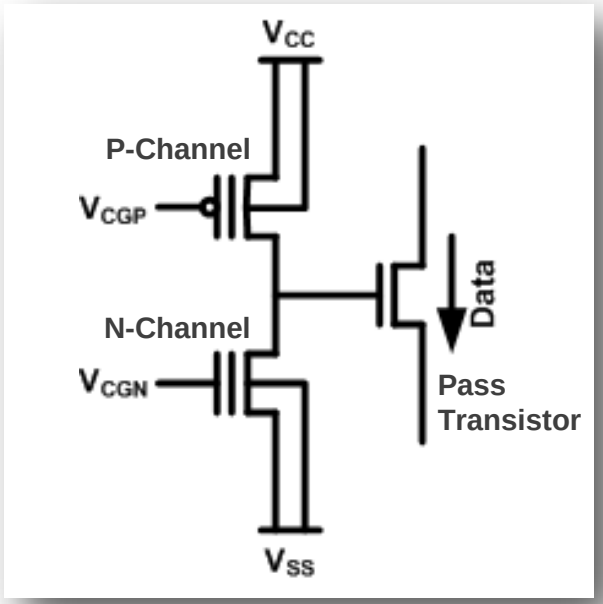
RTG4 Radiation Updates

- WP0191: Mitigation of Radiation Effects in RTG4 Radiation-Tolerant FPGAs
- Space Forum: RTG4 Radiation Test Results and Test Plans
- Conference Papers:
  - A Novel 65 nm Radiation Tolerant Flash Configuration Cell Used in RTG4 Field Programmable Gate Array
    - This paper describes the flash cell used for RTG4 configuration and its impact on RTG4 TID performance beyond 100 Krad.
  - TID and SEE characterization of Microsemi's 4th generation radiation tolerant RTG4 flash-based FPGA
    - This paper includes RTG4 TID and SEE test results in heavy ion: configuration SEU, SEL, flip-flop SEU and LSRAM/uSRAM SEU
- In-orbit reconfiguration testing ongoing
  - Preliminary data shows parts can be reprogrammed successfully after being irradiated up to 106 Krad of heavy ion
  - High priority item for further radiation testing
- Planned SEE testing in 2016:
  - SEU: LSRAM/uSRAM with EDAC
  - SET: Fabric, DSP, clocks, SpaceWire, MSIO, MSIOD
  - SEFI: PLL, SERDES, PCIe, DDR controllers, System Controller

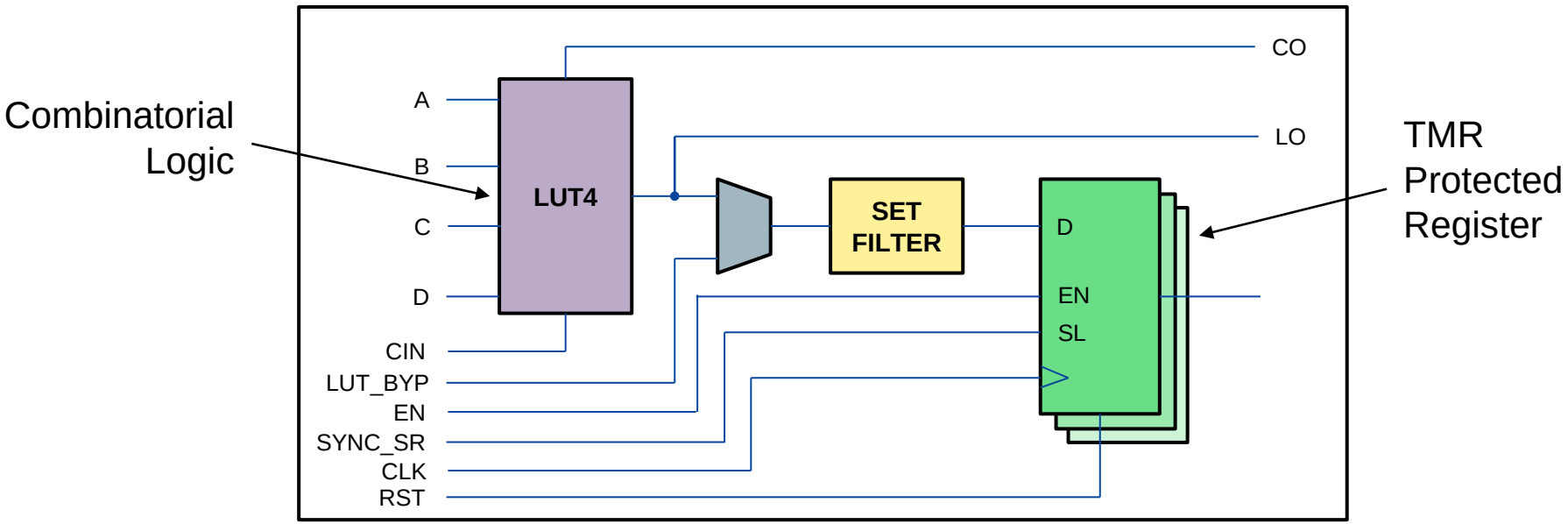
TID Mitigation in RTG4 Flash FPGAs

- RTG4 TID-tolerant interconnect
  - RTG4 FPGAs functional after TID > 125 Krad
  - Change in propagation delay ~ 0% after TID > 125 Krad
  - Pass transistor is indirectly coupled to floating gate devices
  - V_T changes in Flash cells don't change pass transistor prop. delay





RTG4 Logic Element Radiation Mitigation

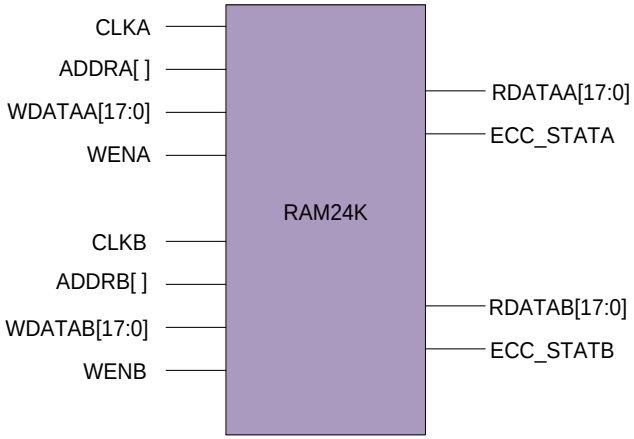


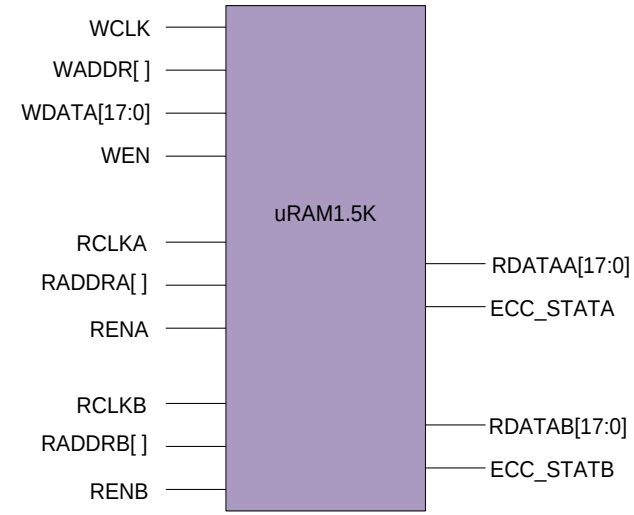
RTG4 Logic Element (LE)

- Dedicated register with efficient triple module redundant (TMR) hardening
- Single event transient (SET) filter mitigates radiation glitches from comb. logic
- Hierarchical routing architecture enables >95% module utilization

RTG4 Memory Blocks

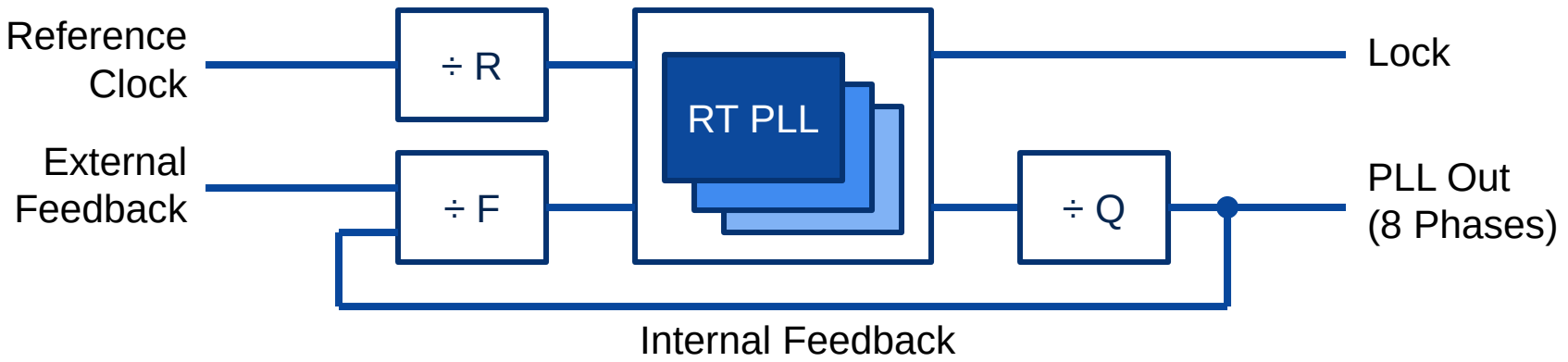
- Radiation Tolerant
  - Resistant to multi-bit upset
  - Built-in optional EDAC (SECDED)
- LSRAM – up to 24 KBit
  - Dual-port and two-port options
  - High performance synchronous operation
  - Example usage
    - Large FFT memory
- uRAM – up to 1.5 KBit
  - Three Port Memory
    - Synchronous Write Port
    - Two Asynchronous or Synchronous Read Ports
  - Example usage
    - Folded FIR filters and FFT twiddle factors



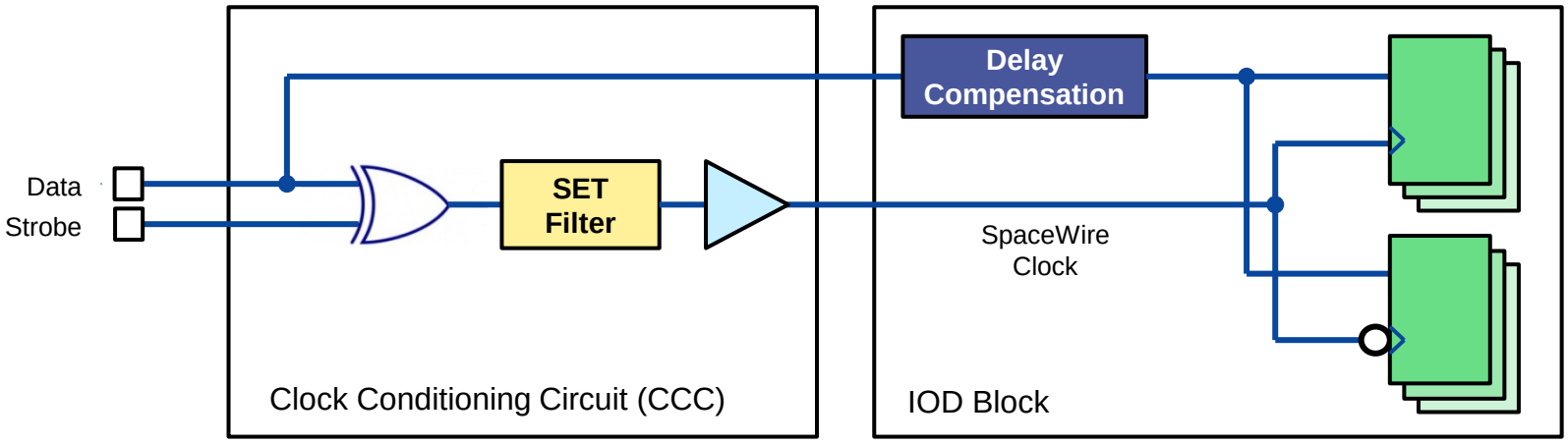


RTG4 Radiation-Tolerant PLL

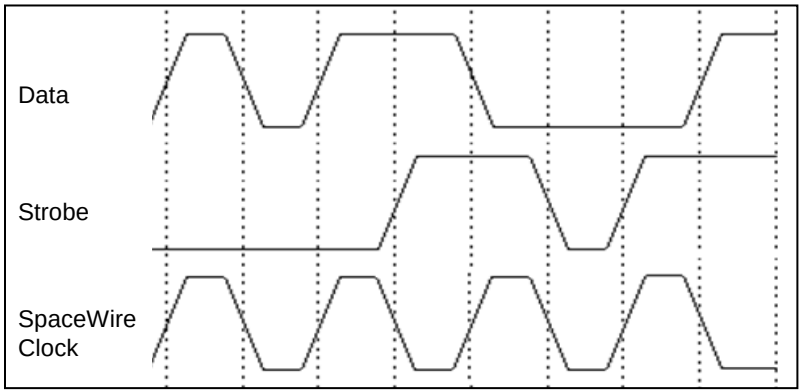
- Radiation-Tolerant PLLs are used in CCC, SERDES and DDR blocks
- Triple module redundant (TMR) PLL in internal feedback mode
  - Reference clock is fed back to all 3 sub-PLLs independently
  - Sub-PLL is SEL immune
- Single PLL in external feedback mode
  - PLL output travels through clock network and is fed back to PLL
  - Common mode used for clock network delay compensation
  - Only 1 sub-PLL is enabled in this mode
  - Sub-PLL is SEL immune



Hardened SpaceWire Clock Recovery



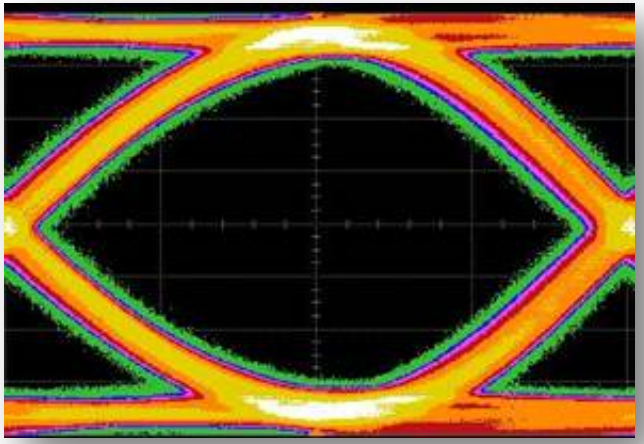
- SpaceWire interface used for command-and-control and data
  - Data and Strobe are XORed to recover SpaceWire clock
  - Hardwired and SET protected
  - Delay compensation available to align data and SpaceWire clock
  - 16 SpaceWire Clock Recovery circuits on each RTG4



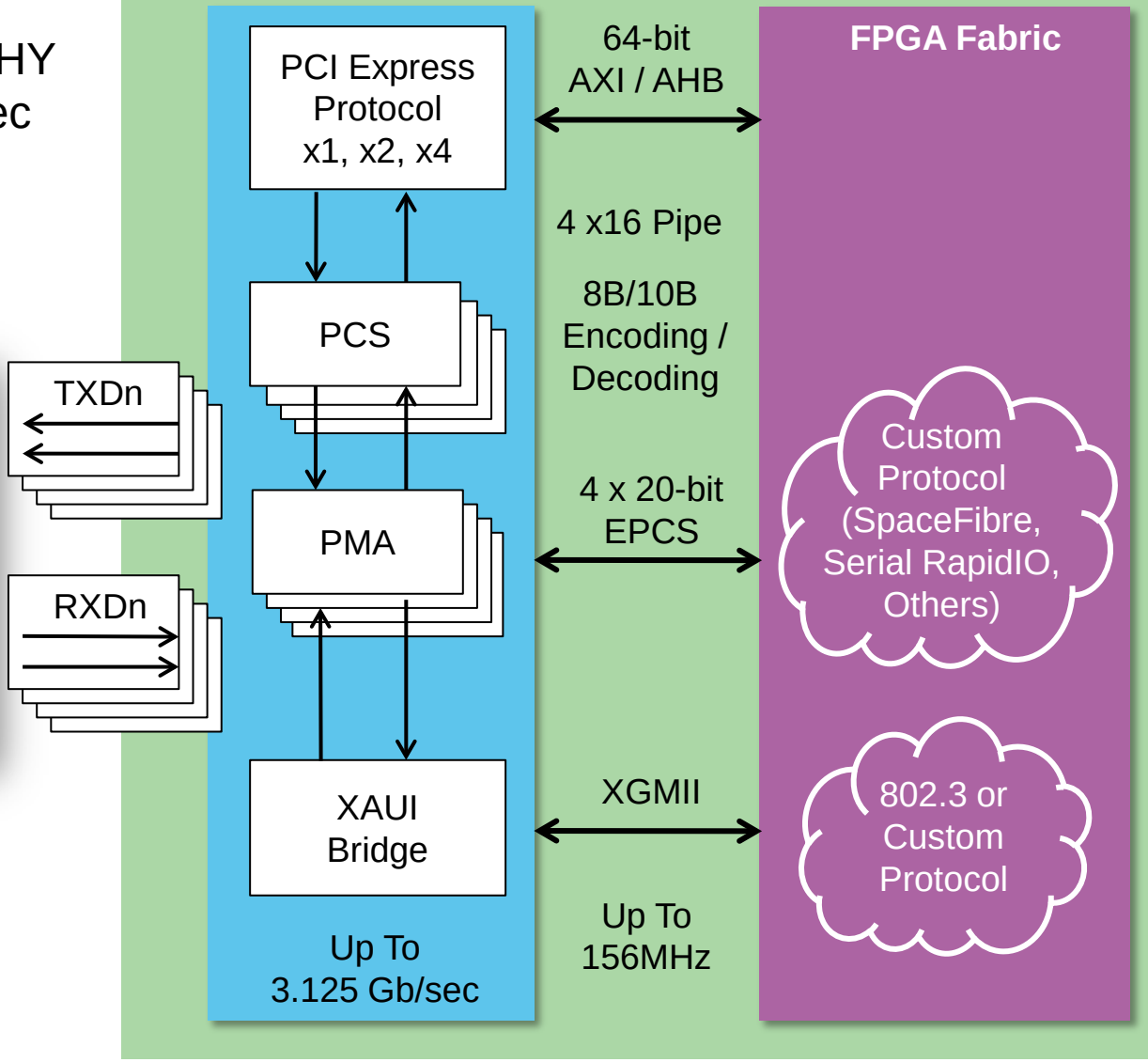
Unique Microsemi RTG4 Feature
See STAR Dundee SpaceWire Demo

3.125 Gb/sec SERDES

PMA Based on PCIe Gen 1 PHY
Performance 1 to 3.125 Gb/sec
Up to 6 blocks with 4 lanes

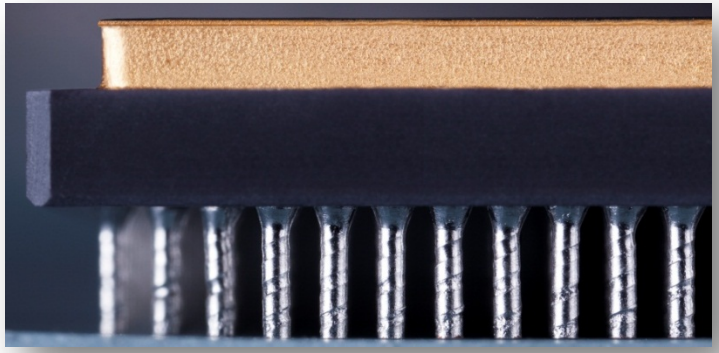


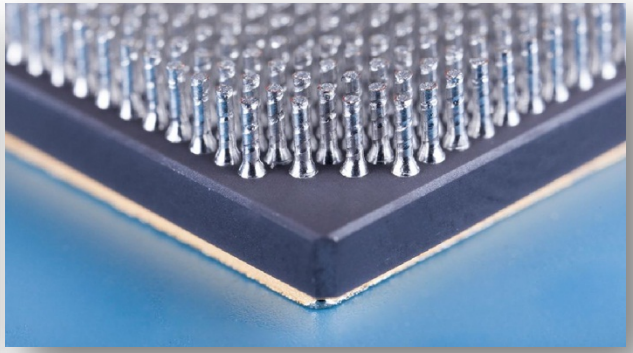
See STAR Dundee SpaceFibre Demo

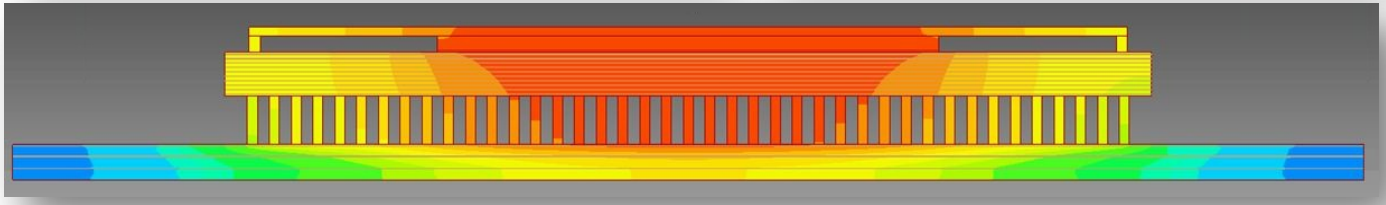


RTG4 Packaging Update

- Hermetically sealed, ceramic packages
  - Embedded decoupling capacitors
    - Flight models will have PME (Precious Metal Electrode) capacitors (Presidio 0508)
  - Column Grid Array,
    Ball Grid Array,
    Land Grid Array,
    Ceramic Quad Flat Pack

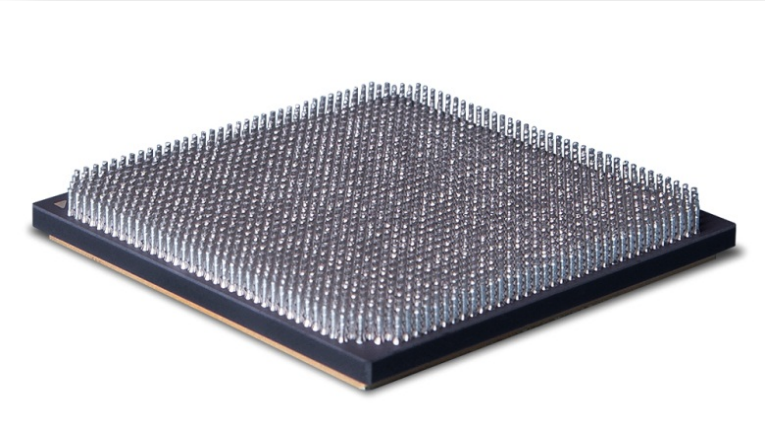




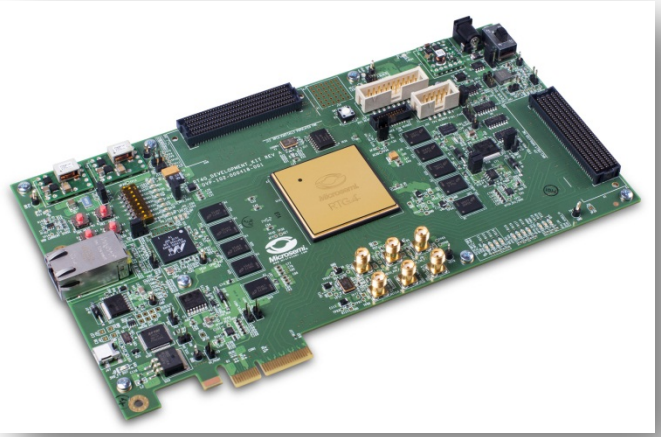


RTG4 Availability, Qualification Schedule

- RTG4 devices for space flight applications
  - Engineering Silicon RT4G150 FPGAs: ***NOW***
  - Libero SoC Design Software: ***NOW***
  - RT4G150 development kit: ***NOW***
  - Daisy chain packages: ***NOW***
  - MIL-STD-883 class B flight units: September 2016
  - QML class Q qualification: Mid 2017
  - QML class V qualification: Early 2018



Ceramic Column Grid Array Package



RT4G150 Development Kit

RTG4 Qualification Update

- MIL-STD-883 Class B Qualification
  - Completes in September 2016
  - Qualification will use RT4G150 in CG/LG1657 package
    - 3 wafer lots, 3 assembly lots
    - 1000 hours HTOL
  - Preliminary results:
    - HTOL: 6 RevA units and 6 RevC units passed 1000 hrs at Tj 146C and 151C
    - ESD: 3/3 units passed 2kV HBM per JEDEC JS-001
    - Latch-up: 3/3 units passed level 1 per JEDEC (JESD78) LU
    - NVM:
      - Non Volatile Cycling Endurance (NVCE; JESD22-A117) : 8/8 passed 400 cycles
      - High Temperature Retention (HTR, JESD22-A117) : 5/5 passed 536 hrs @ Tj=250C
- QML Class Q Qualification
  - SMD first draft in progress
- QML Class V Qualification
  - It is our intention to achieve QML-V

RTG4 IP Cores

- SpaceWire – StarDundee
  - Demonstrated in RTG4 Rev A silicon at 200Mb/sec
  - To be validated in Rev C silicon

- SpaceFibre – StarDundee
  - Demonstrated in RTG4 Rev A silicon at 2.5Gb/sec
  - To be validated in Rev C silicon

COBHAM

Cobham Gaisler AB

- Leon3FT – Cobham Gaisler
  - Performance benchmark in Libero 11.7 software in progress

- Cortex M1 – ARM
  - Licensing agreement with ARM in final phase
  - To be validated in Rev C silicon. Target completion by June

ARM®

- SRIO – IP vendor evaluation in progress

RTG4 Software Update

- Libero SoC v11.6 SP1 – Released on 12/24/2015
  - Updated clock power contribution in SmartPower
- Libero SoC v11.7 – Released on 2/11/2016
  - Enable Rev C programming for RT4G150 device
  - Support up to 206 asynchronous resets
    - RT4G150 designs from previous Libero releases will be invalidated
    - RT4G150_ES designs from previous Libero releases will be given option to update to latest cores
  - Fabric-generated clocks can be routed to nearest CCC to use CCC's SET filter
  - SynplifyPro
    - Infer non-pipelined ECC for LSRAM and uSRAM using directive "syn_ramstyle=ecc"
    - Infer sequential-shift construct and map to uSRAM through a directive
  - Tie-off unused FDDR, SERDES, CCC, uPROM to save power
  - SmartPower includes updated static power and adds uPROM power
  - Improved Repair Min-delay feature by increasing the number of violated paths analyzed
- Power Estimator v3j – Released in Feb 2016
  - Added maximum process
  - Updated static power for core, IO bank and VPP

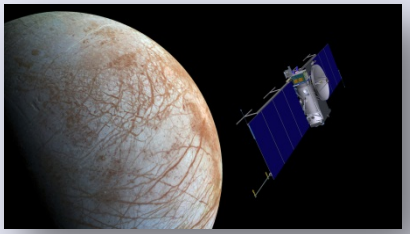
Programs Baselining RTG4

TESS
(NASA)

Orion
(NASA)

JUICE
(ESA)

Europa
(JPL)

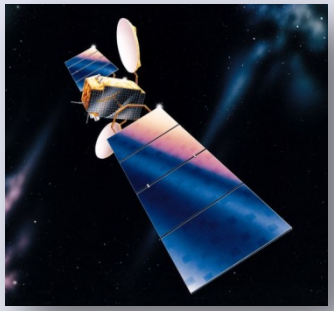


Digital Channelizer
(Commercial)

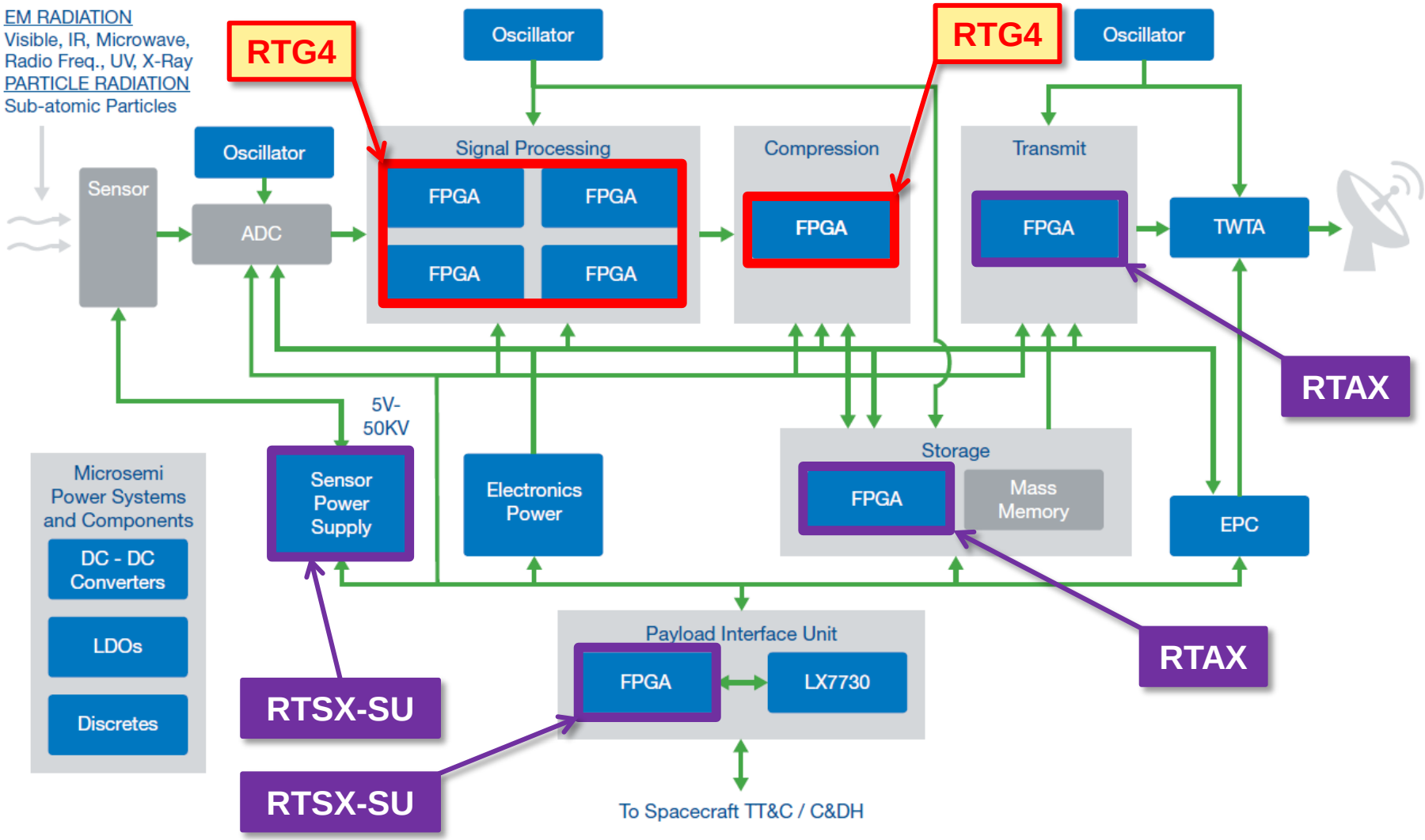
AIDA
(ESA, DLR, NASA)

SLIM
(JAXA)

Commercial
Program

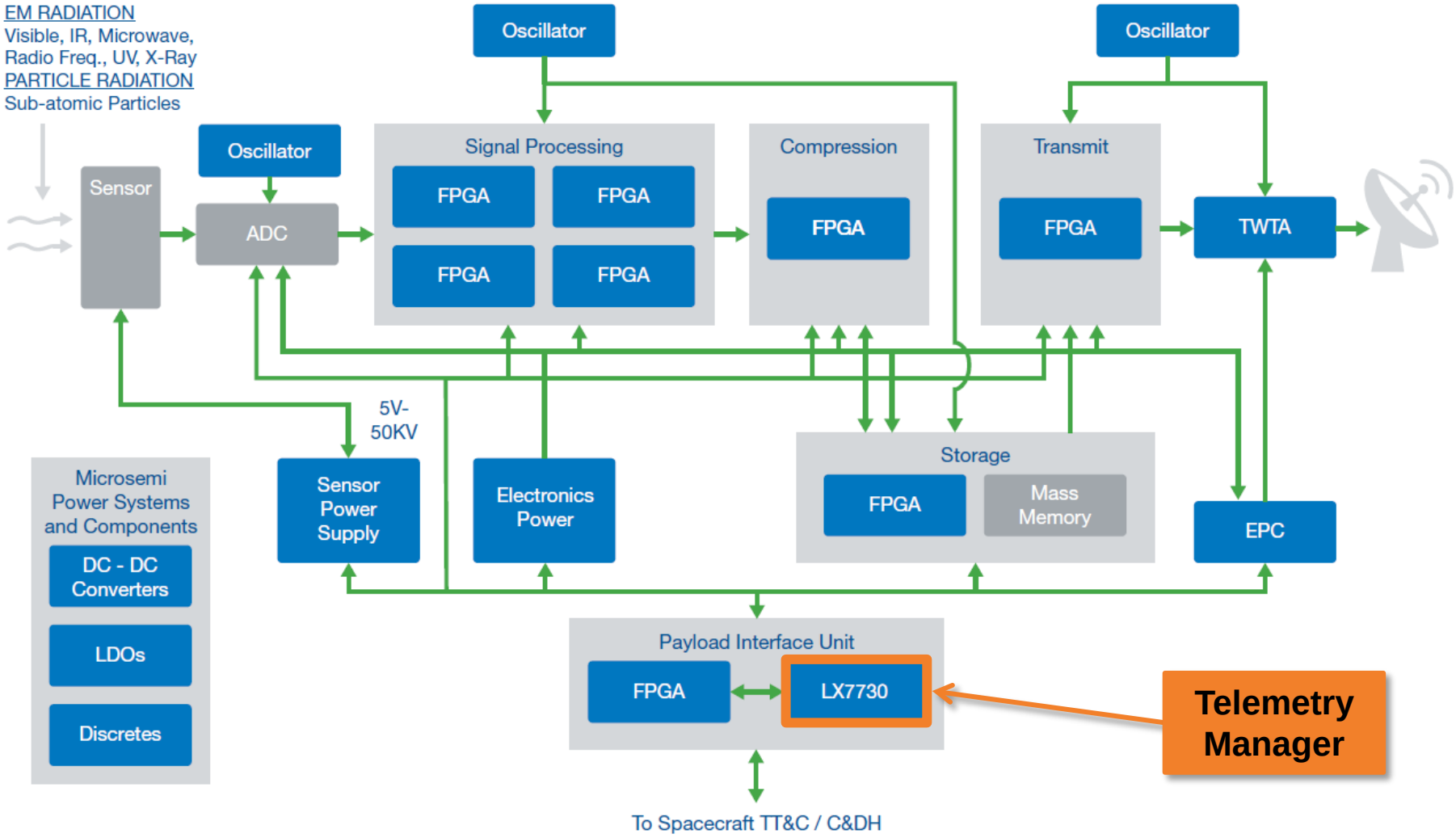


FPGAs in Remote Sensing Payload



RTG4 complements existing Microsemi Radiation Tolerant FPGAs

Space System Managers in Remote Sensing Payload

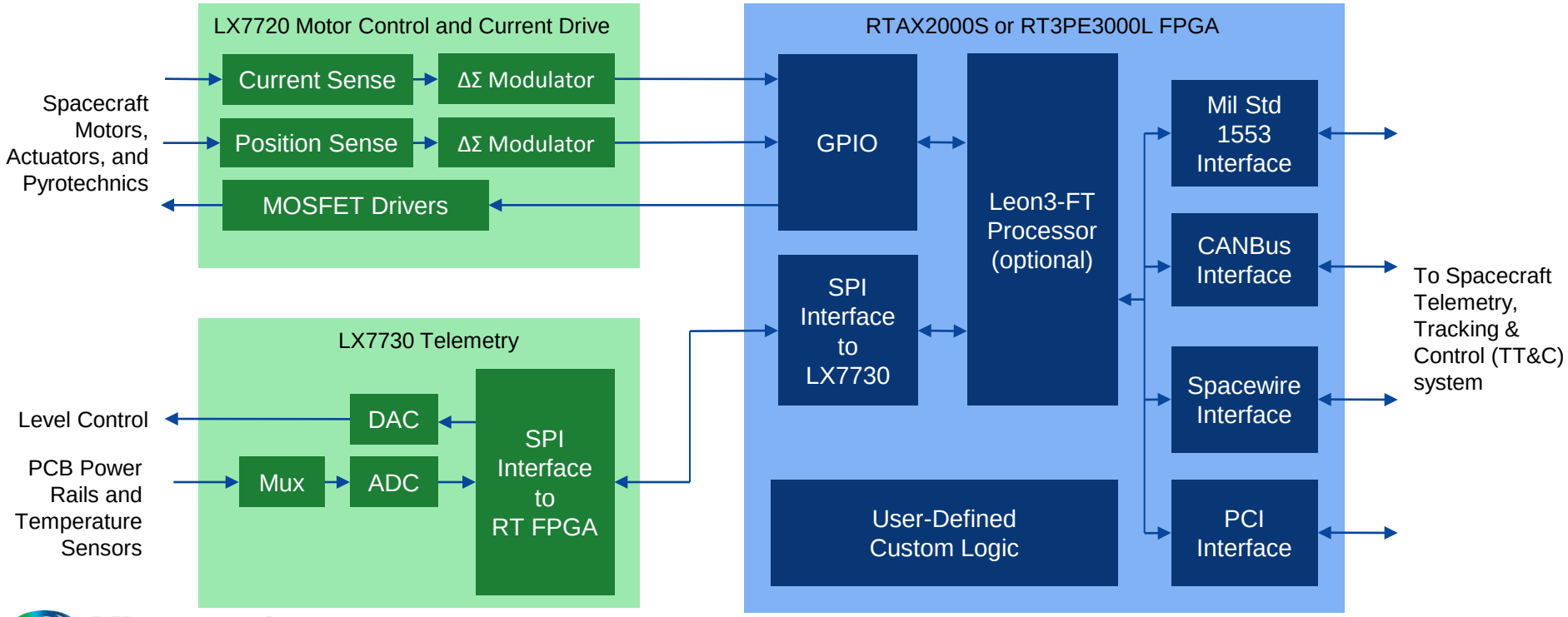


RTG4 complements other Microsemi space products

Space System Managers

Space System Managers

- Standard off-the-shelf solutions for telemetry and power driver in space
- Microsemi mixed signal standard ASICs
  - LX7720 current sense, rotary position sense and MOSFET drivers
  - LX7730 voltage, current and temperature telemetry
- Microsemi RT FPGAs implement digital interface with satellite control bus



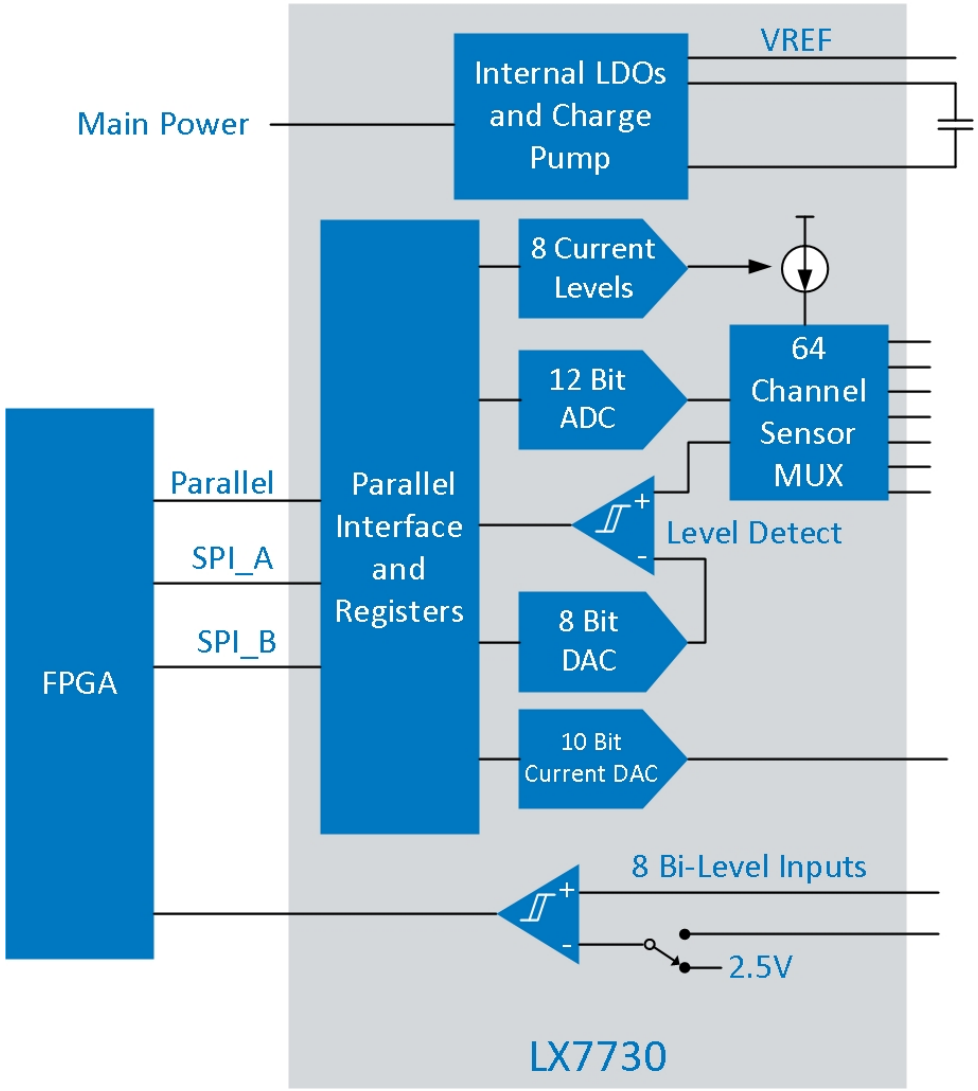
LX7730 Telemetry Controller

Features

- 64 channel MUX
- 25kSPS 12 bit ADC
- 2% Precision Adjustable Current Source
- 1% Precision 5.00V Source
- Threshold Monitoring
- 8 x Bi-level Logic
- 10 bit DAC
- Parallel or Dual SPI Interface
- Radiation Tolerant: 100krad TID, 50krad ELDRS, SE immune

Applications

- Spacecraft Environment Monitoring
- Attitude Control
- Payload Equipment



LX7730 Performance Highlights

Parameter	Comment	Min	Typ	Max	Units
SE or Diff sensor input		0		5	V
Differential Sensor common mode		-5		5	V
ADC conversion rate			25		kHz
ADC acquisition time			20		us
Reference voltage	Internal VREF	4.95	5.00	5.05	V
ADC non-linearity (integral or diff)		-2	0	2	LSB
MUX settling time			1.5		us
MUX leakage current	Power on or off	-100		100	nA
Bi-level threshold range		0.5		4.6	V
Bi-level propagation delay			1		us
DAC compliance range		0		3.0	V
DAC full scale current	Sourcing	1.94	2.00	2.06	mA

LX7730 Single Event Radiation Test Results

Test	Conditions	Results
SEL Testing	Test up to 1e8 part/cm^2 and 87.85MeV/mg.cm^2	SEL Immune
SET Testing	Test up to 2.46e5 part/cm^2 and 83.13MeV/mg.cm^2	SET Immune on all generated voltages
SEU Scan Chain Test (269 FF)	Test up to 1.01e5 part/cm^2 and 83.13MeV/mg.cm^2	SEU Immune on all internal FFs
SEE DC Telemetry Test	Test up to 1.21e5 part/cm^2 and 43.64MeV/mg.cm^2	SE Immune to radiation events up to LET of 43.64MeV/mg.cm^2
SEE AC Telemetry Test	Test up to 7.0e6 part/cm^2 and 83.13MeV/mg. cm^2	SE Immune to radiation events up to LET of 83.13MeV/mg.cm^2
SEE Current Source Test	Test up to 1.0e6 part/cm^2 and 43.64MeV/mg.cm^2	SE Immune to radiation events up to LET of 43.64MeV/mg.cm^2
SEE Current DAC Test	Test up to 1.0e6 part/cm^2 and 43.64MeV/mg.cm^2	SE Immune to radiation events up to LET of 43.64MeV/mg.cm^2
SEE Cold Spare Test	Test up to 1.0e6 part/cm^2 and 43.64MeV/mg.cm^2	SE Immune to radiation events up to LET of 83MeV/mg.cm^2

LX7730 Availability Update

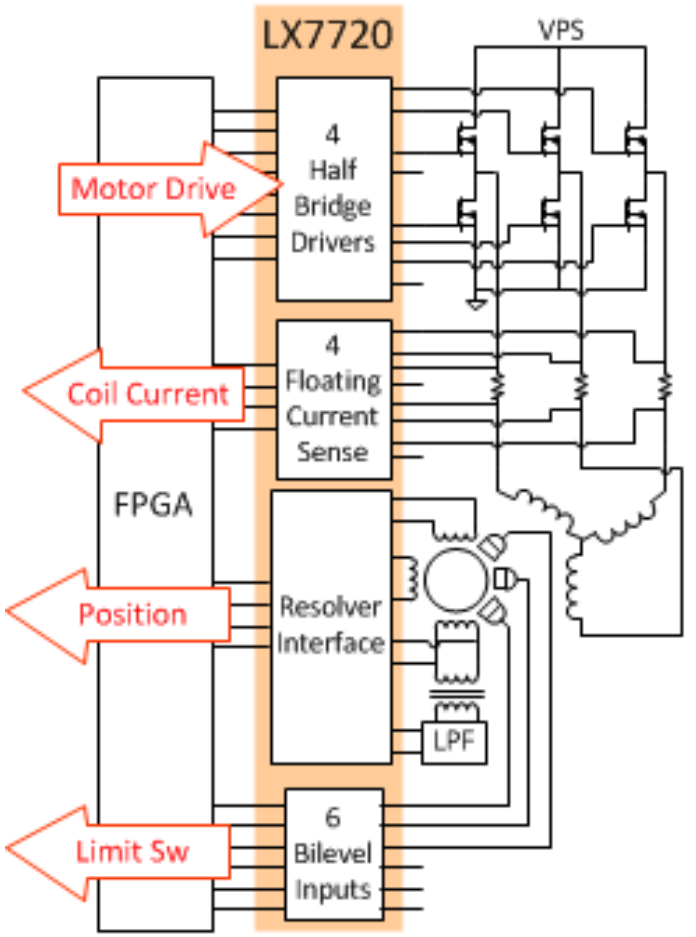
- Available now – LX7730 Engineering Silicon (ES) and LX7730 Evaluation Board (EVB)
- Product Availability

Part Number	Silicon	Availability
LX7730-ES & EVB	Production version	Now
LX7730MFQ-EQ samples	Pre-production Q flow samples	CQ2 2016
LX7730MFQ-EQ production	Production	CQ4 2016
LX7730MFQ-EV samples	Pre-production V flow samples	CQ2 2016
LX7730MFQ-EV production	Production	CQ4 2016

- We are seeking QML-Q and QML-V qualification

LX7720 Power Driver

- Provides MOSFET motor drivers
  - 3 phase motors
  - Unipolar or bipolar steppers
- 4 high and low side relay drivers
- Up to 4 current sensors
  - Phase currents or RTN currents
  - Average current control loops
- Sensing for resolver or LVDT
- Detecting pulse sensors and limit switches
- Combination of LX7720 and FPGA provides a closed loop system



LX7720 Performance Highlights

Parameter	Comment	Min	Typ	Max	Units
Motor Power Supply	De-rated by 20%	20	48	150	V
MOSFET driver impedance	Source or sink			1	Ω
PWM frequency		DC		200	kHz
Current sense differential range		-250		250	mV
Current sense accuracy			7		bits
Current sense latency			1.5		uS
Resolver carrier frequency		0.36		20	kHz
Resolver accuracy			16		bits
Bi-level threshold range		0.5		4.6	V
Bi-level propagation delay			1		us

LX7720 Availability Update

- Launch and customer sampling in summer 2016
- Product Availability

Part Number	Silicon	Availability
LX7720-ES & EVB	Preliminary version	CQ3 2016
LX7720MFQ-EQ samples	Pre-production Q flow samples	CQ2 2017
LX7720MFQ-EQ production	Production	CQ3 2017
LX7720MFQ-EV samples	Pre-production V flow samples	CQ2 2017
LX7720MFQ-EV production	Production	CQ4 2017

- We are seeking QML-Q and QML-V qualification

Conclusion

- RTG4 High-Speed RT FPGAs
  - High-bandwidth signal and data processing in radiation applications
  - Radiation hardening by design
    - TID immune to > 125 kRAD
    - SEL and configuration upset immune to 103 MeV-cm^2/mg
  - MIL-STD-883 Class B qualification to be completed in Sept 2016
  - Contact:
    Minh.U.Nguyen@microsemi.com, Ken.O'Neill@microsemi.com

- Space System Managers
  - Standard mixed signal IC for space applications
  - Radiation hardening by design
    - TID immune to 100 kRAD
    - SEL immune to 87 MeV-cm^2/mg
  - Contact:
    Dorian.Johnson@microsemi.com, Ken.O'Neill@microsemi.com

Summary

- Microsemi is dedicated, focused, and investing in space products and capabilities
- Microsemi has been in the space business as a partner with our customers for more than 55 years
- Microsemi has the system, circuit, and production experience in space to be a long term supplier of state-of-the-art products for long life cycles
- Microsemi uses a system view of applications, and a broad range of technology and design experience to build the best-in-class products for space

Microsemi Space Forum

- Presentations available at http://www.microsemi.com/spaceforum