NEPP Roadmaps, COTS, and Small Missions

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Sundown at SCRIPPS Proton Therapy Center, Ken LaBel

Outline

- NEPP Frame of Reference
- NEPP Tasks and Technology Selection
  - NEPP Technology Criteria
  - Selective Task “Roadmaps” including COTS
  - A Few Other Cool Tasks
- NEPP and Small Missions/Alternate “Assurance” Approaches
- Beyond Today
- Summary

Acronyms

Acronym	Definition
3D	Three Dimensional
ACE	Absolute Contacting Encoder
ADAS	Advanced Driver Assistance Systems
ADC	Analog to Digital Converter
AEC	Automotive Electronics Council
AES	Advanced Encryption Standard
AF	Air Force
AF SMC	Air Force Space and Missile Systems Center
AFRL	Air Force Research Laboratory
AMS	Agile Mixed Signal
ARM	ARM Holdings Public Limited Company
Avalanche STT	Avalanche Technology Spin Transfer Torque
BAE Systems	Marconi Electronic Systems (MES) and British Aerospace (BAe) merged to form BAE Systems
BGA	Ball Grid Array
BOK	Body of Knowledge
CAN	Controller Area Network
CBRAM	Conductive Bridging Random Access Memory
CGA	Column Grid Array
CMOS	Complementary Metal Oxide Semiconductor
CN	Xilinx ceramic flip-chip (CF and CN) packages are ceramic column grid array (CCGA) packages
CN/Kyocera	CN Package assembled at Kyocera
Corp.	Corporation
COTS	Commercial Off The Shelf
CRC	Cyclic Redundancy Check
CU	Control Unit
Cu	Cu alloy
DDR	Double Data Rate (DDR3 = Generation 3; DDR4 = Generation 4)
DMA	Direct Memory Access
DoD	Department of Defense
DSP	Digital Signal Processing
dSPI	Dynamic Signal Processing Instrument
DTRA	Defense Threat Reduction Agency
Dual Ch.	Dual Channel
ECC	Error-Correcting Code
EEE	Electrical, Electronic, and Electromechanical
EMAC	Equipment Monitor And Control
EMIB	Multi-die Interconnect Bridge
ESA	European Space Agency
eTimers	Event Timers
FCCU	Fluidized Catalytic Cracking Unit
FeRAM	Ferroelectric Random Access Memory
FinFET	Fin Field Effect Transistor (the conducting channel is wrapped by a thin silicon "fin")
FPGA	Field Programmable Gate Array
FPU	Floating Point Unit
FY	Fiscal Year
GaN	Gallium Nitride
GAN GIT	Panasonic GaN GIT Eng Prototype Sample

Acronym	Definition
Gb	Gigabyte
GIC	Global Industry Classification
GPU	Graphics Processing Unit
GSFC	Goddard Space Flight Center
GSN	Goal Structured Notation
GTH/GTY	Transceiver Type
HALT	Highly Accelerated Life Test
HAST	Highly Accelerated Stress Test
HBM	High Bandwidth Memory
HDIO	High Density Digital Input/Output
HDR	High-Dynamic-Range
HMC	Hybrid Memory Cube
HP Labs	Hewlett-Packard Laboratories
HPIO	High Performance Input/Output
HPS	High Pressure Sodium
I/O	input/output
I2C	Inter-Integrated Circuit
i2MOS	Microsemi second generation of Rad-Hard MOSFET
IBM/GF	International Business Machines/Global Foundaries
IC	Integrated Circuit
IP	Intellectual Property
JPEG	Joint Photographic Experts Group
KB	Kilobyte
LinFlex	Local Interconnect Network Flexible
L-mem	Long-Memory
LP	Low Power
LVDS	Low-Voltage Differential Signaling
LW HPS	Lightwatt High Pressure Sodium
M/L BIST	Memory/Logic Built-In Self-Test
MBSE	Model-Based Systems Engineering
Mil/Aero	Military/Aerospace
MIPI	Mobile Industry Processor Interface
MMC	MultiMediaCard
MMU	Memory Management Unit
MOSFETs	Metal-Oxide-Semiconductor Field-Effect Transistors
MPFE	Multiport Front-End
MPU	Microprocessor Unit
MRAM	Magnetic Random Access Memory
NASA	National Aeronautics and Space Administration
Navy Crane	Naval Surface Warfare Center, Crane, Indiana
NEPP	NASA Electronic Parts and Packaging
NGSP	Next Generation Space Processor
NOR	Not OR logic gate
NRL	Naval Research Laboratory
NRO	United States Navy National Reconnaissance Office
OCM	on-chip RAM
PBGA	Plastic Ball Grid Array
PCB	Printed Circuit Board
PCIe	Peripheral Component Interconnect Express
PLL	Phase Locked Loop
PoP	Package on Package

Acronym	Definition
PPAP	Production Part Approval Process
Proc.	Processing
PS-GTR	High Speed Bus Interface
QFN	Quad Flat Pack No Lead
QSPI	Serial Quad Input/Output
R&D	Research and Development
R&M	Reliability and Maintainability
ReRAM	Resistive Random Access Memory
RGB	Red, Green, and Blue
RH	Radiation Hardened
SAR	Successive-Approximation-Register
SATA	Serial Advanced Technology Attachment
SCU	Secondary Control Unit
SD	Secure Digital
SD/eMMC	Secure Digital embedded MultiMediaCard
SD-HC	Secure Digital High Capacity
SDIO	Secure Digital Input/Output
SDM	Spatial-Division-Multiplexing
SEE	Single Event Effect
SERDES	Serializer/Deserializer
Si	Silicon
SiC	Silicon Carbide
SK Hynix	SK Hynix Semiconductor Company
SLU	Saint Louis University
SMC	Air Force Space and Missile Systems Center
SOA	Safe Operating Area
SOC	Systems on a Chip
SPI	Serial Peripheral Interface
STT	Avalanche Technology Spin Transfer Torque
STT	Spin Transfer Torque
TBD	To Be Determined
TCM	Trellis Code Modulation
Temp	Temperature
THD+N	Total Harmonic Distortion Plus Noise
T-Sensor	Temperature-Sensor
TSMC	Taiwan Semiconductor Manufacturing Company
UART	Universal Asynchronous Receiver/Transmitter
USB	Universal Serial Bus
VNAND	Vertical NAND
WBG	Wide Band Gap
WDT	Watchdog Timer
WSTS	World Semiconductor Trade Statistics

NEPP - Frame of Reference

- **EEE (electrical, electronic, and electromechanical) parts are:**
  - **All the things that are on printed circuit boards (PCB) inside of electronics boxes.**
- **This includes:**
  - **Integrated Circuits (ICs or chips) like processors and memories as well as passives such as capacitors and resistors,**
  - **Hybrid devices or multi-chip modules: Small packages that house multiple chips internally that are placed on the PCB, and,**
  - **Connectors and wires used to send electrical or power signals between boards, boxes, or systems.**
- **This does not include:**
  - **The PCB - NASA Workmanship Program responsibility.**

PCB from Mars Rover
Image courtesy NASA

Image courtesy BAE Systems

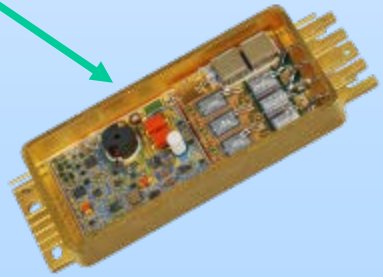
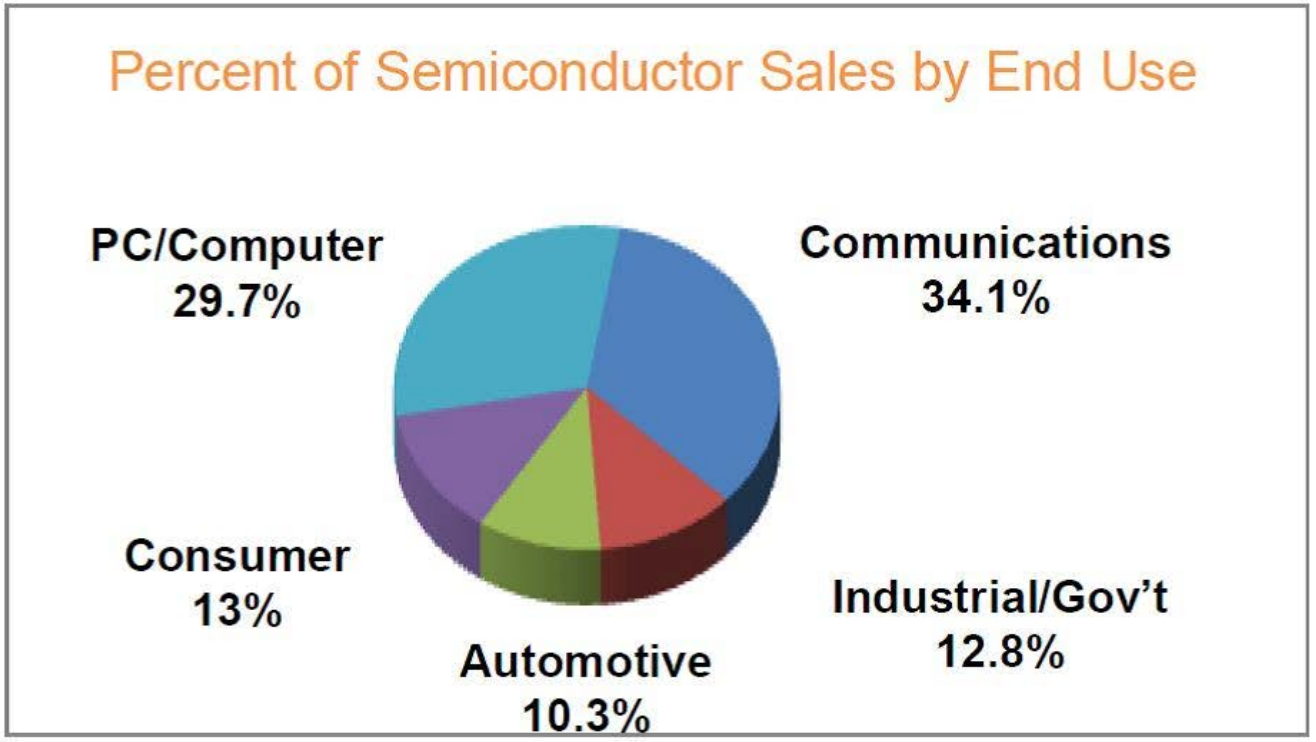


Image courtesy NASA

Motivational Factors

2015 Global Semiconductor Market: $335 Billion



Source: WSTS End Use Report, 2015
Note: Military is <1% and is included in Industrial/Gov't

Military and Aerospace share is estimated at ~$3.1B in 2015. Aerospace is a small percentage of this amount.

In 1975, Military and Aerospace market share was ~$50%!

Conclusion: Mil/Aero community has to leverage.

There's no business model to go it alone!

Technology Selection Criteria for NEPP Investigations

- **The technologies should satisfy all or most of the following criteria:**
  - **Wide applicability,**
  - **Product level or in productization, and,**
  - ***No distinction:*** **COTS to high-reliability aerospace.**
- **In general, we avoid:**
  - **Laboratory technologies, e.g., <TRL3,**
  - **Limited application devices with certain exceptions (critical application or NASA center specialization).**
- **Note: Partnering arrangements with other organizations preferred.**
  - **Industry examples: Microsemi, Xilinx, Altera (Intel), TI**
  - **Other U.S. Government: AF SMC, AFRL, DTRA, Navy Crane, NRO, NRL, etc…**

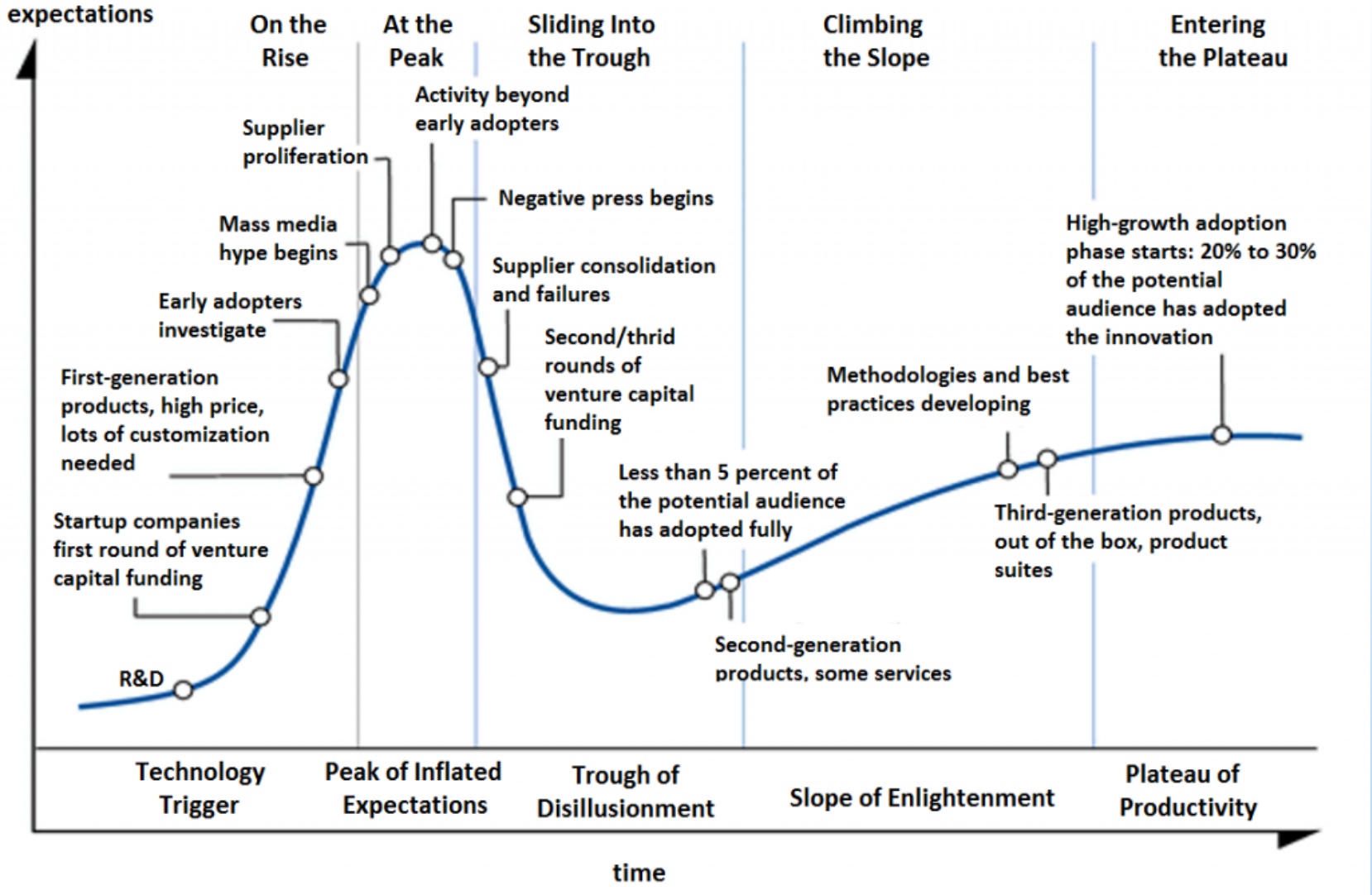
NEPP – Deeper Dive for Tasks

- **NEPP has multiple rationale for evaluating a specific device or technology:**
  - **If the device/technology has the potential for widespread usage across the Agency,**
  - **If the device has true enabling characteristics for next generation mission needs, or,**
  - **As a means of gathering assurance information for future mission insertion or screening/qualification methods.**
- **The following roadmap charts are focused on the advanced power and digital electronics regimes.**
  - **NEPP has efforts not being presented on connectors, capacitors, and other categories.**
    - **Ex. Cu wirebonds is an active future area currently in discussion on tasks.**

Technology Investigations: Sample Roadmaps Discussion

- **Caveats:**
  - ***Guidelines are often a product of technology evaluation tasks.***
  - **Only major product categories shown.**
- **Notes:**
  - **Separate CMOS roadmap not included.**
    - **NEPP leverages samples from ongoing DoD and/or commercial sources.**
    - **1xnm is current target (IBM/GF, INTEL, Samsung, TSMC).**
  - **"Reliability testing" may include product and/or package testing.**
  - **"Body of Knowledge" BOK document provides a snapshot status on a technology (manufacturing, reliability, radiation) and identifies gaps for future work.**
- **Technology areas not on NEPP Roadmap, but under consideration include:**
  - **Electro-optics (fiber optics),**
  - **Advanced analog and mixed-signal devices,**
  - **Imaging sensors,**
  - **Modeling and simulation,**
  - **High-speed communication (SERDES, fast data switches), and,**
  - **Adjunct processors (eg., graphics, signal processing).**

Gartner Hype Cycle Concept



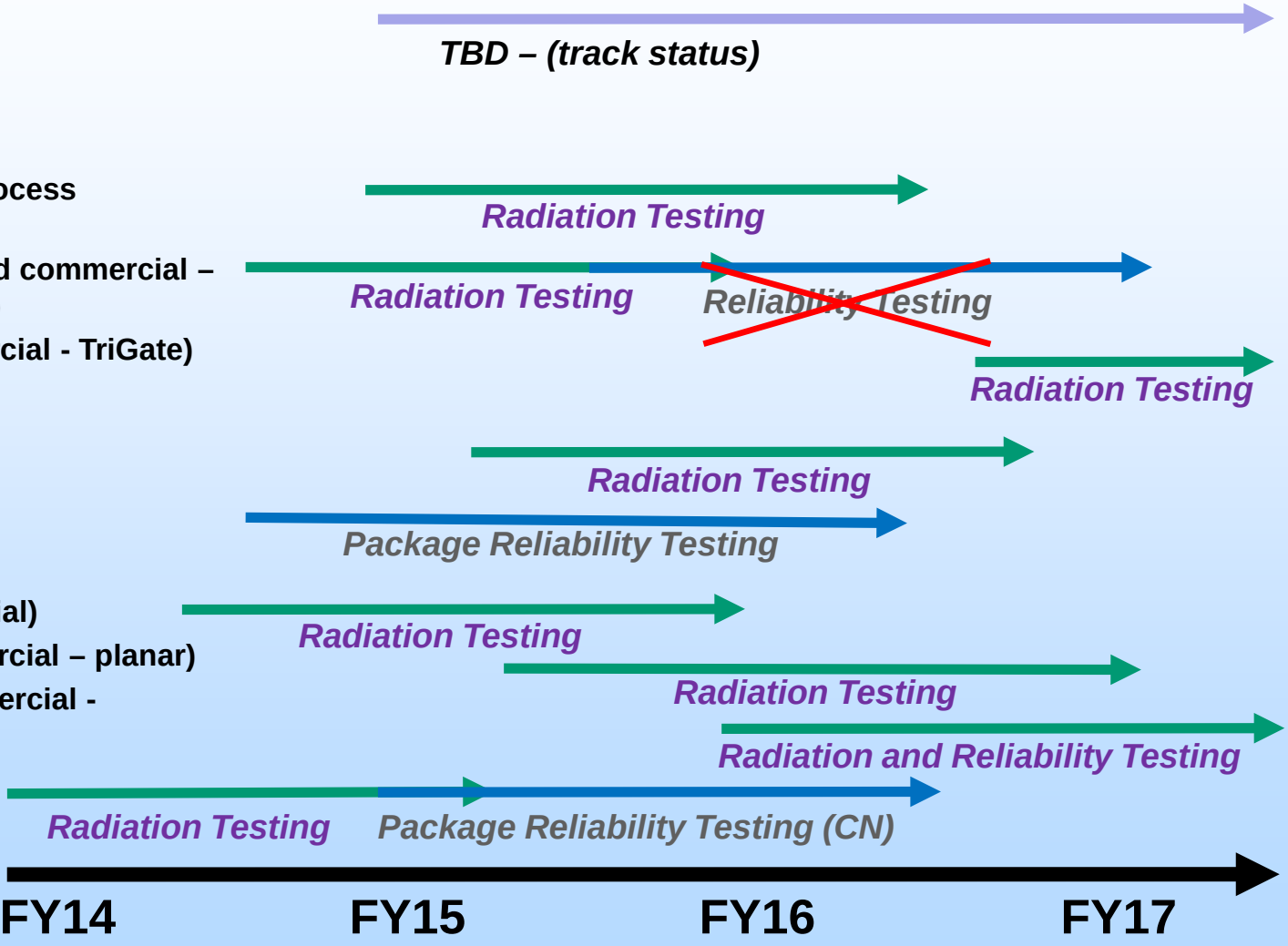
Field Programmable Gate Arrays (FPGAs)

New "Space" FPGAs from the "Agencies"
- DoD-led Trusted FPGA
- ESA "BRAVE" FPGA

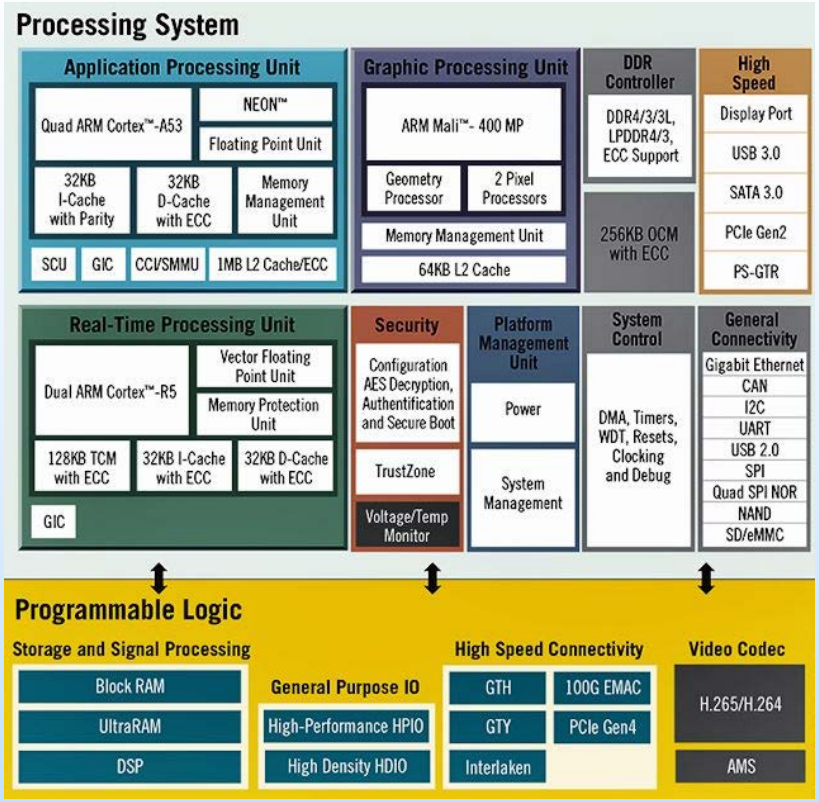
Altera
- Stratix 5 (28nm TSMC process commercial)
- Max 10 (55nm NOR based commercial – small mission candidate)
- Stratix 10 (14nm commercial - TriGate)

Microsemi
- RTG4 (65nm RH)

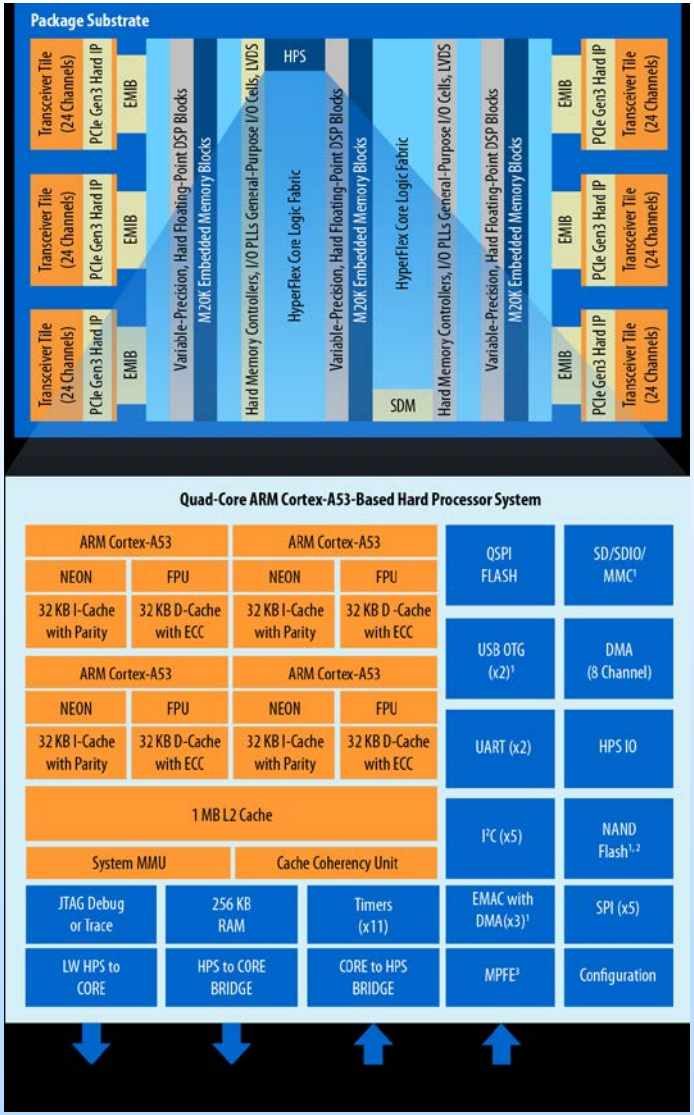
Xilinx
- 7 series (28nm commercial)
- Ultrascale (20nm commercial – planar)
- Ultrascale+ (16nm commercial - vertical)
- Virtex 5QV (65nm RH)



Next Generation “FPGAs”?



From Xilinx.com



From Altera.com

Advanced Processors

Next Generation Space Processor (NGSP)
- **Joint NASA-AFRL Program for RH multi-core processor**

TBD – (track status)

14nm CMOS Processors (w/Navy Crane)
- **Intel 14nm FinFET commercial**
  - **5th and 6th generation**
- **Samsung 14nm LP Snapdragon 820**

Radiation Testing

Radiation Testing

Freescale Processors
- **P2020 Communication Processor (w/Air Force)**
- **P5040 Network Processor**

Radiation Testing

Radiation Testing

RH Processor
- **BAE Systems RAD5510/5545**
  - **Leverages P5040 architecture**

Radiation Testing

Microcontrollers and Mobile Processors (Small Missions)

Radiation Testing

FY14 FY15 FY16 FY17

Note: Future considerations include adding Graphics Processing Units (GPUs) to NEPP Roadmap in FY17.

Commercial Memory Technology

- collaborative with Navy Crane

Other
- MRAM (Avalanche STT, other)
- FeRAM

TBD – (track status/test when available)

Resistive
- CBRAM (Adesto)
- ReRAM (Panasonic)
- ReRAM (Tezzaron)
- TBD (HP Labs, others)

Radiation and Reliability Testing

45nm options

Radiation and Reliability Testing

Radiation and Reliability Testing

TBD – (track status)

DDR
- Intelligent Memory (robust cell twinning)
- 1xnm DDR3, DDR4, LP (TBD)

Radiation Testing

Radiation and Reliability Testing

Hybrid or wide I/O
- HMC, HBM, Wide I/O

TBD – (track status or test)

FLASH
- Samsung VNAND (gen 1 and 2)
- Micron 16nm planar
- Micron 3D
- SK Hynix 3D, other commercial

Radiation and Reliability Testing

Radiation and Reliability Testing

Radiation and Reliability Testing

Radiation and Reliability Testing

FY14 **FY15** **FY16** **FY17**

Alternate Grade Electronics: Automotive

- **NEPP has three goals for automotive electronics efforts**
  - **Determine exactly what:"automotive grade" does or does not entail.**
    - **Includes understanding:**
      - **Automotive Electronics Council (AEC) documents, and,**
      - **Manufacturer Production Part Approval Process (PPAP).**
  - **Perform "snapshot" screening and testing on representative automotive grade electronics.**
  - **Explore application of resilient automotive electronics system designs for space purposes.**

Automotive application constraints or standard compliance	To be implemented and managed at different levels			
	Audio IP	SoC	Application firmware/ software	PCB
Noisy ground(s) voltage	Common mode rejection			Passive components' accuracy
Audio perception and spatialization	THD+N, gain mismatch, Pop-up Noise	SoC routing resistance	Processing, starting and stopping sequences	Application Schematics consideration
Security	Primary diagnostic circuitry	Redundant audio interface	audio diagnostic firmware	Protection circuitry
High Temperature operation (AEC-Q100 Grade 0/1 qualification)	High performance at junction Temperature -40 °C to 125 °C	Package thermal dissipation consideration		PCB material and component soldering technology consideration

http://www.design-reuse.com/news_img/20141209_2.jpg

Small Missions/ Automotive

EEE Parts Guidelines

- Small missions (Class D, CubeSat – 2 documents)
- System on a chip (SOC) single event effects (SEE) guideline
- Board-level proton test guideline

Small Mission Commodities

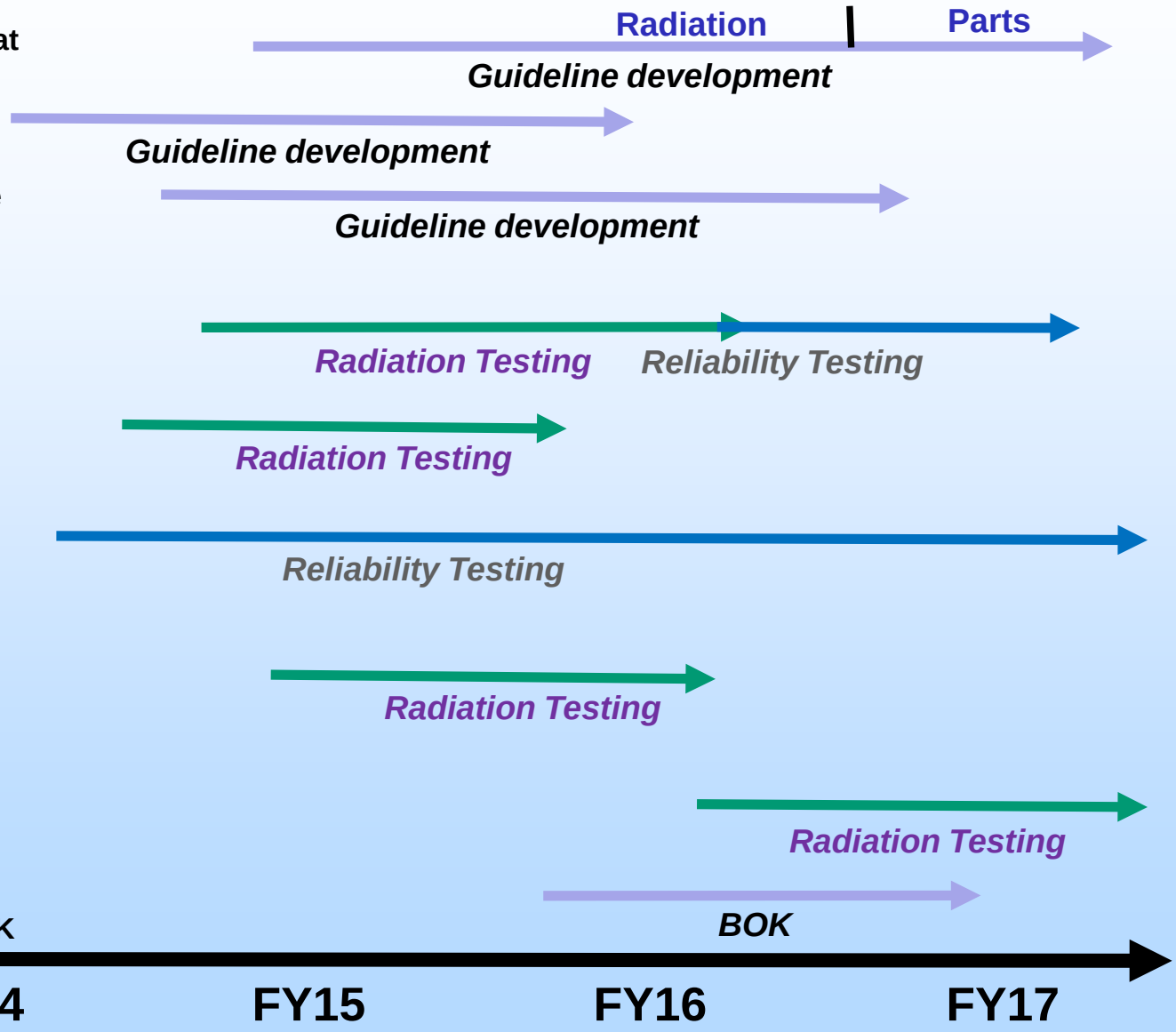
- See commodities roadmaps for processors, memory, FPGAs, power
- CubeSat Star Tracker

Automotive grade electronics

- Multiple classes of electronics (passives, actives, ICs)
  - NASA and Navy Crane
- Freescale MPC56XX

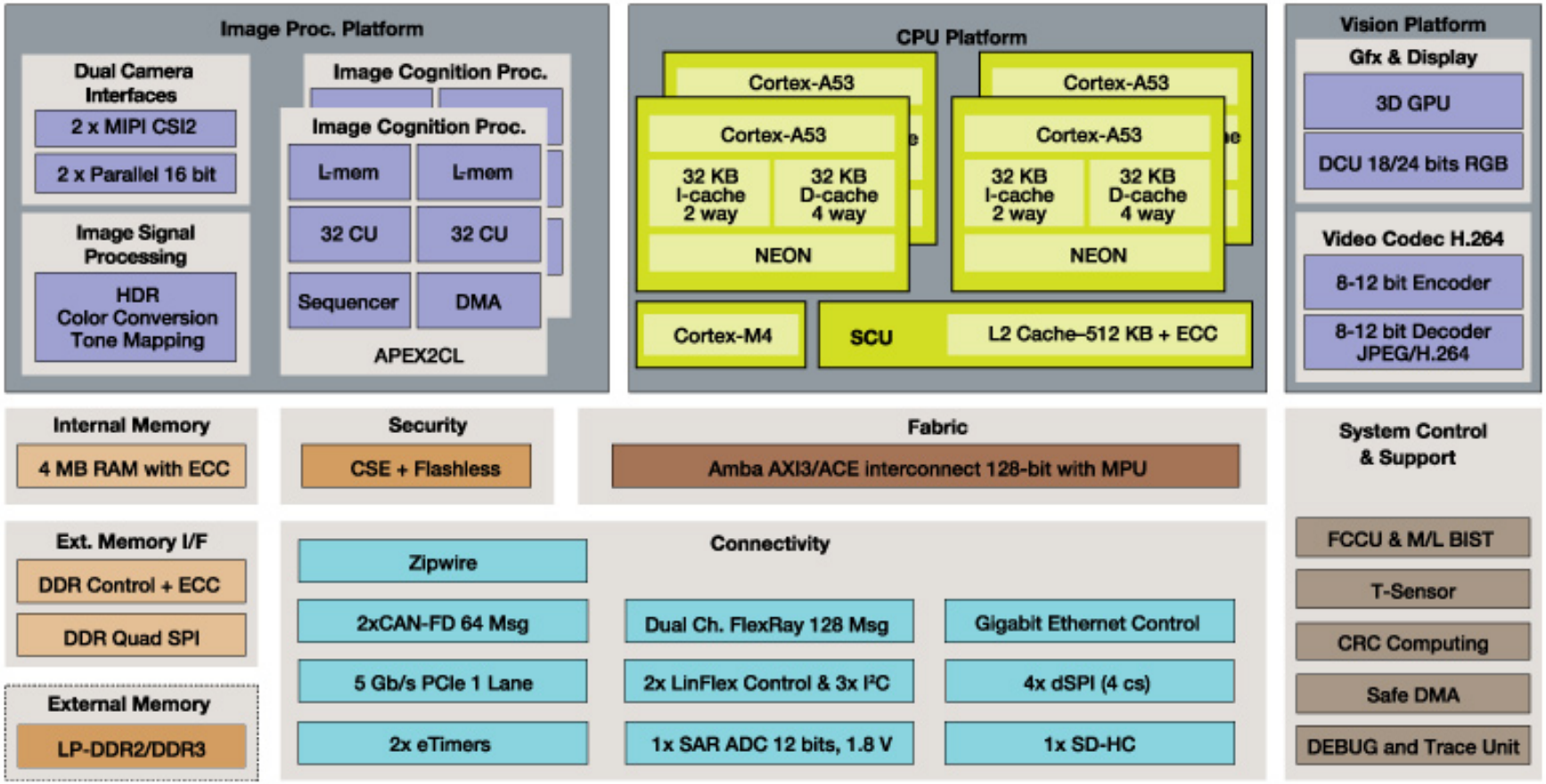
Alternate system tests

- Automotive resilience system tests
- Use of board-level testing for screening and qualification - BOK



Automotive - Advanced Driver Assistance Systems (ADAS) for *Space*?

S32V234 Block Diagram



From Freescale.com

Power and Wide Band Gap (WBG) Devices

Si MOSFETs – Rad Hardened

- Microsemi i2MOS
- Infineon superjunction 100 V, 600 V (target)

Si Schottky Diodes

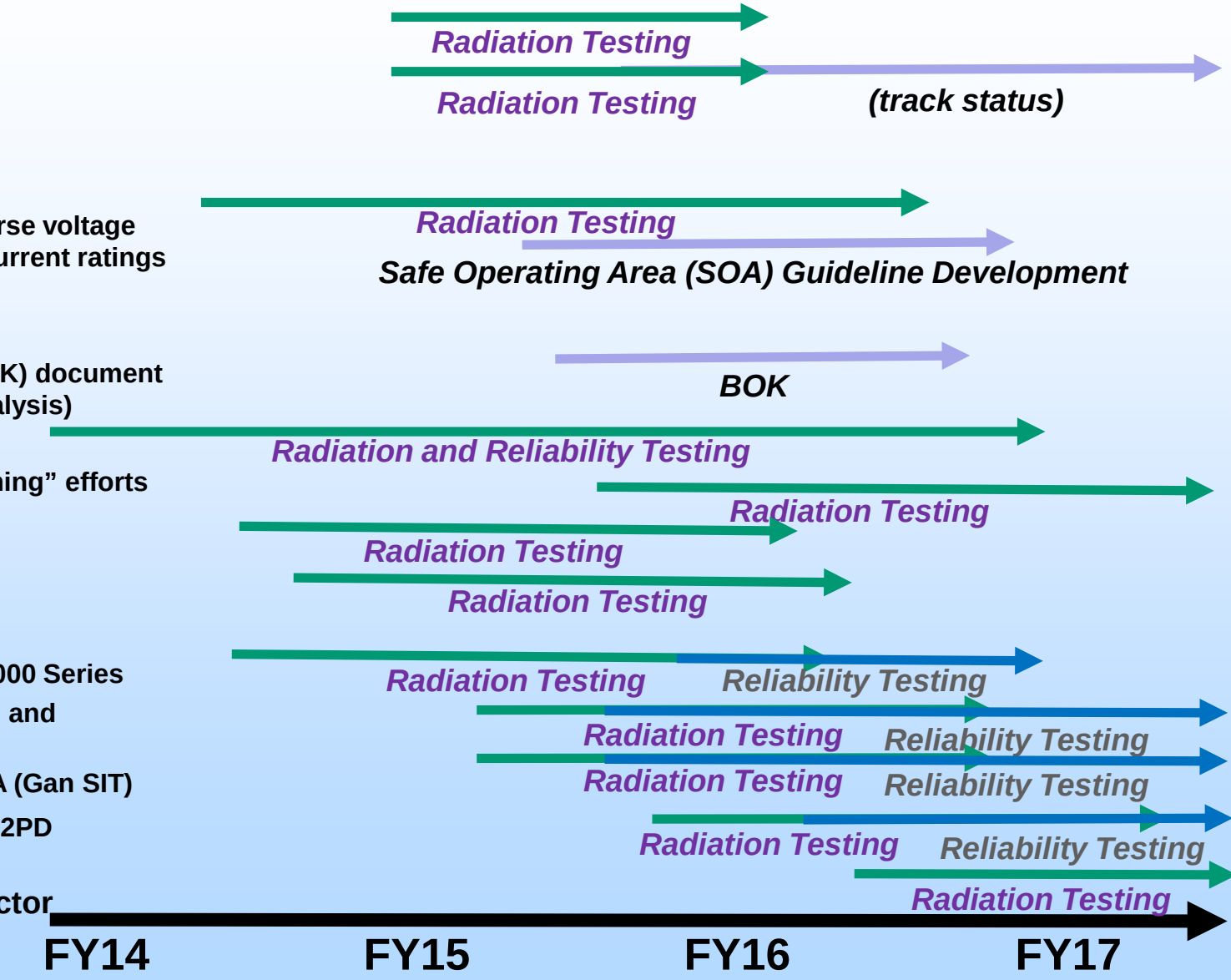
- Multiple vendors, reverse voltage ratings, and forward current ratings

SiC

- Body of Knowledge (BOK) document (knowledge and gap analysis)
- Cree Gen 1-3
- Collaboration w "hardening" efforts
- Baseline diodes
- Logic devices

GaN

- EPC 2012 (Gen3) and 8000 Series
- GaNSystems - GS61008 and GS66508 commercial
- Panasonic PGA26E19BA (Gan SIT)
- Thransphorm TPH3202PD (Cascode)
- Freebird Semiconductor



IC Packaging

High Density, Non-hermetic Column Grid Array (CGA)
- Xilinx CN/Kyocera Daisy Chain
- Microsemi Daisy Chain

HALT Methodology/Qualification
- HALT/HAST comparison
- Plastic BGA matrix

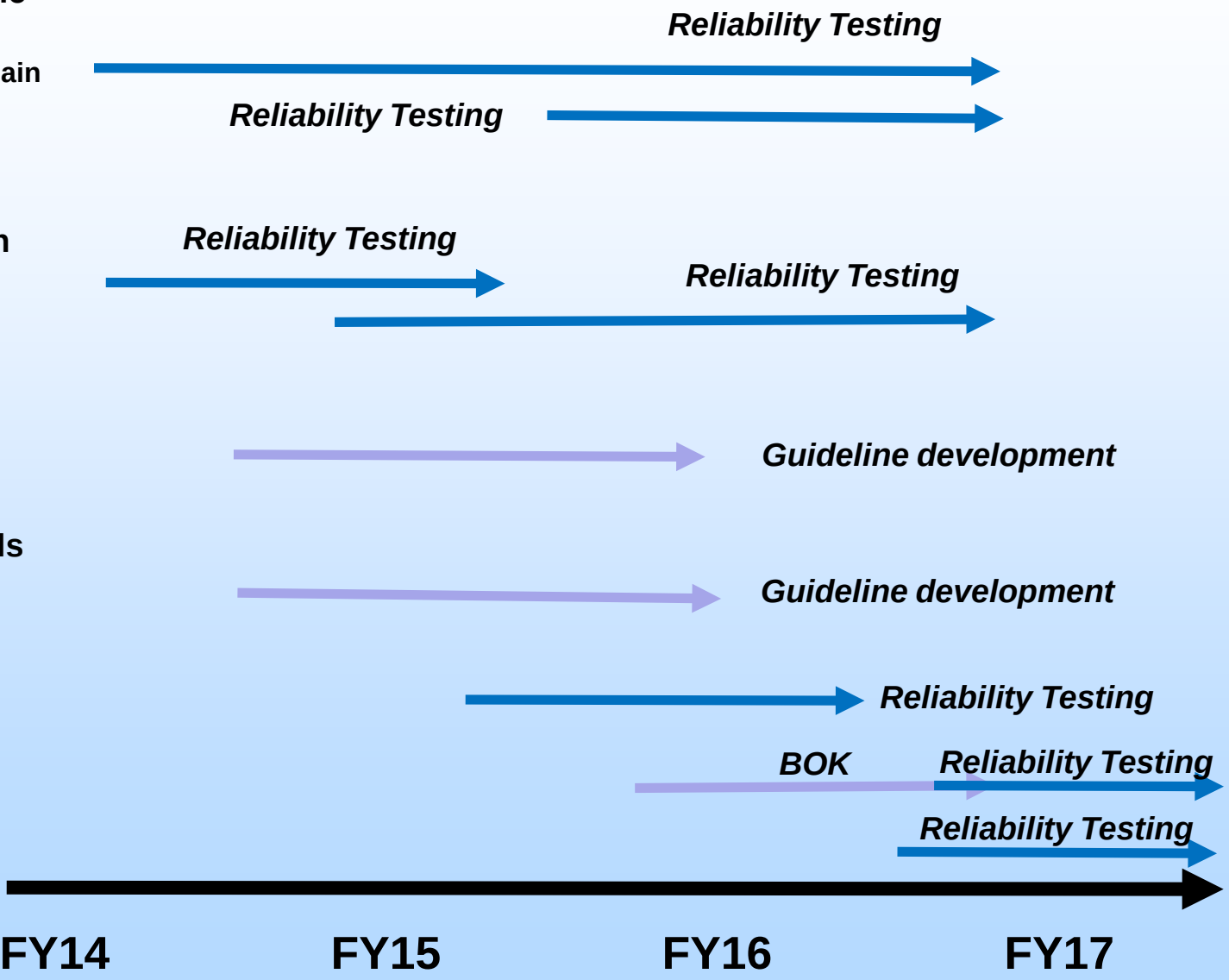
Area Array Column
- Selection guide

Thermal Interface Materials
- Selection guide

PBGA Thermal Cycle Evaluation

2.5/3D Packaging

QFN package reliability



A Few Other Cool Tasks…

- **CubeSat mission success/failure root cause analysis**
  - **Grant to Saint Louis University**
- **Using a model-based systems engineering (MBSE) approach to radiation assurance**
  - **Grant to Vanderbilt**
  - **Co-sponsored by NASA Reliability and Maintainability Program**
  - **Uses a tool called “Goal Structured Notation”**
- **Keeping the CRÈME website alive**
  - **Support to Vanderbilt**
  - **Just standard maintenance and operation, no upgrades**
- **Proton test facilities**
  - **See poster on 6/14.**

Beyond Today – Sample Challenges

- **Complexity and sub-microscopic feature size issues for inspection, screening, device preparation, and test**
  - **2.5/3D Packages/ICs**
  - **Package on Package (PoP) Commercial Devices**
  - **FPGAs combined with an SOC**
  - **Cu Wirebonds**
  - **14 nm and below feature sizes**
  - **ESD susceptibility**
  - **Trust**
- **Assurance**
  - **Automotive and catalog commercial EEE parts?**
  - **Increasing risk with a worldwide supplier base**
    - **Traceability**
    - **Change control**
    - **Screening?**
  - **Consolidation**
    - ***What if the only source left is in an inhospitable or unauditable part of the world?***

NEPP and Small Missions/ Alternate "Assurance" Approaches

- **Sample Current Efforts**
  - **Radiation Hardness Assurance for Small Missions**
  - **Root Cause Analysis and Success Tracking of CubeSats (Prof. Michael Swartwout/SLU) – we're looking for possible low hanging fruit for university-class CubeSats**
  - **Model-Based Missions Assurance for CubeSats:**
    - **1st task is a Goal Structured Notation (GSN) exemplar of a CubeSat board – this is joint with the NASA Reliability and Maintainability (R&M) Program**
  - **Board-level proton test guideline**
  - **Automotive grade EEE parts**
  - **CubeSat parts database – both kit manufacturers and usage within NASA**
  - **Multiple COTS evaluation tasks relevant to CubeSat usage including microcontrollers, memories star trackers, power devices, and FPGAs…**
- **Future considerations**
  - **COTS, COTS, COTS (and alternate grade electronics)**
  - **Continue and extend R&M collaboration (Bayesian methods, anyone?)**
  - **EEE Parts Best Practices for Small Missions**

Summary and Comments

- **NEPP Roadmaps and Tasks are constantly evolving as technology and products become available.**
  - **Like all technology roadmaps, NEPP's is limited to funding and resource availability.**
    - **Many other efforts are not being shown today (60+ tasks total)**
  - **Partnering is the key:**
    - **Government,**
    - **Industry, and,**
    - **University.**
- **We look forward to further opportunities to partner.**

https://nepp.nasa.gov