Tailoring TOR
for
Class D Missions
Getting the Most Reliability for Your Analysis Buck

WCCA
WORST CASE
CIRCUIT
ANALYSIS

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ANALYTICAL **HEAVY** LIFTING

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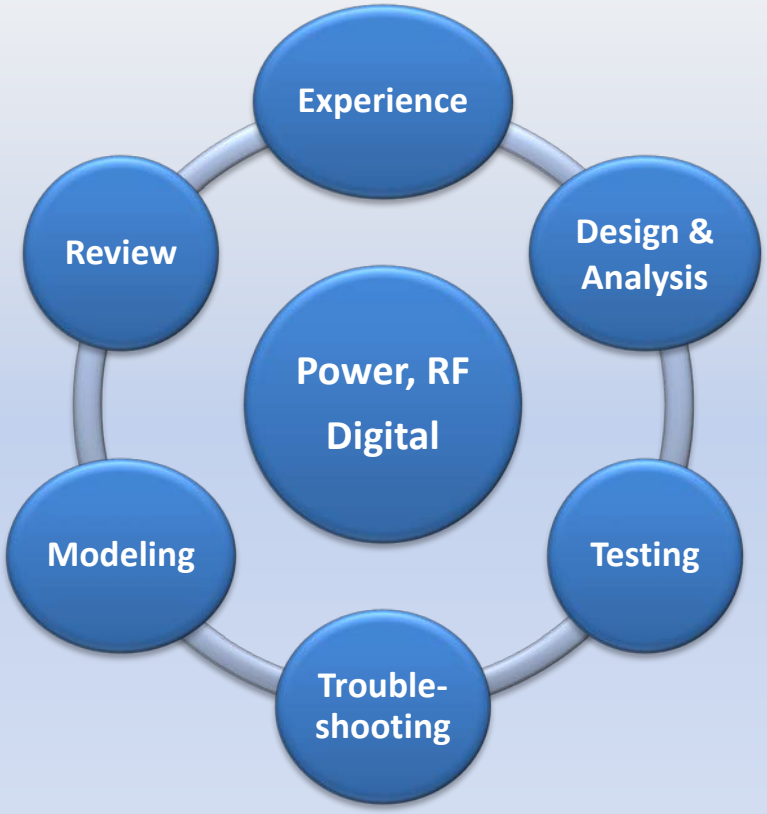
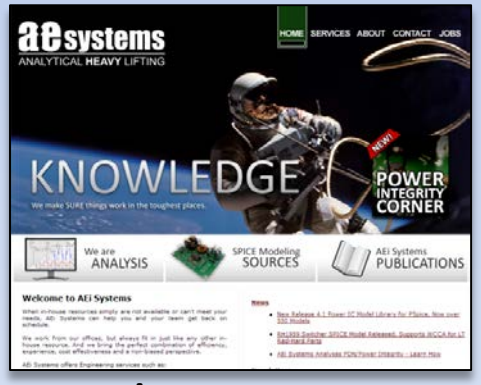
Electrical, Electronic, and Electromechanical (EEE)
Parts for Small Missions Workshop 9/11/2014

AEi Systems – A Unique Resource

For almost 20 years AEi Systems has been a leading provider of engineering services to the majority of satellite prime contractors and Gov agencies





aeisystems.com

Founders active in design and analysis for space programs since the 1970's

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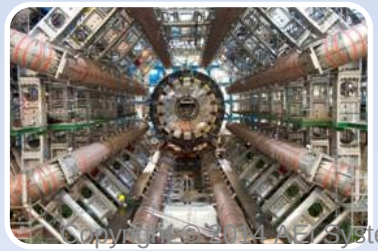
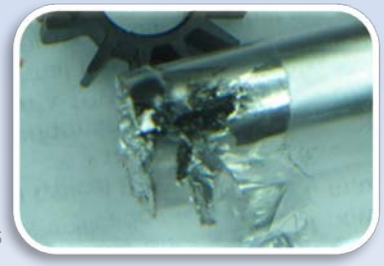
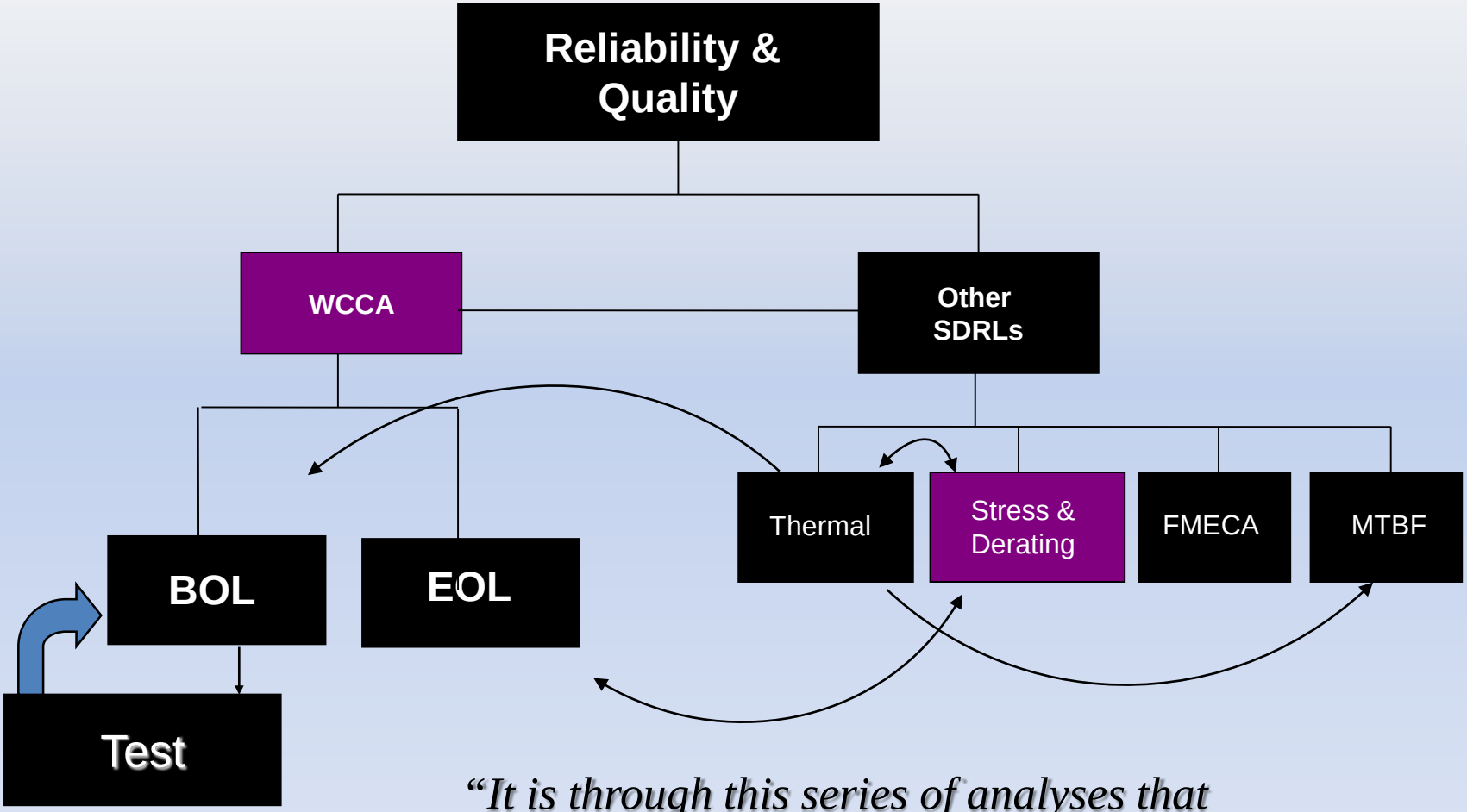




Reliability and WCCA



"It is through this series of analyses that performance aspects of the system and design are examined, quantified, and evaluated."

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What are the Goals?

- **To meet the requirements over the design life**
  - Within Cost Projection and Schedule – We need to save money
- **Need to achieve the highest reliability based on our expectation of risk vs. mission priorities**

– Hurdles
  - Mission Success rates are lower than we would like
  - Costs are constrained – Resources are often limited
  - We don't do enough analysis (correctly) as it is
  - Analysis Escapes Hurt Reliability

- **Solution: Tailor (Don't Ignore) TOR Guidelines on WCCA**
  - TOR-2012(8960)-4, REV. A Electrical Design Worst-Case Circuit Analysis: Guidelines and Draft Standard, 2012 MAIW "Short Version" - Non-ITAR

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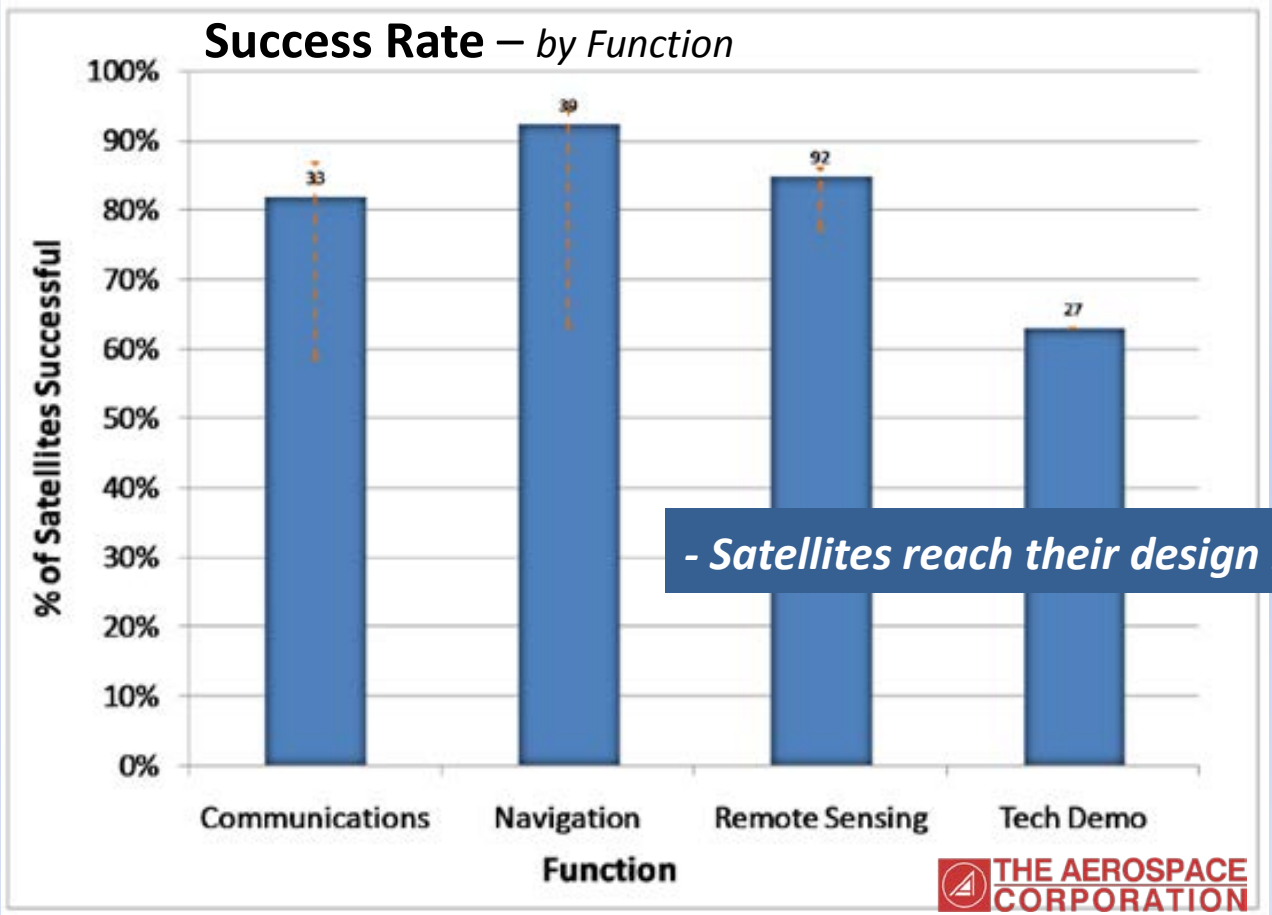
Mission Assurance – How are we doing?



Launched 1980-2010
US Military and US Civil Sats only
Earth orbiting

- Satellites reach their design life >80% of the time

Tech Demo satellites have experienced a low success rate than other mission types

"Gone too Soon? How successful are U.S. satellites at reaching their design life?" – Space Power Workshop 2014

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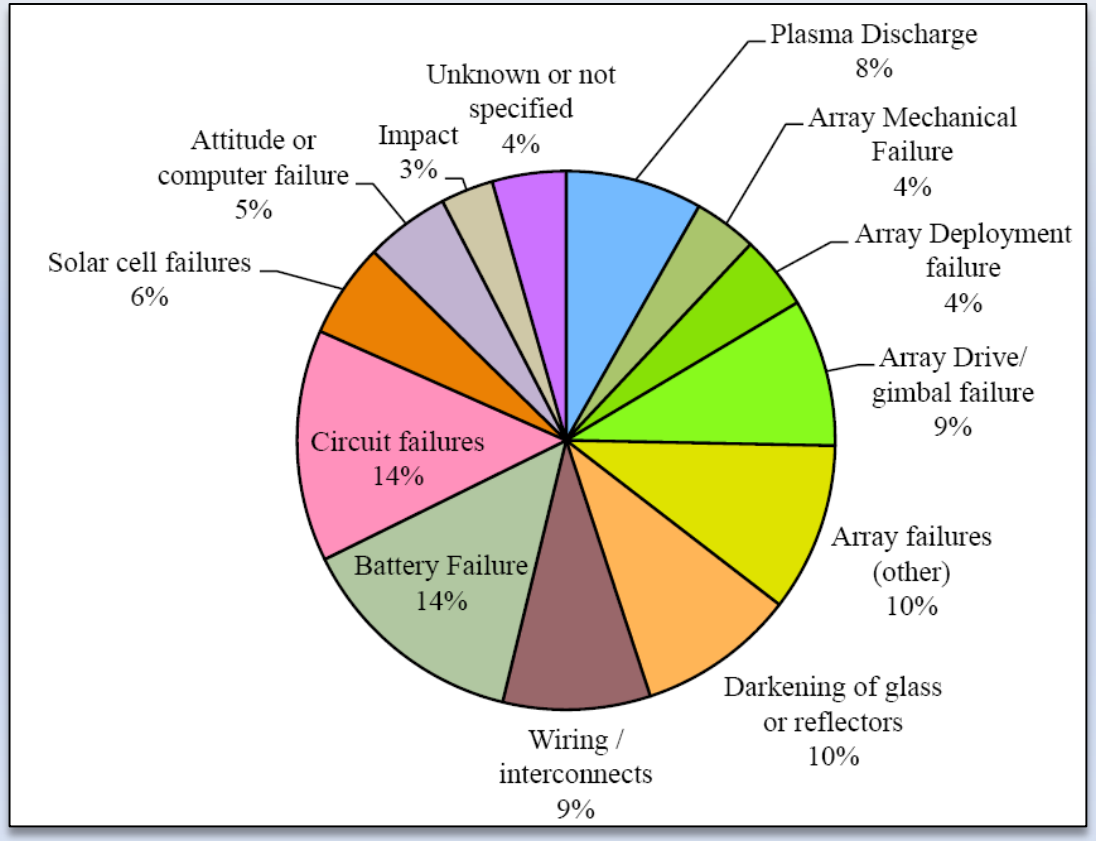
What's the Real Cost Driver?

- **Circuit failures (soft and hard) are one of the larger causes of mission failure**



Power-related failures, % (all incidents)

Tabulation of Power-related Satellite Failure Causes, G. Landis – NASA John Glenn Research Center

- 25% of satellite failures on orbit, nearly 50% of the insurance claims, are related to the electrical power system
- Loss of performance % is >>
- **> $400MM lost per year**

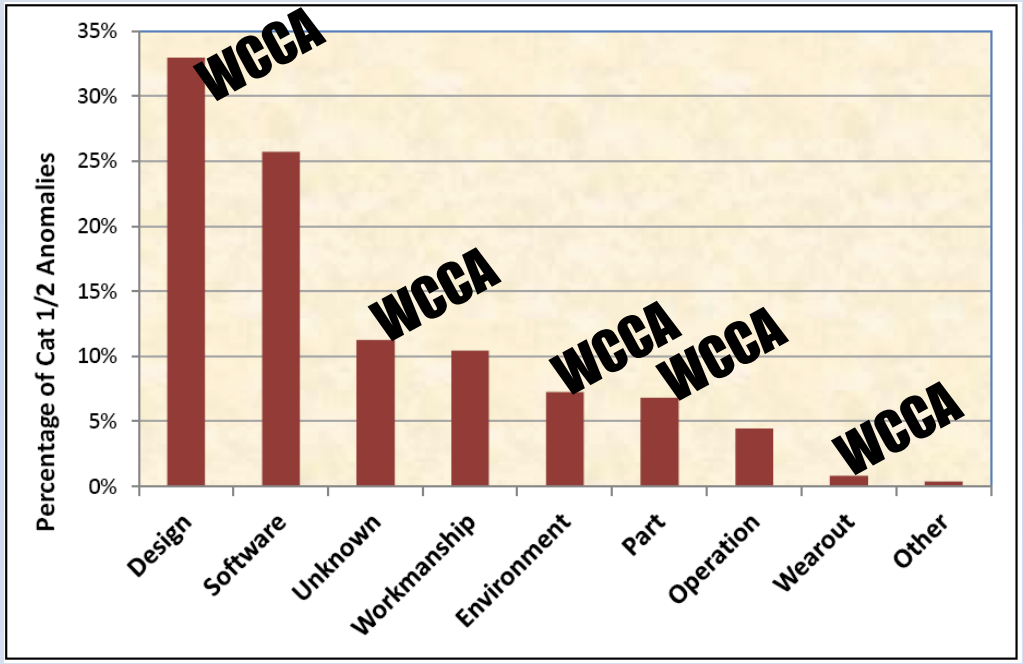
Insurance Costs Dominate

MA Cost, 2-5% of Spacecraft Cost

Cheaper than insurance, 6-33%

Escapes Have Impact

- We are clearly not doing enough WCCA since 32% of early on-orbit failures are design related



Causes of on-orbit anomalies - first 3 years

- Removing WCCA will likely ESCALATE costs due to the resulting increases in insurance costs
- WCCA is Not the cost driver
- The high rate of FAILURE and the cost of remedies with few degrees of freedom IS the ISSUE

"Proposed Common Data Views And General Trends From Anomaly Escape Assessment", Aerospace Corp, 2009

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Excuses Not to Do Analysis

- **Analysis is too Expensive/too Time Consuming**
  - The circuit has Heritage
  - We have Redundancy
  - We perform extensive testing
- **"Worst Case" Doesn't Happen**
  - **30-75% of the WC Analyses Are Non-Compliant**
- **Not 'Required'**
- **FAILURE IS AN OPTION**

"I have 10 units on-orbit and solid test data. Do I still need to do a WCCA?"

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Why Would you Do a WCCA

- **To know the margins – To quantify the risks (BOL and EOL)**
  - WCCA determines what tolerances/characteristics are critical - Sensitivities
- **We don't know a lot about the parts we buy (despite testing)**
  - Its not just about failures - Initial tolerances for many parameters are wide and often uncontrolled – we need to know what the design is sensitive to
  - Many parameters not rad tested
  - Testing many important characteristics is difficult/costly and can damage hardware
    - Current Limit, Bus Transients, Derived Requirements…
  - WCCA is the key to using new technology
- **WCCA can better address requirements creep/changes in objectives, parts substitutions/radiation requirements changes**
  - Assess SET
  - RDM Suspect – Only WCCA can tell you what total tolerance stack-up is acceptable
- **The process of WCCA (and not the effort) improves designs and catches many of the issues before they make it to the spacecraft**

"Lessons Learned from WCCA" – Space Power Workshop 2012

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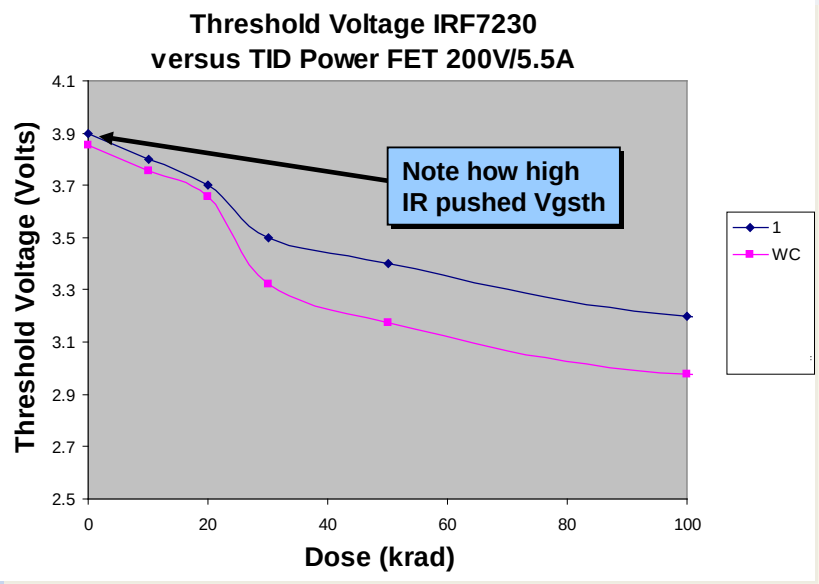
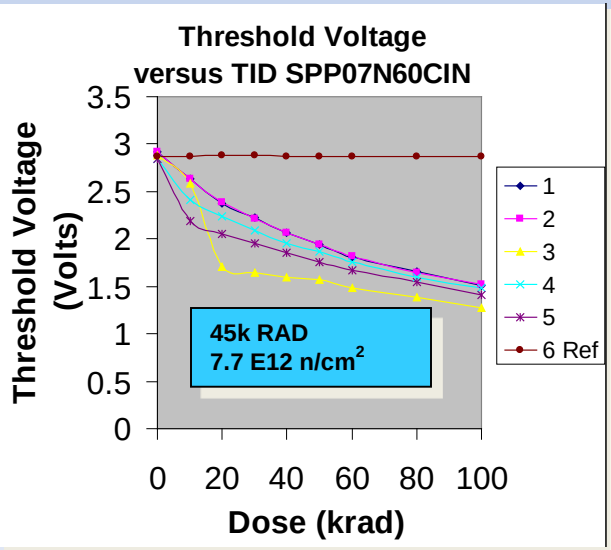
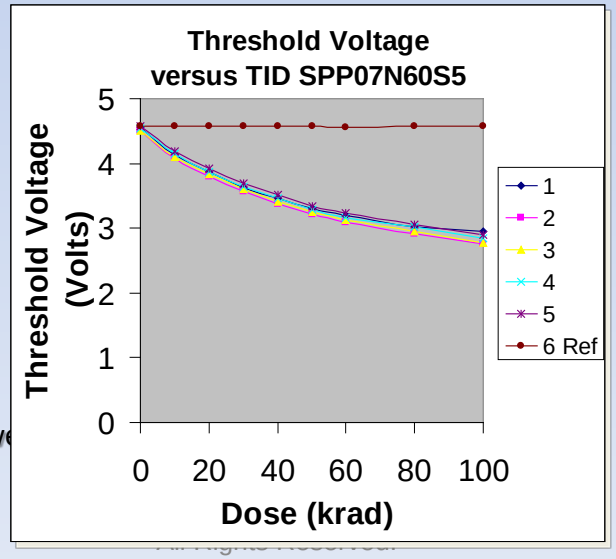
Example COTS Usage

- **LHC Atlas Power Supply uses COTS**
- **Its not simply about hard failures or fault tolerance**
- **We need to understand the tolerance stack-up**
- **How did we know what levels were acceptable? Analysis**
- Initial 2-4V Range, EOL < 1V
- Rad 0-2V, Temp. -4 - -10mV/C







Commercial FETs Vgs falls approximately 1.5V @ 100kRad

Cost per device w/o screening, $5.00 ea.

Where We Find Most Problems

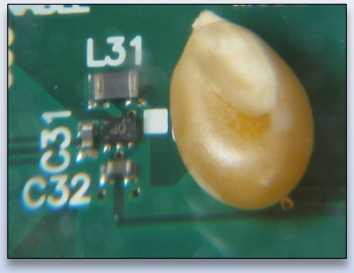
- **Power Supplies**
  - Poor Stability
    - Filter instability due to multiple converters/source impedance
    - Opamp buffers
    - LDOs and Voltage references - ESR impacted performance
  - Hybrids not analyzed to correct source/loading impedance
  - Startup and Shutdown – Inrush, Overshoot
  - Cross-Conduction, efficiency, Current Limit, UVLO, Switching Frequency, EMI Filtering
- **Signal & Power Integrity**
  - SSO Noise, PDN Resonances
  - Monotonicity
  - WC Timing
  - Logic Compatibility, improper terminations

Where We Find Most Problems

- **Simple Circuits**
  - High 'Q' Circuits
  - Opto-couplers: minimum CTR - leakage
  - Gate Drives
  - Opamp stability in unity gain configurations
- **"Minor" Design Changes**
- **Derived Requirements**
- **Heritage designs used for "updated" requirements**
- **Startup, Sequencing**
- **Interfaces**

Problems with Test Data

- **Insufficient equipment**
- **Insufficient knowledge of what to look for**
- **Misinterpretation of the results**
- **Test Isn't Cheap – TLYF (mission based)**



- **Many of the things we need to look at are simply not tested or even testable**
  - There is NO SUCH THING as 100% Test

New Book: "Power Integrity: Measuring, Optimizing, and Troubleshooting Power-Related Parameters in Electronics Systems" – Picotest.com

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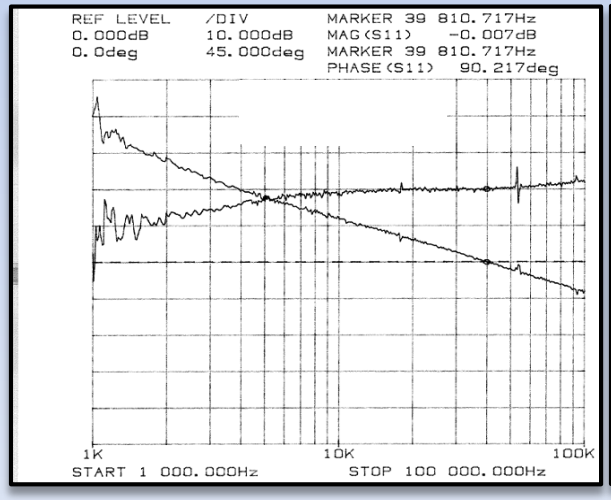
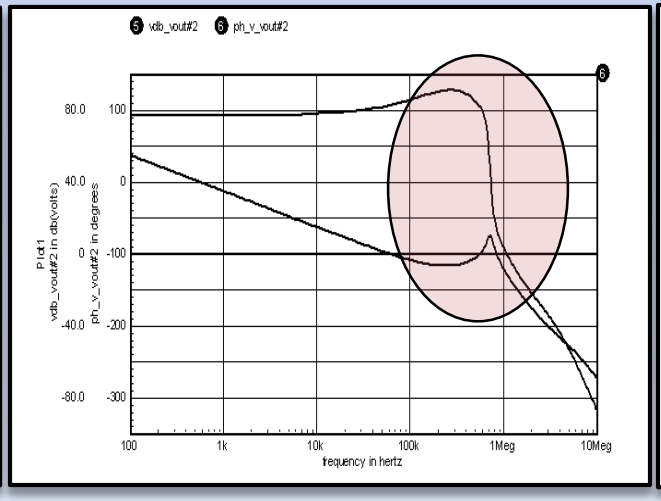
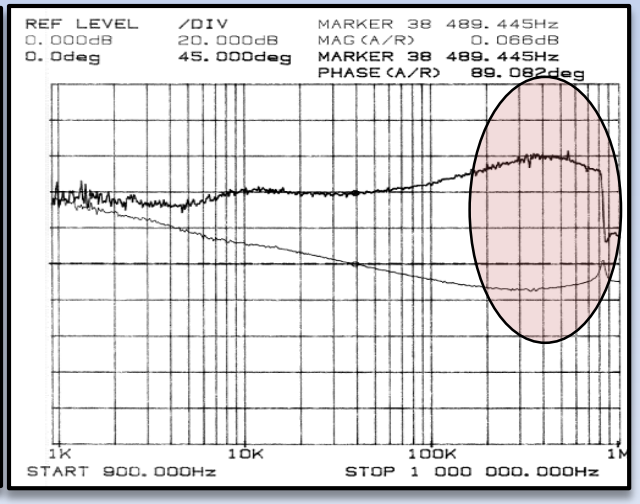
Problems with Test Data

- Test conditions are often not defined
- Test data is often not over a wide enough range to see issues
- Signals are often overdriven to get clean (but incorrect) plots
- Analysis Done Without Hardware







Examples Where Test Didn't

- **Battery Charger - WCCA used to assess on-orbit failure**
  - Skipped pulses at low current, no WCCA was done initially, not all conditions were tested
  - Both Mosfets could be on at EOL
  - Poor gate drive ringing cased FET turn-on

- **Motor Controller – Unstable amplifier caused array motor to oscillate, no WCCA was done initially**

- **WCCA ALWAYS results in improved reliability not to mention improved engineers**

Expanded VTF Margin Testing

- **NASA has determined that an expanded Voltage / Temperature / Frequency Margin Test set is a viable alternative to WCCA**
- **Why/When is this not the case? What does it miss?**
  - When Initial tolerance are large or not impacted
  - When aging or radiation is significant and/or not temperature dependent
  - Part stresses or degradation are not seen
- **(Another NASA lesson learned) - From Flight experience**
  - Bounded design environments are exceeded
  - Worst case environment doesn't always occur at the bounds
- **Inherently doesn't quantify risk/margin**

ACTIVITY	WHAT IS DONE	WHY IT IS DONE	WHEN IT IS CALLED FOR	WHEN IT IS PERFORMED
Voltage / Temperature Margin Test	Exceed the expected flight limits of voltage, temperature, and frequency to simulate hardware worst case functional performance.	Permits real-time review of complex circuits, allowing the weighing of alternative design actions.	A viable alternative to Worst Case Analysis for flight programs/projects where tradeoffs of risk versus	System design and integration.

How to Fix the Problem

- **TOR Establishes Risk Reducing, Cost Effective Guidelines**

- **It starts with a well coordinated WCCA Plan**
  - Define Requirements, Analyses, Methods, Tolerances, Models, Tests, & People
- **Intelligent Rigorousness is the Goal**
  - Tailoring = Balancing Risk vs. Analysis Coverage
  - How much risk can the program accept?

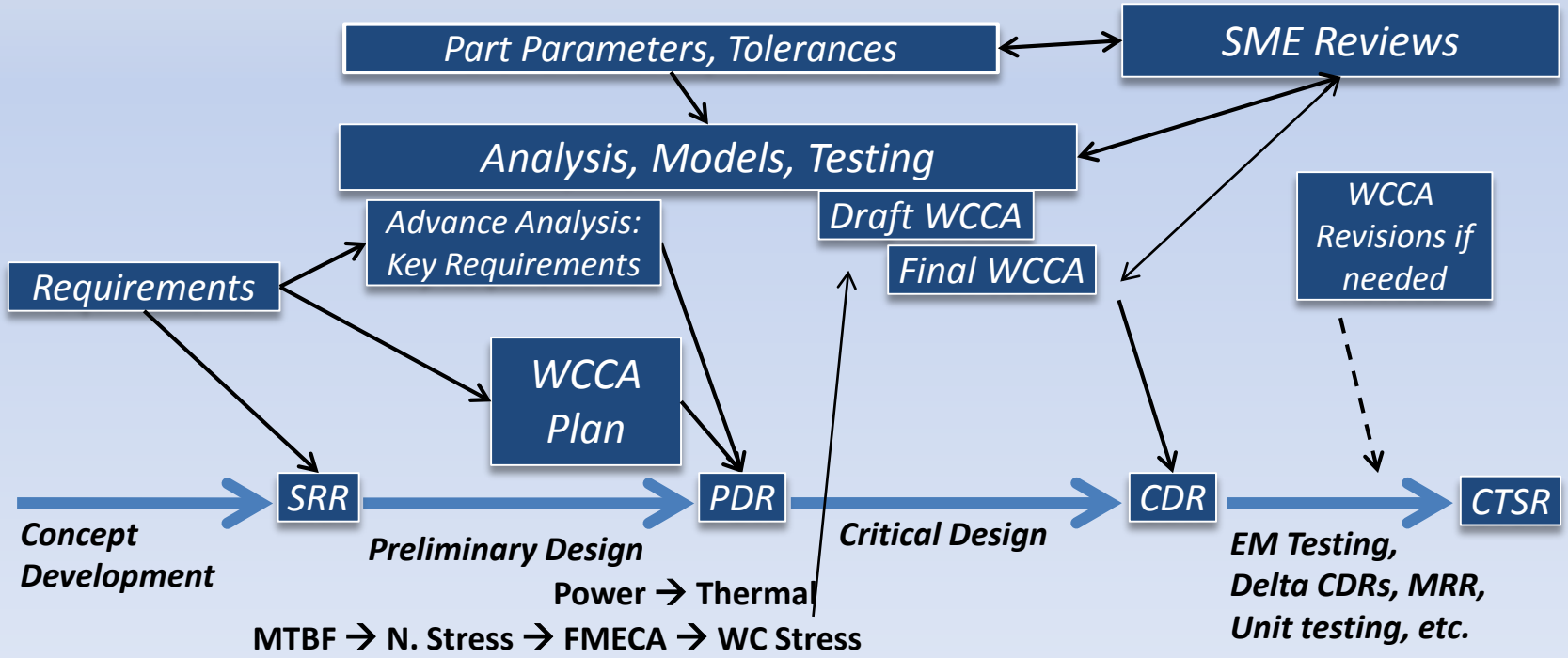
WCCA PLAN - What the TOR Suggests:

List of applicable documents
List of Design Elements
Detailed List of Circuits and Analyses
WCCA Compliance Matrix (WCM)
Analysis Methods and Tools
WC Operating Modes and Conditions
Personnel Resources
Parts Characterization Resources
Desc. of Model Validation Approaches
Testing Necessary for WCCA
Schedule with Key Milestone Dates
Review Personnel and Scheduling

APC DESIGN			Mission Life 22 Years, RAD 100k, 2E11				Analysis Information	
Specifications, Requirements, Design Objectives	R#	DRD #	Compliance	Requirement	BOL Status Nominal	EOL Status RSS-RSS EVA-EVA	Analysis Description	Analysis Method
MODULE 1 – Tolerance Analysis – High Risk Analysis								
Stability - Gain and Phase Margin & Negative Input Impedance	1							
Conducted Susceptability - CS	2							
Input Conducted Emissions - CE	3							
Input Filter - Damping, Attenuation	4							
Input Under Voltage ON/OFF threshold/ Latch off, no oscillations	5							
Output Ripple	6							
Switching Frequency Tolerance	7							
Efficiency	8							

When To Analyze?

- **The new TOR expands the time over which WCCA occurs**
  - Sequence in important – Some analyses must proceed in series/wait for layout
- **Schedule compression is a common escape**
  - Analyses reduced, Shorter time to fix/reanalyze
- **Timing is Key (Test Data and Analysis Need to Meet Up)**



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Tailor TOR Elements Based on Risk

- **Grey Beard Design Review – Find soft spots, establish risk**
  - Continue with Informal Concurrent Peer review
- **Let WCCA Plan, FMECA, Stress, and Review Drive Analysis Checklists**
  - Analysis List → Models, Tolerances and Test Data Needed
  - Use WCCA to Assess Margins and FIX problems
- **Prototype Early – Gather correlation & performance data**
  - TLYF – ALYF - EDUs and Prototypes Concurrent with WCCA
- **Parallelize and Be Efficient**
  - Apply Validated Models and Math developed during the design phase
  - SPICE simulation has many pitfalls – Use Sensitivity Analysis
    - RSS Tolerances, Double RSS(2.5 σ 99%) $2\sigma \approx 95\%$, $1\sigma \approx 68\%$
- **Limit the documentation and meetings (Sacrifice Reviewability)**

Summary

- Test, FMECA, and Stress analysis are not sufficient
- Correlation of hardware test with WCCA and its models is the best way to verify and validate a design
- Well coordinated and reviewed test-analysis pairing is the best path to mission assurance
- When implemented properly, WCCA Does NOT "Cost" money, its cheap insurance

"Don't pare down to the bone unless you know where the bone is."

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