Radiation Hardened FPGA Technology for Space Applications MAPLD 2008

Leonard Rockett[1], Dinu Patel[1], Steven Danziger[1], J.J. Wang[2], and Brian Cronquist[2]
Frank Hawley[2]
[1]BAE Systems, 9300 Wellington Road, Manassas, VA 20110-4122
[2]Actel Corporation, 2061 Stierlin Court, Mountain View, CA 94043-4655

October 17, 2008

RHAX250-S effort supported by the Defense Threat Reduction Agency

BAE SYSTEMS

RHFPGA Programs at BAE SYSTEMS

- RH FPGA Product Roadmap
- RH FPGA Technologies
  - ONO (Oxide Nitride Oxide – Antifuse)
  - M2M (Metal to Metal Antifuse)
- RH FPGA Program Status Review
  - Reinstall RH1020/RH1280 FPGA
  - RHAX FPGA Demonstration and Qualification Program
- Summary and Outlook

Radiation Hardened FPGA Roadmap

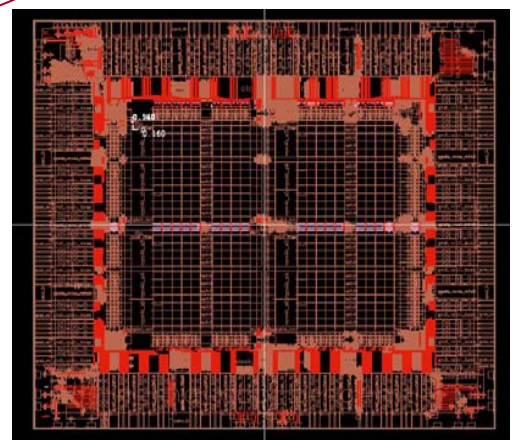
BAE SYSTEMS

Rad Hard FPGA Product

Past

- Heritage: Actel ONO RH1280 and RH1020
  - Anti-fuse technology, non-volatile
  - 0.8µm RH CMOS, 5V Supply
  - In production since 1996, over 25,000 shipped

Re-install in progress



Present

- M2M Anti-fuse Technology:
  - 250K-gate (RHAX250-S)
  - RH15 CMOS, 1.5V Core / 3.3V I/O
  - Flight Orders in 2009

Entry Vehicle

Future

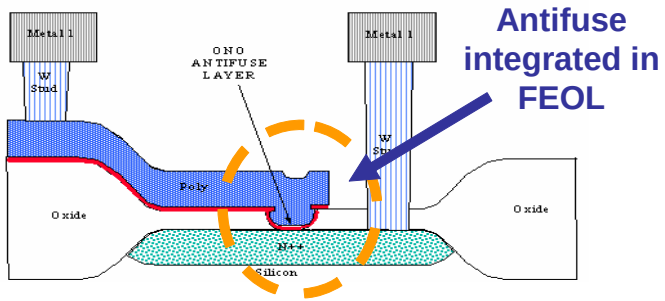
- ≥3M-gate, re-programmable, non-volatile
- Radiation Hardened, high speed
- RH15 CMOS, 1.5V Core / 3.3V I/O
- Projected qualification starts in 2009

BAE Supporting RHFPGA Needs for RHOC requirements

Actel

ONO RHFPGA Program

BAE SYSTEMS



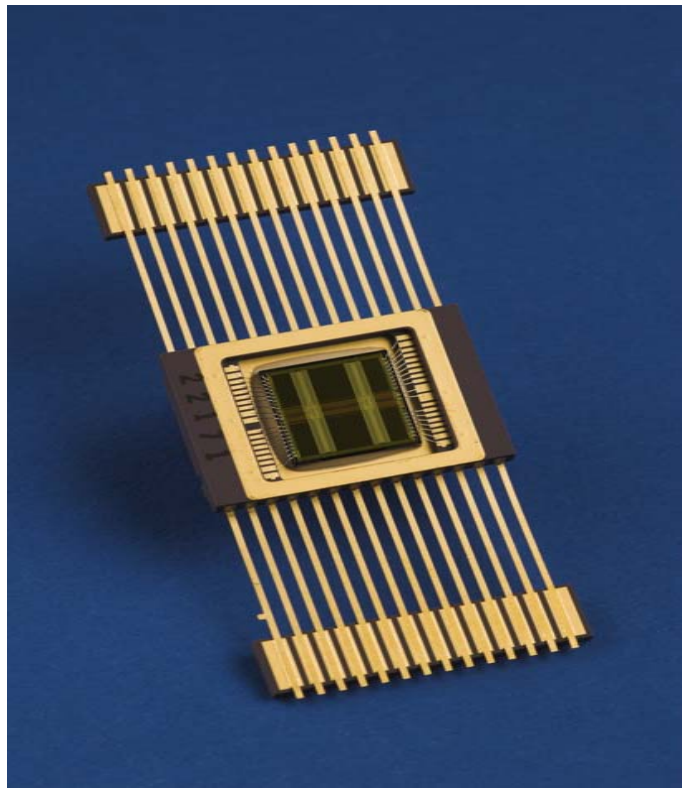
Actel

- ONO technology : (0.8 micron features)
  - Flight qualified production (with build-out inventory) [1996-2002]
  - Process line re-tooled to support 250 and 150 nm technology nodes on 150mm wafers
- ONO technology now reinstalled in modernized foundry to restart FPGA & PROM product to supply continued demand [2007-]
  - ➢ Used same design data ⇒ same form, fit, and function as product built previously
  - ➢ Keeping same 0.8 micron features

PROM Features

BAE SYSTEMS

- Features and Capabilities
  - Low voltage version: 32K x 8, 3.3V
    - SMD #5962G02502
  - High voltage version: 32K x 8, 5V
    - SMD #5962R96891
  - Latch-up immune
  - Total dose: 200 Krad(Si)
- Schedule and Status
  - In Production
  - Delivery in 8 weeks



ONO Rad Hard FPGA Technology Features

BAE SYSTEMS

Features

- Guaranteed Total Dose Radiation Capability
- Low Single Event Upset Susceptibility
- High Dose Rate Survivability
- Latch-Up Immunity Guaranteed
- QML Qualified Devices
- Commercial Devices Available for Prototyping and Pre-Production Requirements
- Gate Capacities of 2,000 and 8,000 Gate Array Gates
- More Design Flexibility than Custom ASICs
- Significantly Greater Densities than Discrete Logic Devices
- Replaces up to 200 TTL Packages
- Design Library with over 500 Macro Functions
- Single-Module Sequential Functions
- Wide-Input Combinatorial Functions
- Up to Two High-Speed, Low-Skew Clock Networks
- Two In-Circuit Diagnostic Probe Pins Support Speed Analysis to 50 MHz
- Non-Volatile, User Programmable Devices
- Fabricated in 0.8 µ Epitaxial Bulk CMOS Process
- Unique In-System Diagnostic and Verification Capability with Silicon Explorer

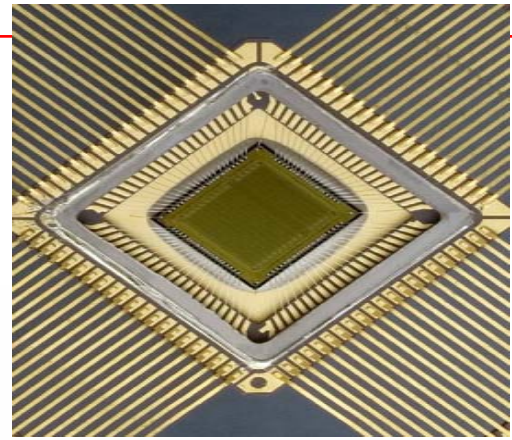
Product Family Profile

Device	RH1020	RH1280
Capacity		
System Gates	3,000	12,000
Gate Array Equivalent Gates	2,000	8,000
PLD Equivalent Gates	6,000	20,000
TTL Equivalent Packages	50	200
20-Pin PAL Equivalent Packages	20	80
Logic Modules	547	1,232
S-Modules	0	624
C-Modules	547	608
Flip-Flops (Maximum)	273	998
Routing Resources		
Horizontal Tracks/Channel	22	35
Vertical Tracks/Channel	13	15
PLICE Antifuse Elements	186,000	750,000
User I/Os (Maximum)	69	140
Packages (by Pin Count)		
Ceramic Quad Flat Pack (CQFP)	84	172

Actel

ONO Rad Hard FPGA Radiation Features

BAE SYSTEMS



Radiation Specifications

Table 1-2 • **Radiation Specifications**[1, 2]

Symbol	Characteristics	Conditions	Min.	Max.	Units
RTD	Total Dose			300 k	Rad (Si)
SEL	Single Event Latch-Up	$-55°C \le T_{case} \le 125°C$		0	Fails/Device-Day
SEU1[3]	Single Event Upset for S-modules	$-55°C \le T_{case} \le 125°C$		1E-6	Upsets/Bit-Day
SEU2[3]	Single Event Upset for C-modules	$-55°C \le T_{case} \le 125°C$		1E-7	Upsets/Bit-Day
SEU3[3]	Single Event Fuse Rupture	$-55°C \le T_{case} \le 125°C$		<1	FIT (Fails/Device/1E9 Hrs)
RNF	Neutron Fluence		>1 E+12		N/cm^2

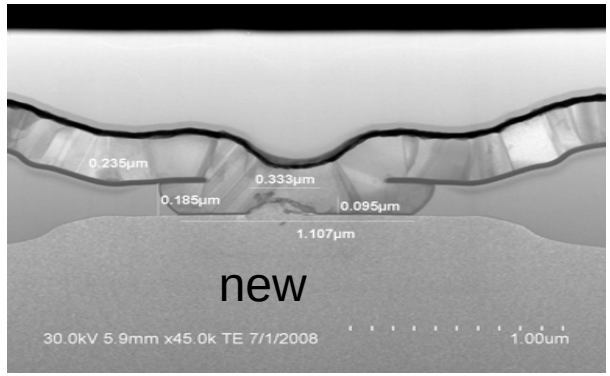
Notes:

1. *Measured at room temperature unless otherwise stated.*
2. *Device electrical characteristics are guaranteed for post-irradiation levels at worst-case conditions.*
3. *10% worst-case particle environment, geosynchronous orbit, 0.025" of aluminum shielding. Specification set using the CREME code upset rate calculation method with a 2 µ epi thickness.*

RH ONO Technology Process Data

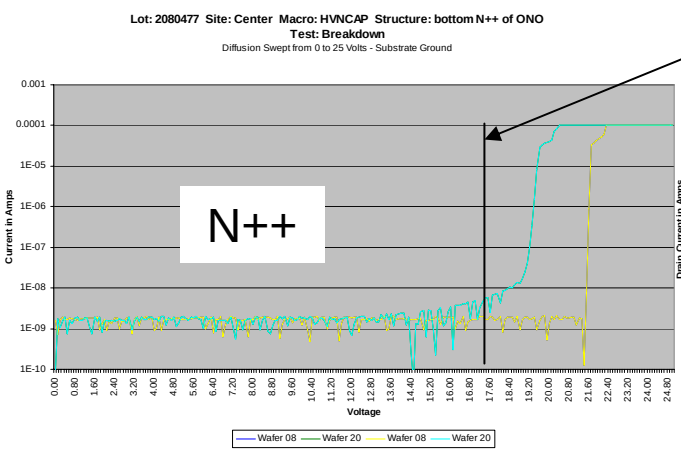
BAE SYSTEMS

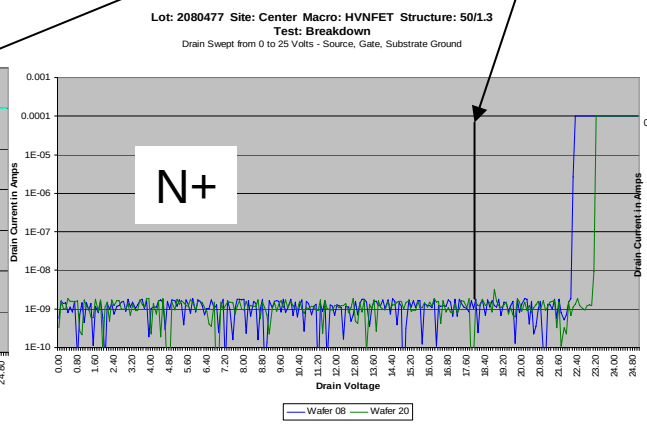
ONO Anti-fuse Cross sections - Programmed

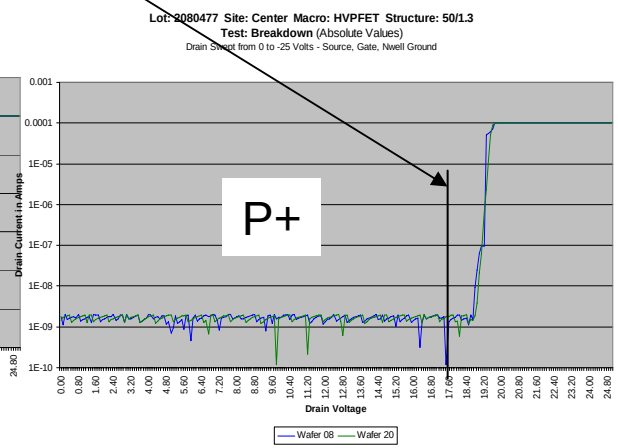


Device Electrical Parameters

Junction Breakdown Requirement



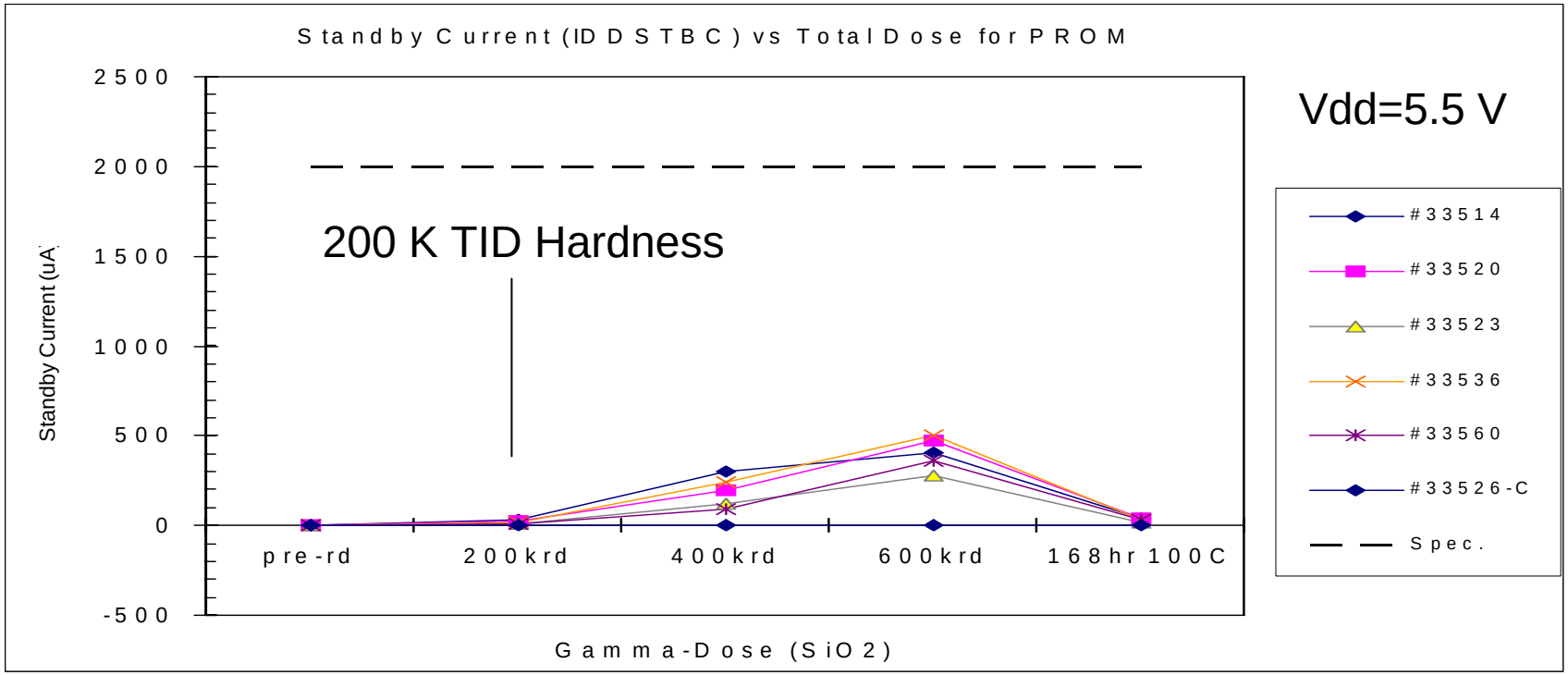




RH ONO Re-installed Technology Meets Device Parameters Requirements

RH ONO Technology TID Data - PROM

BAE SYSTEMS



- Active current, VIL, VIH, Access time and chip enable time all remain stable through 600 Krd

RH PROM Exceeds 200 Krad TID Requirements

ONO RHFPGA Program Status

BAE SYSTEMS

- Successfully reinstalled ONO process technology
- Flight-qualified PROM production restarted
- RH1280B prototype hardware successfully delivered, flight hardware in qualification.
  - BAE acquired license from Actel to produce, market and sell RH1280 FPGA's
  - SEGR completed successfully, TID testing in progress
- RH1020 FPGA build underway for prototype and flight Qualification

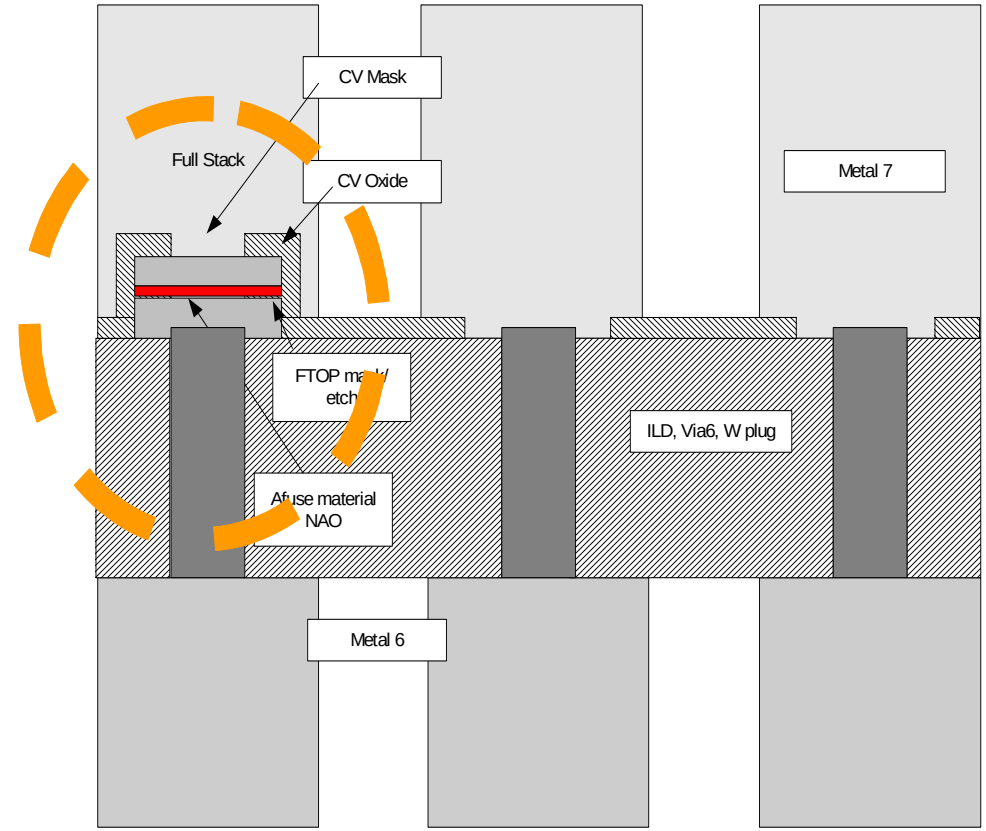
ONO FPGA Flight Hardware in Production

Orders being taken for shipments in 2008

BAE SYSTEMS

Metal to Metal Antifuse Based FPGA's

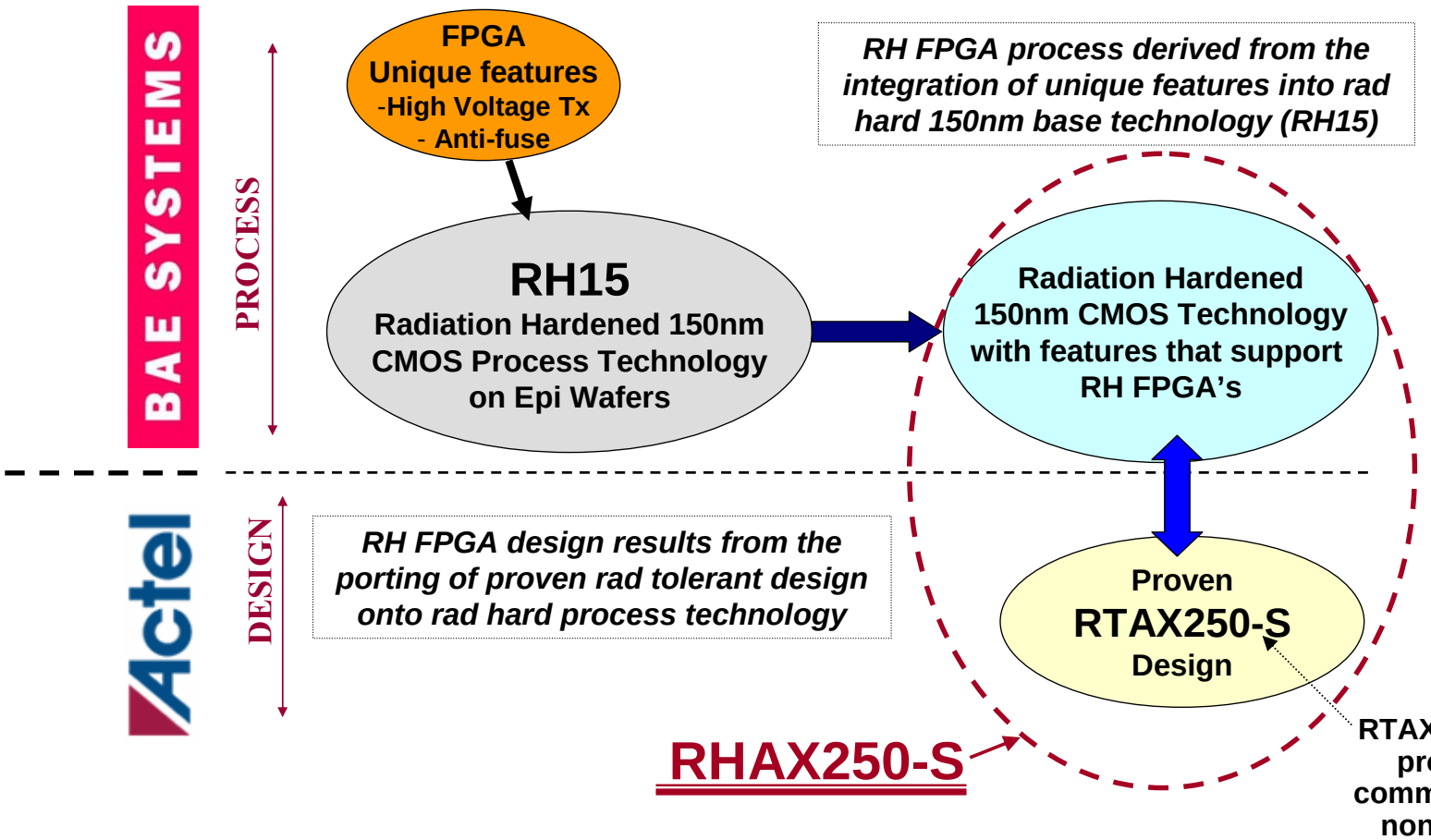
Antifuse integrated in BEOL



Actel

Product Installation Approach

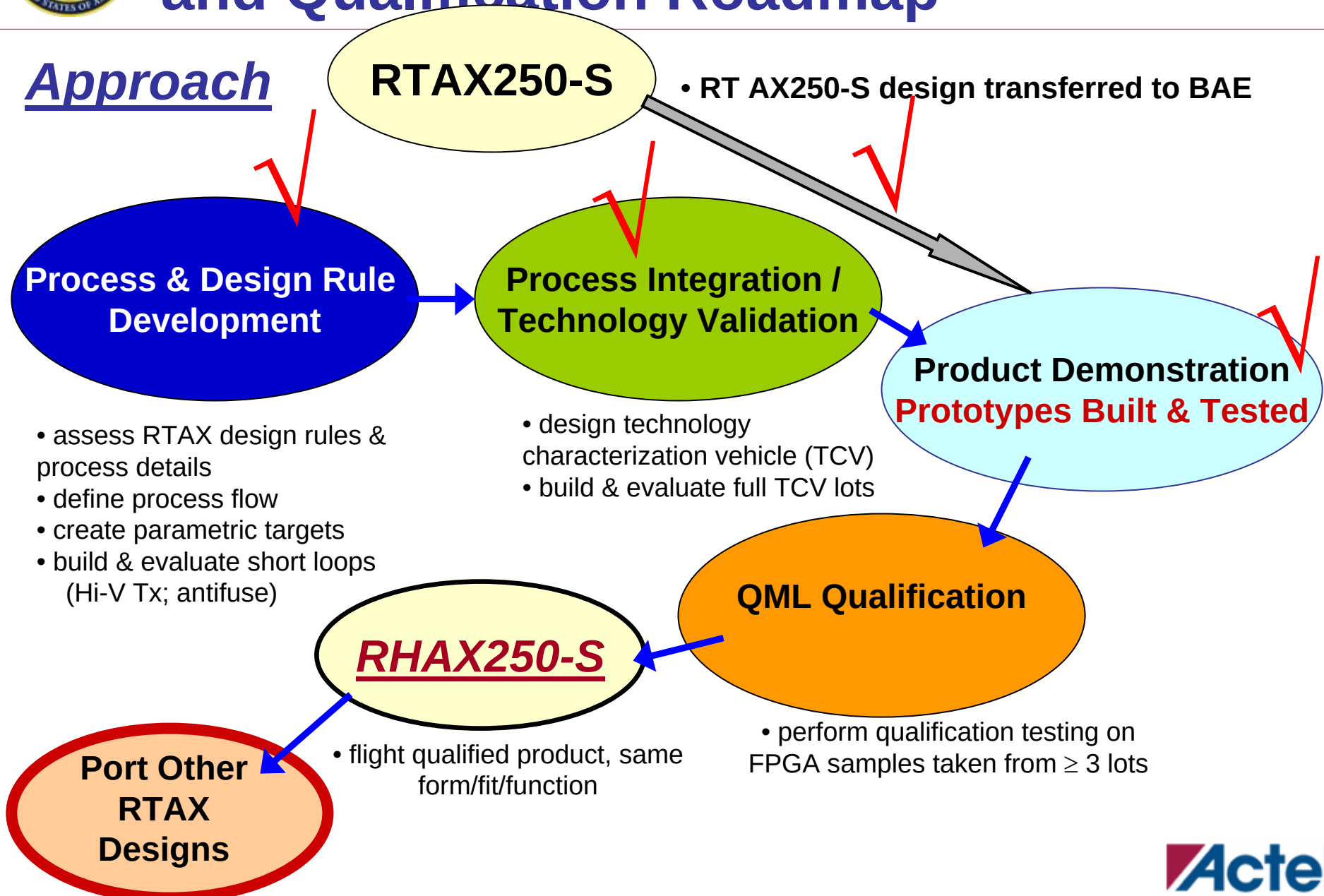
Low Risk: Port a proven RT design to a validated RH process.



RHAX250-S Installation and Qualification Roadmap

BAE SYSTEMS

Approach

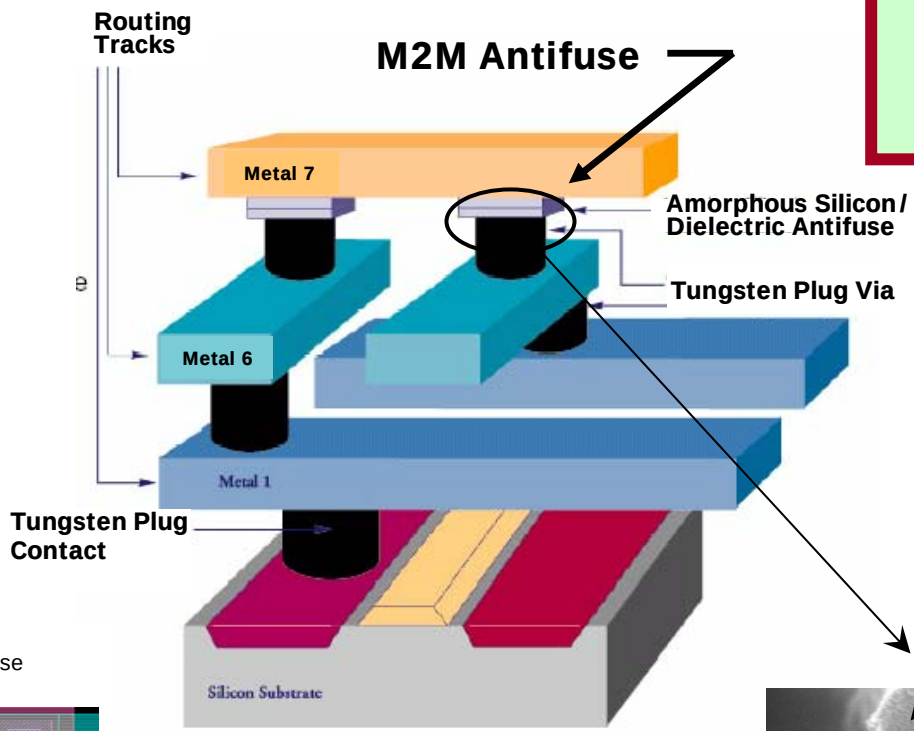


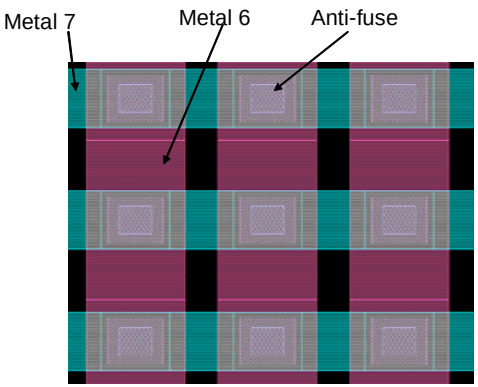
Actel

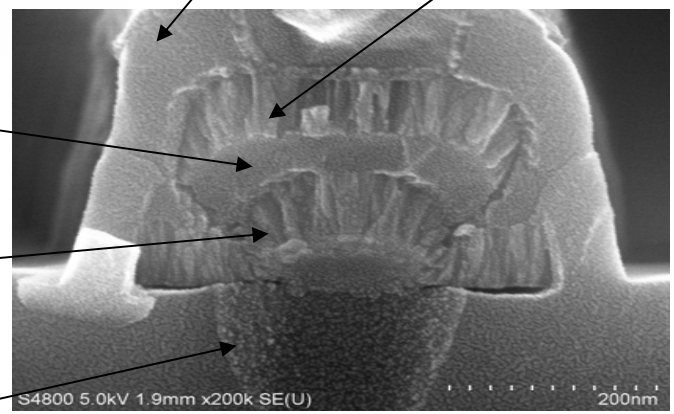
Metal-to-Metal Antifuse

BAE SYSTEMS

Antifuse Placement:
Between to last two metal layers, NOT inside the via but above the W-stud.







Actel

RHAX250-S Product Profile

Device	RHAX250-S
Capacity	
Equivalent System Gates	250,000
ASIC Gates	30,000
Modules	
Register (R-Cells)	1,408
Combinatorial (C-Cells)	2,816
Flip-Flops (Maximum)	2,816
Embedded RAM/FIFO (without EDAC)	
Core RAM Blocks	12
Core RAM Bits (K = 1,024)	54 K
Clocks Segmentable	
Hardwired	4
Routed	4
I/O's	
I/O Banks	8
User I/O's (Maximum)	248
I/O Registers	744
Package	
CCGA/LGA	-
CQFP	208, 352

Performance

- 1.5V Core; 3.3V I/O
- High-Performance Embedded FIFOs
- 350+ MHz System Performance
- 500+ MHz Internal Performance
- 700 Mb/s LVDS Capable I/Os

Radiation Hardness Targets

TID	≥ 1Mrad(Si)
DR Upset	> 1E9 rad(Si)/sec
SEL	Immune
SEU_{REGS}	< 1E-10 errors/bit-day (TMR-hardened)
$SEU_{e\text{-}RAM}$	< 1E-10 errors/bit-day (EDAC)

RHAX FPGA will have the identical form, fit, and function of its RTAX counterpart.

Predicted SEU Rates
vs. logic level & freq.

BAE SYSTEMS

Test data taken on RTAX Product

Predicted SEU Rates (errors/bit/day) *

Levels of Intervening Logic	Signal Frequency 15 MHz	37.5 MHz	75 MHz	150 MHz
8-Levels	5.31E-09	7.88E-09	3.75E-08	8.17E-08
4-Levels	2.01E-09	8.71E-09	1.89E-08	6.29E-08
0-Levels	6.08E-10	5.14E-09	2.84E-08	5.84E-08

Worsening SEU Rate

(Probability of Generating an SET)

Logic

* assumed radiation environment: GEO-min and 100-mil Al shielding

Frequency

(Probability of Capturing an SET)

Impact of SET on error rate depends on circuit design and signal frequency.

Further SEU Enhancements projected in Rad Hard Process using Epi layer

Actel

BAE SYSTEMS

RHAX250-S Prototype Hardware

Prototype RHAX250-S FPGA's have yielded functional hardware,

Modules were programmed for total ionizing dose testing.

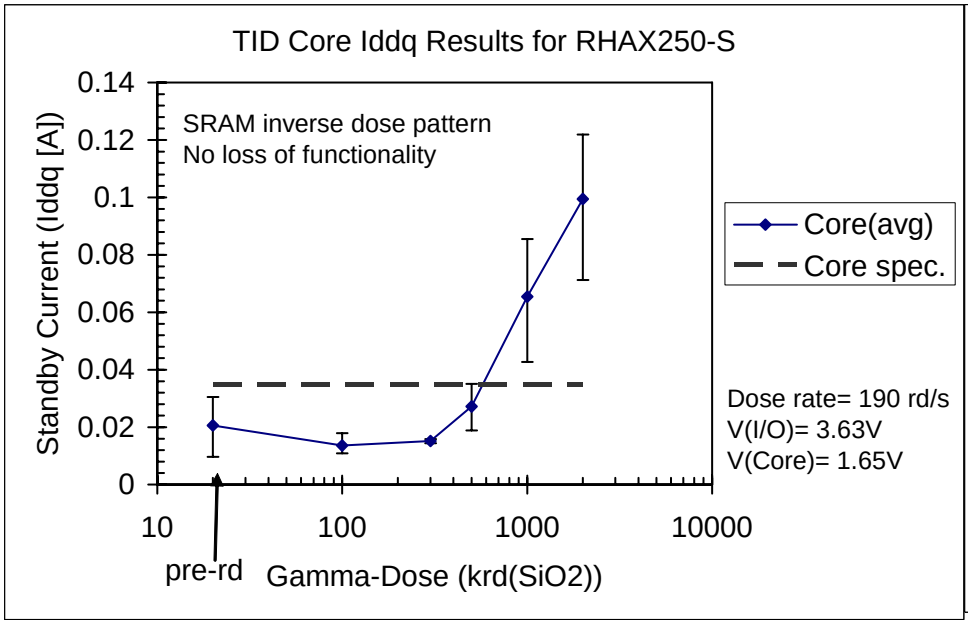
Circuit elements tested per module:

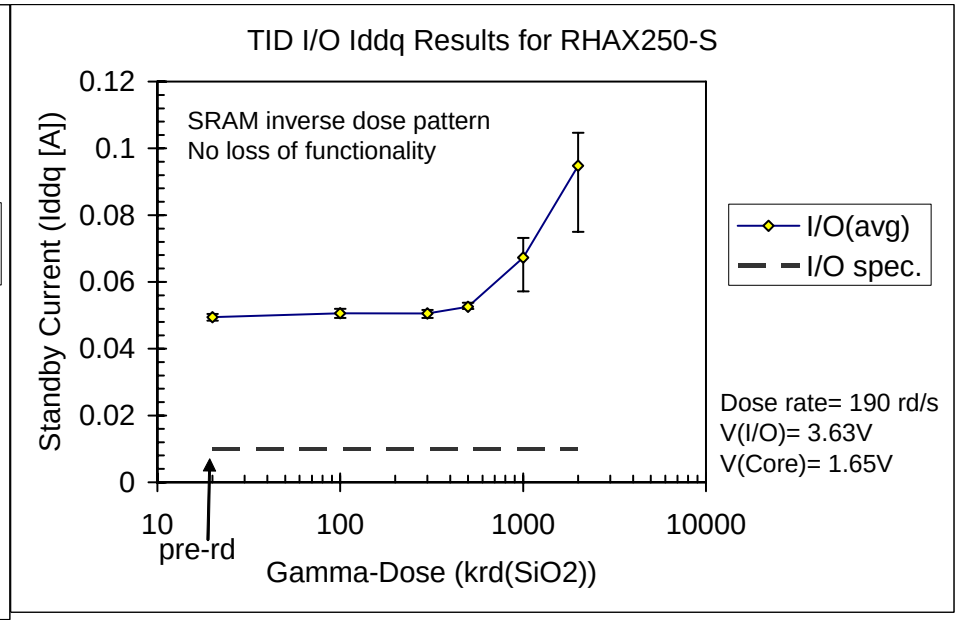
- 12 blocks of 4Kx1 SRAM (total: 48K)
- 1408-stage DFF register string
- Two 1408-stage logic chains

Actel

RHAX250-S TID Test Results

RHAX250-S modules remained fully functional throughout testing to 2Mrd($Si0_2$)





TID test results on prototype FPGA's demonstrate improved hardness. Hardening process adjustments are being implemented to further enhance hardness.

Process Improvements

- Parts successfully programmed at Actel, with latest QCMON
  - **Used <u>NASA-Industry Tiger Team</u>** Algorithm
  - Parts pass all 346 tests at 125 Degrees C except Icca , standby current exceeded specification limit
  - Further leakage reduction required for flight parts

Lot 421 QCMON (346 Total Tests)									
PARTS	Contact Test	QCMON Funct	QCMON Hi Z	Input Current High	Input Current Low	Input Pull Ups	Input Pull Dns	Pwr Supply Stdby Currents	Icca Stdby Current
Mod # 1	P	P	P	P	P	P	P	P	20.3mA*
Mod # 2	P	P	P	P	P	P	P	P	31.5mA*
P=PASS		* **Note: Spec limit is 20 mA.**							

Work in progress

- Build more hardware incorporating identified process enhancements for further leakage reduction
- Subject functional hardware to full battery of reliability and radiation testing
- QML qualify the RHAX process technology
- Begin full RHAX250-S wafer production to supply Actel
- Port additional Actel RTAX FPGA designs onto rad hard process technology at BAE to extend rad hard offerings.

Summary

- BAE and Actel are continuing their >12 year collaboration as rad hard FPGA suppliers.
- Next generation rad hard product is being built and tested.
- Total dose test results on RHAX250-S hardware demonstrates improved hardness over RTAX250-S.
- Single-event effects test results on AX250 demonstrates product design's high tolerance.
- Electrical, radiation, and reliability testing is on-going.
- Full flight-qualified production in progress for ONO technology and projected to start M2M technologies in early 2009

Acknowledgements

The authors gratefully acknowledge the support for this effort provided by the Defense Threat Reduction Agency under contract DTRA01-03-D-0007 / 0004.

BAE SYSTEMS

BAE SYSTEMS

Actel