The View from 10,000 ft – what is happening and what it means for flight electronics

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Outline

- What’s New with Electronics
- What’s Unique About Space and Electronics
- How is NEPP Approaching the Problem

Atomic Interactions
  - Direct Ionization

Interaction with Nucleus
  - Indirect Ionization
  - Nucleus is Displaced

The Amazing Progression of the Integrated Circuit (IC)

• We have been eyewitnesses to the revolution that’s taken place in the semiconductor industry
  – What was once inconceivable is now the ordinary
• Several factors have been at the forefront of this movement
  – Integration
    • Increasing functionality in decreased space
  – Material science
    • Using science to modify the silicon transistor and it’s package

Note: this talk has a bit more radiation focus than reliability due to my background
The Growth in IC Availability

- The semiconductor industry has seen an explosion in the types and complexity of devices that are available over the last several decades
  - The commercial market drives features
    - High density (memories)
    - High performance (processors)
    - Upgrade capability and time-to-market (FPGAs)
    - Wireless (RF and mixed signal)
    - Long battery life (Low-power CMOS)

Zilog Z80 Processor
circa 1978
8-bit processor

Intel 65nm Dual Core Pentium D Processor
circa 2007
Dual 64-bit processors

Integrated Cycling Bib
and MP3
Types of Electronic Parts for Space

- One may view electronic parts for space as meeting needs in three categories
  - **Standard electronics**
    - E.g., capacitors
      - Basic components
  - **Standard building blocks**
    - E.g., Field Programmable Gate Arrays (FPGAs)
      - Widespread usage in most systems
  - **Custom devices not available as “off-the-shelf”**
    - E.g., nuclear power or EVA
      - Needed for a specific application - ASIC
- **Note:** Commercial-of-the-shelf (COTS) assemblies (e.g., commercial electronic cards or instruments) also may be considered
  - Screening is more complicated than ever before!

ACTEL RTSX72S FPGA

A part that passed “standard” qualification, but requires more complex testing
A Critical Juncture for Space Usage – Commercial Changes in the Electronics World

• **Scaling of technology**
  - Increased gate/cell density per unit area (as well as power and thermal densities)
  - Changes in power supply and logic voltages (<1V)
    - **Reduced electrical margins within a single IC**
      - Increased device complexity, # of gates, and hidden features
      - Speeds to >> GHz (CMOS, SiGe, InP…)
  - Changes in materials
    - Use of antifuse structures, phase-change materials, alternative K dielectrics, Cu interconnects (previous – Al), insulating substrates, ultra-thin oxides, etc…

• **Increased input/output (I/O) in packaging**
  - Use of flip-chip, area array packages, etc

• **Increased importance of application specific usage to reliability/radiation performance**

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The Changes in Device Technology

- Besides increased availability, many changes have taken place in
  - Base technology,
  - Device features, and,
  - Packaging
- The table below highlights a few selected changes

<table>
<thead>
<tr>
<th>Feature</th>
<th>circa 1990</th>
<th>circa 2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base technology</td>
<td>bulk CMOS/NMOS</td>
<td>CMOS with strained Si or SOI</td>
</tr>
<tr>
<td>Feature size</td>
<td>&gt; 2.0 um</td>
<td>65 nm</td>
</tr>
<tr>
<td>Memory size - volatile (device)</td>
<td>256 kb</td>
<td>1 Gb</td>
</tr>
<tr>
<td>Processor speed</td>
<td>64 MHz</td>
<td>&gt; 3 GHz</td>
</tr>
<tr>
<td>FPGA Gates</td>
<td>2k</td>
<td>&gt; 1M</td>
</tr>
<tr>
<td>Package</td>
<td>DIP or LCC - 40 pins</td>
<td>FCBGA - 1500 balls</td>
</tr>
<tr>
<td>Advanced system on a chip (SOC)</td>
<td>Cache memory</td>
<td>&gt;Gbps Serial Link, Serdes,</td>
</tr>
<tr>
<td>features</td>
<td></td>
<td>embedded processors,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>embedded memory</td>
</tr>
</tbody>
</table>
Are you prepared for what lurks below 130nm?
What is a Scaled CMOS anyway?

- It’s all about transistors and sizing (known as gate or channel lengths) and the desire to pack as many transistors on a chip as possible
  - Transistor node space is now commercially at 32nm (and 25nm is sampling!)
Package Complexity - Evolution

Dual in-line Package (DIP)
- 10’s of pins
- Wirebonded, through hole

Quad Flatpack (QFP)
- 100’s of pins
- Wirebonded, surface mount

Area Array Package
- 1000’s of pins
- Bump bonded, surface mount or columns added

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The Challenge for Selecting ICs for Space

- Considerations since the “old days”
  - High reliability (and radiation tolerant) devices
    - Now a very small market percentage
  - Commercial “upscreening”
    - Increasing in importance
    - Measures reliability, does not enhance
  - System level performance and risk
    - Hardened “systems” not devices

System Designer

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Trying to meet high-resolution instrument requirements AND long-life in a space environment
Microelectronics: Categories

- Microelectronics can be viewed several ways
  - Digital, analog, mixed signal, other
  - Complementary Metal Oxide Semiconductor (CMOS), Bipolar, etc...
  - Function (microprocessor, memory, …)

- There are only two commercial foundries (where they build devices) in the US dedicated to building radiation hardened digital devices. Several others have “foundryless” options.
  - Efforts within DoD to provide alternate means of developing hardened devices
    - Hardened-by-design (HBD)
    - Provides path for custom devices, but not necessarily off-the-shelf devices
  - Commercial devices can have great variance in radiation tolerance from device-to-device and even on multiple samples of same device
    - No guarantees!
  - Analog foundry situation is even worse

- New technologies have many unknowns
  - Ultra-high speed, nanotechnologies, microelectromechanical systems (MEMS and the optical versions – MOEMS), …
### NEPP: If we used strictly commercial parts

<table>
<thead>
<tr>
<th></th>
<th>Terrestrial</th>
<th>Space</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lifetime</strong></td>
<td>1-3 years, then replaced or thrown out</td>
<td>1-20 years and rarely replaceable</td>
</tr>
<tr>
<td><strong>Thermal</strong></td>
<td>0-70°C</td>
<td>-55 to +125°C with extremes much higher and lower</td>
</tr>
<tr>
<td><strong>Shock</strong></td>
<td>Oops! I dropped it. Time to get an upgrade anyway…</td>
<td>Launch vibration</td>
</tr>
<tr>
<td><strong>Anomaly</strong></td>
<td>Reboot or power cycle or return to dealer</td>
<td>Anomaly or failure</td>
</tr>
<tr>
<td><strong>Radiation</strong></td>
<td>Is the microwave on?</td>
<td>Protons, electrons, cosmic rays, …</td>
</tr>
</tbody>
</table>

- NEPP is the only entity at NASA that
  - Trains young engineers in the difference and provides a growth path for developing project parts and radiation engineers
  - Develops and validates qualification methods
  - Provides knowledge that allows insertion of modern devices into our space systems
  - Shares and gathers knowledge with all the industry

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Space Environments and Related Effects

Plasma

Particle radiation

Neutral gas particles

Ultraviolet & X-ray

Micro-meteoroids & orbital debris

Charging

Ionizing & Non-Ionizing Dose

Single Event Effects

Drag

Surface Erosion

Impacts

- Degradation of micro-electronics
- Degradation of optical components
- Degradation of solar cells
- Data corruption
- Noise on Images
- System shutdowns
- Circuit damage
- Torques
- Orbital decay
- Degradation of structural integrity
- Structural damage
- Decompression

Space Radiation Effects

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Space Radiation Environment

Deep-space missions may also see: neutrons from background or radioisotope thermal generators (RTGs) or other nuclear source. Atmosphere and terrestrial may see GCR and secondaries.
Implications for Electronics in Space

• With all these changes in the semiconductor world, what are the implications for usage in space? Implications for test, usage, qualification and more
  - Speed, power, thermal, packaging, geometry, materials, and fault/failure isolation are just a few for emerging challenges for radiation test and modeling.
    • Reliability challenges are equally as great
  - The following chart (courtesy of Vanderbilt University) looks at some of the recent examples of test data that imply shortfalls in existing radiation performance models.
    • Technology assumptions in standard tools such as CREME96 are no longer valid

Typical device cross-section. Current generations of digital devices take over 1500 processing steps.

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Sample Radiation Modeling Shortfalls

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Where we are –
Radiation test methods and what has changed in the world

• Existing test methods
  – SEE
    • JEDEC JSD 57
    • ASTM, F1192-00
  – TID
    • MIL-STD-883B, Test Method 1019.8
    • ASTM, F1892-06
• All had prime development in the mid-90s with some updates since, however, many new issues have been discovered that may not be covered adequately

• Examples: Recent SEE Phenomena
  – Angular effects in SOI technologies
  – Role of single event transients (SETs) and commensurate speed-related issues in both analog and digital circuits
  – Ion penetration and range issues in power and packaged components
  – Approaches to die access
  – Impact of application and reconfigurable approaches to SEE performance
  – Role of nuclear reactions from heavy ion particle interactions

Reliability testing has had commensurate complications

Courtesy ISDE, Vanderbilt University
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### Hypothetical New Technology Part Qualification Cost Circa 2008

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parts Procurement (500-1000 devices for testing only)</td>
<td>$25-1000K</td>
<td>Individual device costs can run from cents to tens of thousands</td>
</tr>
<tr>
<td>“Standard” Qualification Tests</td>
<td>$300K</td>
<td></td>
</tr>
<tr>
<td>Radiation Tests and Modeling</td>
<td>$400K</td>
<td>Assumes total dose and single event (heavy ion) only</td>
</tr>
<tr>
<td>Failure Modes Analysis</td>
<td>$300K</td>
<td>Out-of-the-box look at the “hows and whats” for non-standard research required for qualification</td>
</tr>
<tr>
<td>Additional Tests, Modeling, and Analysis based on Failure Modes</td>
<td>$500K</td>
<td></td>
</tr>
<tr>
<td>Total cost for one device type</td>
<td>$1.5-3M</td>
<td>Not all new technologies will meet standard qualification levels: technology limitations document</td>
</tr>
</tbody>
</table>

Assumption: 12-24 months to develop sufficient data for technology confidence
Device Complexity Drives Cost and Schedule!
- Ex., Standard Memory

<table>
<thead>
<tr>
<th>1996 SEE Test of a 4M SRAM</th>
<th>2006 SEE Test of SDRAM</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Description</strong></td>
<td><strong>Description</strong></td>
</tr>
<tr>
<td>Man-weeks or units</td>
<td>Cost in $</td>
</tr>
<tr>
<td>Heavy Ion at BNL SEUTF</td>
<td>Includes eng, rad, other to define what needs to go into test set with project.</td>
</tr>
<tr>
<td>Test plan</td>
<td>0.20</td>
</tr>
<tr>
<td>Device procurements</td>
<td>10.00</td>
</tr>
<tr>
<td>Misc parts</td>
<td>1.00</td>
</tr>
<tr>
<td>Device delidding</td>
<td>0.05</td>
</tr>
<tr>
<td>Test board design - electrical and layout</td>
<td>0.40</td>
</tr>
<tr>
<td>Board fab and population</td>
<td>1.00</td>
</tr>
<tr>
<td>Board/tester debug</td>
<td>0.50</td>
</tr>
<tr>
<td>Rad expert (test oversight and plan)</td>
<td>0.40</td>
</tr>
<tr>
<td>Heavy ion test performance - contractor</td>
<td>2.00</td>
</tr>
<tr>
<td>BNL Beam</td>
<td>6.00</td>
</tr>
<tr>
<td>Data analysis</td>
<td>1.00</td>
</tr>
<tr>
<td>Test report (eng, rad expert, rad lead)</td>
<td>0.50</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td><strong>Total:</strong></td>
</tr>
<tr>
<td></td>
<td>$23,525.00</td>
</tr>
</tbody>
</table>

1996 vs 2006 a **3X Cost Delta**

Other test costs (radiation and reliability) have increased commensurately with ~3X schedule increase as well! **Now >> $100K**

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NEPP Mission

- To provide guidance to NASA:
  - Selection and application of microelectronics technologies
  - Improved understanding of risks related to the use of these technologies in the space environment
  - Appropriate evaluations to meet NASA mission assurance needs for electronic systems

- NEPP evaluates new* and emerging** electronic parts technologies and provides assurance support for technologies in current use in NASA spaceflight systems

*New – Recently marketed, commercially available
**Emerging – Available in limited quantities for evaluation, on path to commercial products
NEPP Overview

• NEPP supports all of NASA for >20 years
  – 7 NASA Centers and JPL actively participate
• The NEPP Program focuses on the reliability aspects of electronic devices
  – Three prime technical areas: *Parts (die), Packaging, and Radiation*
• Alternately, reliability may be viewed as:
  – Lifetime, inherent failure and design issues related to the electronic parts technology and packaging,
  – Effects of space radiation and the space environment on these technologies, and
  – Creation and maintenance of the assurance support infrastructure required for mission success.

*Electrical overstress failure in a commercial electronic device*

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NEPP Works Two Sides of the Equation

• Assurance
  – *Issues that are applicable to space systems being designed and built (i.e., currently available technologies)*
  – Examples
    • Cracked capacitors
    • DC-DC converter reliability
    • Enhanced Low Dose Rate Sensitivity (ELDRS)
  – Communication infrastructure via website and working groups
    • NASA Electronic Parts Assurance Group (NEPAG)
  – Audit and review support

• New electronics technology
  – *Issues that are applicable to the next generation of space systems in conceptualization or preliminary design*
  – Examples
    • 45-90 nm CMOS
    • SiGe
    • State-of-the-art FPGAs
  – Collaboration with manufacturers and government programs for test, evaluation, and modeling
  – Development of new predictive performance tools
Typical Spacecraft Electrical Architecture

- **C&DH**: Command and Data Handling
- **GN&C**: Guidance, Navigation, and Control
- **Propulsion**: Propulsion System
- **Thermal**: Thermal System
- **Power**: Power System
- **Power Bus (ses)**: Power Bus System
- **Instruments/Payload**: Instruments and Payload System
- **RF to/from Ground or other spacecraft**: Radio Frequency communication
- **Ground Antenna**: Antenna for communication with ground

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Typical Spacecraft Electrical Architecture

The 90/90 Goal

Sample NEPP Technology Areas
- Memories
- FPGAs
- Capacitors
- SiGe
- Power devices

90% of NEPP efforts should support 90% of NASA flight missions

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Typical Spacecraft Electrical Architecture

The 90/90 Goal - Example

Sample NEPP Technology Areas

Memories

Used in any processing application and for data storage on a spacecraft.

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NEPP Has a Wide Range of Efforts

- Tasks vary extensively in the technologies of interest
  - Building blocks like capacitors
  - Standard products like DC-DC Converters, linear bipolar devices, and A-to-D Converters
  - New commercial devices such as FPGAs and memories
  - Test structures on emerging commercial or radiation hardened technologies
  - Specialized electronics such as IR arrays and fiber optics
  - New assurance methods and investigations

- NEPP ETW provides forum to present recent results, as well as current and future plans

- Currently in FY11 planning cycle
  - PRELIMINARY PLANS FOLLOW

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NASA Electronic Parts Assurance Group (NEPAG)

Core Areas are Bubbles; Boxes underneath are elements in each core

NEPAG Focus Areas

- Failure Investigations
  - Investigate
  - Assess NASA Impact
  - Test/Analyze
  - Corrective Action
  - Lessons Learned

- Specs and Standards
  - US MIL
  - VCS

- Audits
  - US MIL

- Collaborations
  - National
    - International
  - Offshore
  - Onshore
  - NASA SAS Database

- Parts Support
  - NPSL
    - Technical Expertise Resource
    - Bulletins
    - Connectors
  - CAVE
    - CALCE

Legend

- DoD and NASA Funded
- NASA-only funded
- Overguide

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FY11 Radiation Plans for NEPP Core (1)

Core Areas are Bubbles, Boxes underneath are variable tasks in each core

NEPP Research Categories – Active Electronics

- SiGe. Mixed Signal
  - SiGe on SOI
  - Scaled SiGe
  - Advanced Data Conversion, Amplifiers, Drivers
  - Architectural comparison
  - Develops students at Georgia Tech, Vanderbilt, Auburn

- Scaled CMOS
  - Commercial Devices
    - Memories – Non-volatile, volatile
    - FPGAs
    - Processors, SOCs
    - Structured ASICs
  - Test Structures
    - Silicon on Insulator (SOI)
    - Ultra-low power
    - 32 and 45 nm
    - CNTs
    - RHBD Support
  - Partners include: AFRL, Cypress, Ball, DoD, IBM, TI, Intel, Boeing, Actel, Atmel, Xilinx, Altera, Cypress

- Sensor Technologies
  - IR
  - Visible
  - Cryo SEL
  - Others

- Photonics
  - Fiber Amplifiers
  - Exotic-doped Fiber components
  - Wavelength Division Multiplexing
  - Free space Optical interconnects
  - Fiber Data Links
  - Optocouplers and PM Optocouplers

- Performance Tools
  - 32 and 45 nm CMOS
  - SiGe
  - Low proton energy
  - Compact model based rate prediction
  - Develops students at Vanderbilt

Legend
- DoD and NASA funded
- NASA-only funded
- Overguide

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FY11 Radiation Plans for NEPP Core (2)

Core Areas are Bubbles; Boxes underneath are variable tasks in each core

NEPP Research Categories – Hardness Assurance

ELDRS Test
- NSC, LT, TI, Intersil, STM Support
- Hydrogen Effects
  - High dose

Temperature Effects
- SEE - Elevated
- TID – Elevated post
- SEE - Cryo
- TID – Elevated during
- Cryo BOK

Power Devices
- SEGR Model/Tool
  - Vendor Eval
  - POLs
  - GaN, SiC
  - High V DC-DC

Combined Effects
- NVMs – Radiation and Reliability
- TID on SEE
- DDD on SEE
- SETs on Reliability
- <90nm Reliability of Irradiated Devices
- Heavy Ion DD of<65nm

Guidelines
- ADC Test
  - Low Proton Energy
- SOC Test Guideline
- NVM Test Guideline
- Standard FPGA Test Method
- SDRAM Test Guideline

Other Overguide Tasks
- Education/training modules
- Microwave Technologies
- Additional SOC Testing

Legend:
- DoD and NASA funded
- NASA-only funded
- Overguide

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FY11 Parts Plans for NEPP Core (1)

Core Areas are **Bubbles**; Boxes underneath are variable tasks in each core

**NEPP Research Categories – Parts Assurance**

- **SiGe. Mixed Signal**
  - Cold temperature effects
  - Scaled SiGe
  - Advanced Data Conversion, Amplifiers, Drivers
  - GaAs, InP, Antemonides

- **Scaled CMOS**
  - Commercial Devices
    - Memories – Non-volatile
      - FPGAs
    - Processors, SOCs
      - Memories - SDRAM
  - Test Structures
    - Silicon on Insulator (SOI)
    - Ultra-low power
    - 32 and 45 nm
    - CNTs
    - Sub 90nm

- **Sensor Technologies**
  - IR
  - Visible
  - ROICs - Cryo
  - Others

- **Photonics**
  - Fiber Amplifiers
  - Exotic-doped Fiber components
  - Wavelength Division Multiplexing
  - Free space Optical interconnects
  - Fiber Data Links
  - Optocouplers and PM Optocouplers

- **Rf Electronics**
  - RF Reliability Guide
    - Advanced RF

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FY11 Parts Plans for NEPP Core (2)

Core Areas are Bubbles; Boxes underneath are variable tasks in each core

NEPP Research Categories – Parts Assurance

Passives
  - Polymer Caps
  - BME Caps
  - Embedded Passives
  - Advanced devices

Temperature Effects
  - Cryo CMOS
  - Mixed Signal - Cryo
  - Extended COTS
  - Hot spot test method
  - Cryo BOK

Power Devices
  - Power Mosfets
  - DC-DC Eval
  - POLs
  - GaN, SiC
  - High V DC-DC

Combined Effects
  - NVMs – Radiation and Reliability
  - TID on SEE
  - DDD on SEE
  - SETs on Reliability
  - <90nm Reliability of Irradiated Devices
  - Heavy Ion DD of<65nm

Guidelines
  - ADC Test
  - Embedded device
  - SOC Test Guideline
  - NVM Test Guideline
  - Standard FPGA Test Method
  - SDRAM Test Guideline

Other Overguide Tasks
  - Education/training modules
  - Microwave Technologies
  - Additional SOC Testing

Legend
  - NASA-only funded
  - Overguide

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Core Element - Packaging

Legend

| NASA-only funded | Overvguide |

Core Areas are Bubbles;
Boxes underneath are variable tasks in each core

NEPP Research Categories – Advanced Packaging

- Area Arrays
  - Ball Grid Arrays
  - Column Grid Arrays
  - Microcoil Spring Array
  - Land Grid Arrays

- Complex Non-Hermetic
  - Area Array
  - MIL Class Y Materials

- Embedded Technologies
  - Actives
  - Passives

- Lead-free
  - Assemblies
  - Tin Whiskers

- Board Installation Damage
  - Cracking
  - Parametric Drift
  - Reverse Polarity

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Samples of NEPP Impact to the Community (1 of 2)

*NASA Flight Projects and some of the related areas that NEPP has provided a knowledge-base that has allowed anomaly/problem resolution*

- **MAP**
  - Single Event Transients (SETs) – anomaly resolution led to NASA alert
- **TERRA**
  - Optocouplers, Solid State Recorders (SSR), High Gain Antenna anomaly
- **AURA**
  - Oscillators
- **AQUA**
  - Interpoint DC-DC converters
- **TRMM, XTE**
  - SSRs, FODBs
- **TOPEX/Poseidon**
  - Optocouplers
- **SeaStar**
  - SSRs
- **Launch Vehicles**
  - Optocouplers
- **Suborbital**
  - Parts screening

- **Hubble Space Telescope**
  - Optocouplers, Capacitors, SSRs, Fiber Optic Data Bus (FODB)
- **Hubble Robotic Servicing**
  - Processors
- **JWST**
  - Detector technologies
- **Cassini**
  - Interpoint DC-DC converters, optocouplers, processors
- **AXAF/Chandra**
  - Optics
- **SWIFT**
  - ACTEL FPGAs
- **MER**
  - ELDRS, Processors, Memories, Packaging
- **ISS**
  - Fiber optics, wire/cable
- **Shuttle**
  - ACTEL FPGAs, capacitors

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Samples of NEPP Impact to the Community (2 of 2)

NEPP has supported DoD and other government anomaly/problem issues, technology developments, as well as joint knowledge-base development that have import to the NASA community.

In addition, NEPP has worked with industry to develop improved products for spaceflight.

- Government partners
  - DoD
    - USD(AT&L)
    - Defense Threat Reduction Agency (DTRA)
    - Air Force Research Laboratory (AFRL)
    - Air Force Space and Missile Command (AFSMC)
    - Missile Defense Agency (MDA)
    - Defense Advanced Research Projects Agency (DARPA)
    - NAVSEA
    - NAVAIR
    - Naval Research Laboratory
    - US Army Strategic and Missile Defense Command (USASMDC)
    - OGA
  - DOE
    - Sandia National Laboratories
    - Lawrence Livermore National Laboratories
    - Brookhaven National Laboratories
  - NSF
    - National Superconducting Cyclotron Laboratory
- Industry partners
  - Actel
  - Lambda/International Rectifier
  - Interpoint
  - Vishay
  - Presidio
  - BAE Systems
  - Honeywell
  - Aeroflex
  - Intersil
  - Xilinx
  - IBM
  - Freescale (formerly Motorola)
  - Cardinal
  - LSI Logic
  - Ball Aerospace
  - Micro RDC, many others
QUESTIONS?