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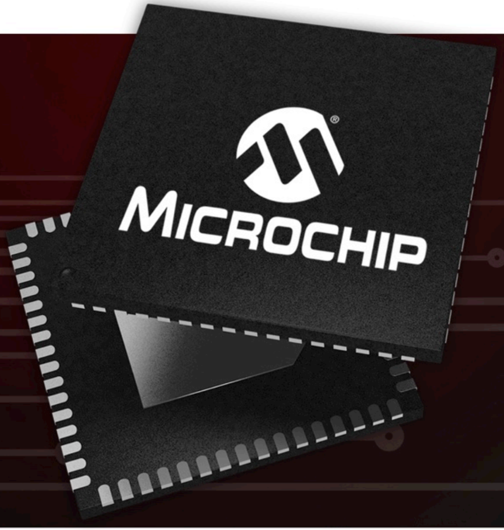


A Leading Provider of Microcontroller, Security, Mixed-Signal, Analog & Flash-IP Solutions

RTG4™ FPGA Update: Qualification, Radiation, Sub-QML

Minh Nguyen

Space Forum 2019

Agenda

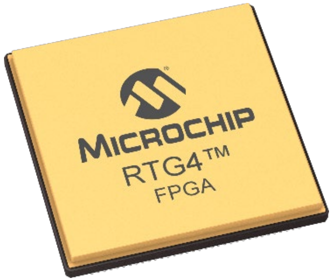
- **RTG4™ FPGA Update**
  - Qualification
  - Radiation

- **Sub-QML FPGAs**

RTG4 FPGA Update

RTG4 Product Overview

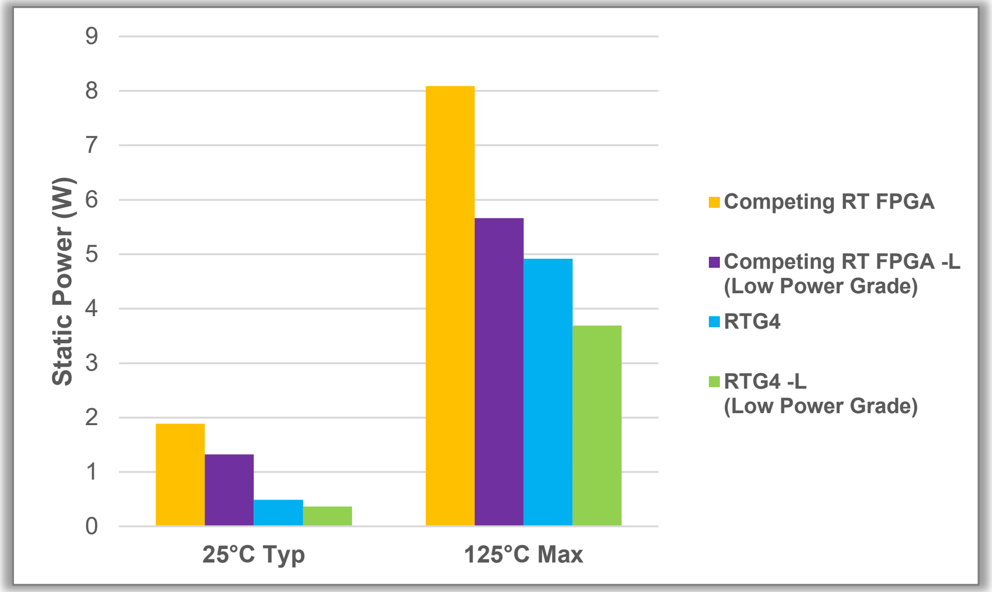
Resources	RT4G150	
	CG1657 / LG1657	**CQ352**
Logic Elements (TMR Register + 4-Input C Logic)	151,824	151,824
18x18 Multiply-Accumulate Blocks	462	462
RAM Mbits (1.5 Kbit and 24 Kbit Blocks, with ECC)	5.2	5.2
UPROM Kbits	381	381
DDR2/3 SDRAM Controller (with ECC)hjhkjhkj	2 x 32	0
PCI Express Endpoints	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
Hermetic, Ceramic Packages		
CG1657 (Ceramic Column Grid Array, Six Sigma Columns) LG1657 (Ceramic Land Grid Array, No Solder Termination) CB1657 (Ceramic Ball Grid Array, For Prototyping Only)	Available Now QML-V Qualified	
CQ352 (Ceramic Quad Flat Pack)		Available Now
Package Body Size	42.5 mm x 42.5 mm	48 mm x 48 mm



NEW!

RTG4 Low-Power Grade

- **Low-power grade (–L) for RTG4 standard speed (-STD) available NOW**
  - 25% quiescent supply current reduction: from 4.1 A to 3.1 A at 125 °C
  - RT4G150**L** device setting available in Libero SoC v12.0 and later, and in power calculator v6a
  - RTG4 continues to be **best-in-class**



RTG4 Qualification Status

- **CG/LG 1657 QML Class Q and Class V qualification completed!**
  - SMD 5962-16208
  - SMD has been approved and is posted on the [DLA web site]
  - SMD numbers are also posted on the [Microsemi web site]

RT4G150	1657-CCGA	RT4G150-CG1657B		5962-1620801QXF
		RT4G150-1CG1657B		5962-1620802QXF
		RT4G150-CG1657E		5962-1620805QXF
		RT4G150-1CG1657E		5962-1620806QXF
		RT4G150-CG1657V		5962-1620809VXF
		RT4G150-1CG1657V		5962-1620810VXF
	1657-LGA	RT4G150-LG1657B	5962-1620803QZC	
		RT4G150-1LG1657B	5962-1620804QZC	
		RT4G150-LG1657E	5962-1620807QZC	
		RT4G150-1LG1657E	5962-1620808QZC	
		RT4G150-LG1657V	5962-1620811VZC	
		RT4G150-1LG1657V	5962-1620812VZC	

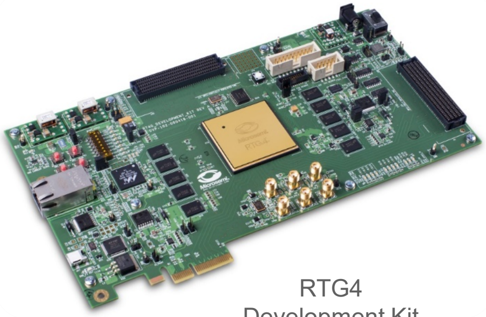
- **CQ352 QML Class Q and QML Class V in progress**
  - QML-Q qualification is expected by end of 2019
  - QML-V qualification is expected in early 2020

RTG4 Availability Schedule

- **RT4G150 PROTO FPGAs: Available to lead time now**
- **RT4G150 development kit: Available to lead time now**
- **CG1657 daisy chain packages: Available to lead time now**

- **CG1657 B, E, V-flow flight units, and CQ352 B, E-flow flight units: Available to lead time now**

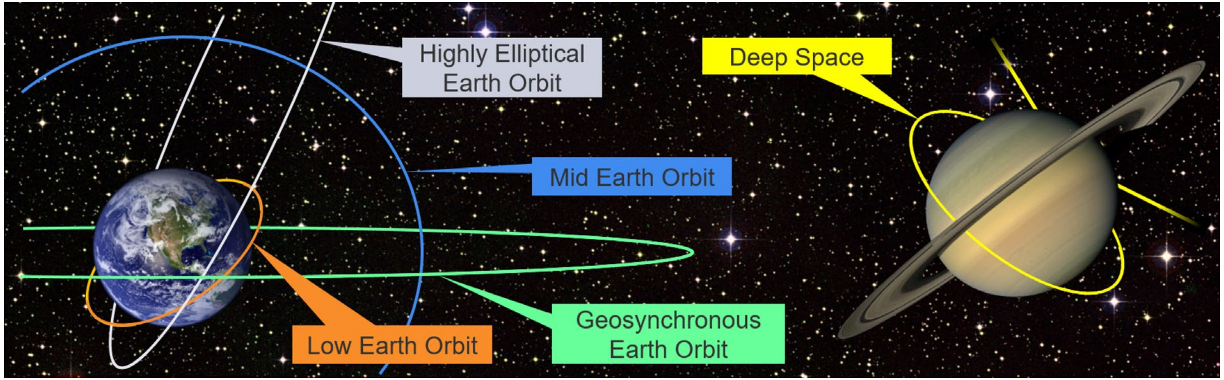
- **CQ352 EV-flow flight units: December 2019**



RTG4
Development Kit

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^2/mg, 100 °C	
Configuration Upset	No failure at facility limit of 103 MeV-cm^2/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, GEO solar min (no EDAC)	1.1E^{-11} errors/bit-day, GEO solar min (with EDAC)
uSRAM Single Event Upset	3.1E^{-8} errors/bit-day, GEO solar min (no EDAC)	2.7E^{-13} errors/bit-day, GEO solar min (with EDAC)



RTG4 Radiation Update

Test	Environment	Test Schedule	Status
Fabric, SRAM and PLL SEE	Proton	Complete	Report available on Microsemi Web
SERDES SEE	Proton	UCD in 10/2018	Less link loss than previous HI testing Report in progress
SERDES SEE	Heavy Ion	LBNL in 10/2018	Report in progress
In-Beam Programming	Proton	UCD in 10/2018	Data available – contact Microsemi
In-Beam Programming	Heavy Ion, Low dose rate Heavy Ion	LBNL in 2016 TAMU in 9/2018	Data available – contact Microsemi Additional report in progress
PLL SEE including TMR	Heavy Ion	TAMU in 2016 TAMU in 11/2018	Report available on Microsemi Web Additional report in progress
Fabric DDR Controller SEE	Heavy Ion	Completed, LBNL 2018	Report available on Microsemi Web
MSIO SEE	Heavy Ion	Complete	Report available on Microsemi Web
POR	Heavy Ion	Complete	Data available – contact Microsemi
RC OSC, uPROM	Heavy Ion	To be scheduled	Pending facility schedule
TID (leakage current and propagation effects)	Gamma, X-ray	Complete (X-ray) Ongoing / per wafer lot (Gamma)	Reports available on Microsemi Web
TID (retention effects)	Gamma, HTOL	Complete	Reports available on Microsemi Web

PLL Results

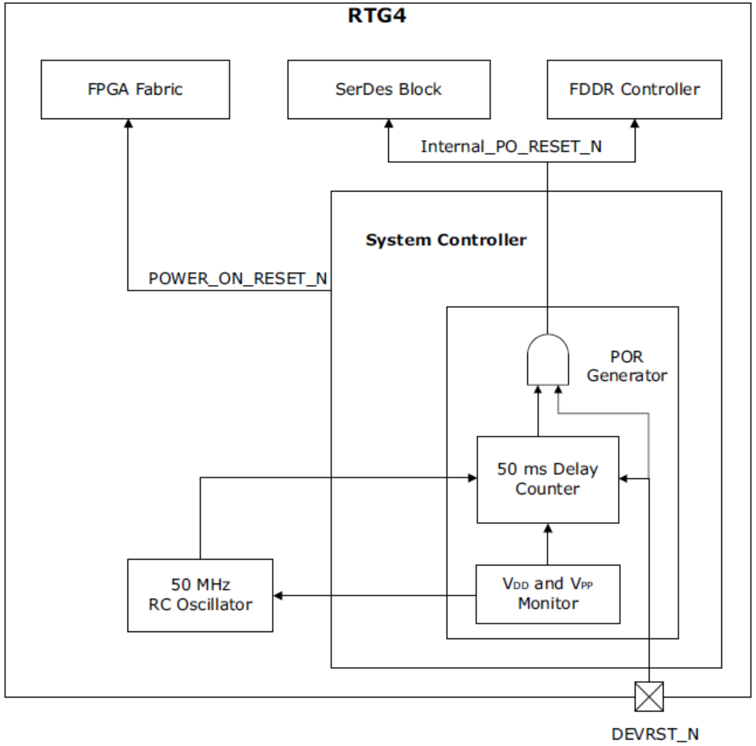
- **Heavy Ion Testing, GEO solar min**

PLL Mode	Clock Source	Recovery	Error rate (upset/PLL/day)	1 Loss of Lock every
Single PLL	External	Self	8.28 E-05	33 years
Single PLL	External	PLL Reset	4.00 E-07	6800 years
TMR PLL	External	PLL Reset	1.88 E-05	145 years

- **Proton Testing**
  - No upsets detected, tested to fluence 5E11 protons/cm^2, 200 MeV protons
  - Equates to fewer than one loss of lock every 165 years, in representative LEO environment (JPSS-1 orbit)

RTG4 Power-On Reset

- **Power-on reset (POR) test in heavy ion beam**
  - Average flux = 46 ions/cm^2/s
  - LET = 37 MeV.cm^2/mg
  - 10 out of 10 attempts were successful

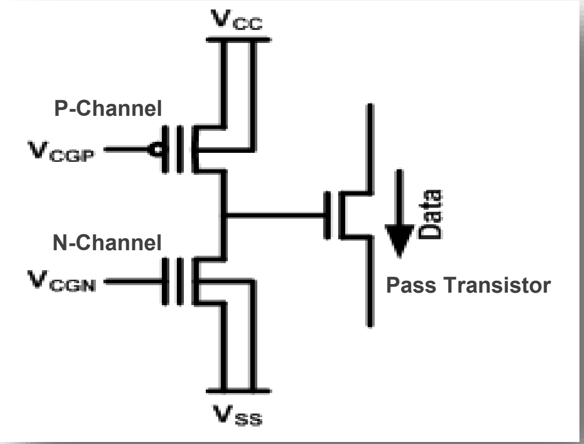


RTG4 In-Beam Programming Radiation Test Campaigns

- **4 test campaigns were performed to test RTG4 in-beam programming**
  1. Heavy ion test done at LBNL (2016) with average flux ~$1x10^3$ ions/cm^2/s
  2. Neutron test at LANL (August 2018)
  3. Heavy ion test at TAMU (September 2018) with average flux ~35 ions/cm^2/s
  4. Proton test at UCD (October 2018)

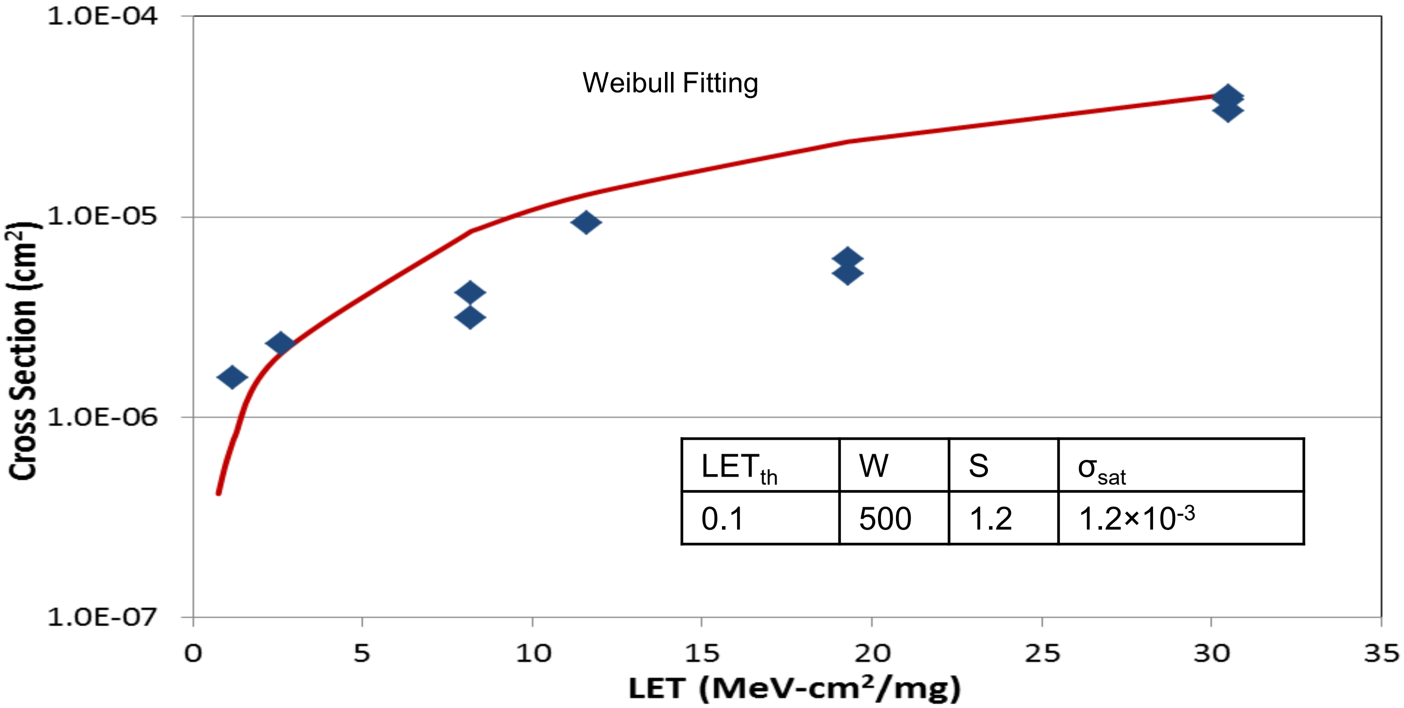
1st Test Campaign: Heavy Ion at LBNL, 2016

- **Single event effects on reprogramming**
  - Reprogramming in-beam performed to maximum LET 30 MeV-cm^2/mg with average flux of 1x10^3 ions/cm^2/s
  - Programming failures detected
    - Programming successful after parts were removed from heavy ion beam
    - Programming circuits are functional after heavy ion irradiation, to the LET level tested
  - Probability of programming success > 99% per attempt
    - Derived from cross section vs LET data (next page)
    - Assumes GEO solar min 0.100" aluminum shielding
  - RTG4 push-pull configuration expected to mitigate any occurrence of gate rupture



- **Total dose effects on reprogramming**
  - No failures observed at 50Krad
  - Unrecoverable programming failures observed at 75Krad and higher

Programming SEFI (LBNL, 2016)



LET_{th}	W	S	σ_{sat}
0.1	500	1.2	1.2×10^{-3}

2nd Test Campaign: Neutron LANSCE (August 2018)

- **Los Alamos National Laboratory LANSCE - WNR**
  - Neutron energies 10 MeV – 800 MeV
- **Programming passed 10 times out of 10 attempts in neutron beam**

Attempt #	1	2	3	4	5	6	7	8	9	10
Program	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
Verify	Pass									Pass

3rd Test Campaign: Heavy ion at TAMU (Sept 2018)

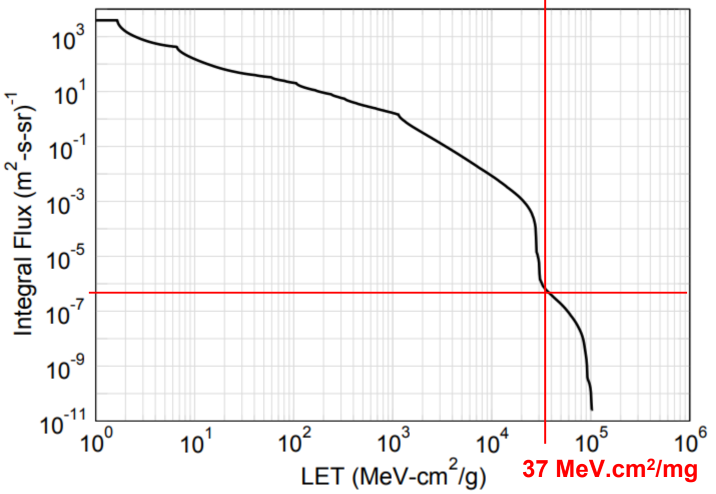
- **Beam parameters at TAMU:**
  - Average flux = 35 ions/cm^2/s
  - LET = 37 MeV-cm^2/mg
- **In beam 2 out of 10 Programming attempts passed; 2 out of 2 Verify failed**
  - If more Verify attempts are tested, it is most likely that Verify will pass

Attempt #	1	2	3	4	5	6	7	8	9	10	11
Program	Fail	Fail	Fail	Pass	Fail	Fail	Fail	Pass	Fail	Fail	Pass (beam OFF)
Verify				Fail (beam ON) Pass (beam OFF)				Fail (beam ON) Pass (beam OFF)			

Comparison Between TAMU & GEO Flux

- Goal: “real” Programming failure rate
- Beam parameter @ TAMU:
  - LET = 37 MeV.cm^2/mg
  - Average flux = 35 ions/cm^2/s
- GEO parameters (CREME96), 100 Mil Al shielding:
  - LET = 37 MeV.cm^2/mg
  - Flux Solar Min ~ 6.41E-10 ions/cm^2/s
  - Flux Solar Max ~ 9.90E-11 ions/cm^2/s
  - Flux Worst day ~ 1.51E-7 ions/cm^2/s
  - Flux Peak 5min ~ 5.44E-7 ions/cm^2/s

GEO Solar Min, 100 Mil Al



Unit ions/(m^2-s-sr) = 1.256E-3 ions/cm^{-2}/s

- The GEO orbit Solar Min flux is **lower by factor ~5.46E+10** than the TAMU flux

4th Test Campaign: Proton at UCD (Oct 2018)

- **In beam, 10 out of 10 programming attempts passed; 10 out of 10 verify passed**
  - UC Davis, 64MeV proton beam

Attempt #	1	2	3	4	5	6	7	8	9	10
Program	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
Verify	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass

RTG4 In-Flight Programming Guidance

- **Current guidance**
  - Highly unlikely that a destructive event will occur during programming in space
  - Probability of first-time success for programming in GEO is estimated > 99%, based on 1st test campaign
  - It is highly likely that in space, no ion will disrupt programming, since the flux in space is 1E10 lower than the flux tested during the 3rd test campaign
    - If an ion does strike the part disrupting programming, it is highly likely that the next programming attempt will succeed, which was proven during the 3rd test campaign
  - Probability of programming success in LEO is very high, based on the 2nd and 4th test campaigns
  - Reprogramming after TID
    - Reprogramming can be accomplished at TID levels up to 50Krad
    - Unrecoverable failure to reprogram at TID levels beyond 50Krad
    - Sufficient for 10 years of GEO and > 20 years of LEO

- **In-flight programming is not guaranteed**

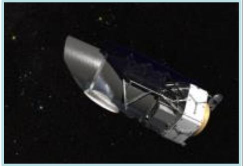
Programs Baselining RTG4

Mission Extension Vehicle MEV-1

Launched Oct 9th, 2019

Orion (NASA)

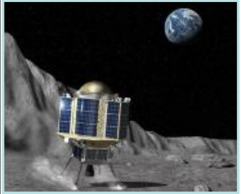
WFIRST (NASA)



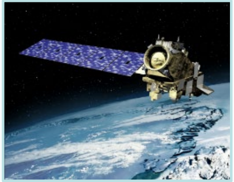
SBC (LANL)

AIDA (ESA, DLR, NASA)

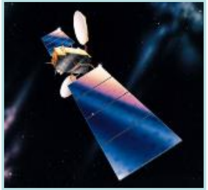
SLIM (JAXA)



JPSS-2 (NOAA)

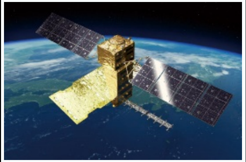


Reconfigurable Processor (Commercial)



ALOS-3 Optical (JAXA)

ALOS-4 SAR (JAXA)



SUB-QML FPGAS

RT FPGAs for New Space

- **Objective**
  - Create versions of RT FPGAs that can meet aggressive price targets to support New Space constellations that would not use traditional B / E / V flow FPGAs
- **Requirements**
  - Reduction in cost and price
  - Faster lead-time / cycle-time
- **Sub-QML RT FPGAs**
  - Ceramic – R Flow (Reduced Flow) and Mil Temp Hermetic
  - Plastic Package – Military Temperature

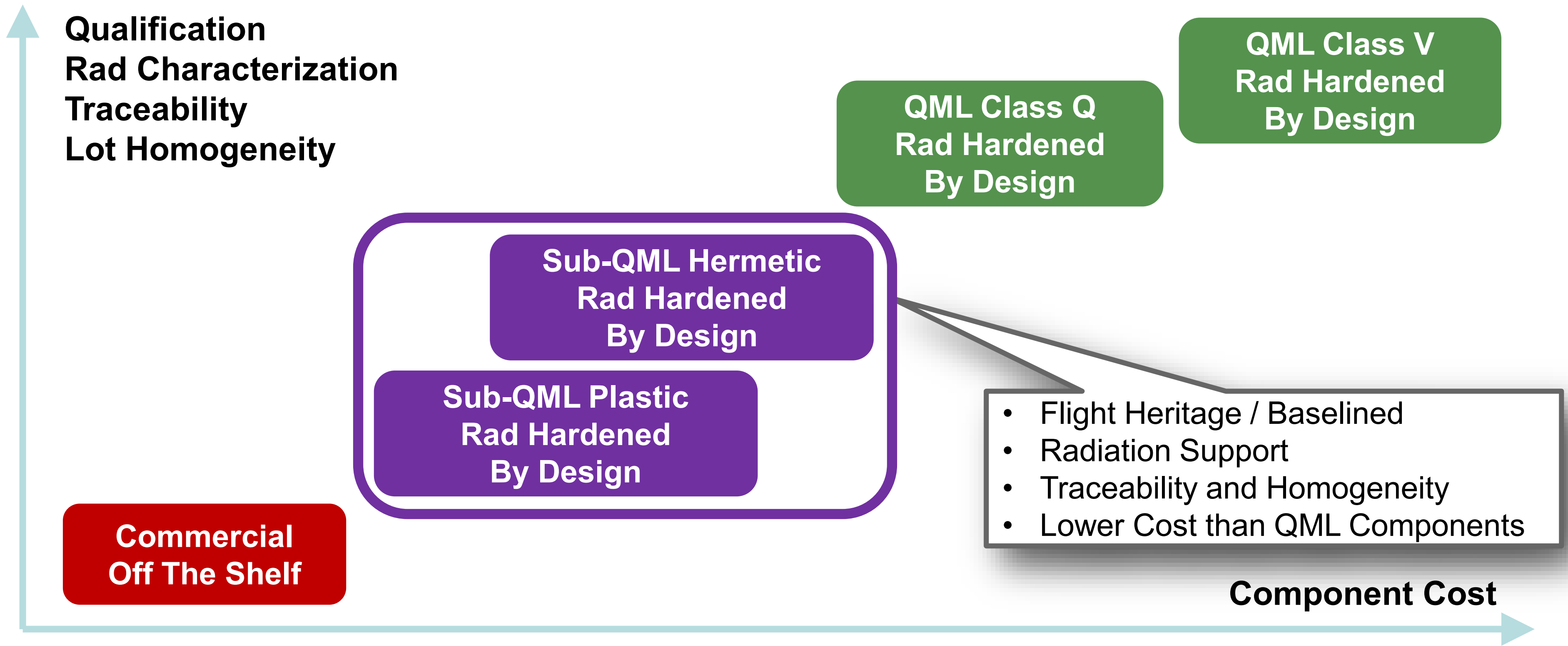
Cost and COTS

- **Satellite operators seeking lower acquisition cost and faster service entry**
- **Commercial Off The Shelf (COTS) components to reduce cost and lead-time**
- **The cost of COTS – *lower* component cost, *higher* cost of ownership**

	General Industry COTS	QML Rad Tolerant
Unit Cost	☑ Low	☒ High
Leadtime	☑ Short	☒ Long
Space-Flight Heritage	☒ No	☑ Yes
Supplier Tech Support	☒ No	☑ Yes
Radiation Data and Support	☒ No	☑ Yes
Reliability Data and Support	☒ No	☑ Yes
Lot Traceability, Homogeneity	☒ No	☑ Yes

Addressing these shortcomings results in hidden cost for organizations using COTS in space systems

Sub-QML: Bridging the Gap Between QML and COTS



Sub-QML Components

- Reducing or eliminating QML testing and documents removes a lot of cost
- Elimination of solder columns removes cost and reduces lead times
- Plastic packaging reduces cost further

	General Industry COTS	QML Rad Tolerant	Sub-QML RT Hermetic	Sub-QML RT Plastic
Unit Cost	☑ Lowest	☒ High	☑ Lower	☑ Lower
Leadtime	☑ Shortest	☒ Long	☑ Shorter	☑ Shorter
Space-Flight Heritage	☒ No	☑ Yes	☑ Yes	☑ Yes
Supplier Tech Support	☒ No	☑ Yes	☑ Yes	☑ Yes
Radiation Data and Support	☒ No	☑ Yes	☑ Yes	☑ Yes
Reliability Data and Support	☒ No	☑ Yes	☑ Yes	☑ Yes
Lot Traceability, Homogeneity	☒ No	☑ Yes	☑ Yes	☑ Yes

RTG4 Screening Flows

Flow	Purpose	Package	Qualification	Screening			
				Burn-In	Temp Test	Life Test	DPA
V	NSS, NASA Class1	Hermetic Ceramic	QML-V	Static Dynamic	-55°C – 125°C	Wafer-Lot	Assy Lot
E	Advanced Traditional Space	Hermetic Ceramic	QML-Q	Static Dynamic	-55°C – 125°C	Generic Group C	Optional
B	Entry Level Traditional Space	Hermetic Ceramic	QML-Q	Dynamic	-55°C – 125°C	Generic Group C	None
R	New Space, Strategic Programs	Hermetic Ceramic	MIL-STD-883 Class B	Dynamic	-55°C – 125°C	None	None
Mil Ceramic	New Space, Strategic Programs	Hermetic Ceramic	MIL-STD-883 Class B	None	-55°C – 125°C	None	None
PROTO	Prototyping	Ceramic (Hermeticity not Guaranteed)	MIL-STD-883 Class B	None	-55°C – 125°C	None	None
Mil Plastic	New Space, Strategic Programs	Plastic Non-Hermetic	JEDEC	None	-55°C – 125°C	None	None

RTG4 Screening Flows for Traditional Space

Flow	Purpose	Package	Qualification	Screening			
				Burn-In	Temp Test	Life Test	DPA
V	NSS, NASA Class1	Hermetic Ceramic	QML-V	Static Dynamic	-55°C – 125°C	Wafer-Lot	Assy Lot
E	Advanced Traditional Space	Hermetic Ceramic	QML-Q	Static Dynamic	-55°C – 125°C	Generic Group C	Optional
B	Entry Level Traditional Space	Hermetic Ceramic	QML-Q	Dynamic	-55°C – 125°C	Generic Group C	None
R	New Spac Strategic P				5°C – 25°C	None	None
Mil Ceramic	New Spac Strategic P				5°C – 25°C	None	None
PROTO	Prototyping	Ceramic (Hermeticity not Guaranteed)	MIL-STD-883 Class B	None	-55°C – 125°C	None	None
Mil Plastic	New Space, Strategic Programs	Plastic Non-Hermetic	JEDEC	None	-55°C – 125°C	None	None

- Flight models with V / EV, E (Extended), and B (Mil Std 883 Class B) screening flows
- PROTO models with military temperature testing

RTG4 Screening Flows: Hermetic Ceramic for New Space

Flow	Purpose	Package	Qualification	Screening			
				Burn-In	Temp Test	Life Test	DPA
V	NSS, NASA Class1	Hermetic Ceramic	QML-V	Static Dynamic	-55°C – 125°C	Wafer-Lot	Assy Lot
E	Advanced Traditional Space	Hermetic Ceramic	QML-Q	Static Dynamic	-55°C – 125°C	Generic Group C	Optional
B	Entry Level Traditional Space	Hermetic Ceramic	QML-Q	Dynamic	-55°C – 125°C	Generic Group C	None
R	New Space, Strategic Programs	Hermetic Ceramic	MIL-STD-883 Class B	Dynamic	-55°C – 125°C	None	None
Mil Ceramic	New Space, Strategic Programs	Hermetic Ceramic	MIL-STD-883 Class B	None	-55°C – 125°C	None	None
PROTO	Prototyping					None	None
Mil Plastic	New Space, Strategic Programs					None	None

- R (Reduced Flow) and M Ceramic require updates to manufacturing flows and paperwork however no engineering work is necessary
- MOQ and NCNR will apply

RTG4 Reduced Flow and Mil Temp Hermetic

- **Reduced Flow**
  - Same test and screening flow as B-flow (no test elimination)
  - Internal gas analysis screened to 10,000 ppm(v) moisture limit
  - Minimum order quantity (MOQ) and non-cancelable, non-returnable (NCNR) will apply
  - No datapack, no assembly lot group B data, no generic group C or group D data will be available
  - No attribute sheet will be available; C of C will ship with the order
  - Solder column visual inspection criteria will be less strict than Mil Std
  - Solder column rework not restricted by Mil Spec, self-imposed limit of 3 times max
  - Parts will not be QML compliant and will not be marked with the SMD
  - Single Lot Date Code will not be available
  - TID will be performed on each wafer lot as usual
- **Mil Temp Hermetic**
  - Hermeticity guaranteed by generic group D testing
  - 100% test at room, hot and cold – no MIL-STD-883 testing

RTG4 Screening Flows – Plastic Packages for New Space

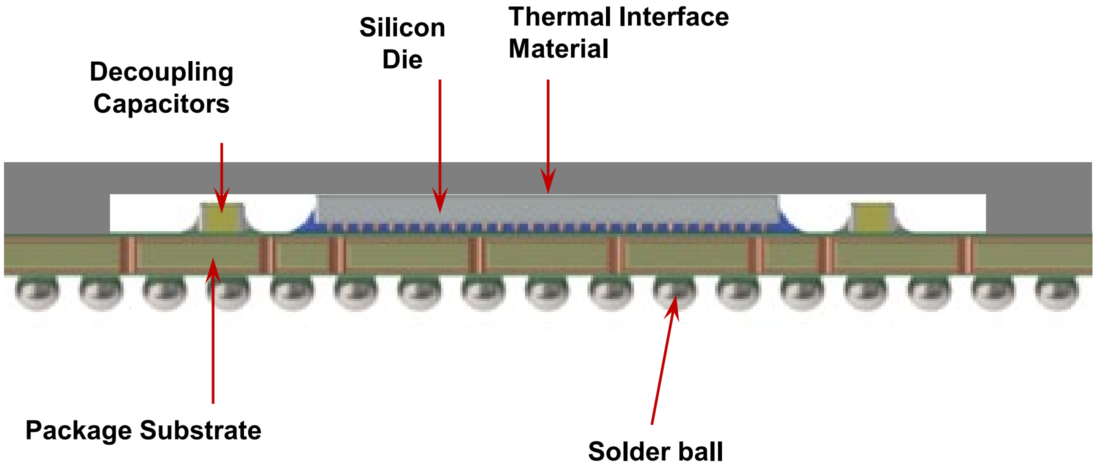
Flow	Purpose	Package	Qualification	Screening			
				Burn-In	Temp Test	Life Test	DPA
V	NSS, NASA Class1	Hermetic Ceramic	QML-V	Static Dynamic	-55°C – 125°C	Wafer-Lot	Assy Lot
E	Advanced Traditional Space						Optional
B	Entry Level Traditional Space						None
R	New Space, Strategic Programs						None
Mil Ceramic	New Space, Strategic Programs	Hermetic Ceramic	Class B	None	125°C	None	None
PROTO	Prototyping	Ceramic (Hermeticity not Guaranteed)	MIL-STD-883 Class B	None	-55°C – 125°C	None	None
Mil Plastic	New Space, Strategic Programs	Plastic Non-Hermetic	JEDEC	None	-55°C – 125°C	None	None

- Plastic packages require new design and tooling, new test hardware, new JEDEC qualification
- MOQ with NCNR will apply
- Samples available NOW
- Mil Plastic flight units ~14 weeks ARO, after JEDEC qualification completion in early 2020

RTG4 Plastic Package

- **Military temperature screening flow**
  - Test all parts at hot, cold and room
  - Guarantee T_J -55°C to 125°C
  - No MIL-STD-883 screening – no burn-in, temp cycle, centrifuge, fine and gross leak, etc.

- **FCG1657 Package**
  - Pin-compatible with CG1657
  - Same footprint as CG1657
  - Software availability:
    - Libero SoC v12.3



Conclusion

- RTG4 achieved QML Class V qualification
- RTG4 achieved first flight heritage on MEV-1
- RTG4 FPGA family continues to grow with low-power version, qualified CQ352 package, and new plastic package
- New RTG4 radiation data available on Microsemi website
- Sub-QML FPGAs bridging the gap between QML and COTS to support New Space constellations