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

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Acronyms

Acronym	Definition
ADAS	Advanced Driver Assistance System
ADC	analog-to-digital converter
AES	Advanced Encryption Standard
AMS	Agile Mixed Signal
ARM	ARM Holdings Public Limited Company
CAN	Controller Area Network
CAN-FD	Controller Area Network Flexible Data-Rate
CCI/SMMU	Cache Coherent Interconnect System Memory Management Unit
Codec	compression/decompression - A codec is an algorithm, or specialized computer program, that reduces the number of bytes consumed by large files and programs.
COTS	Commercial off the Shelf
CRC	Cyclic Redundancy Check
CSE	Computer Science and Engineering
CU	Cu alloy
DCU	Display Controller Unit
DDR	Double Data Rate
DMA	Direct Memory Access
DRAM	Dynamic Random Access Memory
DSP	Digital Signal Processing
dSPI	Dynamic Signal Processing Instrument
Dual Ch	Dual Channel
ECC	Error-Correcting Code
ECC	Error-Correcting Code
EEE	Electrical, Electronic, and Electromechanical
EMAC	Equipment Monitor And Control
eMMC	embedded MultiMediaCard
eTimers	Event Timers
FCCU	Fluidized Catalytic Cracking Unit
FinFET	Fin Field Effect Transistor (the conducting channel is wrapped by a thin silicon "fin")
FlexRay	FlexRay communications bus
G	Gigabit
Gb/s	gigabyte per second
GIC	Global Industry Classification
GIC	Global Industry Classification
GPU	Graphics Processing Unit
GTH	transceivers unique library name
GTY	transceivers unique library name
HDIO	High Density Digital Input/Output
HDR	High-Dynamic-Range
HPIO	High Performance Input/Output

Acronym	Definition
I/O	Input/Output Operating System
I2C	Inter-Integrated Circuit
JPEG	Joint Photographic Experts Group
KB	Kilobyte
L2 Cache	independent caches organized as a hierarchy (L1, L2, etc.)
LEO	Low Earth Orbit
L-mem	Long-Memory
LPDDR	Low-Power Double Data Rate
M/L BIST	Memory/Logic Built-In Self-Test
MB	Megabyte
MIPI	Mobile Industry Processor Interface
MPSoC	Multi-Processor System on a Chip
MPU	Micro-Processor Unit
NAND	non-volatile computer memory
NOR	Not OR logic gate
PC	Personal Computer
PCIe	Peripheral Component Interconnect Express
PCIe Gen2	Peripheral Component Interconnect Express Generation 2
PCIe Gen4	Peripheral Component Interconnect Express Generation 4
POF	Physics of Failure
Proc.	Processing
PS-GTR	Global Regulation on Pedestrian Safety
R&D	Research and Development
RAM	Random Access Memory
RGB	Red, Green, and Blue
SAR	Successive-Approximation-Register
SATA	Serial Advanced Technology Attachment
SCU	Secondary Control Unit
SD	Secure Digital
SD-HC	Secure Digital High Capacity
SMMU	System Memory Management Unit
SOC	System on a Chip
SPI	Serial Peripheral Interface
SwaP	Size, Weight, and Power
TCM	Tightly Coupled Memory
Temp	Temperature
T-Sensor	Temperature-Sensor
UART	Universal Asynchronous Receiver/Transmitter
USB	Universal Serial Bus
WDT	Watchdog Timer

Abstract

- As the space business rapidly evolves to accommodate a lower cost model of development and operation via concepts such as commercial space and small spacecraft (aka, CubeSats), traditional EEE parts screening and qualification methods are being scrutinized under a risk-reward trade space. In this presentation, two basic concepts will be discussed:
  - The movement from complete risk aversion EEE parts methods to managing and/or accepting risk via alternate approaches; and,
  - A discussion of “over-design” focusing on both electrical design performance and bounding margins.
- Example scenarios will be described as well as consideration for trading traditional versus alternate methods.

Outline

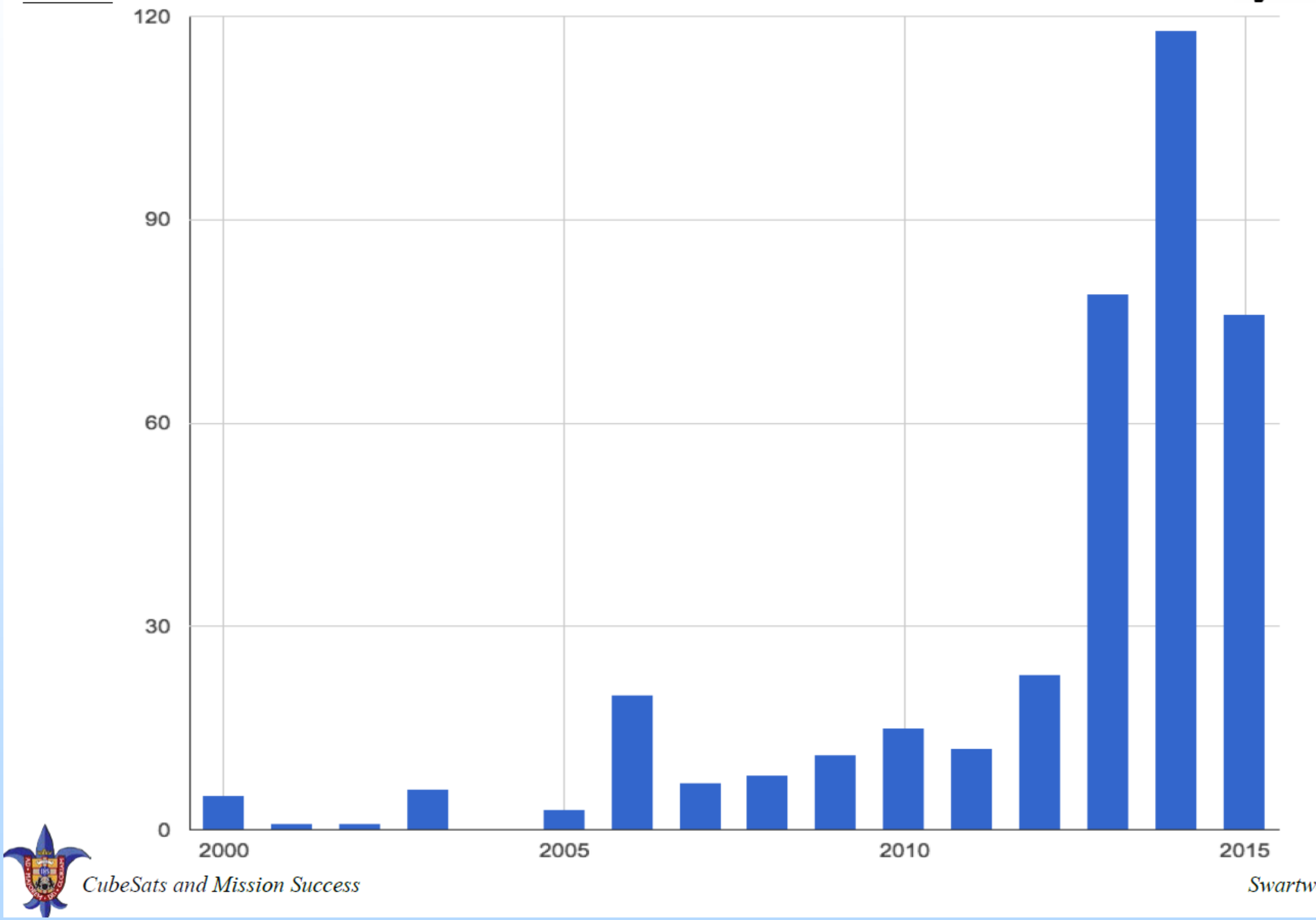
- The Changing Space Market
  - Commercial Space and "Small" Space
- EEE Parts Assurance
- Modern Electronics
  - Magpie Syndrome
- Breaking Tradition: Alternate Approaches
  - Higher Assembly Level Tests
  - Use of Fault Tolerance
- Mission Risk and EEE Parts
- Summary

Hubble Space Telescope courtesy NASA

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 Mil/Aero parts such as Automotive grade (see Mike Sampson's talk) and "architectural reliability" approaches.**

Number of CubeSats On-Orbit



EEE Parts Assurance

Assurance for EEE Parts

- ***Assurance*** **is**
  - **Knowledge of**
    - **The supply chain and manufacturer of the product,**
    - **The manufacturing process and its controls, and,**
    - **The physics of failure (POF) related to the technology.**
  - **Statistical process and inspection via**
    - **Testing, inspection, physical analyses and modeling.**
  - **Understanding the application and environmental conditions for device usage.**
    - **This includes:**
      - **Radiation,**
      - **Lifetime,**
      - **Temperature,**
      - **Vacuum, etc., as well as,**
      - **Device application and appropriate derating criteria.**

Reliability and Availability

- **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 and when you need it to?***

What does this mean for EEE parts?

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

Traditional Approach to Confidence

- **Part level qualification**
  - **Qualification processes are designed to statistically understand/remove known reliability risks and uncover other unknown risks inherent in a part.**
    - **Requires significant sample size and comprehensive suite of piecepart testing (insight) – *high confidence method***
- **Part level screening**
  - **Electronic component screening uses environmental stressing and electrical testing to identify marginal and defective components within a procured lot of EEE parts.**

However, tradition doesn't match the changing space market and alternate EEE parts approaches that may be

"good enough"

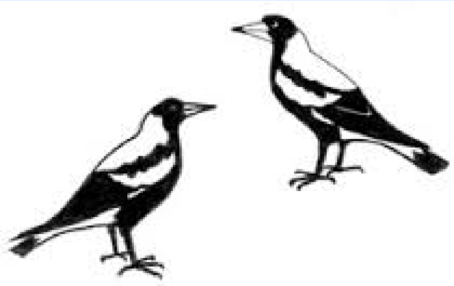
are being used.

(Discussed later in presentation.)

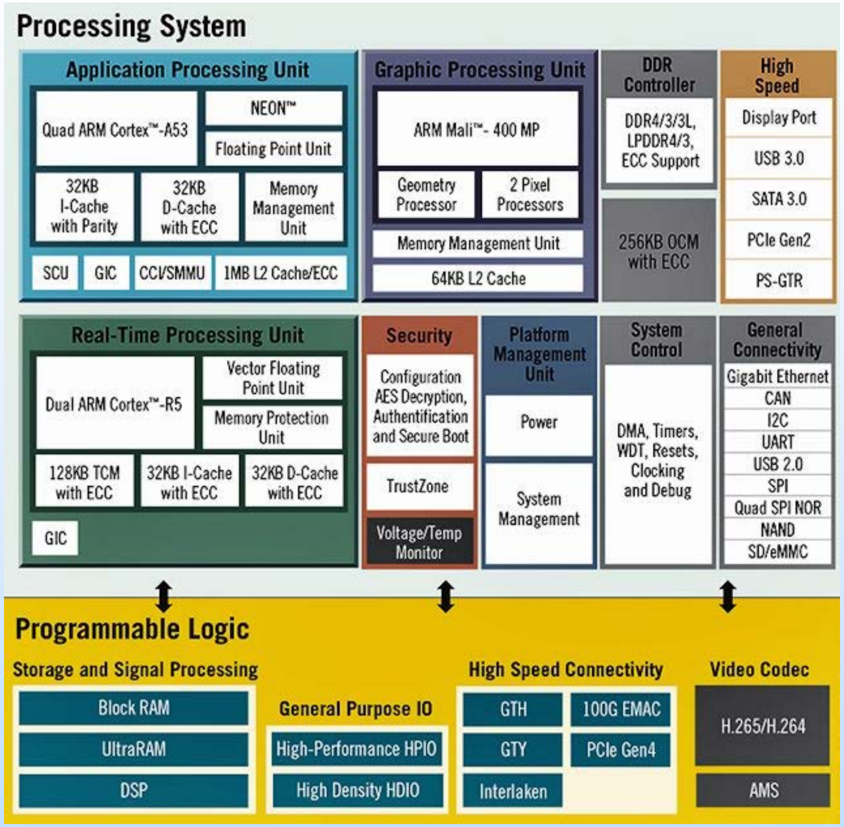
Modern Electronics

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 state-of-the-art devices and EEE parts technologies.
    - These can be any grade of EEE parts that aren't qualified for space nor radiation hardened.
  - 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…

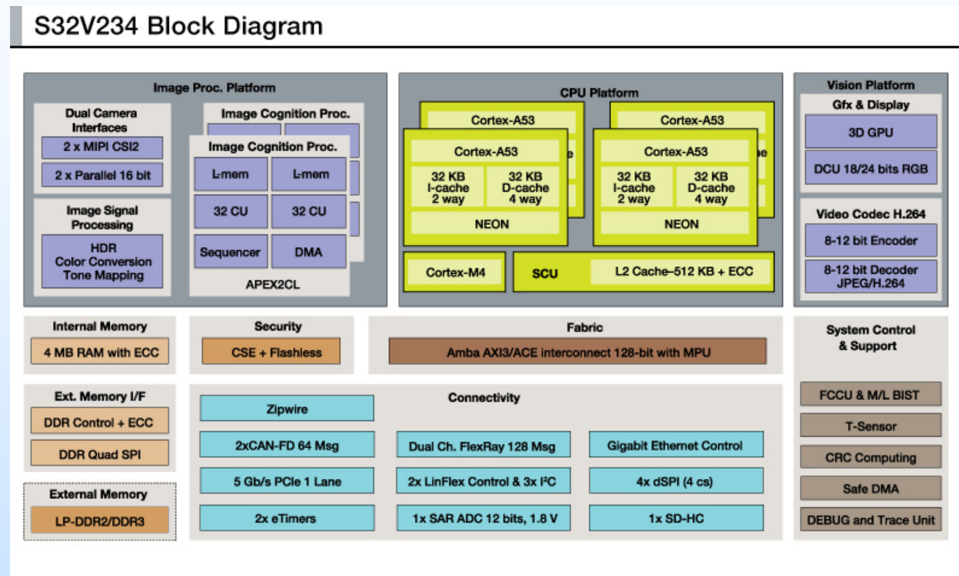


Example Magpie EEE Parts



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

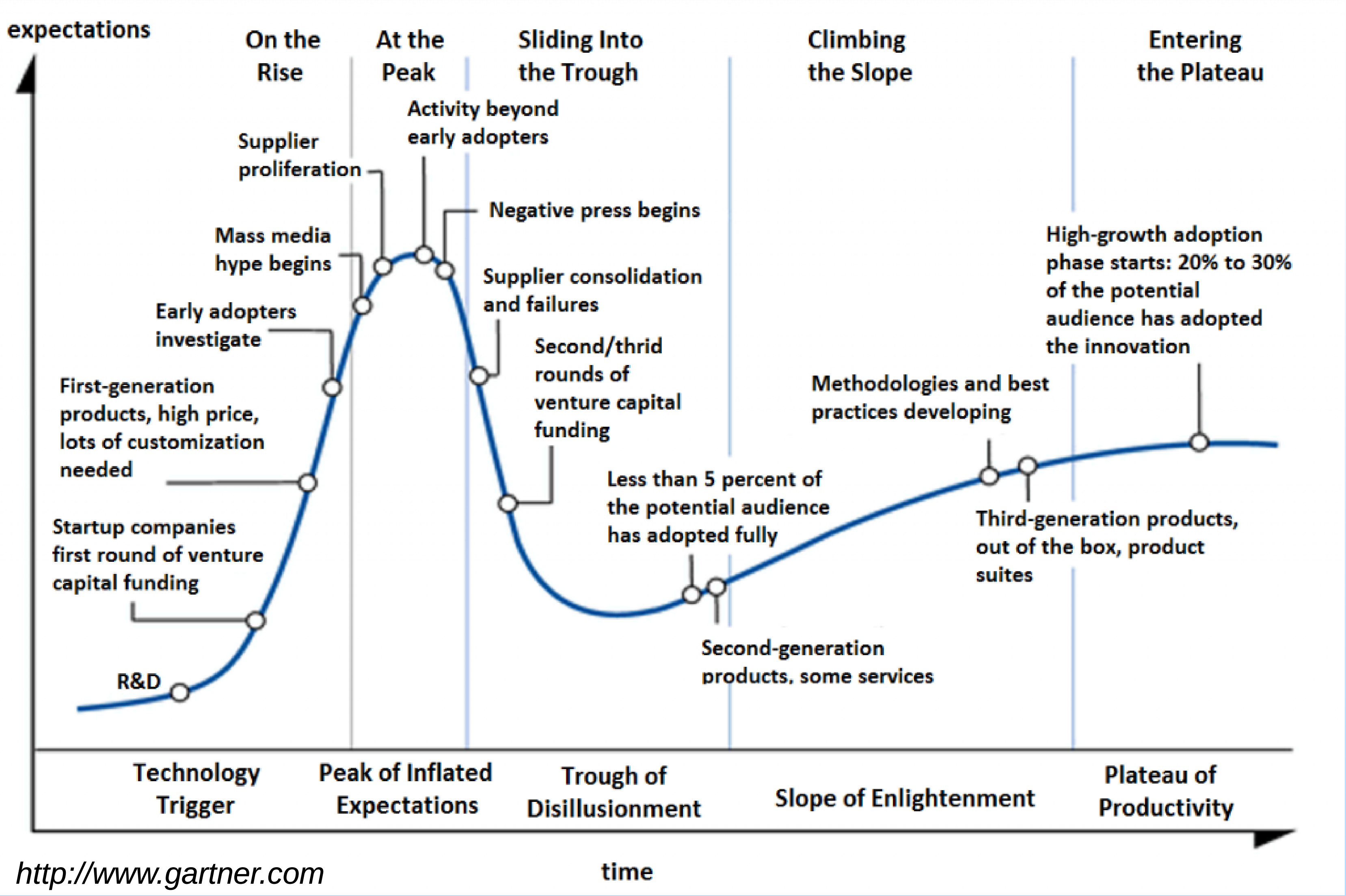
Xilinx.com



Advanced Driver Assistance System (ADAS)
Sensor Fusion Processor

Freescale.com

Gartner Hype Cycle –
Reality of Shiny New Things



When Should a Magpie Fly?

- **While not designed for usage in the harsh environs of space, there are still multiple scenarios where usage of Magpies may be considered:**
  - **Mil/Aero alternatives are not available,**
    - **Ex., SWaP or functionality or procurement schedule,**
  - **A mission has a relatively short lifetime or benign space environment exposure,**
    - **Ex., 6 month CubeSat mission in LEO,**
  - **A system can assume possible unknown risks,**
    - **Ex., technology demonstration mission,**
  - **Device upscreening (per mission requirements) and system validation are performed to obtain confidence in usage,**
  - **System level assurances based on fault tolerance and higher assembly level test and validation are deemed sufficient.**
    - **This is a systems engineering trade that takes a multi-disciplinary review.**
  - **Or maybe as a pathfinder for future usage.**
    - **Out of scope for this talk: use of flight data for "qualification".**

Magpie Constraints

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

- **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.**
    - **Note: Discovery of a upscreened part failure occurs regularly.**
- **The following charts discuss alternate approaches.**

Breaking Tradition: Alternate Approaches

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

CompactPCI™

ZIATECH CORPORATION

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 assemblies having two distinct categories
  - Off the shelf (you get what you get) such as COTS, and,
  - Custom (possibility of having "design for test" included")
    - Still won't be as complete as single part level testing, but it does reduce some challenges.
- For COTS assemblies, some of the specific concerns are:
  - 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,
    - Lot-to-lot and even device-to-device differences in reliability/availability.

Sample Challenges for Testing Assemblies

- Limited statistics versus part level approaches due to sample size.
- Inspection constraints.
- Acceleration factors
  - Temperature testing limited to “weakest” part.
  - Voltage testing may be limited by on-board/on-chip power regulation.
- Limited test points and I/O challenge adequate stress data capture.
- Ensuring adequate fault coverage testing.
- Visibility of errors/failures/faults due to limited I/O availability.
- System operation.
  - Ex., Using nominal flight software versus a high stress test approach.
- Error propagation
  - An error occurs but does not propagate outward until some time later due to system operations such as those of an interrupt register.
- Fault masking during radiation exposure
  - Too high a particle rate or too many devices being exposed simultaneously.

Using Fault Tolerance

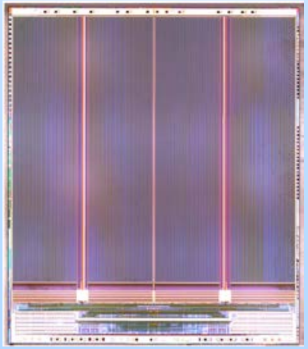
- **Making a system more "reliable/available" can occur at many levels**
  - **Operational**
    - **Ex., no operation in the South Atlantic Anomaly (proton hazard)**
  - **System**
    - **Ex., redundant boxes/busses or swarms of nanosats**
  - **Circuit/software**
    - **Ex., error detection and correction (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 TID improvement**
  - **Material**
    - **Ex., addition of an epi substrate to reduce SEE charge collection (or other substrate engineering)**

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

Example:
Is Radiation Testing Always Required for COTS?

- **Exceptions for testing may include**
  - **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 tractable.**
  - **Negligible effect**
    - **Ex., A 2 week mission on a shuttle may have a very low Total Ionizing Dose (TID) requirement.**

Memory picture courtesy NASA/GSFC, Code 561



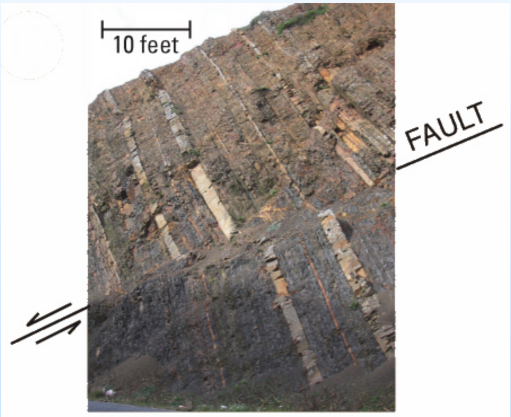
A flash memory may be acceptable without testing if a low TID requirement exists or not powered on for the large majority of time.

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

- **The system *may* work, but do we have adequate confidence in the system to have adequate reliability and availability prior to launch?**
  - **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.***

Bottom Line on Assembly Testing and Fault Tolerance

- While clearly ANY testing is better than none, assembly testing has limitations compared to the individual EEE part level.
  - This is a risk-trade that's still to be understood.
  - No *definitive* study exists comparing this approach versus traditional parts qualification and screening.
- Fault tolerance needs to be validated.
  - Understanding the fault and failure signatures is required to design appropriate tolerance.
  - The more complex the system, the harder the validation is.

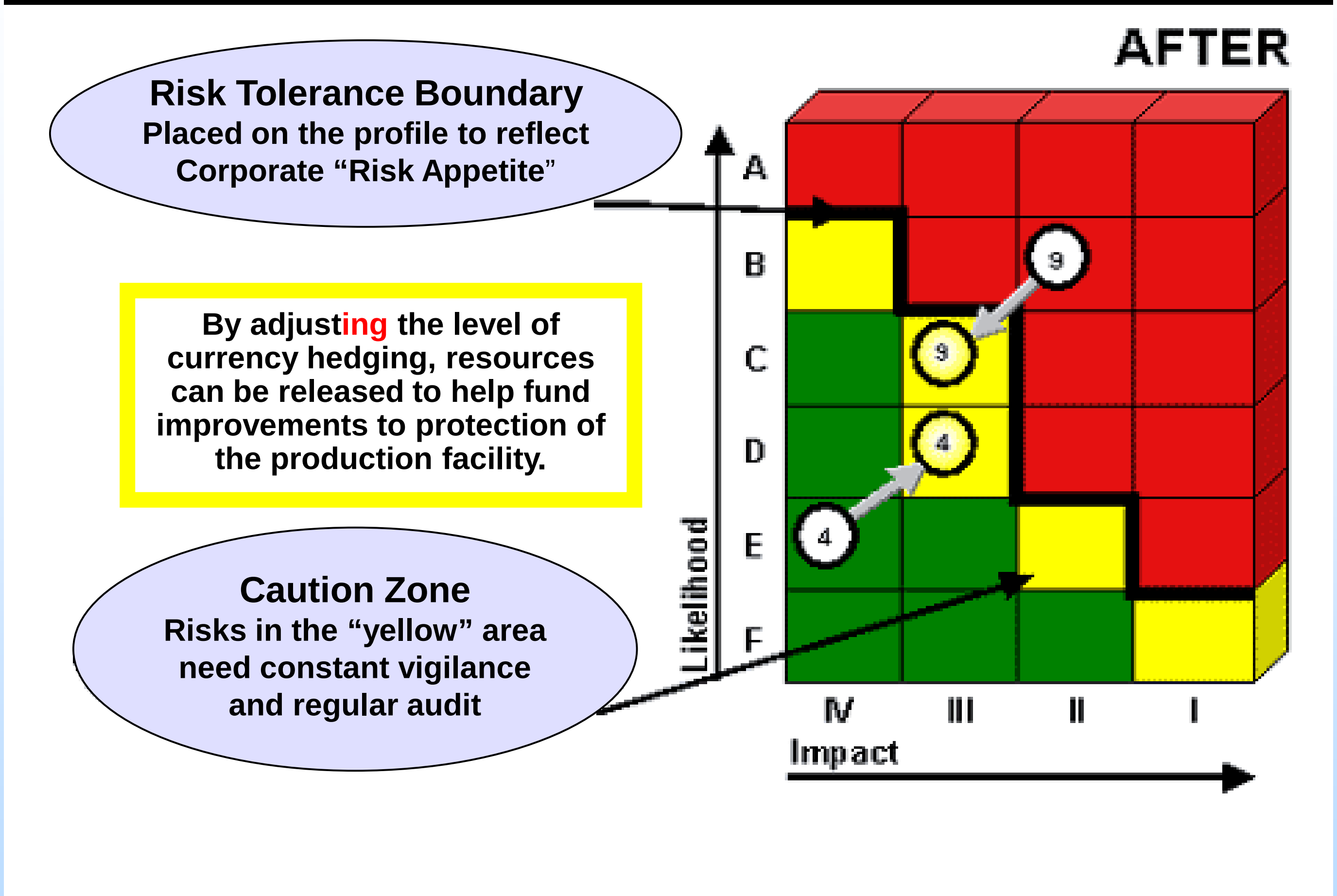


Mission Risk and EEE Parts

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***

Background: Traditional Risk Matrix



Likelihood Scale:	A: Very High	B: High	C: Occasional	D: Low	E: Very Low	F: Almost Impossible
Impact Scale:	I: Catastrophic	II: Critical	III: Significant	IV: Marginal		

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 grade that is not space qualified and radiation hardened.**
  - **Level 1 and 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

A Few Details on the "Matrix"

- **When to test:**
  - **"Optional"**
    - **Implies that you might get away without this, but there's residual risk.**
  - **"Suggested"**
    - **Implies that it is good idea to do this, and likely some risk if you don't.**
  - **"Recommended"**
    - **Implies that this really should be done or you'll definitely have some risk.**
  - **Where just the item is listed (like "full upscreening for COTS")**
    - **This should be done to meet the criticality and environment/lifetime concerns.**
- **The higher the level of risk acceptance by a mission, the higher the consideration for performing alternate assembly level testing versus traditional part level.**
- **All fault tolerance must be validated.**

Good mission planning identifies where on the matrix a EEE part lies.

Summary

- **In this talk, we have presented:**
  - **An overview of considerations for alternate EEE parts approaches:**
    - **Technical, programmatic, and risk-oriented**
      - **Every mission views the relative priorities differently.**
- **As seen below, every decision type may have a process.**
  - **It's all in developing an appropriate one for your application and avoiding "buyer's remorse"!**

Five stages of Consumer Behavior

http://www-rohan.sdsu.edu/~renglish/370/notes/chapt05/