



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

**Kenneth A. LaBel**  
**ken.label@nasa.gov**  
**301-286-9936**

**Co- Manager NEPP Program**

**<http://nepp.nasa.gov>**

*The View from 10,000 Feet presented by Kenneth A. LaBel at NEPP ETW, NASA/GSFC – June 22, 2010*

1

## **Outline**



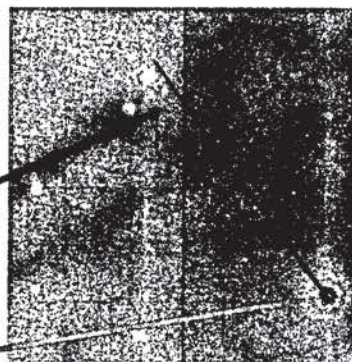
- **What's New with Electronics**
- **What's Unique About Space and Electronics**
- **How is NEPP Approaching the Problem**

### **Atomic Interactions**

- **Direct Ionization**

### **Interaction with Nucleus**

- **Indirect Ionization**
- **Nucleus Is Displaced**



*–<http://www.stsci.edu/hst/mcos/performance/anomalies/buger.html>*

*The View from 10,000 Feet presented by Kenneth A. LaBel at NEPP ETW, NASA/GSFC – June 22, 2010*

2

## 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

Inside Apple's iPhone



Inside a Apple iPhone™ player

*Note: this talk has a bit more radiation focus than reliability due to my background*

*The View from 10,000 Feet presented by Kenneth A. LaBel at NEPP ETW, NASA/GSFC – June 22, 2010*

3

## The Growth in IC Availability



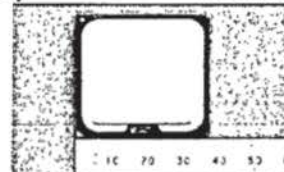
- The semiconductor industry has seen an explosion in the types and complexity of devices that are available over the last several decades
  - The commercial market drives features
    - High density (memories)
    - High performance (processors)
    - Upgrade capability and time-to-market (FPGAs)
 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



Integrated Cycling Bib and MP3



Zilog Z80 Processor  
circa 1978  
8-bit processor



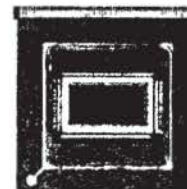
Intel 65nm Dual Core Pentium D Processor  
circa 2007  
Dual 64-bit processors

4

## 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

The View from 10,000 Feet presented by Kenneth A. LaBel at NEPP ETW, NASA/GSFC – June 22, 2010

5

## 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**

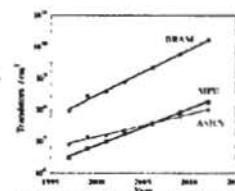
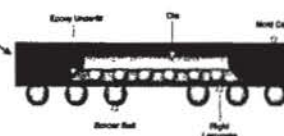


Figure 1. The number of transistors per unit area (per square centimeter) of the technology.



The View from 10,000 Feet presented by Kenneth A. LaBel at NEPP ETW, NASA/GSFC – June 22, 2010

6

## 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

<u>Feature</u>	<u>circa 1990</u>	<u>circa 2007</u>
Base technology	bulk CMOS/NMOS	CMOS with strained Si or SOI
Feature size	> 2.0 $\mu\text{m}$	65 nm
Memory size - volatile (device)	256 kb	1 Gb
Processor speed	64 MHz	> 3 GHz
FPGA Gates	2k	> 1M
Package	DIP or LCC - 40 pins	FCBGA - 1500 balls
Advanced system on a chip (SOC) features	Cache memory	>Gbps Serial Link, Serdes, embedded processors, embedded memory

7

Are you prepared for what lurks below 130nm?



The View from 10,000 Feet presented by Kenneth A. LaBel at NEPP ETW, NASA/GSFC - June 22, 2010

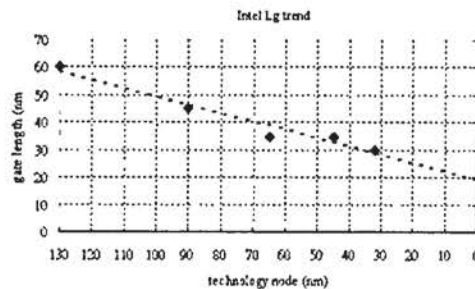
8



## 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!)

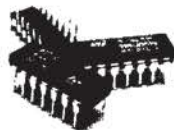


The View from 10,000 Feet presented by Kenneth A. LaBel at NEPP ETW, NASA/GSFC – June 22, 2010

## Package Complexity - Evolution



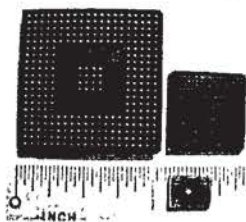
Dual In-line Package (DIP)  
10's of pins  
Wirebonded, through hole



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



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



The View from 10,000 Feet presented by Kenneth A. LaBel at NEPP ETW, NASA/GSFC – June 22, 2010

10

## 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

ADCs?      SerDes?  
SDRAM?  
Processor?      ASICs?  
DSPs  
Flash?      FPGAs?



System Designer

*Trying to meet high-resolution instrument requirements AND long-life in a space environment*

The View from 10,000 Feet presented by Kenneth A. LaBel at NEPP ETW, NASA/GSFC – June 22, 2010

11

## 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), ...

A MOEMS in action



The View from 10,000 Feet presented by Kenneth A. LaBel at NEPP ETW, NASA/GSFC – June 22, 2010

12

## NEPP:

### If we used strictly commercial parts

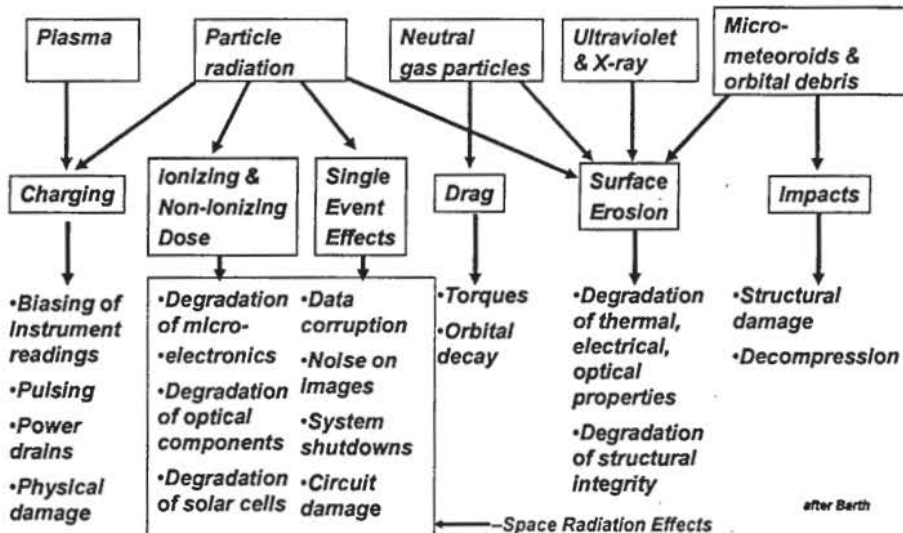
	Terrestrial	Space
Lifetime	1-3 years, then replaced or thrown out	1-20 years and rarely replaceable
Thermal	0-70C	-55 to +125C with extremes much higher and lower
Shock	Oops! I dropped it. Time to get an upgrade anyway...	Launch vibration
Anomaly	Reboot or power cycle or return to dealer	Anomaly or failure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

- 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
    - If the flight projects don't know there's a problem...

The View from 10,000 Feet presented by Kenneth A. LaBel at NEPP ETW, NASA/GSFC - June 22, 2010

13

## Space Environments and Related Effects



The View from 10,000 Feet presented by Kenneth A. LaBel at NEPP ETW, NASA/GSFC - June 22, 2010

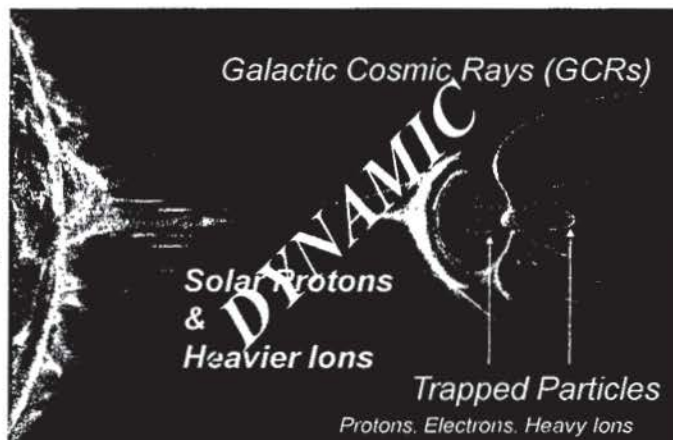
14



# Space Radiation Environment



after  
Nikkei Science, Inc.  
of Japan, by K. Endo



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

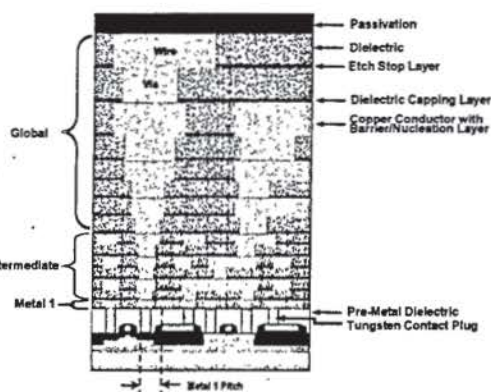
The View from 10,000 Feet presented by Kenneth A. LaBel at NEPP ETW, NASA/GSFC – June 22, 2010

15

## 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.

The View from 10,000 Feet presented by Kenneth A. LaBel at NEPP ETW, NASA/GSFC – June 22, 2010

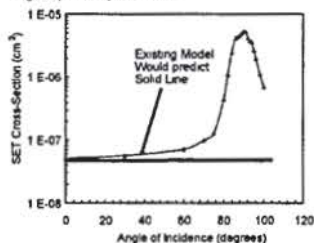
16



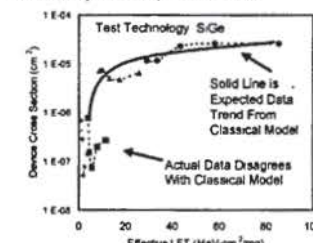
## Sample Radiation Modeling Shortfalls



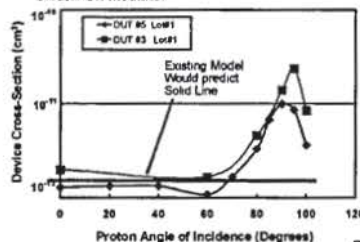
High-Speed Optical Link



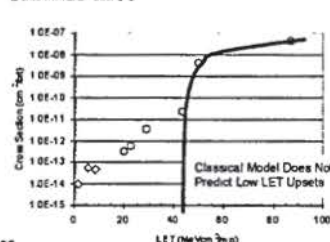
SiGe Heterojunction Bipolar Transistor



Silicon On Insulator



Bulk RHBD CMOS



The View from 10,000 Feet presented by Kenneth A. LaBel at NEPP ETW, NASA/GSFC - June 22, 2010

17

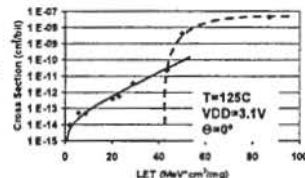
## Where we are –

### 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  
The View from 10,000 Feet presented by Kenneth A. LaBel at NEPP ETW, NASA/GSFC - June 22, 2010

18

## Hypothetical New Technology Part Qualification Cost Circa 2008



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

Assumption: 12-24 months to develop sufficient data for technology confidence

19

## Device Complexity Drives Cost and Schedule! - Ex., Standard Memory



1996 SEE Test of a 4M SRAM

Description	Man-weeks of units	Cost in \$	Total	Note
Heavy ion at BNL, SEUTF				
				Includes eng, rad, other to define what needs to go into test set with project.
Test plan	0.20	\$4,000.00	\$800.00	
Device procurements	10.00	\$50,000.00	\$500.00	
Misc parts	1.00	\$250.00	\$250.00	Sockets, connectors, etc...
Device deidding	0.05	\$3,600.00	\$175.00	
Test board design - electrical and layout	0.40	\$4,000.00	\$1,800.00	
Board fab and population	1.00	\$3,500.00	\$3,500.00	In-house board build
Board tester debug	0.50	\$4,000.00	\$2,000.00	
Rad expert (test oversight and plan)	0.40	\$5,000.00	\$2,000.00	
Heavy ion test performance - contractor	2.00	\$1,500.00	\$3,000.00	
BNL Beam	0.50	\$700.00	\$4,200.00	Simple data: bit flips, latchup
Data analysis	1.00	\$2,000.00	\$2,000.00	
Test report (eng, rad expert, rad lead)	0.50	\$4,000.00	\$2,000.00	

Total: **\$23,525.00**

2008 SEE Test of SDRAM

Description	Man-weeks of units	Cost in \$	Total	Note
Heavy ion at TAMU				
				Includes eng, rad, other to define what needs to go into test set with project.
Test plan	1.00	\$4,000.00	\$4,000.00	
Device procurements	10.00	\$75.00	\$750.00	
Misc parts	1.00	\$1,000.00	\$1,000.00	Higher speed drives cost
				Assumes FBGA package, if this does not work, more expensive test facility like NSCL needed >\$100K data
Device thinning and package processing	10.00	\$350.00	\$3,500.00	
Daughterboard Board design - electrical	0.40	\$4,000.00	\$1,800.00	
Daughterboard Board design - PCB	0.50	\$1,500.00	\$1,750.00	
Test Boards	10.00	\$500.00	\$5,000.00	
Board population	0.40	\$1,500.00	\$1,400.00	
Board tester debug	0.50	\$4,000.00	\$2,000.00	
Tester VIDL development	3.00	\$4,000.00	\$12,000.00	
Technician	1.00	\$2,500.00	\$2,500.00	
Rad expert (test oversight and plan)	0.40	\$5,000.00	\$2,000.00	
Heavy ion test performance - contractor	2.00	\$2,000.00	\$4,000.00	
				2X time required, more data, more error types, more
TAMU	18.00	\$750.00	\$12,000.00	complex results
Data analysis	3.00	\$3,500.00	\$10,500.00	
Test report (eng, rad expert, rad lead)	1.00	\$4,000.00	\$4,000.00	

Total In **\$70,000.00**

1996 vs 2006 a 3X Cost Delta

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

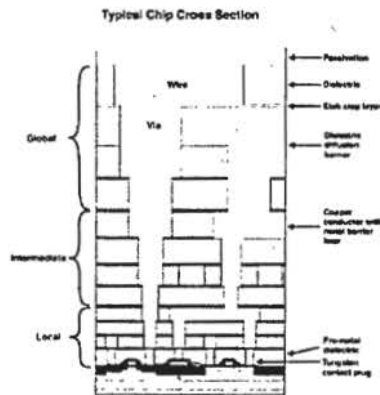
The View from 10,000 Feet presented by Kenneth A. LaBel at NEPP ETW, NASA/GSFC - June 22, 2010

20

## 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

The View from 10,000 Feet presented by Kenneth A. LaBel at NEPP ETW, NASA/GSFC – June 22, 2010

21

## 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*



The View from 10,000 Feet presented by Kenneth A. LaBel at NEPP ETW, NASA/GSFC – June 22, 2010

22



## NEPP Works Two Sides of the Equation

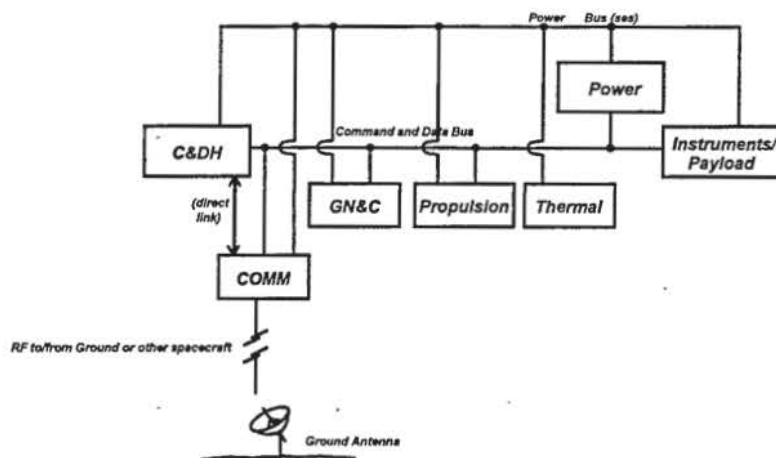


- Assurance
  - Issues that are applicable to space systems being designed and built (i.e., currently available technologies)
  - Examples
    - Cracked capacitors
    - DC-DC converter reliability
    - Enhanced Low Dose Rate Sensitivity (ELDRS)
  - Communication infrastructure via website and working 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

The View from 10,000 Feet presented by Kenneth A. LaBel at NEPP ETW, NASA/GSFC – June 22, 2010

23

## Typical Spacecraft Electrical Architecture



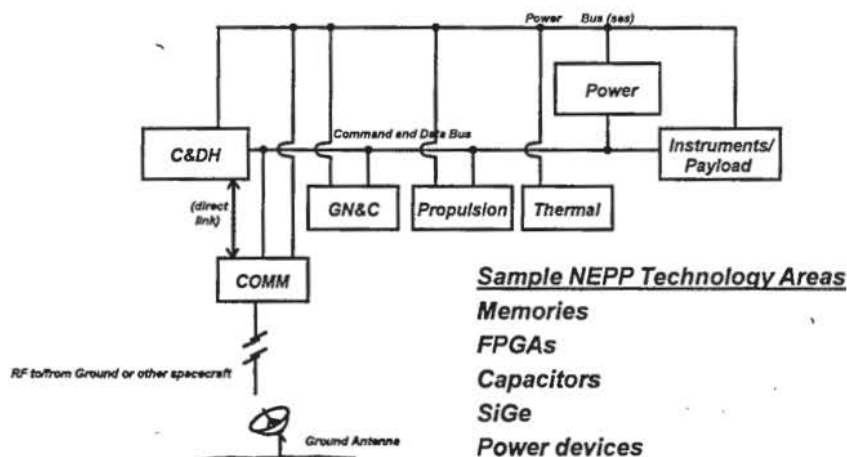
The View from 10,000 Feet presented by Kenneth A. LaBel at NEPP ETW, NASA/GSFC – June 22, 2010

24

## Typical Spacecraft Electrical Architecture



### The 90/90 Goal



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

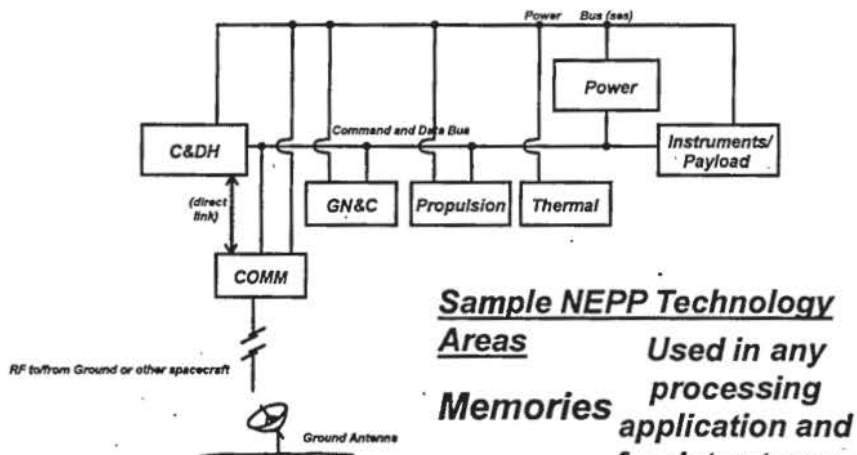
The View from 10,000 Feet presented by Kenneth A. LaBel at NEPP ETW, NASA/GSFC – June 22, 2010

25

## Typical Spacecraft Electrical Architecture



### The 90/90 Goal - Example



The View from 10,000 Feet presented by Kenneth A. LaBel at NEPP ETW, NASA/GSFC – June 22, 2010

26

## 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**

The View from 10,000 Feet presented by Kenneth A. LaBel at NEPP ETW, NASA/GSFC – June 22, 2010

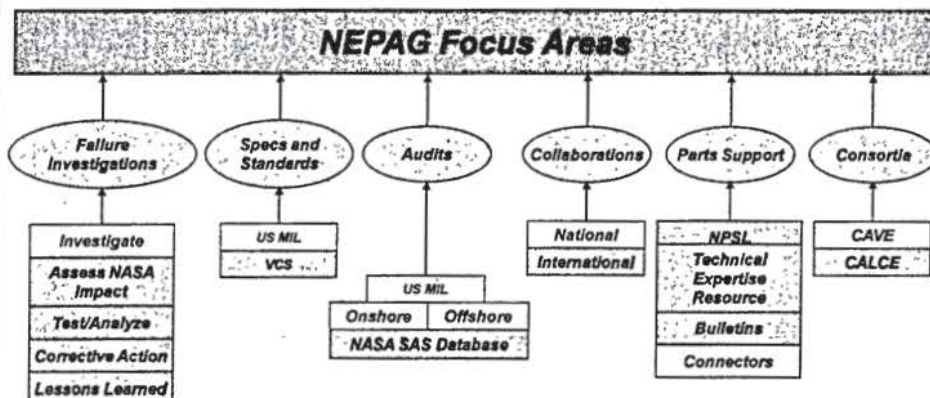
27

## NASA Electronic Parts Assurance Group (NEPAG)



Core Areas are Bubbles  
Boxes underneath are elements in each core

Legend	
DoD and NASA Funded	
NASA-only funded	
Overguide	



The View from 10,000 Feet presented by Kenneth A. LaBel at NEPP ETW, NASA/GSFC – June 22, 2010

28



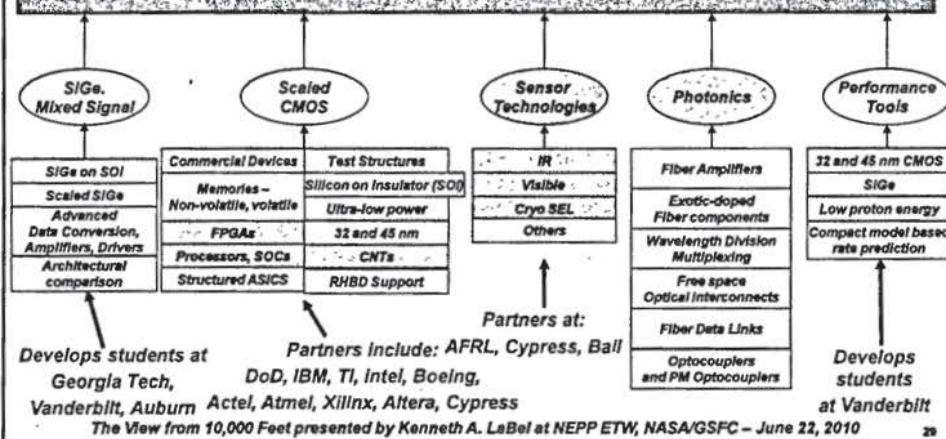
## FY11 Radiation Plans for NEPP Core (1)



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

Legend
DoD and NASA funded
NASA-only funded
Overguide

### NEPP Research Categories -- Active Electronics



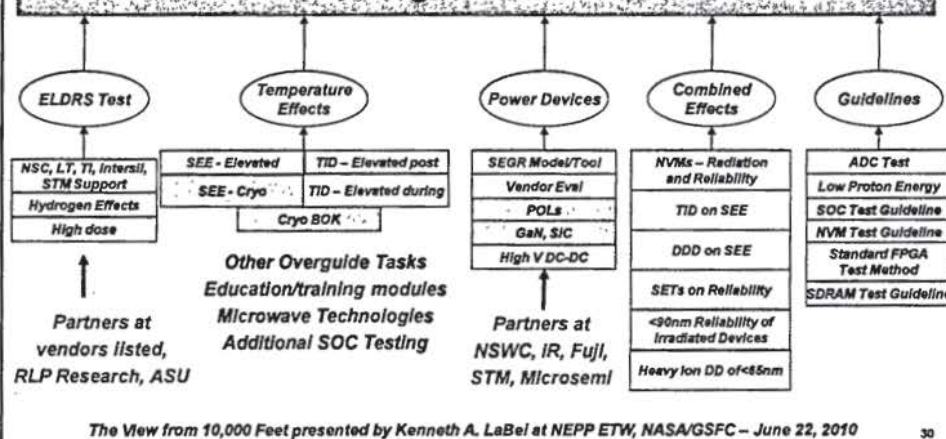
## FY11 Radiation Plans for NEPP Core (2)

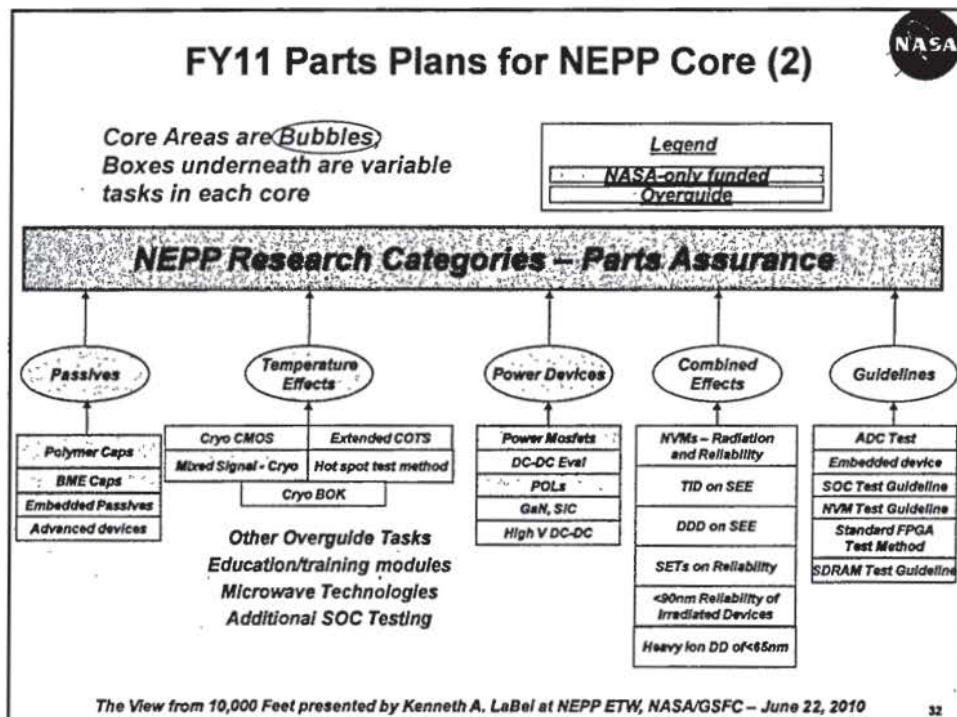
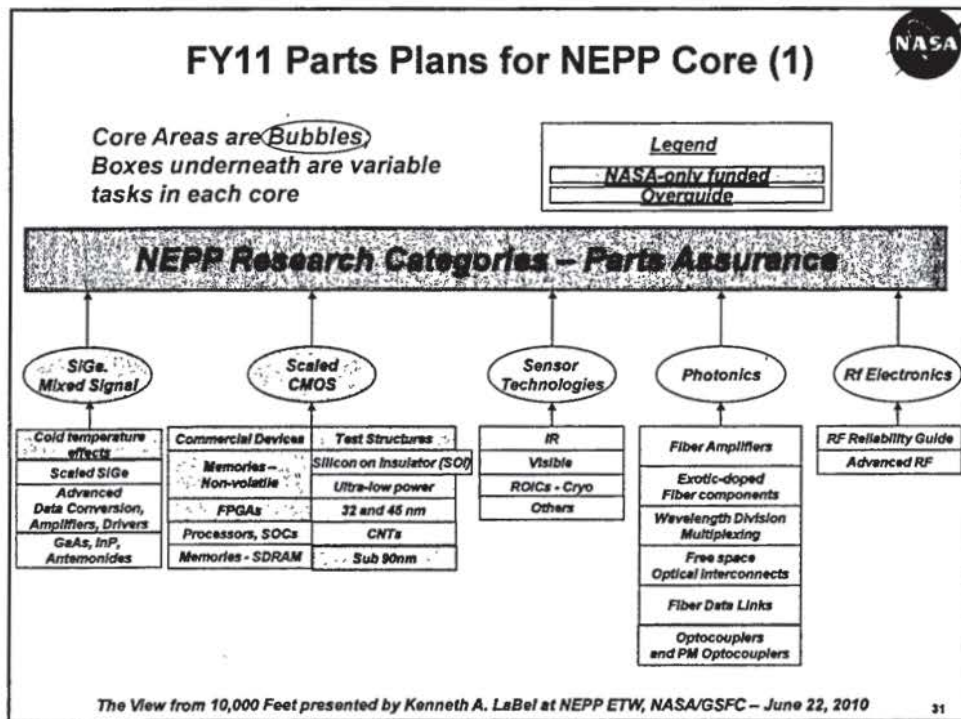


Core Areas are Bubbles  
Boxes underneath are variable  
tasks in each core

Legend
DoD and NASA funded
NASA-only funded
Overguide

### NEPP Research Categories -- Hardness Assurance



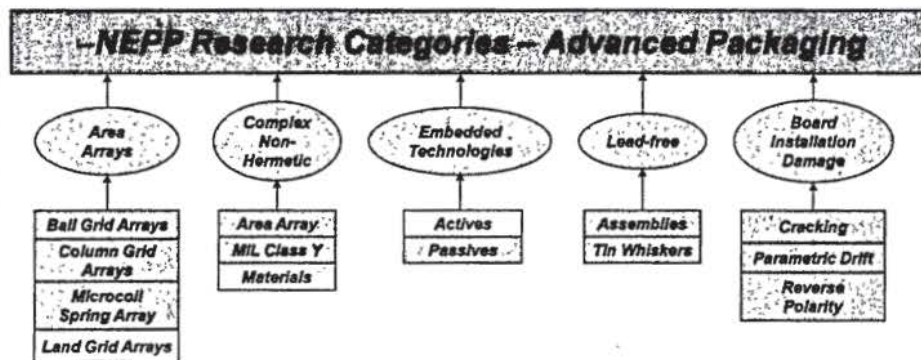


## Core Element - Packaging



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

Legend
NASA-only funded
Overview



The View from 10,000 Feet presented by Kenneth A. LaBel at NEPP ETW, NASA/GSFC - June 22, 2010

33

## 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

The View from 10,000 Feet presented by Kenneth A. LaBel at NEPP ETW, NASA/GSFC - June 22, 2010

34



## 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 (USASDMC)
  - OGA
- DOE
  - Sandia National Laboratories
  - Lawrence Livermore National Laboratories
  - Brookhaven National Laboratories
- NSF
  - National Superconducting Cyclotron Laboratory
- ESA
- JAXA
- CNES

### – 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

The View from 10,000 Feet presented by Kenneth A. LaBel at NEPP ETW, NASA/GSFC – June 22, 2010

35

# QUESTIONS?



The View from 10,000 Feet presented by Kenneth A. LaBel at NEPP ETW, NASA/GSFC – June 22, 2010

36