Electrical, Electronic and Electromechanical (EEE) Parts in the New Space Paradigm: *When is Better the Enemy of Good Enough?*

Kenneth A. LaBel, Michael J. Campola

michael.j.campola@nasa.gov

301-286-5427

NASA/GSFC

NASA Electronic Parts and Packaging (NEPP) Program

http://nepp.nasa.gov

Michael J. Sampson, Jonathan A. Pellish

Unclassified

Outline

- NASA Electronic Parts and Packaging
- The Changing Space Market (you already know)
- EEE Parts Assurance
- Modern Electronics
- Breaking Tradition: Alternate Approaches

NEPP Mission Statement

Provide leadership for developing and maintaining guidance for the screening, qualification, test, and <u>reliable use</u> of EEE parts by NASA, in collaboration with other government agencies and industry.

Note: The NASA Electronic Parts Assurance Group (NEPAG) is a portion of NEPP

General NASA EEE Parts Interfaces

Agency EEE Parts

Assurance	Development		Facilities
Office of Safety & Mission Assurance	Office of the Chief Engineer	Flight Projects	Mission Support
NEPP Workmanship Quality Model Based Mission Assurance (MBMA) Reliability and Maintainability (R&M)	Capability Leadership NESC	Field Centers Mission Directorates	Space Environments Testing Management

NEPP View of SmallSat Assurance

Space Missions:
How Our Frontiers Have Changed

- **Cost constraints and cost "effectiveness" have led to dramatic shifts away from traditional large-scale missions (ex., Hubble Space Telescope).**
- **Two prime trends have surfaced:**
  - ***Commercial space ventures* where the procuring agent "buys" a service or data product and the implementer is responsible for ensuring mission success with limited agent oversight. And,**
  - ***Small Missions* such as CubeSats that are allowed to take higher risks based on mission purpose and cost.**
- **These trends are driving the usage of non traditional electronic part types such as those used in automotive systems as well as "architectural reliability" (aka, resilience) approaches for mission success.**

Understanding Risk

- **The risk management requirements may be broken into three considerations**
  - **Technical/Design – "The Good"**
    - **Relate to the circuit designs not being able to meet mission criteria such as jitter related to a long dwell time of a telescope on an object**
  - **Programmatic – "The Bad"**
    - **Relate to a mission missing a launch window or exceeding a budgetary cost cap which can lead to mission cancellation**
  - **Radiation/Reliability – "The Ugly"**
    - **Relate to mission meeting its lifetime and performance goals without premature failures or unexpected anomalies**
- ***Each mission must determine its priorities among the three risk types***

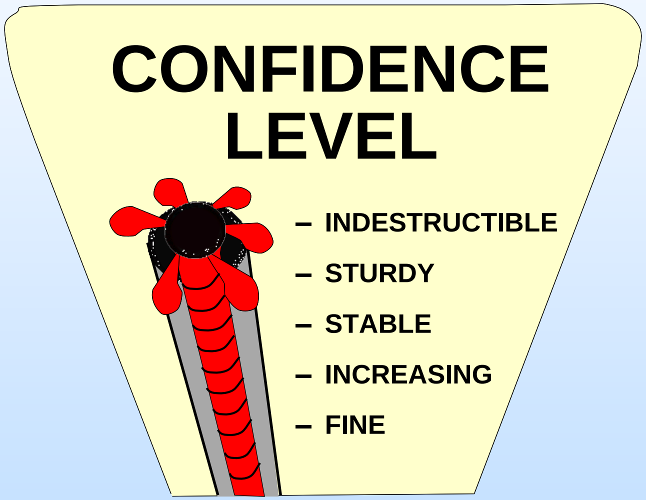
Graphic from Free Vector Art.

Reliability and Availability

- **Definitions**
  - **Reliability (Wikipedia)**
    - **The ability of a system or component to perform its required functions under stated conditions for a specified period of time.**
      - ***Will it work for as long as you need?***
  - **Availability (Wikipedia)**
    - **The degree to which a system, subsystem, or equipment is in a specified operable and committable state at the start of a mission, when the mission is called for at an unknown, *i.e.,* a random, time. Simply put, availability is the proportion of time a system is in a functioning condition. This is often described as a mission capable rate.**
      - ***Will it be available when you need it to work?***
- **Combining the two drives mission requirements:**
  - ***Will it work for as long as you need, when you need it to?***

What does this mean for EEE parts?

- *Understanding* of a device's failure modes and causes drives
  - Higher *confidence* level that it will perform under the mission environments and lifetime
  - *High confidence* = "it has to work"
    - High confidence in both reliability and availability.
  - *Less confidence* = "it may work"
    - Less confidence in both reliability and availability.
    - It may still work, but prior to flight there is less certainty that it will.



Modern Electronics and The Magpie Syndrome:

The Electrical Designer's Dilemma

- **Magpie's are known for being attracted to bright, shiny things.**
- **In many ways, the modern electrical engineer is a Magpie:**
  - ***They are attracted to the latest commercial state-of-the-art devices and EEE parts technologies.***
  - **These bright and shiny parts may have very attractive performance features that aren't available in higher-reliability parts:**
    - **Size, weight, and power (SwaP),**
    - **Integrated functionality,**
    - **Speed of data collection/transfer,**
    - **Processing capability, etc…**

Graphic from Clip Arts Free net.

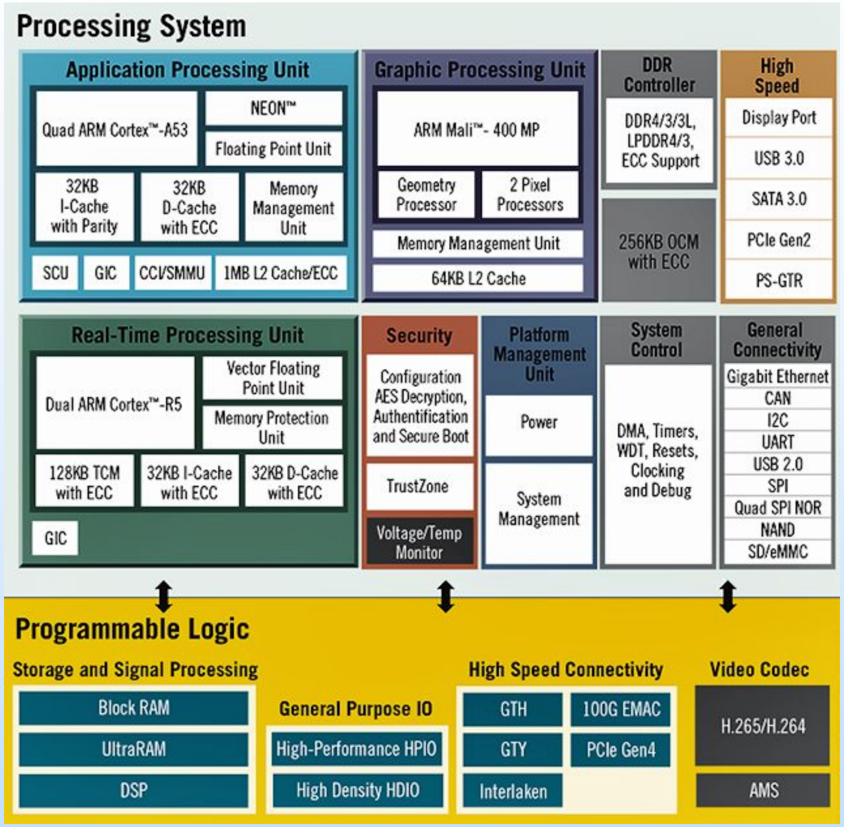
Magpie Constraints

- **But Magpies aren't designed for space flight**
  - **Just some aviary (bird) aviation at best!**
- **Sample differences include:**
  - **Temperature ranges,**
  - **Vacuum performance,**
  - **Shock and vibration,**
  - **Lifetime, and**
  - **Radiation tolerance.**

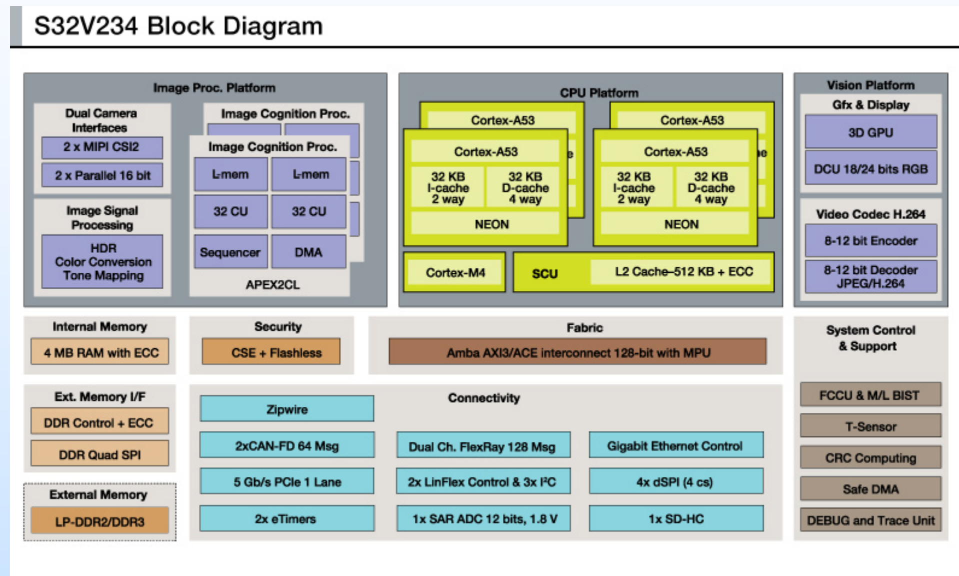
Graphic from Free Vector Art.

- **Traditionally, *"upscreening"* at the part level has occurred.**
  - **Definition: A means of assessing a portion of the inherent reliability of a device via test and analysis.**
    - **It does not increase reliability!**
  - **Note: Discovery of a part not passing upscreening is a regular occurrence.**

Example Magpie EEE Parts

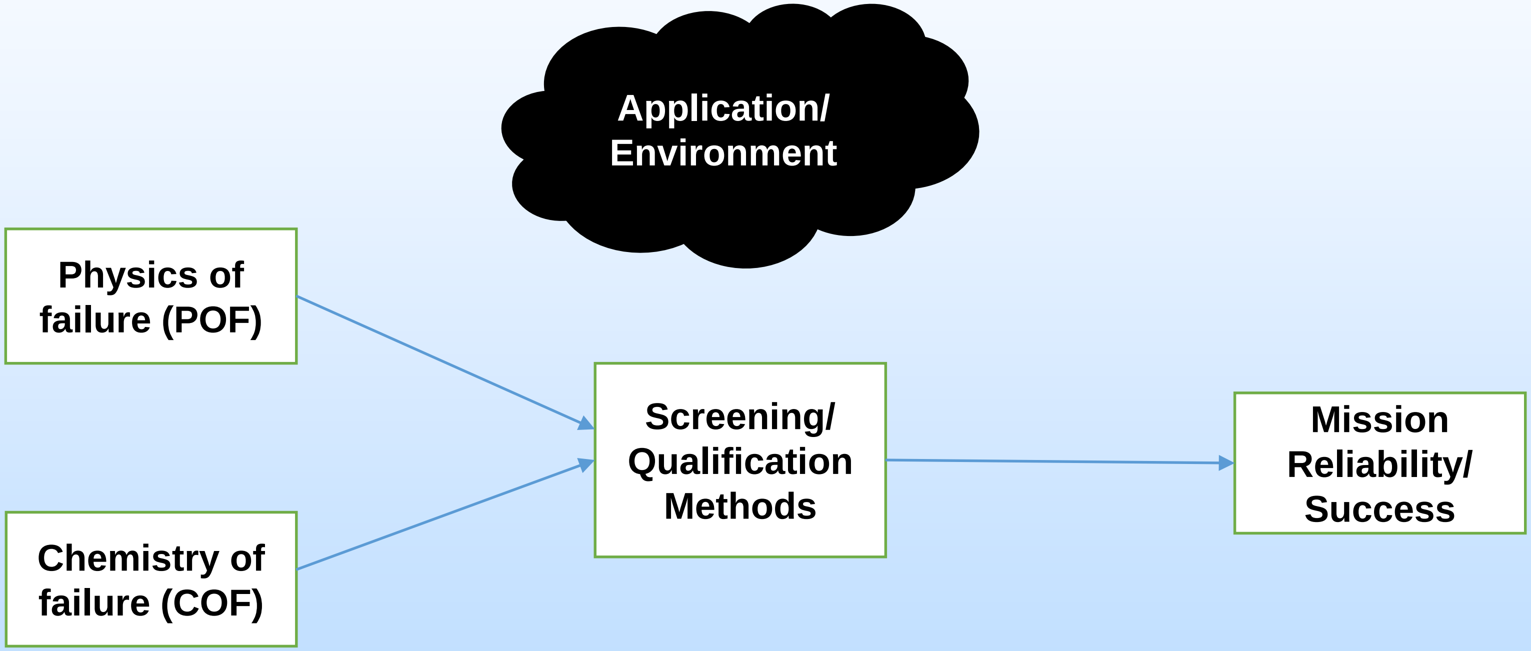


Xilinx Zynq UltraScale+
Multi-Processor System on a Chip (MPSoC) -
16nm CMOS with Vertical FinFETS
Xilinx.com



Advanced Driver Assistance System (ADAS)
Sensor Fusion Processor
Freescale.com

Taking a Step Back…



It's not just the technology,

but how to view the need for safe insertion into space programs.

EEE parts are available in "grades"

- **Grades – Designed, certified, qualified, and/or tested for specific environmental characteristics.**
  - **E.g., Operating temperature range, vacuum, radiation, exposure,…**
- **Example grades:**
  - **Aerospace, Military, Space Enhanced Product, Enhanced Product, Automotive, Medical, Extended-Temperature-Commercial, and Commercial (often called commercial off the shelf - COTS).**
  - ***Aerospace Grade* is the traditional choice for space usage, but has relatively few available parts and their performance lags behind commercial counterparts (speed, weight, and power - SWaP).**
    - ***Designed and tested for radiation and reliability for space usage.***
- **NASA uses a wide range of EEE part grades depending on multiple factors including technical, programmatic, and risk.**

Product Grades “Decoder Ring”

R. Baumann, “From COTS to Space Electronics: Improving Reliability for Harsh Environments,” 2016 Single Event Effects (SEE) Symp. and the Military and Aerospace Programmable Logic Devices (MAPLD) Workshop, May 23-26, 2016.

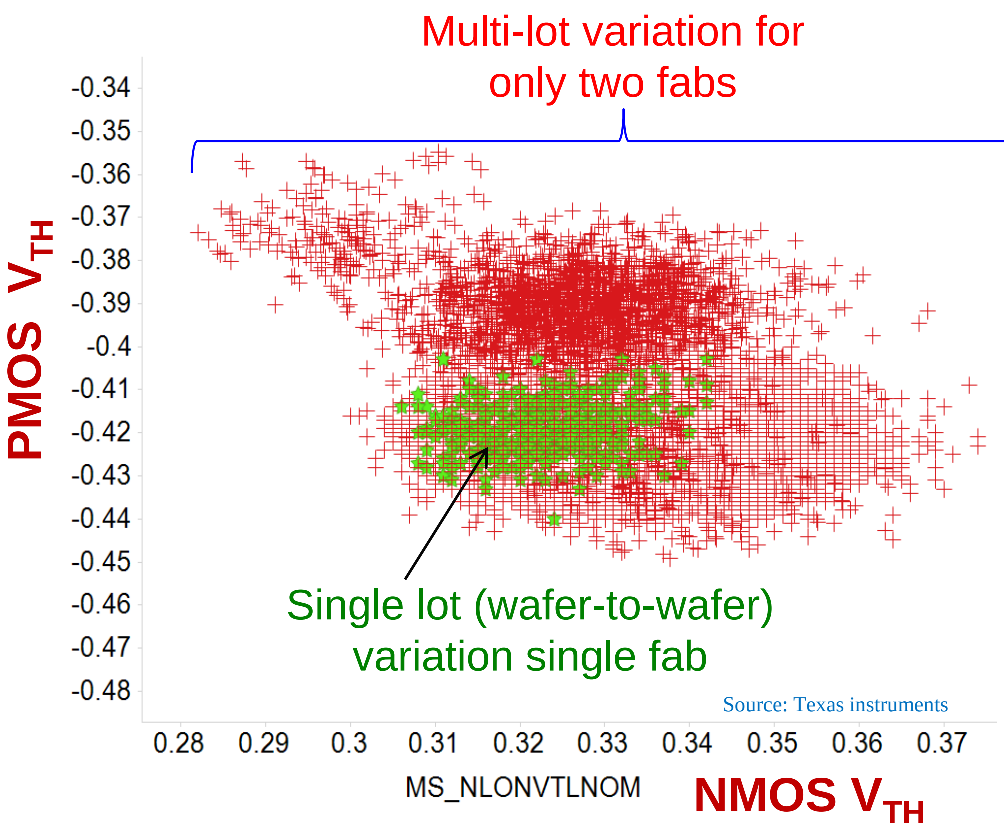
Quality / Reliability

	COTS / COTS+		Enhanced Intermediate Grades			Space Grade	
	Commercial	AEC-Q100	EP	QMLQ	Space EP	QML-V	QMLV-RHA
Packaging	PLASTIC	PLASTIC	PLASTIC	CERAMIC	PLASTIC	CERAMIC	CERAMIC
Single Controlled Baseline	NO	NO	YES	YES	YES	YES	YES
Bond wires	Au or Cu	Au or Cu	Au	Al	Au	Al	Al
Pure Sn Used	YES	YES	NO	NO	NO	NO	NO
Burn-in Performed	NO	NO	NO	NO	NO	YES	YES
Radiation Tested	NO	NO	NO	NO	YES	YES	YES
Radiation Assured	NO	NO	NO	NO	YES	NO	YES
Temperature Range	-40 to 85ºC	-40 to 125ºC (only grade 1)	-55 to 125ºC (majority)	-55 to 125ºC	-55 to 125ºC (majority)	-55 to 125ºC	-55 to 125ºC
100% 3 Temp Test	NO	NO	NO	YES	25, 125ºC	YES	YES
Extra Qual/Process Monitors	NO	YES	YES	YES	YES	YES	YES
Life Test per lot	NO	NO	NO	NO	NO	YES	YES

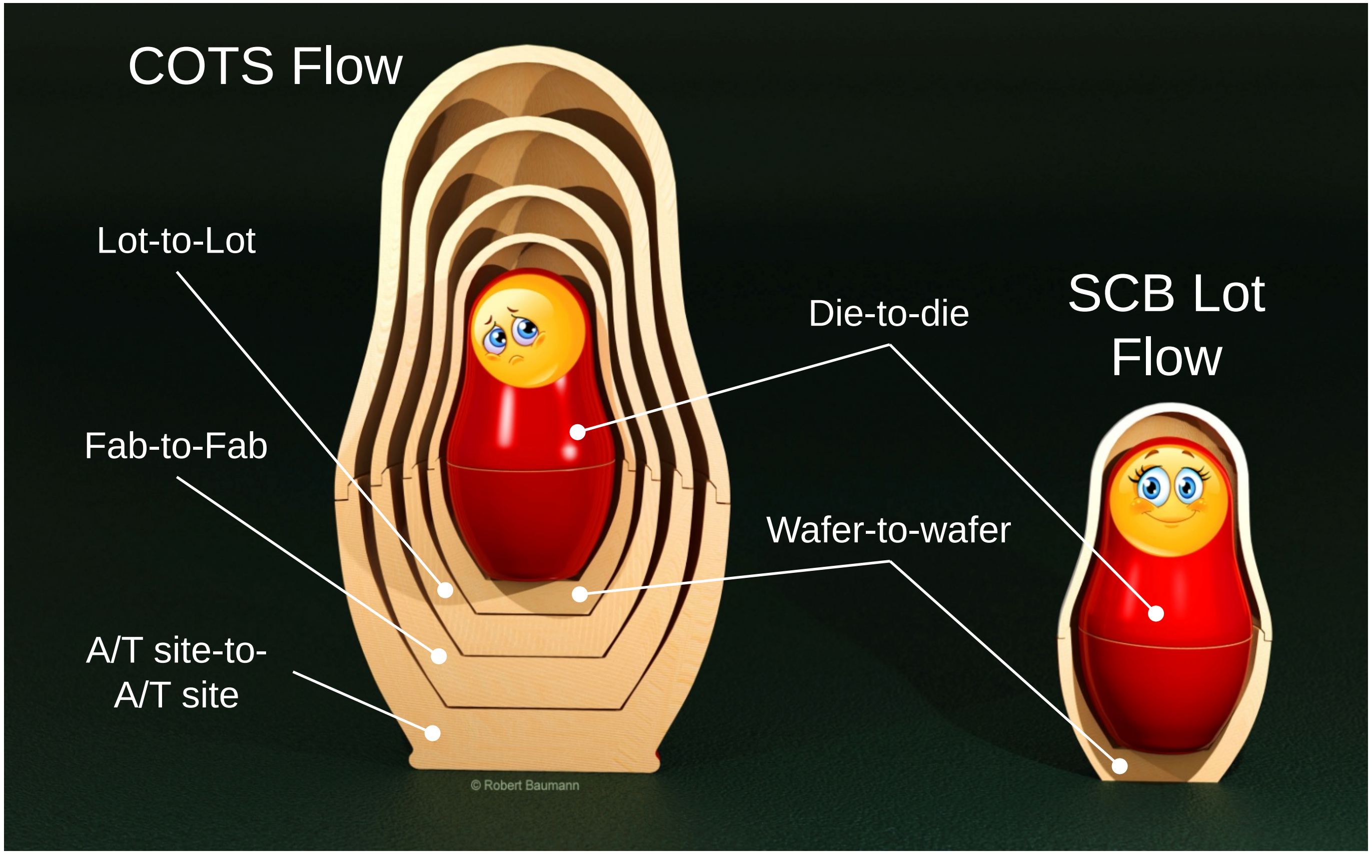
The move to the middle!

Multi-Fab Variability Example
- Why Single Controlled Baseline is Important

- **Fab-to-Fab**
  - Usually worse than Lot-to-Lot
  - Fab equipment set / version
  - Fab layout / cycle time
  - Fab recipe / starting material
  - Fab metrology coverage
  - Fab controls / methods
  - Revisions / shrinks
  - Design sensitivity / component choice
- **Lot-to-Lot**
  - Usually worse than wafer-to-wafer
  - Process has a natural variation
  - Processes / Equipment drifts over time
  - Process tweaks to boost yield

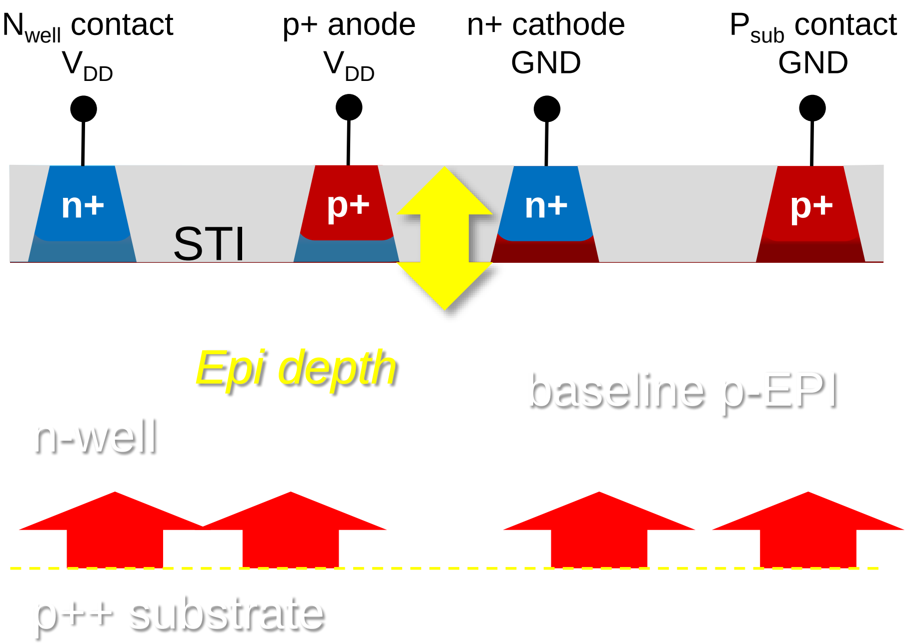


Variation and the "Matryoshka Paradigm"



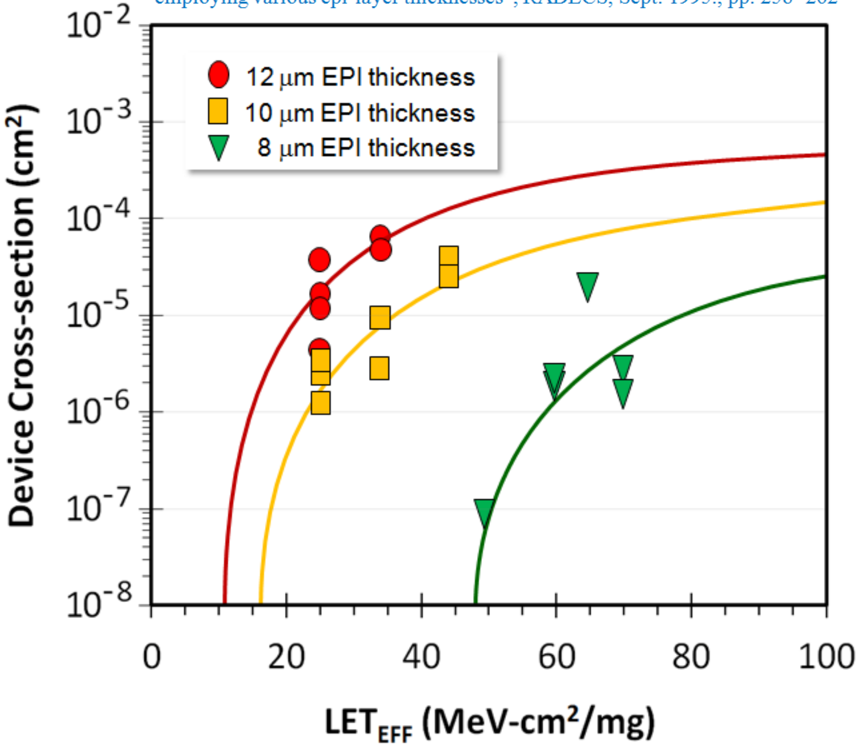
Mitigation of Single Event Latchup by Process

Example Variation Impact on Radiation Tolerance



Substitute standard p substrate with highly-doped substrate w thin baseline EPI

from K. LaBel, et al., "Single event effect characteristics of CMOS devices employing various epi-layer thicknesses", RADECS, Sept. 1995., pp. 258- 262



Breaking Tradition:

Alternate Approaches to EEE Parts Assurance

Is knowledge of EEE Parts Failure Modes Required To Build a Fault Tolerant System?

- **The system *may* work, but is there adequate confidence in the system to meet reliability and availability after launch?**
- **In no particular order:**
  - **What are the "unknown unknowns"? Can we account for them?**
  - **How do you calculate risk with unscreened/untested EEE parts?**
  - **Do you have a common mode failure potential in your design?**
  - **I.e., a design with identical redundant strings rather than having independent redundant strings.**
  - **How do you adequately validate a fault tolerant system for space?**
    - ***This is a critical point.***

Using Fault Tolerance to Improve "Reliability/Availability"

- **Operational**
  - **Ex., no operation in the South Atlantic Anomaly (proton hazard)**
- **System**
  - **Ex., redundant boxes/busses or swarms of nanosats**
- **Circuit/software**
  - **Ex., error detection and correction (EDAC) scrubbing of memory devices by an external device or processor**
- **Device (part)**
  - **Ex., triple-modular redundancy (TMR) of internal logic within the device**
- **Transistor**
  - **Ex., use of annular transistors for Total Ionizing Dose (TID) improvement**
- **Material**
  - **Ex., addition of an epi substrate to reduce Single Event Effect (SEE) charge collection (or other substrate engineering)**

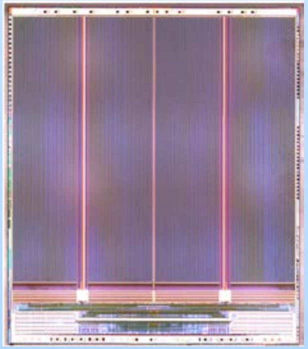
Good engineers can invent infinite solutions, but the solution used must be adequately validated.

It's easy to show a working block diagram, it's hard to provide sufficient validation details.

Possible Exceptions:
Is Radiation Testing Always Required for COTS?

- **Operational**
  - Ex., The device is only powered on once per orbit and the sensitive time window for a single event effect is minimal
- **Acceptable data loss**
  - Ex., System level error rate (availability) may be set such that data is gathered 95% of the time.
    - Given physical device volume and assuming every ion causes an upset, this worst-case rate may be acceptable.
- **Negligible effect**
  - Ex., A 2 week mission may have a very low Total Ionizing Dose (TID) requirement.

Memory picture courtesy NASA/GSFC, Code 561



A flash memory may be acceptable without testing if a low TID requirement exists or not powered on for the large majority of time.

Space Missions: EEE Parts and Risk

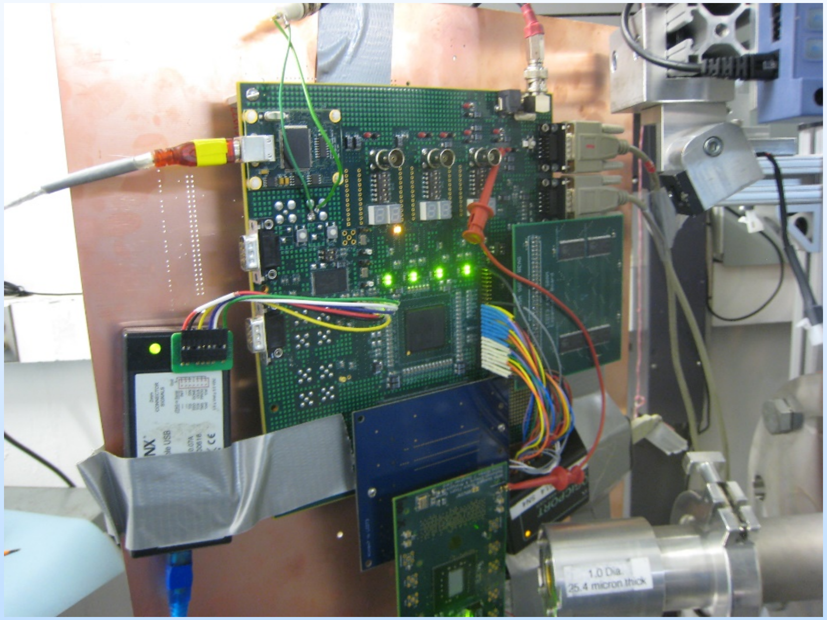
- **The determination of acceptability for device usage is a complex trade space.**
  - **Every engineer will "solve" a problem differently:**
    - **Ex., software versus hardware solutions.**
- **The following chart proposes an alternate mission risk matrix approach for EEE parts based on:**
  - ***Environment exposure*****,**
  - ***Mission lifetime*****, and,**
  - ***Criticality*** **of implemented function.**
- **Notes:**
  - **"COTS" implies any parts grade that is not space qualified and radiation hardened.**
  - **Level 1 and level 2 refer to traditional space qualified EEE parts.**

Notional EEE Parts Selection Factors

Criticality			
High	Level 1 or 2 suggested. COTS upscreening/ testing recommended. Fault tolerant designs for COTS.	Level 1 or 2, rad hard suggested. Full upscreening for COTS. Fault tolerant designs for COTS.	Level 1 or 2, rad hard recommended. Full upscreening for COTS. Fault tolerant designs for COTS.
Medium	COTS upscreening/ testing recommended. Fault-tolerance suggested	COTS upscreening/ testing recommended. Fault-tolerance recommended	Level 1 or 2, rad hard suggested. Full upscreening for COTS. Fault tolerant designs for COTS.
Low	COTS upscreening/ testing optional. Do no harm (to others)	COTS upscreening/ testing recommended. Fault-tolerance suggested. Do no harm (to others)	Rad hard suggested. COTS upscreening/ testing recommended. Fault tolerance recommended
	Low	Medium	High

Environment/Lifetime

Assembly Testing: Can it Replace Testing at the Parts Level?



NASA GSFC Picture of FPGA tester.

We can test devices,

but how do we test systems?

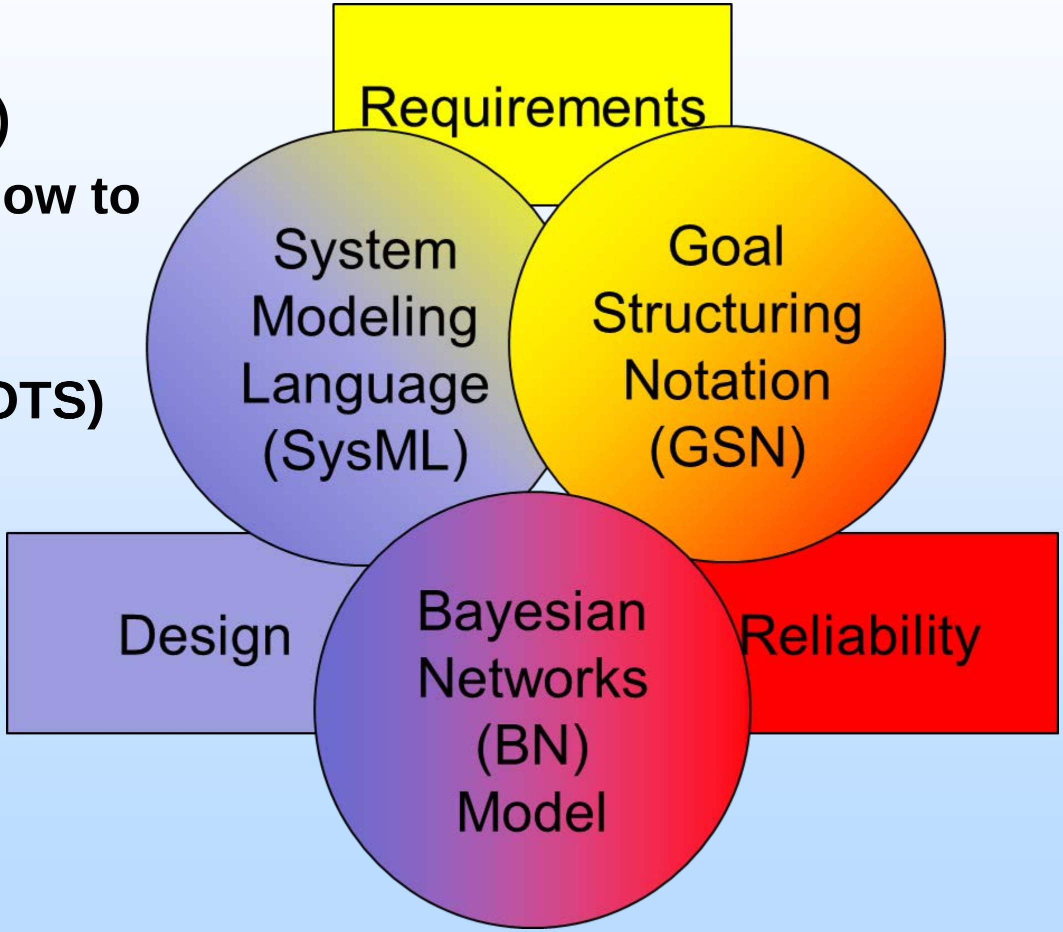
Or better yet, systems of systems on a chip (SOC)?

Not All Assemblies are Equal

- Consider two distinct categories of assemblies:
  - Off the shelf (you get what you get) such as COTS, and,
  - Custom (possibility of having specific "design for test")
    - Still won't be as complete as single part level testing, but it does reduce some challenges.
- For COTS assemblies, some specific concerns include:
  - Bill-of-materials may not include lot date codes or device manufacturer information.
  - Individual part application may not be known or datasheet unavailable.
  - The possible variances for "copies" of the "same" assembly:
    - Form, fit, and function EEE parts may mean various manufacturers, or,
    - Other variation as discussed earlier (lot-to-lot, fab-to-fab).

Model Based Mission Assurance (MBMA)

- Motivation
  - Commercial parts (COTS)
  - Document-centric work flow to model-based system engineering
  - System mitigation (for COTS)
  - Single source of system design parameters



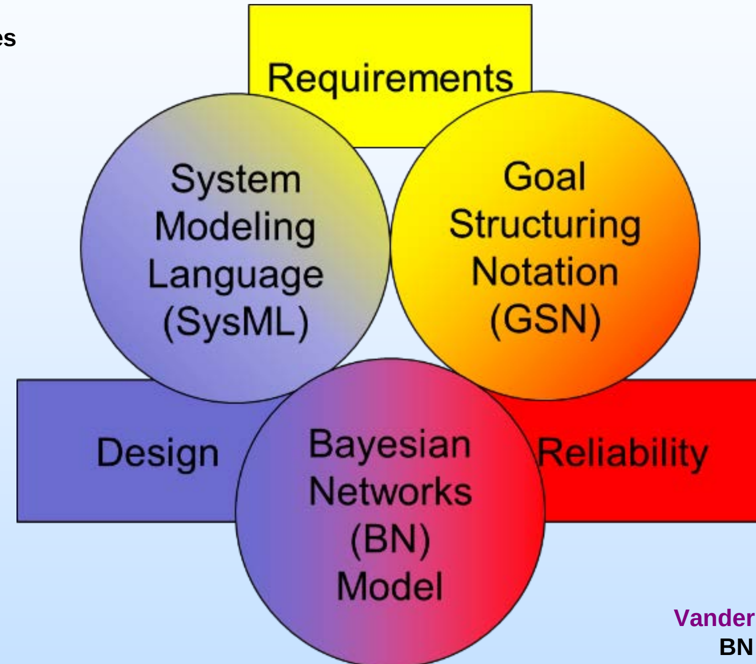
https://modelbasedassurance.org/

NEPP Small Mission Efforts and MBMA (w/ NASA MBMA Program)

NASA/GSFC (Campola)
Small Mission RHA
TBD
Small Mission EEE Parts Best Practices

NASA/GSFC (Xapsos)
RHA Confidence Approach

Air Force SMC
CubeSat Supply Chain and "Mid-space" Grade Electronics Survey and Requirements Definition



Saint Louis University
CubeSat Success Study

JPL
CubeSat EEE Parts Databases

TBD
CubeSat EEE Parts Testing

TBD
Resilience, autonomy

Vanderbilt University
GSN Exemplar (SEE) – complete
TBD
GSN Exemplar – EEE parts reliability

NASA/GSFC (Berg)
SEE Classic Reliability

Vanderbilt
CRÈME Toolsuite

Vanderbilt University
BN follow-on
BN integrated into SEAM

Other
Integration with Small Spacecraft Virtual Institute (NASA/ARC)
https://www.nasa.gov/smallsat-institute

Emerging Modeling
Vanderbilt University
Web-based tool (SEAM)
NASA/GSFC (Campola) - Vanderbilt
Notional RHA Tool (R-GENTIC)

Other
MAIW
SmallSat Reliability Initiative (NASA/AF/ others)

https://modelbasedassurance.org/

Tenet:* *the best ideas will die on the vine without integration into standard approaches or tools. It's all about access.

Ongoing NEPP Efforts