



Introduction to WCCA

An in-depth discussion of the challenges facing WCCA analysts along with the skills, data, techniques, personnel, and resources required to effectively perform a worst case analysis

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WCCA Topics

- What is Worst Case Circuit Analysis (“WCCA”)
- Why and When to Perform Worst Case Analysis
- Why Stress Analysis Isn’t Sufficient
- Who should perform the analysis and Why Your In-House Resources May Not Be Up to the Task
- WCCA Successes - Good (and Bad)
- WCCA Today Under the New Aerospace TOR Guidelines
- Cost and Schedule Savers and Drivers
- Improving Your WCCA
- Future Challenges



This presentation discusses various aspects of Worst Case Circuit Analysis. The content is taken from various papers, application notes, and lectures given by Charles Hymowitz (Managing Director) and Steve Sandler (Chief Engineer), as well as, the AEi Systems Worst Case Circuit Analysis Training Workshop.

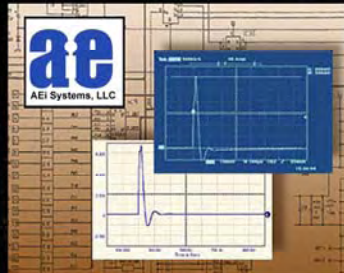
INTRODUCTION

Worst Case Circuit Analysis (WCCA) combined with Stress & Derating, Failure Modes & Effects Criticality (FMECA) and MTBF analyses are essential to the design of any reliable system. It is through this series of analyses that performance aspects of the system and design are examined, considered, and evaluated, in minute detail.

Actions taken to understand and modify designs based on these analyses increase the statistical likelihood that the analyzed design will meet the identified performance requirements throughout the product’s lifetime and particularly at the End-of-Life.

WCCA is not simple to perform or trivial. As you go through the presentation you will be able to get a feel for the range of skills, data, and capabilities that are required to successfully pull off an analysis including SPICE/simulation, part and circuit testing, modeling, circuit mathematics, part tolerances, reporting, etc.

Who is AEi Systems?



AEi Systems, LLC is a recognized leader in worst case, failure and reliability analysis, SPICE modeling, and other analysis SDRLs

www.AENG.com Approaching 20 Years of Service

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AEi Systems, LLC is an engineering services provider to major military, aerospace and commercial systems contractors, their subcontractors, and most Fortune 50 Aerospace companies.

AEi Systems was established as Analytical Engineering in 1995 to support the increasing demand for Worst Case Circuit Analysis in the Space market. AEi System's core strengths in linear, digital, power and RF circuit analysis, component test and troubleshooting, and SPICE simulation and modeling has allowed AEi Systems to expand into a wide variety of engineering reliability services.

In 2014, AEi Systems follows the AEi tradition of service to a demanding clientele. Our offerings continue to grow dramatically through repeat business and referrals.

Most recently, AEi Systems was recognized by Boeing Satellite Systems with an Achievement Award for the GPS IIF Clock Worst Case Circuit Analysis.

(<http://www.aeng.com/press.htm>)

Engineering Experience

- **Charles Hymowitz**
 - Managing Director of AEi Systems and co-founder of Intusoft
 - SME WCCA - Key Member of Aerospace WCCA Standards Team
- **Steve Sandler**
 - AEi Founder, Chief Engineer
 - 35 Years of Space Design and Analysis Experience



Charles E. Hymowitz, Managing Director

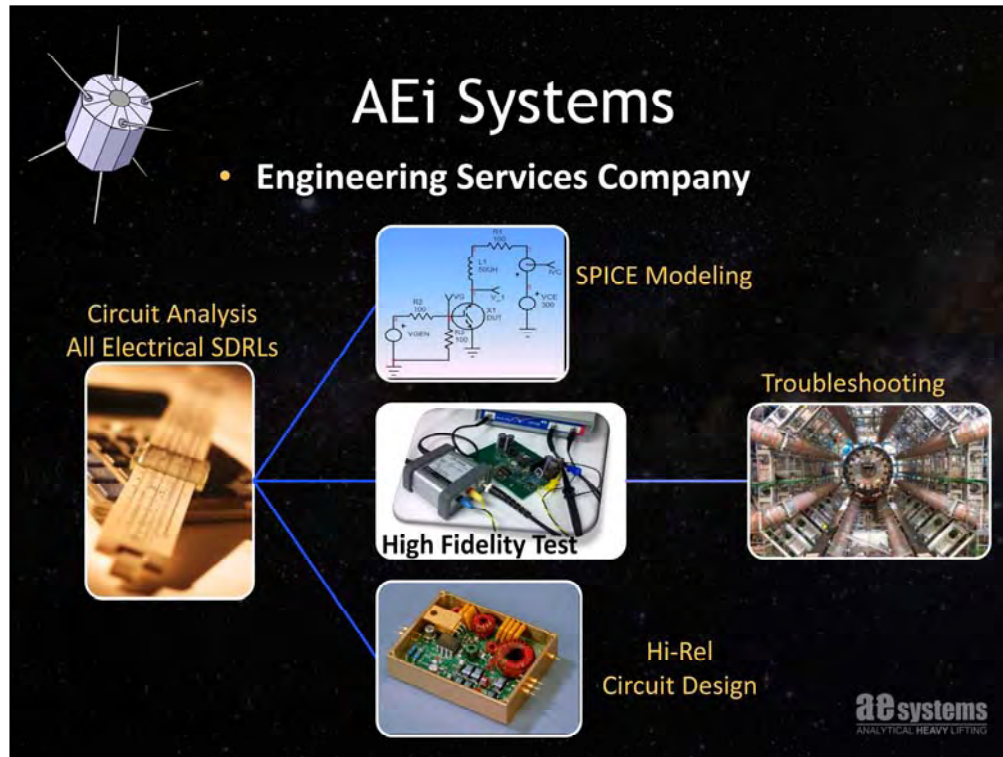
Mr. Hymowitz is a technologist and business executive with over 30 years of experience in the engineering services and EDA software markets. Mr. Hymowitz has been Chairman and Director of AEi Systems, LLC since its re-organization in 2002. He currently guides all aspects of the company's operations including technical services, product quality, sales and a staff of over 30 in-house and consulting engineers. While at the helm of AEi Systems, revenues and customer base have grown over 10 fold.

In 2012, Charles Hymowitz was recognized as the only independent (not employed directly by a prime aerospace contractor) SME (subject matter expert) on Worst Case Analysis. Mr. Hymowitz was a key contributor to the creation of Aerospace Corporations' industry guidelines for WCCA.

Mr. Hymowitz co-founded Intusoft, a leading CAE/EDA software corporation where he was a Director and held several positions, including Vice President, Product Development and, most recently, Chief Operating Officer. He is the co-author and editor of the books, "SPICE Circuit Handbook", "Simulating with SPICE", "The SPICE Cookbook", "Power Specialist's App Note Book" and "The SPICE Applications Handbook."

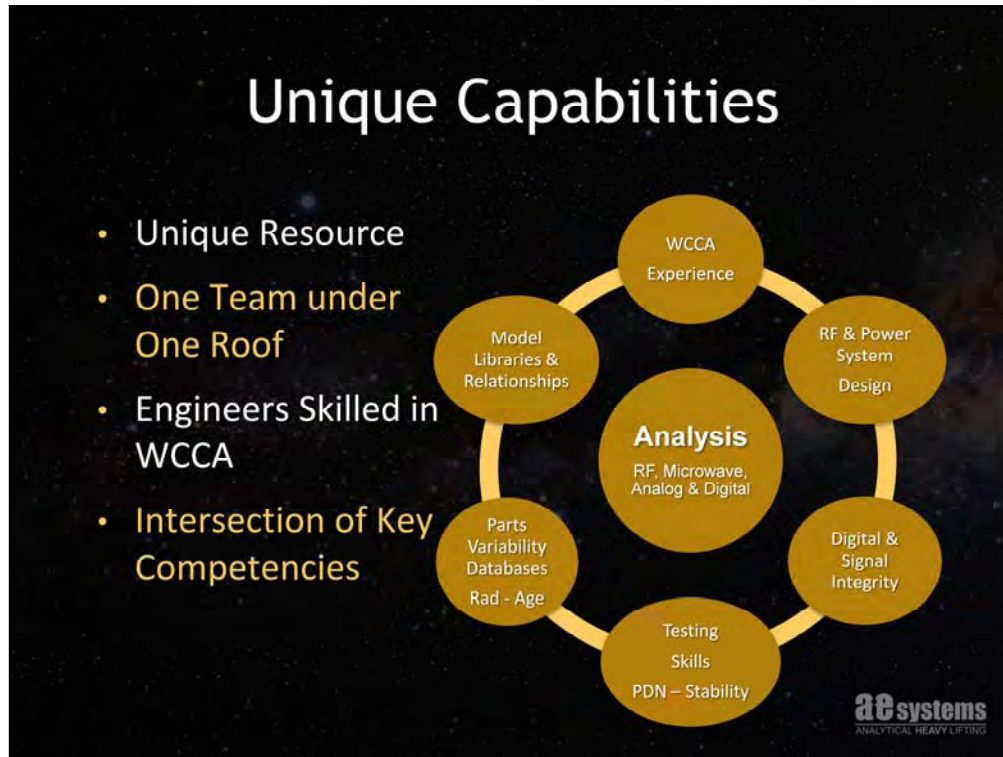
Steve Sandler, Chief Engineer, Founder

Mr. Sandler is the founder and former CEO of Analytical Engineering, Inc., the predecessor of AEi Systems. He has over 35 years experience in the design and analysis of power conversion equipment for military and space applications. In his current position, Mr. Sandler is responsible for the design, worst case analysis, and reliability analysis of RF and power electronic systems. Mr. Sandler also spearheaded the development of a complete power IC model library for SPICE simulators. Mr. Sandler has worked on numerous satellite projects such as Milstar II Defense Satellite, International Space Station, Tempo, P-81, HS-702, LS-1300, CRiS, GPS II/III, Globalstar, Omegasat, and many others. He is the author of several books on simulation and test. His latest book is entitled Power Integrity: Measuring, Optimizing, and Troubleshooting Power-Related Parameters in Electronics System.



AEi Systems Services (<http://www.aeng.com/services.htm>) include:

- Worst-Case Circuit Analysis (<http://www.aeng.com/wcca.htm>)
 - Power, RF, Digital, and Linear systems of ALL TYPES
- Other Analyses - SDRLs
 - MTBF/Reliability
 - FMEA/FMECA
 - Stress & Derating
 - Radiation Analysis
- Signal, Power Integrity, and Board Level Digital Circuit Analysis
- Customized Rad-Hard Circuit Designs – For License and Self-Build
- Hardware Failure Analysis and Troubleshooting
- Component and Circuit Testing
- SPICE Modeling



AEi Systems maintains a talented staff of full-time analysts who enable us to deliver our services on time, under budget, and to customer specification.

We have expertise in analog circuits, power systems, RF and Microwave, and digital applications from low to high speed.

AEi Systems is the world's leader in SPICE Modeling. We have been the go to resource for the leading analog IC manufacturers, as well as EDA software providers. We support all SPICE variants including PSpice, SIMetrix, LTspice, SIMPLIS, and others.

You can find AEi Systems' models on the web sites of Linear Technology, ON Semiconductor, Intersil, International Rectifier, Microsemi, National Semiconductor, Vishay, Micrel, Analog Devices, Texas Instruments, Semicoa, and many others.

AEi's Broad Customer Base

- Aeroflex
- Allied Signal
- Alstom-Schilling
- Analog Devices
- Ball Aerospace
- BAE Systems
- Boeing
- DELL
- EDO
- Excelitas
- Ford
- Goodrich
- General Dynamics
- Honeywell
- Hughes
- Intersil
- IR
- ITT
- L3
- Linear Technology
- Lockheed-Martin
- Lucix
- Medtronic
- Micrel
- Motorola/GDD
- National Semiconductor
- NGC
- ON Semiconductor
- Raytheon
- Sierra Microwave
- Smith-Nephew
- Space Systems Loral
- Seakr
- Texas Instruments
- Vishay
- Visteon
- Watkins-Johnson

Partial Program List

- Space Station
- Milstar
- Tempo
- P-81
- SMUJ
- Omegasat
- HS-702
- XPC
- Intellsat
- Globalstar
- Spaceway
- CMIS
- MUOS
- GPS IIR-I/II/III
- P1196
- CRIS
- GOES
- GLM
- JUNO
- WGS
- OASIS
- MSV
- P321
- P734

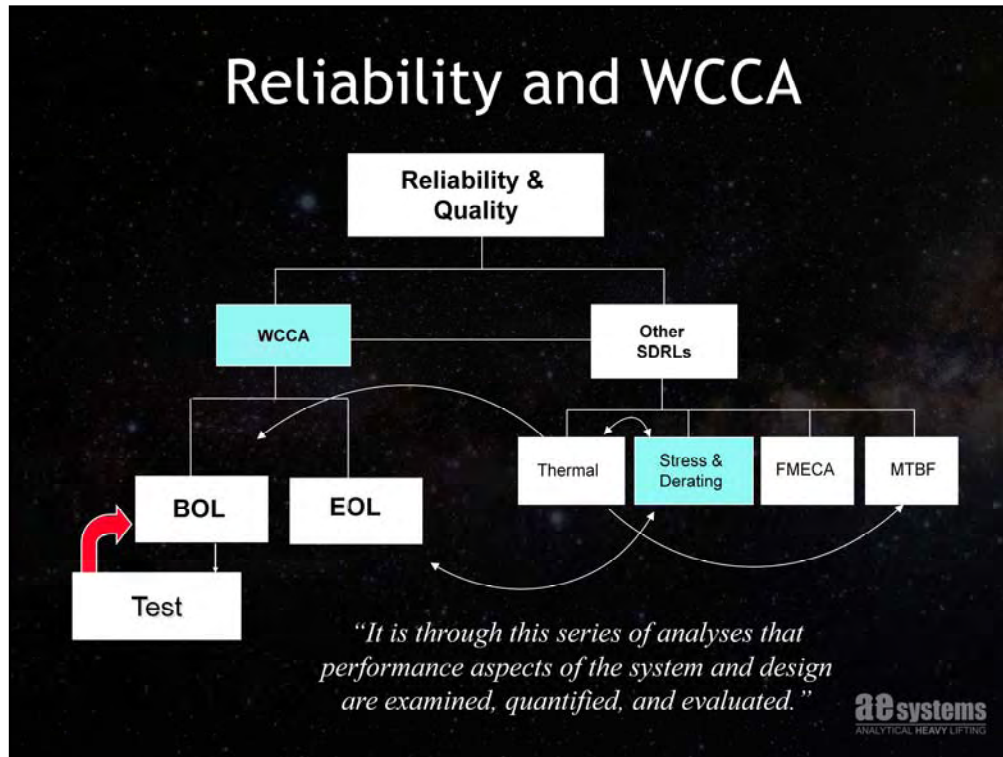
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AEi Systems has specialized in WCCA for over 20 years. We count as our customers the majority of the prime aerospace manufacturers and dozens of their subcontractors.

We have been called in to troubleshoot some of their toughest problems on such space projects as the Space Station, GPS II and III, as well as terrestrial projects such as the Large Hardon Collider at CERN, implantable medical products, and many automotive designs.

AEi Systems services all high reliability industries including Medical, Automotive, and Aerospace.

While most of our business is for the Aerospace field we also perform analysis for Military and Commercial customers, specializing in high reliability applications such as medical, nuclear, and communications.



Reliability analyses increase the likelihood that the design will meet the intended performance requirements throughout the product's lifetime and particularly at the End-of-Life.

Worst Case Circuit Analysis (WCCA) combined with Stress & Derating, Failure Modes & Effects Criticality (FMECA) and MTBF analyses are essential to the design of any reliable system.

For more reasons why a WCCA is critical to mission success, please see:

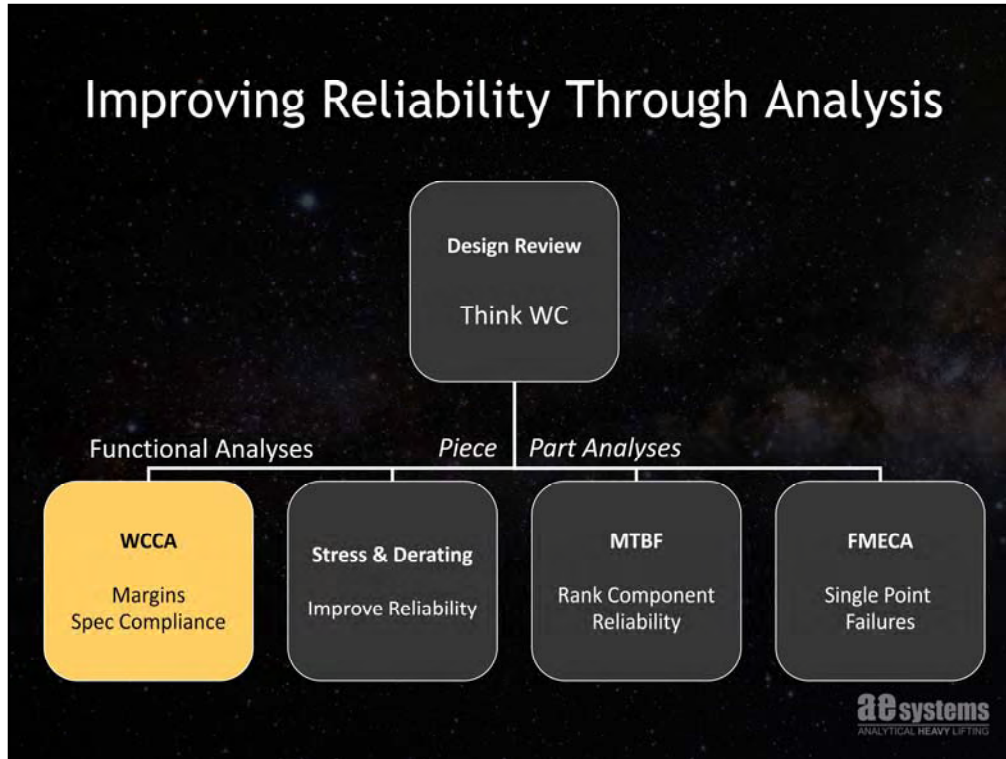
http://www.aeng.com/design_analysis.htm - "Why Do a WCCA?"

BOL = Beginning-of-Life

EOL = End-of-Life

MTBF = Mean Time Between Failures

SDRL = Subcontractor Documentation Requirements List



The “Worst Case” Design Review presents a unique opportunity to highlight and correct findings and non-compliances prior to the commencement of the actual WCCA. It is the MOST COST EFFECTIVE activity that can be performed prior to production, often saving design changes and board iterations.

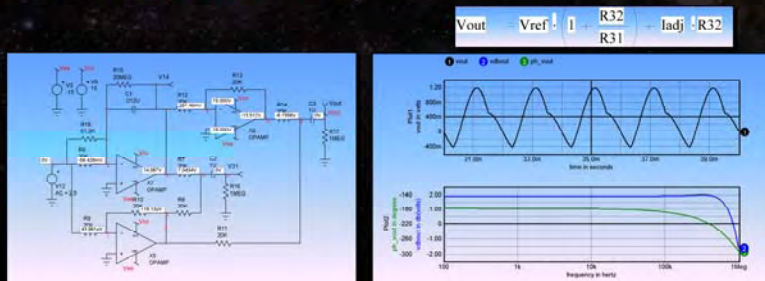
MTBF, FMECA, and Stress & Derating analyses are all part based analyses. They do not focus on what WCCA focuses on which is functional analysis.

FMECA (Failure Mode Effects Criticality Analysis) - Focuses the WCCA Effort – Which functions are the most critical and cause the most damage. The FMECA can be used to pinpoint high risk items that can then be further analyzed for their worst case performance. FMECA requires a stress analysis and an MTBF analysis.

Stress & Derating – A heavily mathematical analysis focusing on assessing various component attribute and whether they meet the manufacturers deratings under various operating extremes. It should be noted that the tolerances, models and math needed for the Stress analyses greatly overlap with those from the WCCA. The two should be done sequentially with WCCA first, but if done in parallel, care should be taken to make sure duplication is avoided. Both a nominal stress analysis (required for the MTBF analysis) and a worst case stress analysis (both steady state and transient) should be performed.

What is a Worst Case Analysis?

“Worst Case Analysis is a quantitative assessment of performance, accounting for manufacturing, environmental, aging, and radiation tolerances”



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Worst Case Circuit Analysis (WCCA) is a cost effective means of screening a design to ensure with a high degree of confidence that potential defects and deficiencies are identified and eliminated PRIOR TO and DURING test, production, and delivery.

The WCCA is not an after-the-fact exercise but a cost-effective integral part of the design process. When a WCCA is performed properly, the results often save companies millions of dollars in lost revenue, dramatically lessen the possibility of human injury, and avert potential disasters both monetary and political.

It's not always clear if WCCA is an art, a science, or a combination of both!

What is a Worst Case Analysis?

Worst Case Circuit Analysis is a Mindset!

Engineers must learn this.
For most it's not easy or natural.

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WCCA examines the effects on electronic circuits caused by potentially large magnitudes of variations of electronic piece-parts beyond their initial tolerance. The variations can be the result of aging or environmental influences, which can cause circuit outputs to drift out of specification.

WCCA also determines the mathematical sensitivity of circuit performance to these variations and provides both statistical and non-statistical methods for handling the variables that affect circuit performance. These results can be invaluable in helping to improve product quality.

But most of all it is a mindset. This is the major challenge for most engineers, especially when engineers are analyzing their own design.

What WCCA Computes

- What typical testing sees: **160kHz**
- What we calculate...a range

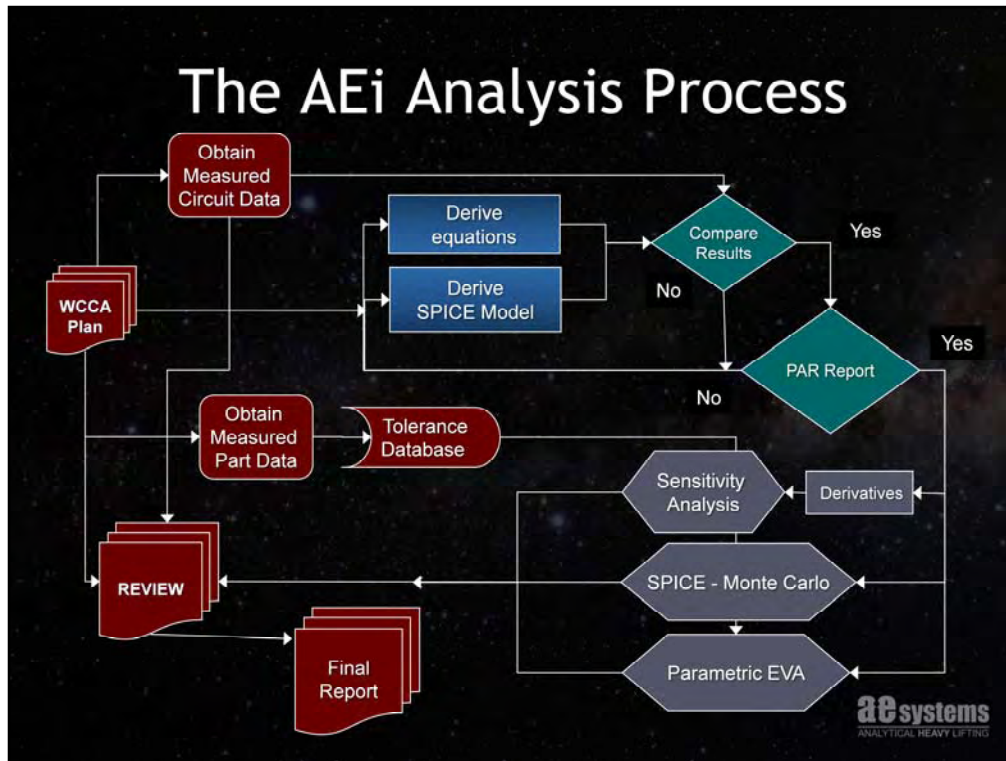
Comply: Yes		Switching Frequency Summary		
Parameter Requirement	Condition	Nominal	BOL RSS-EVA	EOLEVA
Switching Freq 130-200kHz		176.15 kHz	147.05 – 205.8 kHz	125.1 – 227.75 kHz
Duty Cycle 0.46 – 0.48		0.468	0.4639 – 0.472	0.455 – 0.481

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Unlike nominal analysis or testing (and in most cases, manufacturer's data), WCCA does not see a single value for most circuit functions; it sees a range due to tolerances and operating condition variations.

Testing does not reveal the range of functionality and the EOL effects of component aging and radiation.

This particular example, power supply switching frequency, can greatly impact issues such as magnetics performance, EMI, and clock jitter.



The items in red usually require interaction with and approval of the program.

The process begins with extensive efforts associated with gathering tolerances, component measurements, and circuit models. Once model correlation is achieved, the analysis process can begin.

AEi Systems validates results using a minimum of two methods and sometimes three methods in order to increase confidence in the results. WCCA is that important.

WCCA Sequence

- Review Circuit, Specifications, Requirements, and Guidelines
- Obtain Measured Data and Tolerances
- Create Models – Correlate - Iterate
- Perform Analysis
- Create Report – Internal Review
- Deliver Report
- Support
- WCCA requires a great deal of investigation and a number of educated assumptions. We really don't know a lot about the performance bounds of the parts we use



Task	WCCA Sequence Steps
Define the Requirements THE WCCA PLAN	• Define the circuitry to be analyzed (analog, digital, interfaces, etc.) • Determine availability of component data and models • Identify the people, tools and reviewers available to support the analysis • Review all relevant specifications and "Theory of Operation" • Involve team to gather "derived specification" requirements (Parts, Reliability, Systems, Marketing, etc.) • Detail all functional interactions (inputs and outputs) for EACH analysis including compliance criteria • Write it down and get approval before proceeding
Obtain the Data	• Requirements and Specifications, Flow-downs • Schematics, Block Diagrams, Interconnection Lists and Wiring Diagrams • Parts Lists with ALL possible manufacturers, data sheets, Mil-Spec drawings, SCDs, and ALL magnetics information • Operational Environments, Thermal Design Analysis, and Radiation Requirements
Develop a Part Parameter Database	• Review the nominal analysis in order to find out for which parameters and characteristics data is needed. • For EACH part, critical parameters include environmental (ambient and self-heating temperature, vibration, humidity, radiation) and aging • Write it down and get approval before proceeding, then LOCK IT DOWN.
Identify Method of Analysis	• Full analysis vs. circuit partitioning to critical functions • Sensitivity, Monte Carlo, Parametric EVA • BOL (For ATP Comparison), EOL, RSS, EVA
Perform the Analysis	• Review the Nominal Math and SPICE • Correlate the answers to Bench data • Make sure analysis conditions MATCH those required by the compliance criteria • Apply the Tolerances for Monte Carlo analyses (How many Sigma?) • Analyze circuit to determine if performance under worst case conditions is achieved • Compare WCCA results with the specifications, documenting all inconsistencies • Analyst must be knowledgeable of the circuit and parameters being examined
Document the Results	• Analysis results should be verifiable (document or reference all information used to develop the analysis - circuit equations, part data sources, and circuit simulation tools used). • Another engineer should be able to verify your results/repeat the analysis without your assistance
Review and Revise	• The WCCA should be FULLY reviewed by experts and team members whose performance the circuit impacts including the original designer

WCCA Example - Plan

- The Analysis Flow and Methodology is Key to Efficiency
- **Intelligent Rigorousness is the Goal**
- Define Analyses, Methods, Models, Tests, & People

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 Susceptibility - 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							

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The WCCA Plan is where things first go wrong. A good portion of what we need to analyze is often not specified or listed in guidelines, requirements documents or the statement of work.

Designers who do their own WCCA often leave out items they perceive as low-risk. This is where we find many non-compliances; the basic stuff.

This is where experience comes into play. When we review someone else's WCCA the first thing we look for is what is missing.

Additionally, as per Aerospace TOR-2012(8960)-4 Rev .A Electrical Design Worst-Case Circuit Analysis: Guidelines and Draft Standard, the WCCA plan is now required before PDR. This is a concern. Often the circuit design not settled and specifications are still in flux. It is critical that the WCCA plan be revisited and updated once the design is complete in order to add analyses that might have been missed.

One last item, the WCCA plan is essential to costing the WCCA effort. Without all the information the scope of the WCCA work (what tolerances are needed, what models/math are needed, what test data is needed, etc.) will not be evident.

WCCA Example - Parts Variability Database

- Obtain Measured Data and Tolerances

Tolerance Type Definition	nominal value	Initial			Temperature			Aging			Radiation		
		RDM	+	-	RDM	+	-	RDM	+	-	RDM	+	-
Derived Quantities													
Frequency	7028					18.09%	18.57%				9.63%		
Vin	10	1.50%						1.50%					
Components													
M55342K		1.00%			0.46%			0.54%			0.00%		
RWR80	68.1	1.00%			4.23%	5.20%	1.00%				0.00%		
CDR8X10		10.00%			15.00%			21.00%					
CWR_C_2.2u	2.2u	10.00%			10%			10.00%			0.00%		
CWR_ESR_2.2u		40.00%				16.50%	11.20%				0.00%		
CWR_C_10u	10u	10.00%			10%			10.00%			0.00%		
CWR_ESR_10u		40.00%				16.50%	11.20%				0.00%		
1N5819_Vf	0.55	18.18%			10.00%			5.00%			8.91%		
HS117_Vref	1.25E+00	3.00%			1.00%			0.40%			4.00%		
HS117_Iadj	5.00E-05	75.00%			25.00%			10.00%			7.00%		

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Tolerances are the heart of the WCCA. One mistake could easily ripple through much of the analysis requiring significant rework.

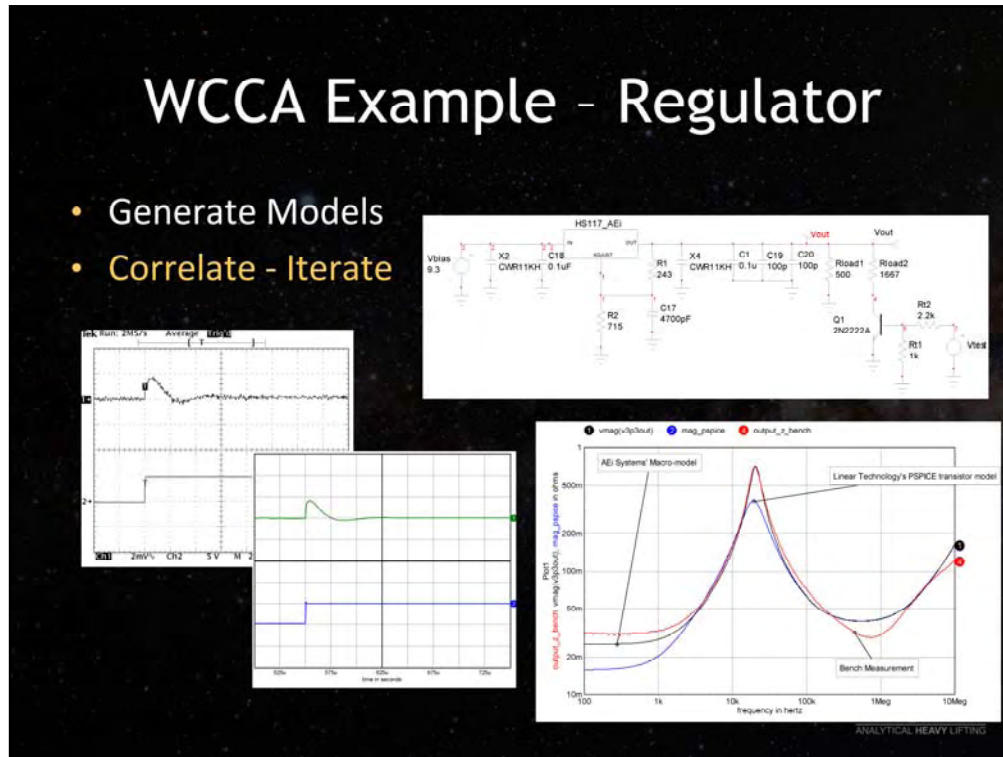
The Parts Variability (Tolerance) Database is a living document. As analyses are completed the results are added so that downstream analyses can use the results.

It is essential that the Database remain under software control, so that changes are reviewed and approved.

Everyone involved in the WCCA should use the same Tolerance Database.

WCCA Example - Regulator

- Generate Models
- Correlate - Iterate



It all starts with a really good model, but how good is good enough? That depends on what analysis needs to be done. Modeling an entire part, with all its nuances is not cost effective.

Fidelity is expensive. (See “Lessons Learned from SPICE” and “SPICE models need correlation to measurements”, http://www.aeng.com/spice_modeling.htm)

You should model parts only to the level required by the analysis result.

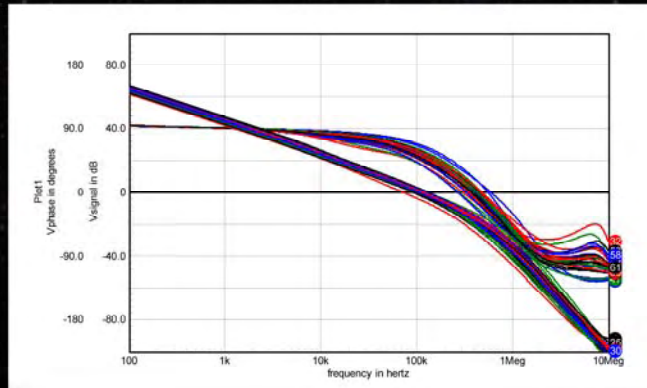
Rarely are vendor supplied models, or the models that come with EDA tools adequate for WCCA. They should be avoided if at all possible. In any case, all models should be thoroughly vetted and correlated.

This is one of the things we first teach our young engineers and it can take years to master.

In SPICE it's easy to get yourself into trouble and not know it.

WCCA Example - Analysis

- Compute the BOL and EOL Responses
- Math and Simulation



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We are often asked, “WCCA seems expensive, what do we get for our money?”

On average over 30%-40% of the requirements we analyze are found to be non-compliant.

WCCA helps to design reliability into hardware for long-term, trouble-free field operation.

Electronic piece-parts fail in two distinct modes: catastrophic and out-of-tolerance limits whereby the circuit continues to function but with degraded performance, ultimately exceeding the circuit's required operating limits. Catastrophic failures can be minimized through MTBF, stress and derating, and FMECA analyses which help ensure that all parts are properly derated and that degradation occurs “gracefully.” A WCCA allows you to predict and evaluate the circuit performance limits under all of the combinations of part tolerances.

WCCA Example - Report

- The Report is the Analysis

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1.1.1

R03000 WCCA

5.1 Stability - Gain and Phase Margin

5.1.1 Scope

The objective of this analysis is to compute the worst case stability performance (phase margin and gain margin) of the R03000 linear regulator application circuit ($0.3V_{IN} = 1.2V_{OUT}$).

Analysis		Stability		
Performed by:		130701		
Issue Run Date:		03/01/13		
Assembly:		R03000		
Manufacturer Analysis:		N/A		
SPICE File:		R03000_12V100.DWG		
Excel File:		Module 1.xls		
Example 1		Stability Summary		
Parameter Requirement	Condition	Simulated	EOS, 1 step	EOS, 4 step
Stability	Full 10 Range	94.1dB	90.71dB - 110.00dB	90.71dB - 110.00dB
Phase Margin	Full 10 Range	83.3°	37.72° - 48.99°	38.87° - 74.14°
Gain Margin	Full 10 Range	15.4dB	15.4dB - 15.4dB	15.4dB - 15.4dB

5.1.2 Functional Descriptions

The V_{OUT} input of the R03000 LDO provides power for the internal circuitry of the device while the V_{IN} input connects directly to the collector of the pass transistor providing the power path to the output regulator. By applying a bias voltage to V_{OUT} , that is at least 1.1V greater than V_{IN} , the R03000 regulator can achieve a dropout voltage as low as $1.0V_{IN}$. As reference current of 1.0mA through resistor R1, which is connected from the SET pin to ground, programs the output voltage. The stability of the R03000 linear regulator is dependent on the operating load current, output capacitance and corresponding ESR, along with the internal transconductance and compensation components.

File 1 | Module 1.xls

Regulator and Compensation
in AEI Systems, LLC

Revision 001/01/13

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The level of documentation, the detail, the amount of explanation, can all vary greatly. The more documentation, the easier the review process, but the more expensive the analysis becomes. The impact of the decision will be significant.

What we strive for at AEi is that the level of detail should be sufficient for a competent engineer to repeat the results WITHOUT having to talk to the designer or the engineers that performed the original analysis.

Why Do a WCCA?

- Quantify Risk, Performance Boundaries, Changes and Margins
- **Assure End-Of-Life Spec Compliance**
- Assure Quality, Robustness, and Reliability
- **Support New Technology**
- Support ATP limits and SCD requirements definition
- **Insurance – Financial, Political and Legal**



Other Reasons to do WCCA

- Assess interfaces to your design/between designs
- Help to make sure critical requirements are defined
- To more easily address requirements creep/changes in objectives, parts substitutions/radiation requirements changes
- Find unacceptable variations early—Before expensive build/test iterations
- Determine when a given part type doesn't work well or represents "Overkill"
- Better understand designs and areas for improvement
- Evaluate things we couldn't easily evaluate otherwise..... destructive, deadly, catastrophic.....
- New Technologies or New Components – WCCA is essential for understanding the impact of new parts

The process of WCCA (and not the effort) improves designs and catches many of the issues before they make it to the product.

When Should we Perform WCCA?

- Schedule compression is VERY BAD for WCCA
 - Reduces analysis performed, shorter time to fix/reanalyze findings
- The new TOR expands the time over which WCCA occurs



WCCA is often shoe-horned between the end of the design process and CDR. Unfortunately, too many programs find themselves still designing right up until CDR and there is little or no time to properly perform the WCCA.

This is potentially disastrous. The WCCA needs time to be completed properly and outages need to be addressed.

When Should We Perform WCCA?

- Prior to PDR through CDR
- Models developed in parallel with Breadboards
- WCCA must be reviewed and updated for EVERY circuit change
 - What is significant?
- Worst-Case Analysis can help find problems early, when there's time to correct them - cost effectively
 - More than 75% of the time our customers ask for analysis either BEFORE or AFTER hardware is available. Both are painful and less than optimal



WCCA must be considered in the early design phases.

Performing the WCCA without test data is not recommended. Models (both part and circuit) need correlation. Performing WCCA after a design is set in stone is also problematic since necessary changes might be too costly to implement.

The breadboard and EM development phase is the ideal time to build circuit models, since correlation data is plentiful and circuit changes are feasible.

To What Extent?

- Specification and 'Derived' requirements drive the analyses
- How much risk can the program accept?
- What is the cost of a failure?
- Heritage is vastly over-valued
 - Usually not statistically significant
 - Parts and conditions change, Mission objectives change
- Success is quickly forgotten, but failure lingers on...

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

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The extent to what is analyzed is often the first casualty of limited time, limited budget, or limited man-power. Deciding on which items are low or high risk must be done with caution and not solely by the designer.

WCCA is not, in general, a question of does the design work. Likely, in the typical case it does. The worst case analysis process is about quantifying the performance boundaries, the margins, and assessing the risk probabilities.

So it doesn't matter what kind of heritage the unit has, that's simply irrelevant to computing the numbers and confidence levels.

In general, WCCA non-compliances are in the 2.5-4.5 sigma range. That is where a WCCA provides visibility. You might see those with one in a hundred units; you might or might not be happy with that %.

Heritage doesn't mean there aren't concerns when tolerances get near their boundaries. In fact, the stack-up of tolerances is one issue that takes most designers by surprise. **So, the problem is not "does the unit work?", the problem is how do you prove it works and meets specs over time without an analysis?**

Who Should Perform the WCCA?

- NOT the Circuit Designer
- Companies and designers are inherently biased
- Program pressures dictate a forced bias
- Experience Matters



When was the last time you walked into your boss's office and said, "wow, look how I can bring my circuit to its knees." Thinking WC is not normal for designers. Incorrect assumptions made in the course of the design will generally be repeated in the analysis.

The designer has a substantial part to play in the WCCA process including the nominal analysis, EVM testing and WCCA review.

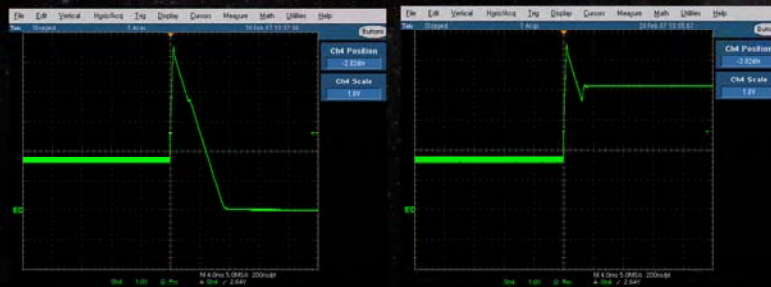
WCCA should be done by an independent group. Independence introduces "checks and balances" to the analysis. The project engineer is often under great schedule pressure, the program budget pressure and the company political pressure.

WCCA is the last line of defense for assessing whether the design will perform properly throughout its lifetime. It's just too important. There are just too many biases and we should not let our egos or budgets drive the analysis.

The selection of personnel is also a significant factor. It's one thing to have a junior engineer working along side a seasoned veteran, but it's not enough to simply have the review done by senior engineers. It must be performed by experienced personnel.

WCCA Success Stories

- No one has ever completed a WCCA with full compliance
 - WCCA ALWAYS results in improved reliability
- BNL/CERN - Power Supply, Could it be Salvaged?
 - WCCA helped identify, quantify, and correct 13 key findings before a 2 year "button-up" phase



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WCCA is a powerful tool for troubleshooting, failure analysis, and optimizing design performance.

WCCA Success Stories

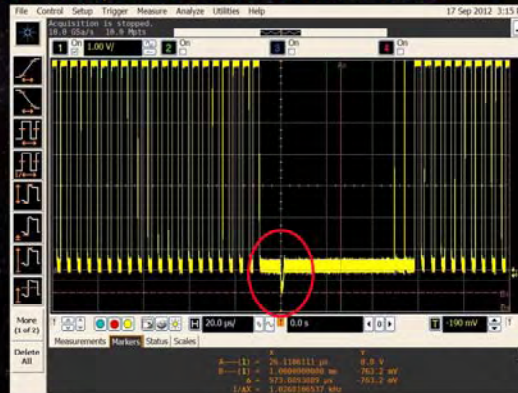
- Implanted Medical Device
 - Expensive Zener diode testing did not reveal tolerances unit was seeing
- Nuclear Power Plant
 - Snubber Cap Failure – WCCA helped guide and define component selection



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WCCA Success Stories

- Security System - Caught power supply negative spike substrate conduction on the PWM IC
 - Result: Improved Circuit Understanding – Saved Design Iterations – Helped Evaluate thermal concerns



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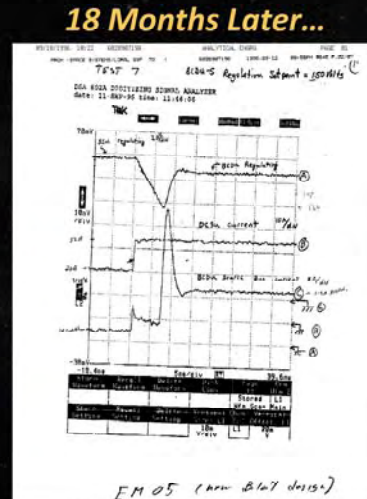
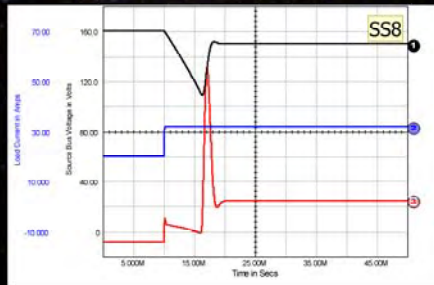
WCCA Success Stories

- Battery Charger Failure Analysis
 - WCCA used to identify and resolve on orbit failure cause
- Motor – Encoder Circuit
 - Predicted the jitter at EOL
 - Revealed flaw in optical sensor, SCD rewritten
- Linear Regulators
 - Identified serious issue related to multiple feedback loops.
Enabled Launch by defining the Statistical Risk
 - Good Models were the Key

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Good Models Help to Catch Problems Early

- Battery Charger
 - Eclipse - normal occurrence
 - Mode transfer - solar array to battery and battery to solar array
 - Master Reset Triggered
 - The pain could have been avoided



Yes, it's true. With SPICE it's garbage in, garbage out. But with high quality/high fidelity models in, the results can be dead on accurate.

In this simulation of the power bus in the Space Station, AEi Systems predicted, two years ahead of time, that a master computer reset would be triggered via a bus dropout every time the spacecraft went through an eclipse. Sure enough, as the picture on the right shows, that's just what preliminary circuitry did. Using the accurate model, AEi Systems was able to confirm a fix for the circuit error.

Slide 29

SS8

Steve Sandler, 8/4/2013

Current Challenges

- The design community does not do enough WCCA
- The WCCA that is performed is often poor
- Few guidelines define the detailed requirements (depth) for a WCCA
- There are many analysis challenges
 - Minimal availability of design data
- Analysis non-compliance is high (>30%)

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Sometimes There's No WCCA

- Some companies only perform Stress and MTBF
 - Part based analyses do not replace functional analysis
 - Testing does not account for many tolerances or operating conditions
- The program did not require it or it was not included in the bid
- Commercial Space???



What Constitutes “Rigorous?”

- Number one WCCA problem we see is a lack of rigorousness
 - This drives mission failures in several areas as noted
- Too few analyses are performed
- Analysis lacks depth
 - 2nd/3rd order effects - Poor documentation

*“The real issue is we analyze what we expect to be problems.
That’s not sufficient. We NEED to look under the hood.”*

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Analysis ‘Escapes’ are driven by:

- Time compression, usually due to a pending milestone payment (CDR)
- Poor or non-existent design specifications
- Budget
- Designers who think they don’t need to do the analysis

The selection of the parameters to be analyzed should NOT be generated by the circuit designer. Mistakes in the design will often be repeated in the analysis. Circuits that the designer believes are too simple, obvious, or heritage may be ignored. This is often where problems lie.

In fact, we often look for which analyses were NOT presented in order to determine where to look for design problems.

Lastly, is the documentation complete and sufficient?

Hybrid WCCA Issues

- WCCA is bid through the parts procurement process
- The WCCA is inadequately scoped and bid
 - Usage data and conditions are not provided
- Manufacturers do as little WCCA as possible
 - WCCA is done from the pins on in mainly to confirm SCD parameters
 - Afraid cost will impact purchase decision



Hybrids generally do not have adequate or accurate WCCA performed.

The WCCA is often bid prior to the circuit the part is used in being designed.

This means that the WCCA bid and scope will not be accurate. The WCCA can not even be performed if the circuit is not defined. Often hybrid manufacturers and the part's procurement people they deal with don't even know the correct questions to ask one another. After all neither are usually WCCA experts.

If the WCCA is done, it will not be to the correct circuit, requirements, or loading, making the WCCA largely inaccurate.

This is a systemic problem in the industry that MUST be corrected.

The WCCA (or Stress analysis for that matter) can not be delivered (let alone bid properly) until the circuit the part is used in (all source and loading, specifications, functional usage, etc.) is fully defined.

In addition, consideration must be given to development of a proper model of the hybrid if the WCCA is going to be performed by the purchasing company. This can be challenging if the hybrid is proprietary. However, this IP hurdle is no excuse and can be overcome because SPICE supports encrypted models.

Why are 30-75% of the Analyses Non-compliant

- Analysis started AFTER the design is 'completed'
- Only NORMAL conditions were assessed
- Testing was in a very limited range
- Ground testing was not considered or analyzed
- Detailed component data, missing, misleading or incorrect
- Circuit designed for different specs or environment



AEi Systems has performed hundreds of WCCAs since its inception in 1995.

Over that span we have found that 30-75% of the analysis requirements for analyzed circuitry are found to show “non-compliance.”

Why are 30-75% of the Analyses Non-compliant

- Designers don't believe...
 - In the Tolerance Stack
 - That Worst Case scenarios can happen
- Infected by the belief that nominal or heritage success diminishes the possible WC performance

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In most instances, the WCCA performed by companies internally, is not sufficiently rigorous to be acceptable to most prime contractors such as LMCO, Boeing, Aerospace Corporation or NASA and usually does not meet their strict guidelines.

Designers simply believe their design will function based on “experience”, or limited breadboard data and not the numbers. They fail time and again to perform analysis on circuitry deemed “too simple” to investigate. Often this is where the problems lie and why anything less than a truly rigorous analysis is inadequate. The WCCA should also be reviewed by at least one independent reviewer. Two or three reviewers are not uncommon.

Where We Find Most Problems

- Power Supplies
- Signal Integrity
- Simple Circuits
- Small Design Changes
- Heritage designs used for “updated” requirements
- Past WCCA (> a decade ago)

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Why is WCCA Late and Expensive

- There are many findings
- Specifications not coherent or achievable
- Not bid well – Cost, Schedule Interference
- Bid before the details are known
 - Often WCCA is bid up-front at fixed price
 - The work is then fit to meet the price or curtailed
- Not planned well
- The review process can be lengthy
- Analysis Challenges

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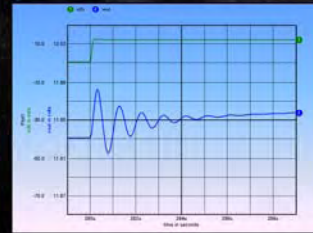
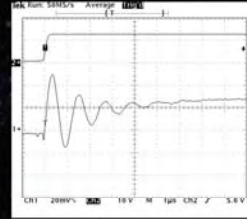
Analysis Challenges

- SPICE simulation has many pitfalls
 - Model Correlation can take a long time to achieve
- Poor or non-existent Device, Circuit, and System Test Data
 - Many labs are severely under equipped
- Hardware and WCCA time frames don't coincide
- Digital – Needs but doesn't get 100% Checkout, Bad IBIS Models
- RF – Models, Tolerances, and Hardware



Too Much Reliance on SPICE

- SPICE places a heavy burden on the quality of models
- Modeling is VERY hard to get right
- With SPICE it's easy to be in trouble and not know it
- It's not always the most efficient path, Math/sensitivity is better



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Modeling is VERY hard to get right

Pitfalls abound; it's extremely difficult to model performance over EOL tolerances and wide operating conditions

Data sheets are fraught with bad and misleading data

The holes in the data are difficult to find and resolve

It's not always the most efficient analysis path

- Math or SPICE?
- For a power supply WCCA $\approx$ 35-40% of the analysis should be in Math

There are two aspects to verify with EVERY SPICE model; does the model emulate the particular characteristic that the analysis requires and second, how accurately is the characteristic emulated over the operating range that the model will see in the simulation.

Why We Make Our Own Models

- Simple Voltage Reference
 - What needs to be right?
 - What is right?
 - Without the right impedance, the stability and dynamic performance isn't right

Voltage Reference	AEi Systems' Model	Vendor A's Model (what they said they got right)
Reverse Breakdown Voltage	✓	✓
Output Impedance	✓	
Reverse Characteristic	✓	
Output Trim Function	✓	✓
Output Voltage	✓	✓
Forward Characteristic	✓	✓



Voltage Reference Effective Inductance / Output Impedance	Calculated Inductance at 50kHz (H)	Calculated Inductance at 100kHz (H)
Commercial Part	11.944E-6	10.562E-6
Rad-Hard Part - SN 0701	9.539E-6	9.029E-6
Rad-Hard Part - SN 0702	9.514E-6	8.899E-6
Average from measurements - all three	10.332E-6	9.496E-6
Average from measurements	9.527E-6	8.964E-6
AEi Model	9.624E-6	9.515E-6
Vendor Model	000.000E+0	000.000E+0
Model error from real data	1.03%	6.15%
Vendor error from real data	Infinite	Infinite

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Accurate WCCA relies to a large degree on accurate SPICE models and modeling capabilities. This is why it is a core competency for AEi Systems. We are the number one source in the world for custom SPICE modeling.

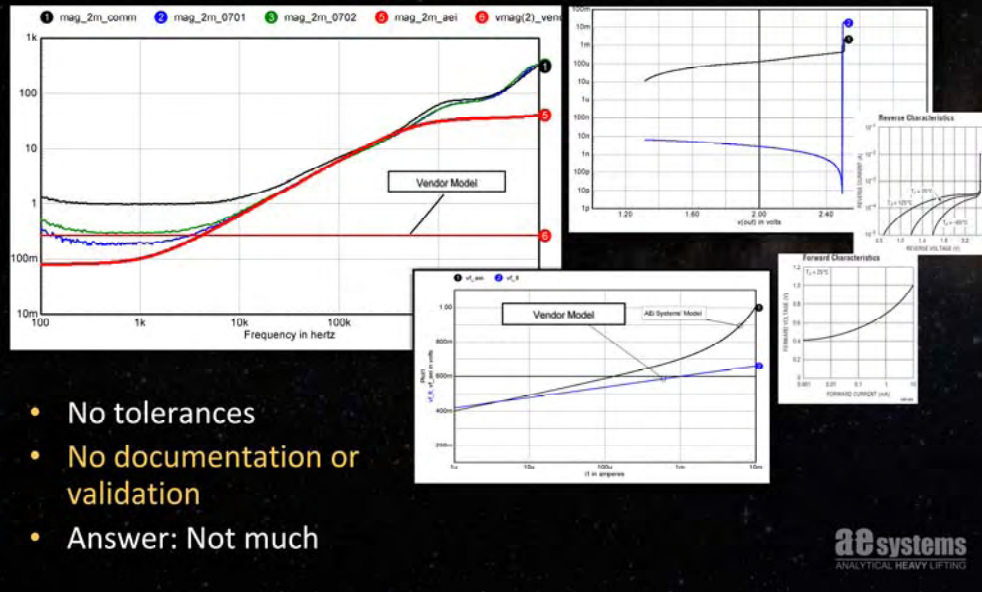
AEi Systems has proprietary agreements and relationships with all the key component manufacturers.

That means that AEi Systems has or is able to obtain proprietary information that is not easily available to others.

This information is critical to getting key performance assumptions correct and enables AEi Systems to perform WCCA faster than other resources.

Investment in models for parts you often used is required to built up a library that you have confidence in AND understand. The investment is well worth it and will save you time and schedule on the next program.

What did the vendor model get right?



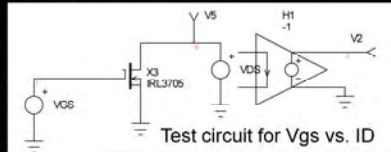
It's sad, but vendors rarely (if ever) test the models they post on their web site against real hardware. Talk about “garbage in, garbage out!”

To perform WCCA, you need a Worst Case model. Nominal won't do.

That means you need to know how to tolerance the model and understand where the parameter ‘knobs’ are.

That means to do WCCA well, you need to be able to make and validate your own models – or use specially verified models such as those produced by AEI Systems. (We are not aware of any other truly reliable source – please let us know who is out there.)

Model Quality/Correlation is Key

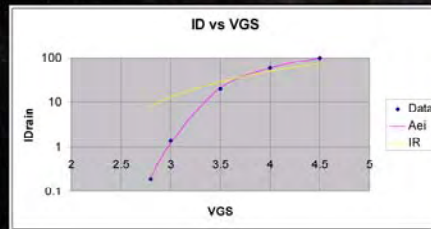


• IRL3705 Gate Threshold

VGS	Data	Aei	Error	IR	Error
2.8	0.2	0.2	-0.5%	8.3	4025.0%
3.0	1.4	1.3	-9.3%	13.1	835.7%
3.5	20.0	21.1	5.5%	29.3	46.5%
4.0	60.0	58.7	-2.2%	50.3	-16.2%
4.5	101.0	101.0	0.0%	75.2	-25.5%
Avg error			-1.3%		973.1%

Model performance comparison using different FET models for VDS=10V

- Just Because It's From A Vendor Doesn't Make It Accurate
- Vendor Models Must Be Validated - No Exceptions



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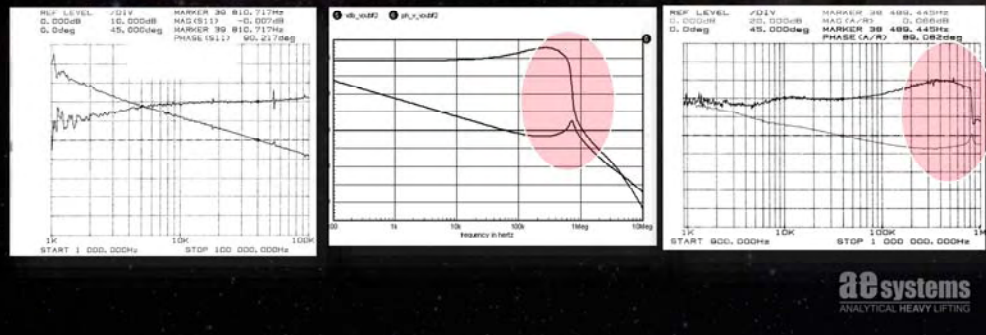
The models available from IC vendors, or in your SPICE package, are generally NOT tested against hardware. Most are made from data sheet information.

Data sheets are not technical documents, they are marketing tools.

Much of the data is misleading and from conflicting operating conditions, making model generation from a coherent set of data that covers the entire operating range of the part difficult if not impossible.

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
- Often the probe or equipment used is insufficient for the measurement being performed



In order to perform a WCCA you need to be able to get reliable test data. Correlation of hardware to test data is essential for a successful and reliable WCCA.

This takes a great deal of skill AND experience, as well as the right test equipment. We often find inadequate test equipment (insufficient bandwidth) and poor interconnects and probes at the heart of bad data.

In this case, the circuit designer didn't test their regulator with sufficient bandwidth (left). AEi System's model revealed a problem with the output impedance and ESR (in the nominal case). Further testing confirmed the finding. AEi Systems worked interactively with the product manufacturer and customer to assess the impact of the poor stability and implement a fix.

Test corrals leaps of faith and assumptions made during the analysis process. The process of correlating part and circuit models to test data is really critical and its usually one of the efforts that gets cut short due to schedule, cost, people, or equipment.

Why We Need to Measure

- Testing can't replace WCCA, but it must be performed to support the WCCA
- Much of what we need to know is not available
- To validate or confirm findings
- Because sometimes what we built is different than what we drew



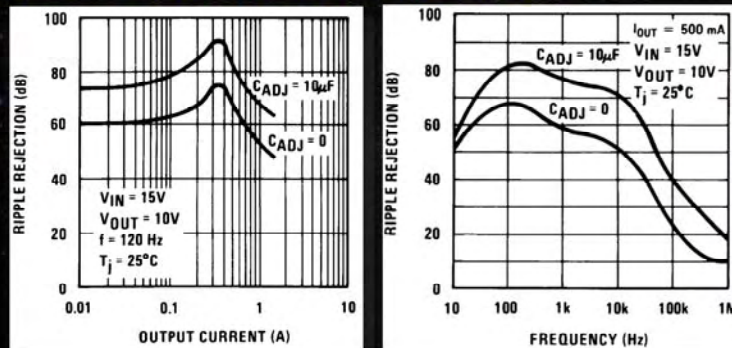
Can't electrical testing be used as a less expensive alternative? The answer is generally “No.” Testing normally only determines Beginning of Life (BOL) performance. In many cases, extended testing must be performed with extreme operating conditions such as temperature, voltage, power, etc. in order to determine aging margins. This can overstress the hardware. Testing is only valid for the measured lot and may vary lot to lot and manufacturer to manufacturer. It requires the parts to be procured PRIOR to completion of the WCCA, which can be very RISKY!! And it can be very costly if many measurements are required.

We need to make measurements at the component level to support the creation of the models to assure our math and models are at the required fidelity and to increase the confidence level. In most cases prototype testing is eliminated all together. This can mean difficulties in getting model and circuit correlation data. EM testing is often hampered by configuration issues, prohibiting easy access to key test points in favor of vetting mechanical issues.

Most people underestimate the testing efforts required, and when they do take data, the data are usually wrong, inadequate, or misinterpreted. Engineers try to make up for the lack of data with analysis, but it can be an unreliable substitute when key unknowns are estimated or missed.

What's Wrong With Datasheets

- Key characterization data is missing or misleading
- Important data lies beyond what is actually shown
- Slew rates are too slow, today's circuit loads are VERY fast!
- Measurements are impacted by the test equipment



From the National LM317 datasheet

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In the figure above, note that PSRR is specified at the optimum current/frequency and with larger $V_i - V_o$ than other tests.

Stability comments are untrue, stability is not defined.

Data does not include the crossover frequency. The effects of poor phase margin are not evident.

Where are the tolerances?

It takes a well trained engineer to see the issues.

What's Wrong with Measurements

- The majority are not included in the data sheet
- 8 of the 12 measurements require external stimulus (e.g. Signal Injectors) for the measurement
- The power supply interacts with the system it is embedded in, so measurements are best made “in the system”
- Pitfalls abound
 - Excessive injection amplitude (Bode plots)
 - Inappropriate equipment (electronic load)
 - Poor interfaces/cabling
 - Misinterpreted results



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Please see <http://www.aeng.com/testing.htm> for a number of articles on testing tips and pitfalls.

- Three Stability Assessment Methods Every Engineer Should Know About
- Five Things Every Engineer Should Know About Bode Plots
- When Bode Plots Fail Us
- Common Oscilloscope Usage Mistakes
- Match Impedances When Making Measurements
- Measure PDN on a Budget

WCCA Cost Drivers

- What drives the cost of a WCCA?
 - Part Variability Data
 - Validated SPICE Models
 - Software Tools – Digital and RF
 - Digital Analysis Complexity
 - Qualified Personnel
 - Interactive Management and Reporting
 - Excessive Documentation
 - Findings



WCCA Schedule Drivers

Program Driven Items That Delay WCCA

- Inadequate Engineering Talent
- Component Availability and Testing
- SPICE and IBIS Models
- EDU or Prototype Availability and Testing

Customer Driven Items That Delay WCCA

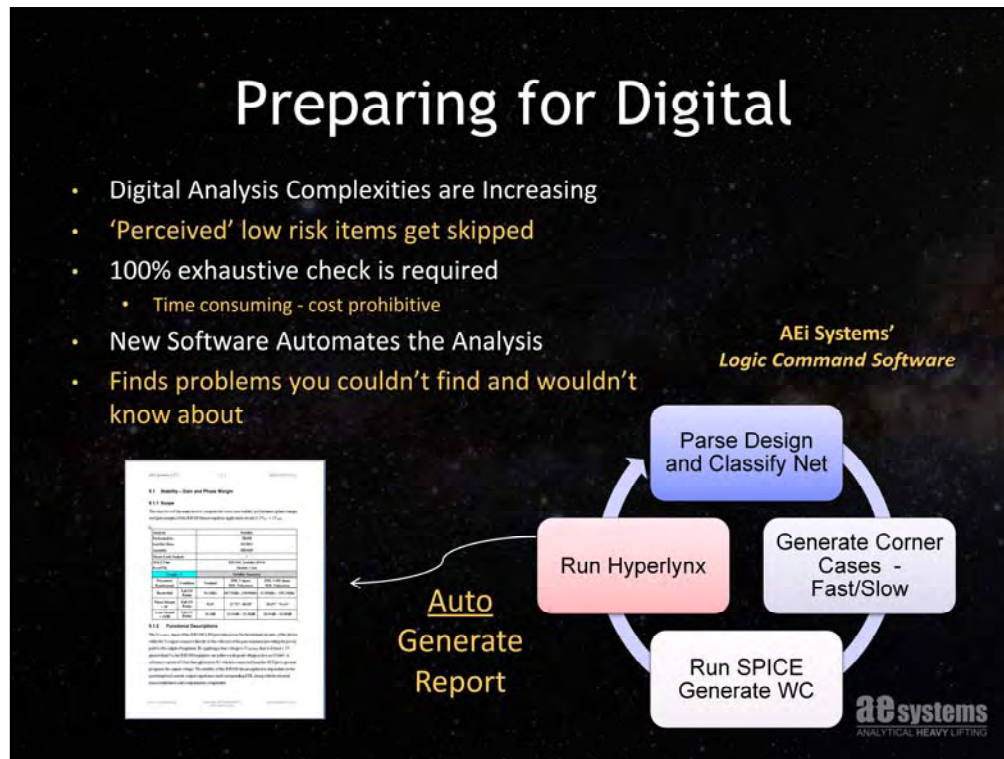
- Interactive Reporting and Communication
- Excessive Documentation
- Review
- Rework - Need to Repeat Some Analyses 2 – 3x



WCCA Cost and Schedule Savers

- Actions That Save Money and Time
 - Initial WC Design Review
 - Well Coordinated WCCA Plan
 - Requirements, Stress & Thermal Analyses
 - Using an Experienced, Well-Trained WCCA Team
 - EDUs and Prototypes Concurrent with Analysis
 - Nominal Simulation Models and Math developed during the design phase
 - Validated/Correlated Models and Circuits
 - Availability of Designers during the WCCA to assist
 - Radiation Data Up Front
 - Appropriate Reviewers

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Digital analysis complexities are increasing. Designs can have 100s – 1000s of nets. Each net can have 2-15 analysis cases. Net extraction can be complex and it's not always obvious what direction the WC parameters should be moved in. Manual analysis is prohibitive. Traditionally this means only analyzing “high risk” nets.

This is not an acceptable solution given the complexities and component requirements.

AEi Systems has developed proprietary software tools that greatly speeds up Signal Integrity analysis and allow a 100% net checkout.

Findings such as inappropriate pull-up/pull down resistors, improperly terminated test interfaces and undocumented features in parts that are not even in datasheet (because models are created using measured data), are often uncovered by the software.

These findings could easily pass detection by testing. The problems would produce unreliable operation yet would be extremely hard to reproduce and fix.

Lessons Learned

- Correlation of early hardware with WCCA and its models is the best way to validate a design
- A quality WCCA effort takes longer and costs more than most anticipate
 - Nothing is more expensive than being wrong
- Performing a WCCA improves organizations (supports CIP)

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A good reference for more material on WCCA is:

“Lessons Learned from WCCA”

http://www.aeng.com/design_analysis.htm

Lessons Learned

- Properly correlated models and analysis, performed rigorously, by the right team, and properly reviewed, is the key to improving reliability and reducing hardware costs

“Don’t pare down to the bone unless you know where the bone is.”

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Thank You

AEi Systems Services

Cheaper than in-house resources

- Our full-time team of top engineers with focused backgrounds in reliability, design, WCCA, and test has all the required core competencies to perform with great efficiency
- We have a significant number of SPICE models already made. We have Parts Variability Databases. We have Radiation Data. Even if you have in-house resources, dealing with models and tolerances can take a significant amount of time. AEi Systems puts the money and time savings in your pocket as we do not charge extra for this valuable IP
- Analysis is all we do; Keep your in-house designers doing what they do best

Faster than in-house resources - ready to go

- Our proprietary software tools, library of proven SPICE models, and our 20 years of analytical engineering experience keep your team ahead of schedule
- No bias - We introduce "checks and balances" to your design process/SDRLs

How can we help you? Contact us for more specific information or a no-obligation quotation.

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www.AEiSystems.com