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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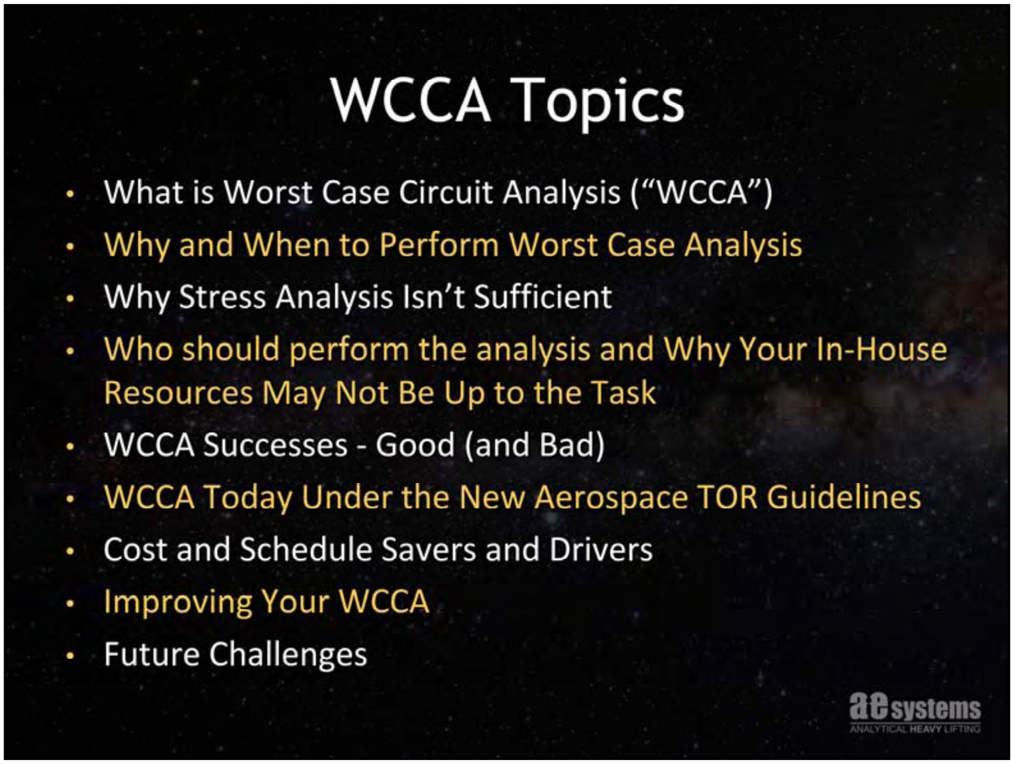


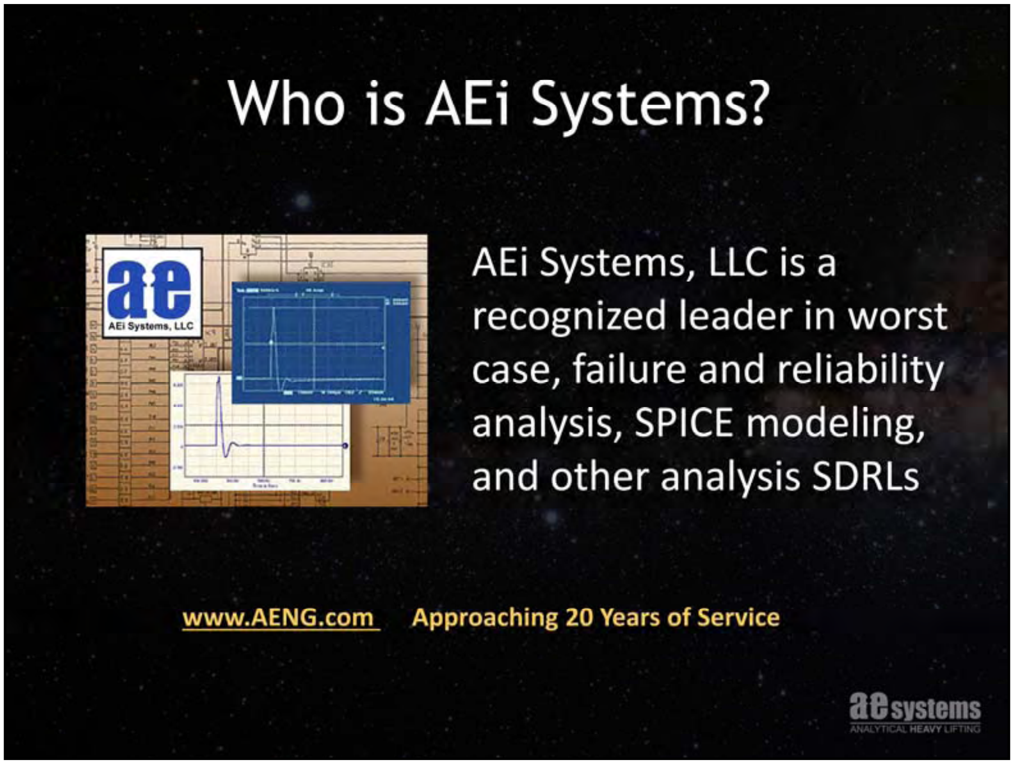
This presentation discusses various aspects of Worst Case Circuit Analysis. The content is taken from various papers, application notes, and lectures given by Charles Hymowitz (Managing Director) and Steve Sandler (Chief Engineer), as well as, the AEi Systems Worst Case Circuit Analysis Training Workshop.

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.

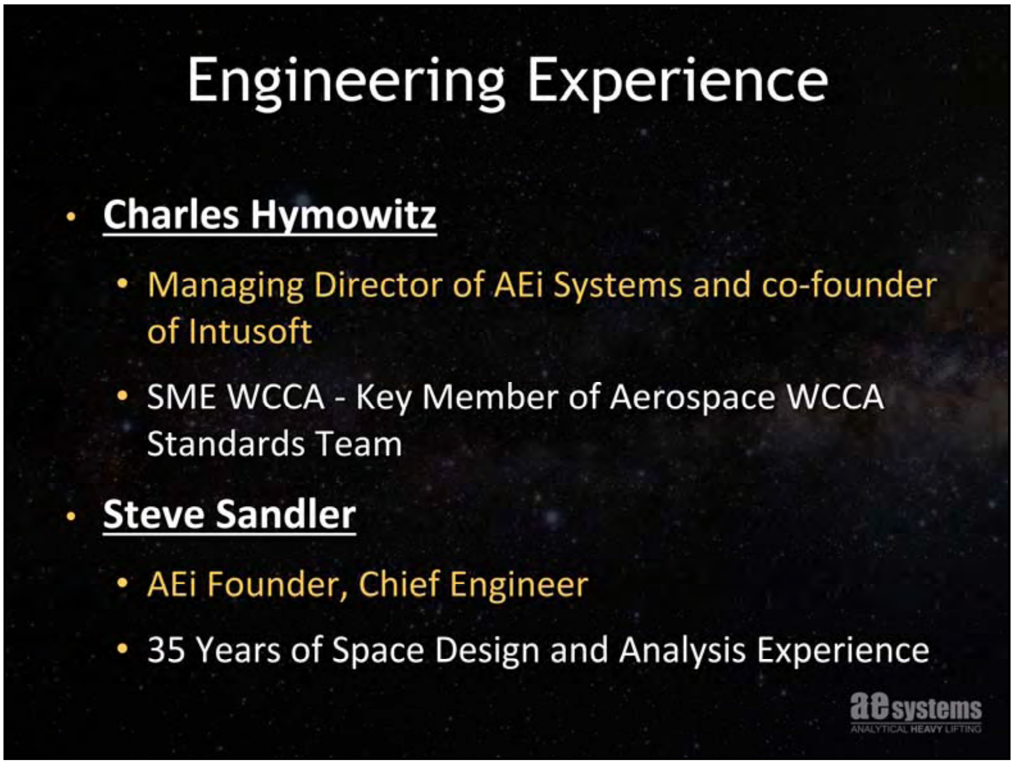


AEi Systems, LLC is an engineering services provider to major military, aerospace and commercial systems contractors, their subcontractors, and most Fortune 50 Aerospace companies.

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)



Charles E. Hymowitz, Managing Director

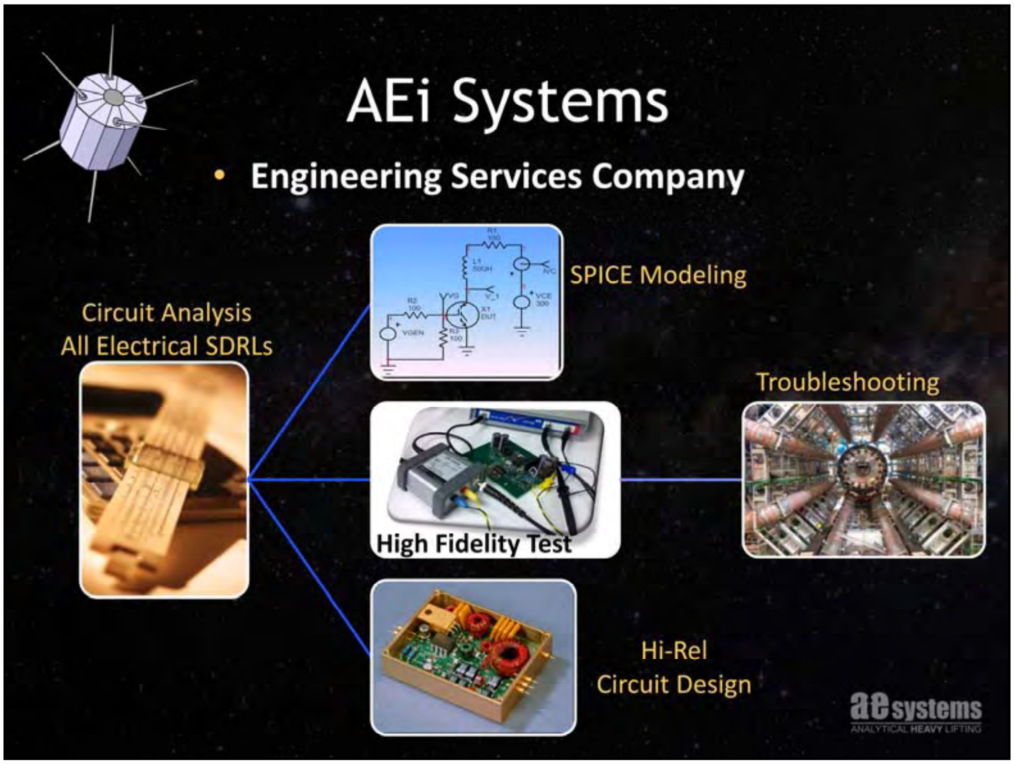
Mr. Hymowitz is a technologist and business executive with over 30 years of experience in the engineering services and EDA software markets. Mr. Hymowitz has been Chairman and Director of AEi Systems, LLC since its re-organization in 2002. He currently guides all aspects of the company's operations including 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."

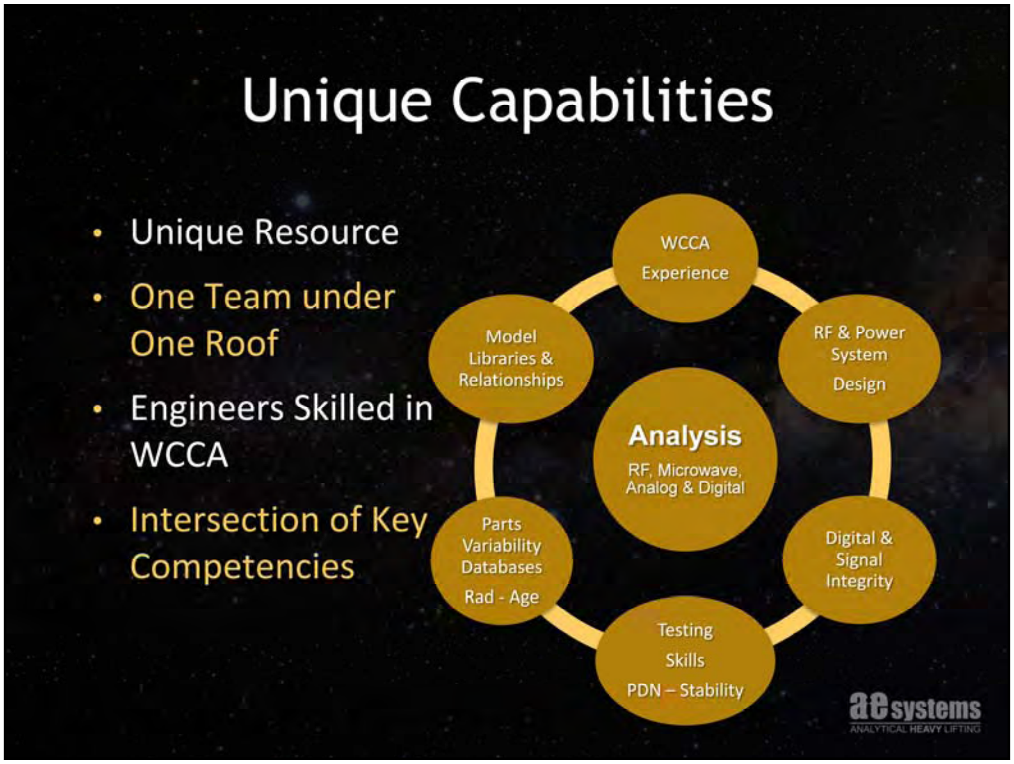
Steve Sandler, Chief Engineer, Founder

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 developed 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.

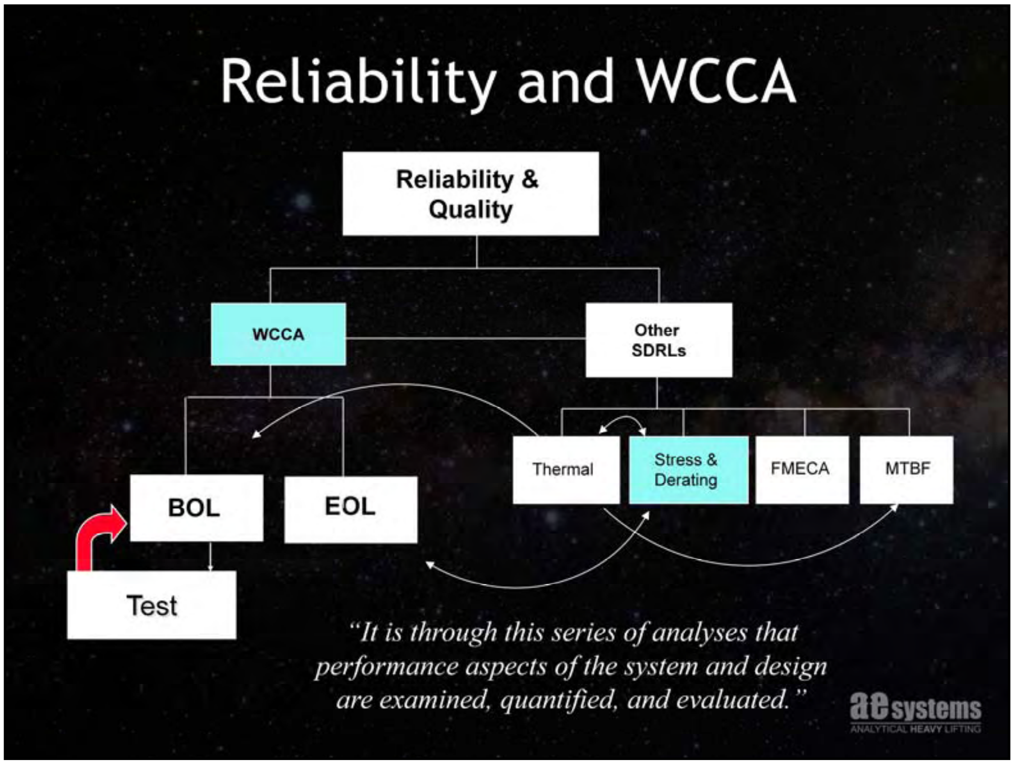
You can find AEi Systems' models on the web sites of Linear Technology, ON Semiconductor, Intersil, International Rectifier, Microsemi, National Semiconductor, Vishay, Micrel, Analog Devices, Texas Instruments, Semicoa, and many others.

AEi 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:

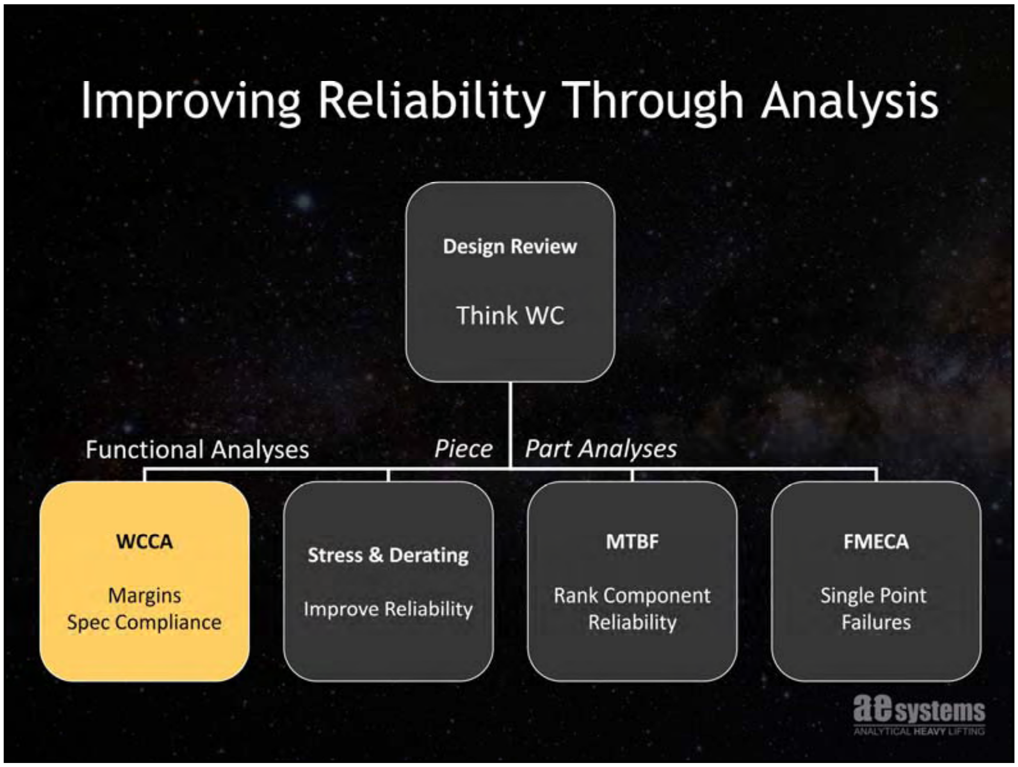
http://www.aeng.com/design_analysis.htm - "Why Do a WCCA?"

BOL = Beginning-of-Life

EOL = End-of-Life

MTBF = Mean Time Between Failures

SDRL = Subcontractor Documentation Requirements List

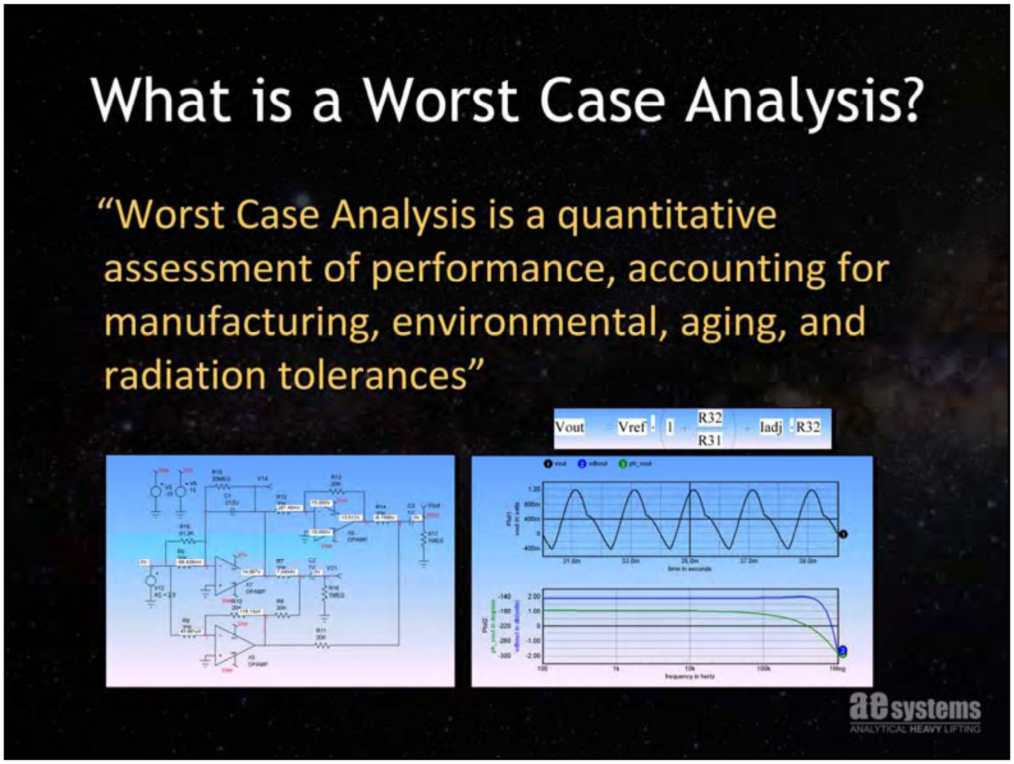


The "Worst Case" Design Review presents a unique opportunity to highlight and correct findings and non-compliances prior to the commencement of the actual WCCA. It is the MOST COST EFFECTIVE activity that can be performed prior to production, often saving design changes and board iterations.

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



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.

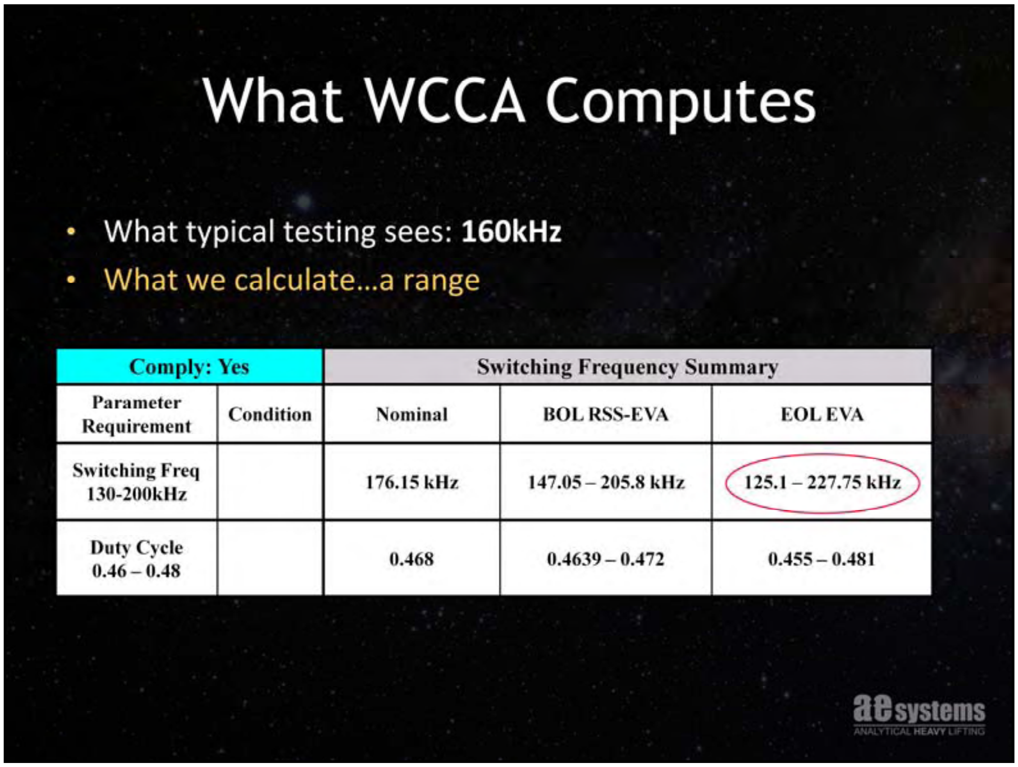
The WCCA is not an after-the-fact exercise but a cost-effective integral part of the design process. When a WCCA is performed properly, the results often save companies millions of dollars in lost revenue, dramatically lessen the possibility of human injury, and avert potential disasters both monetary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

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

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.

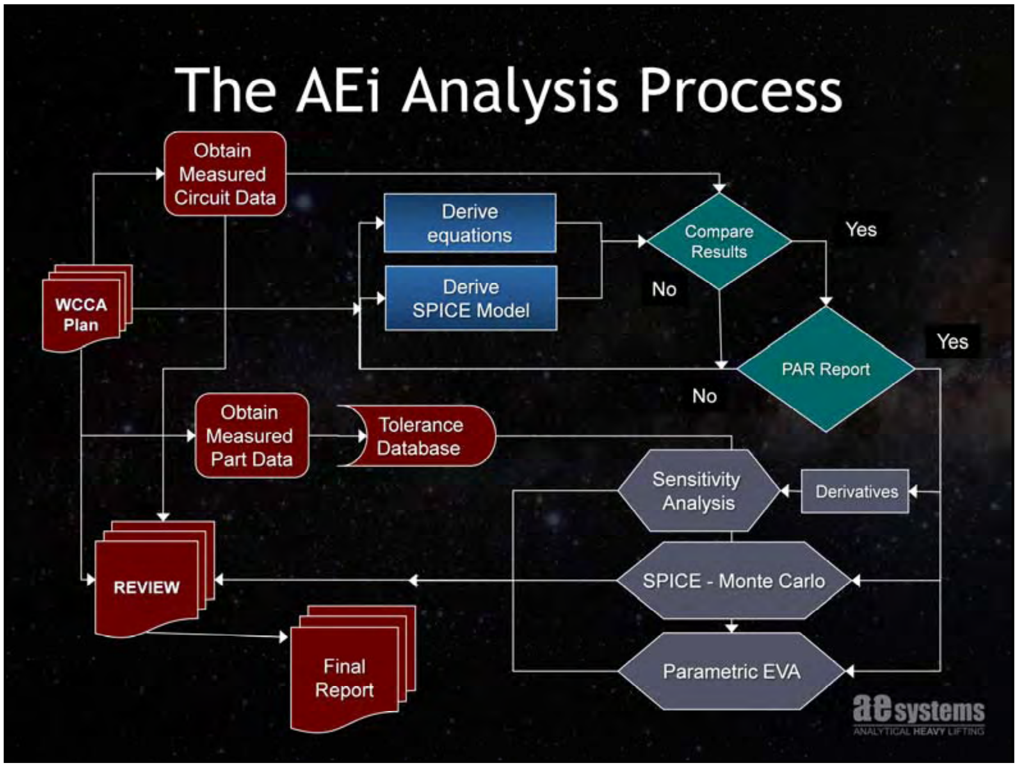
But most of all it is a mindset. This is the major challenge for most engineers, especially when engineers are analyzing their own design.



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.

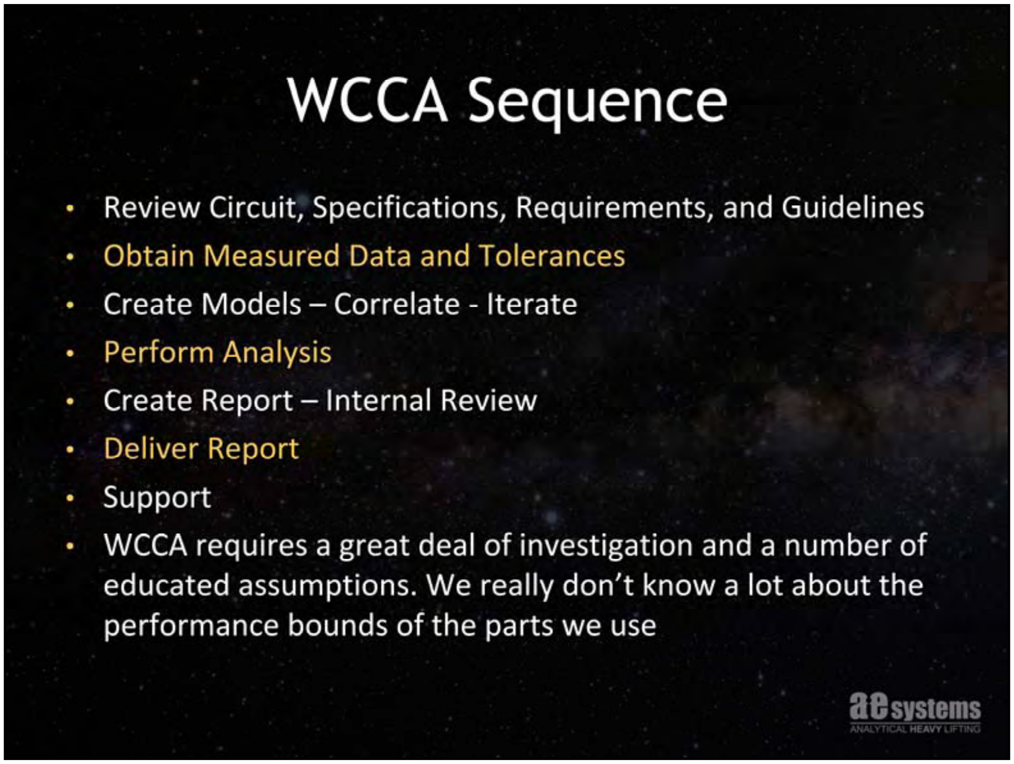
This particular example, power supply switching frequency, can greatly impact issues such as magnetics performance, EMI, and clock jitter.



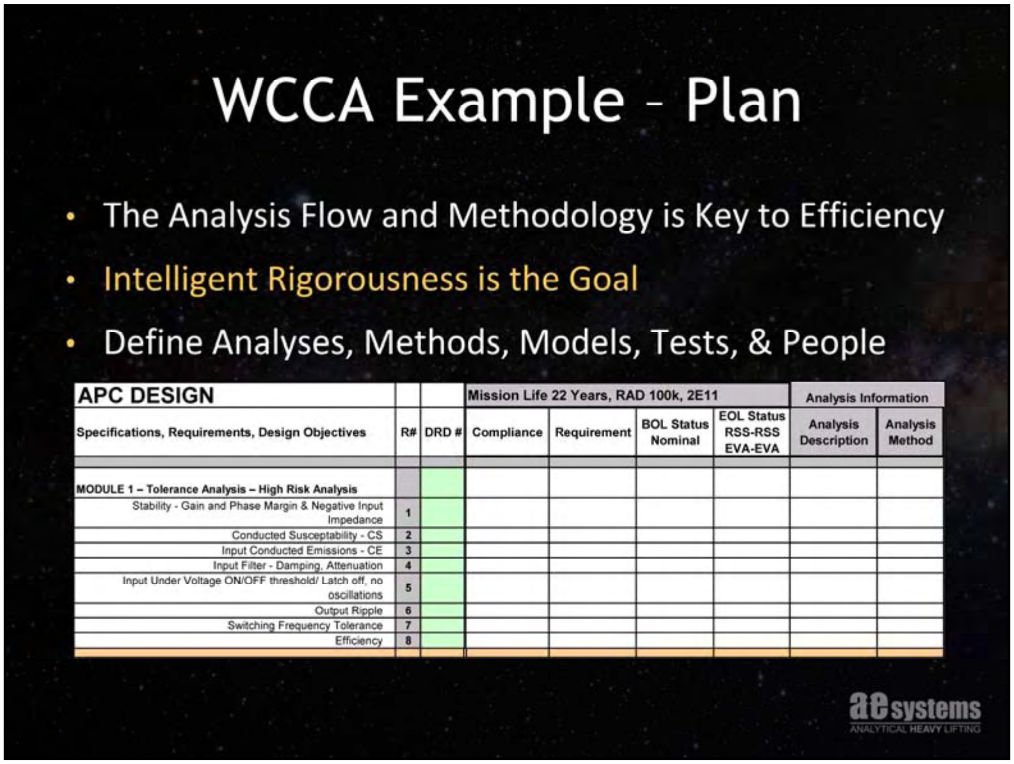
The items in red usually require interaction with and approval of the program.

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.



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



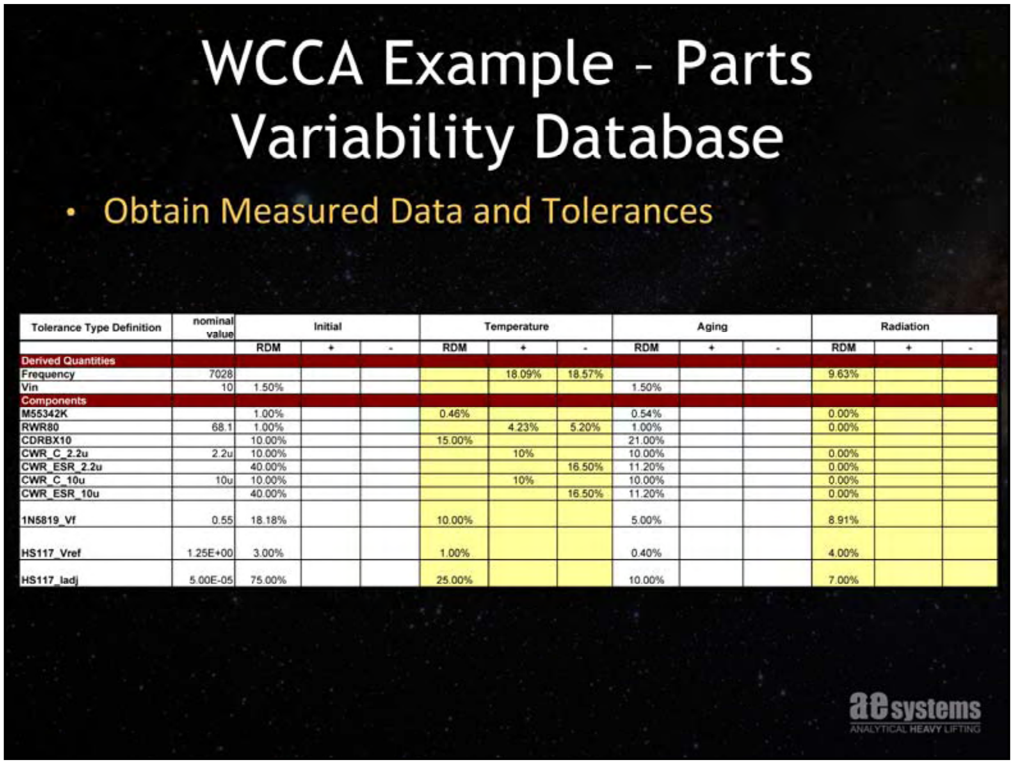
The WCCA Plan is where things first go wrong. A good portion of what we need to analyze is often not specified or listed in guidelines, requirements documents or the statement of work.

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 evident.



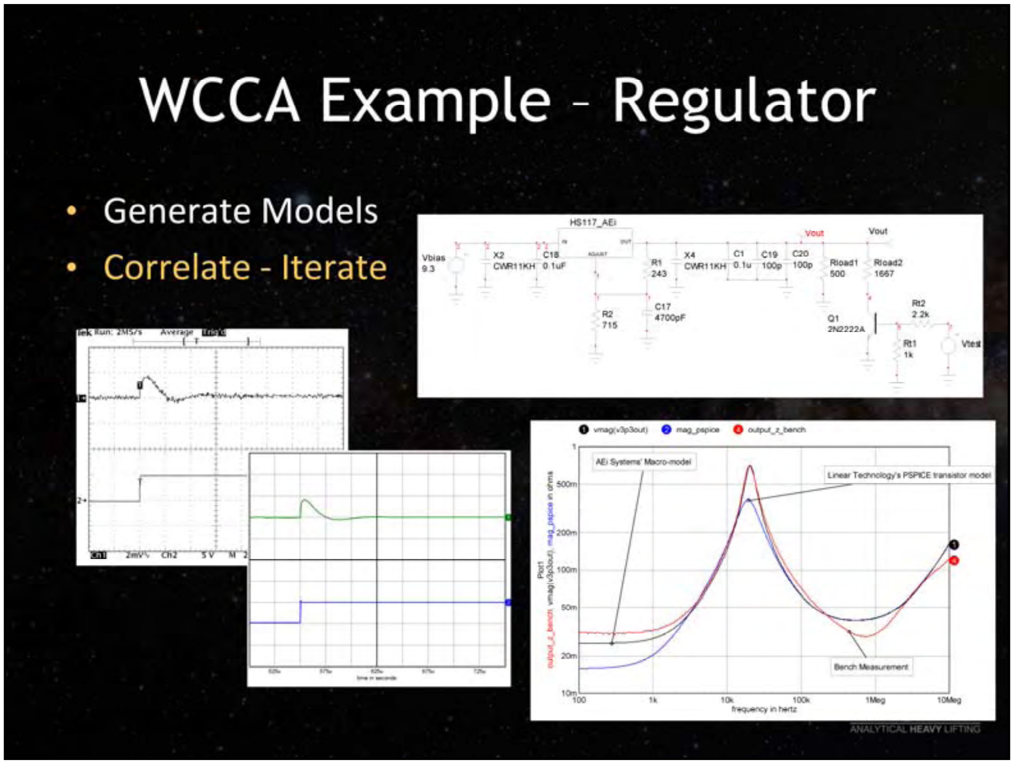
Tolerance Type Definition	nominal value	Initial			Temperature			Aging			Radiation		
		RDM	+	-	RDM	+	-	RDM	+	-	RDM	+	-
Derived Quantities													
Frequency	7028					18.09%	18.57%				9.63%		
Vin	10	1.50%						1.50%					
Components													
M55342K		1.00%			0.46%			0.54%			0.00%		
RWR80	68.1	1.00%				4.23%	5.20%	1.00%			0.00%		
CDRBX10		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%		

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.



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.

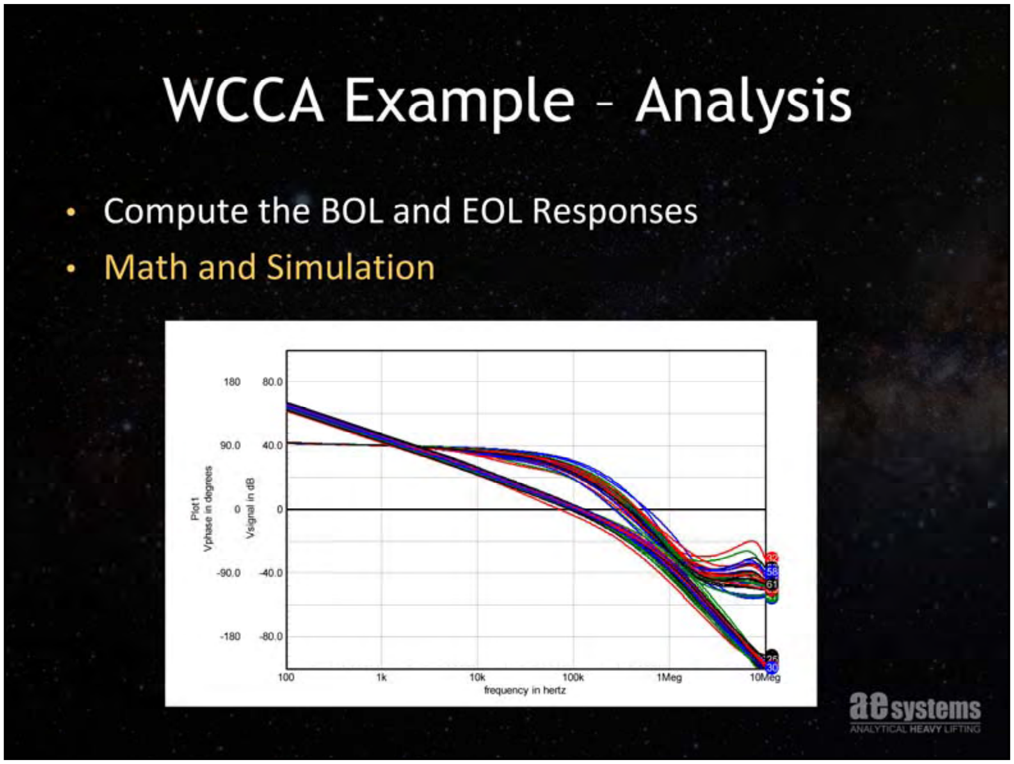
Fidelity is expensive. (See "Lessons Learned from SPICE" and "SPICE models need correlation to measurements", http://www.aeng.com/spice_modeling.htm)

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.

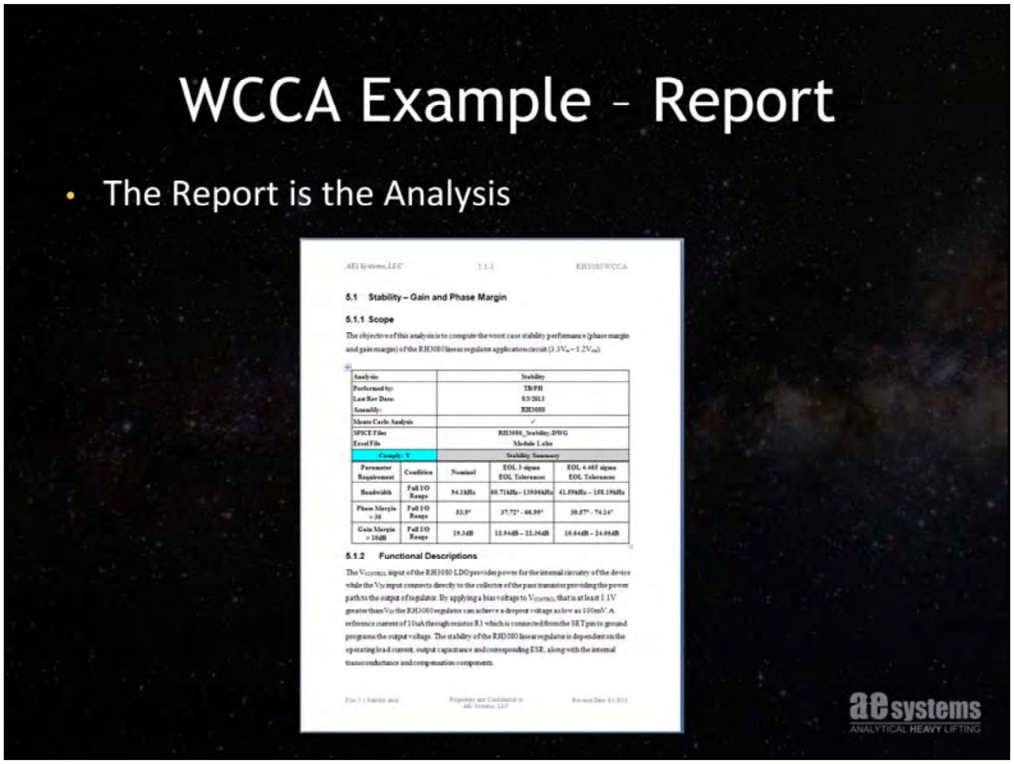


We are often asked, “WCCA seems expensive, what do we get for our money?”

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.



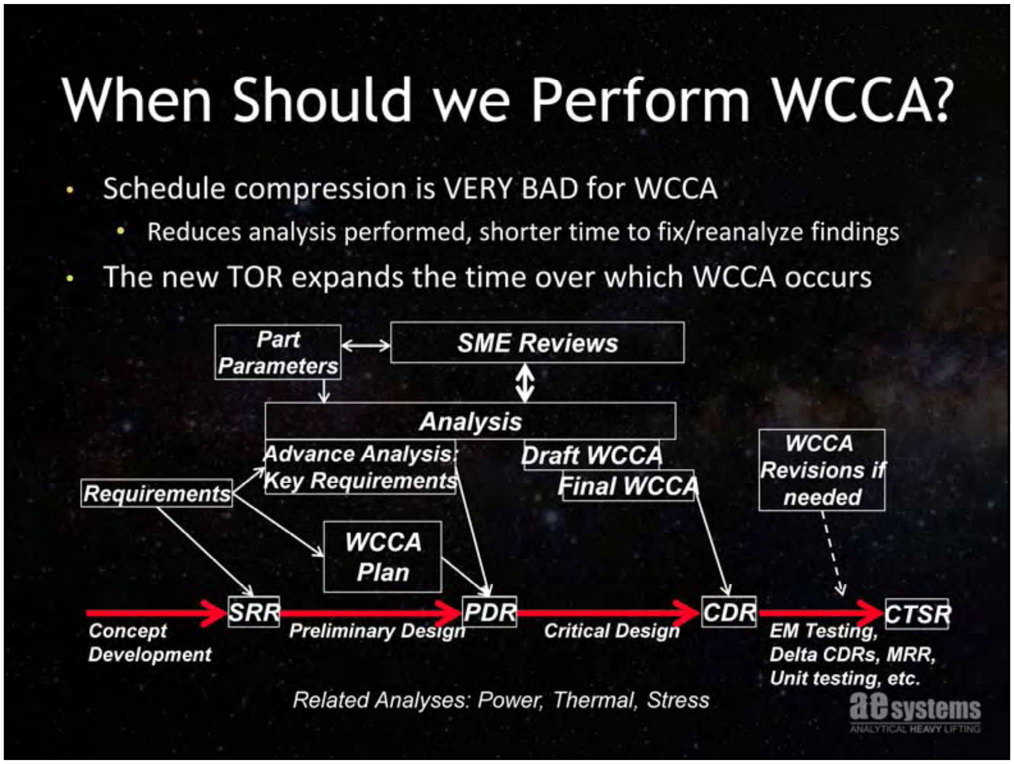
The level of documentation, the detail, the amount of explanation, can all vary greatly. The more documentation , the easier the review process, but the more expensive the analysis becomes. The impact of the decision will be significant.

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.

Other Reasons to do WCCA

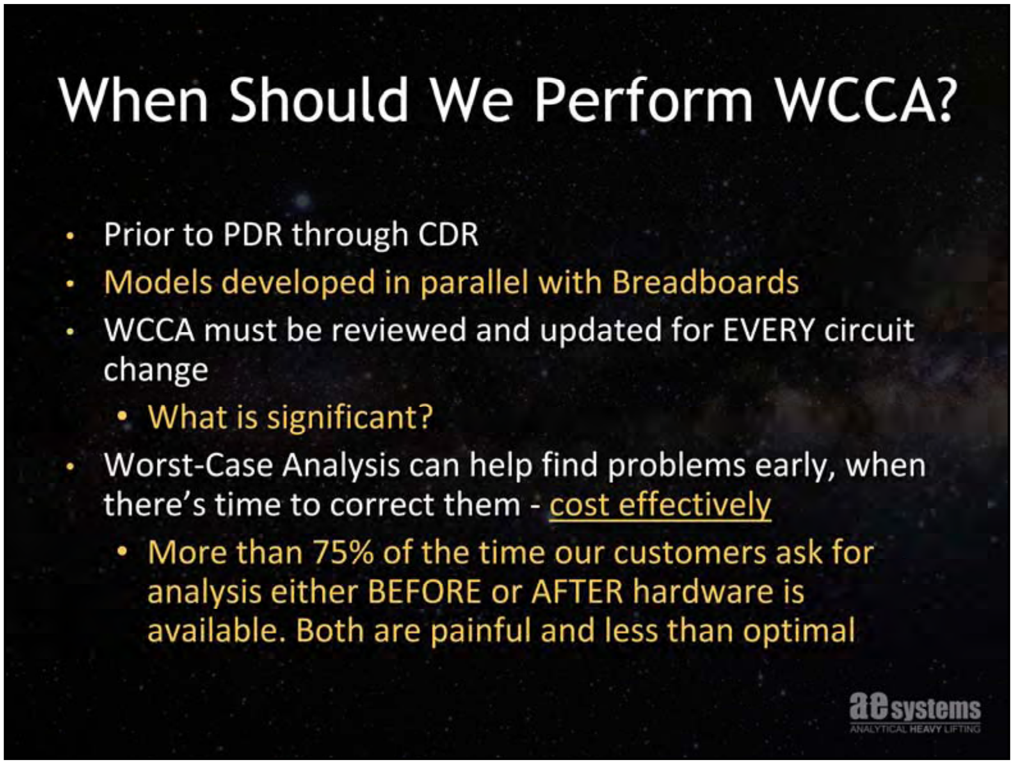
- Assess interfaces to your design/between designs
- Help to make sure critical requirements are defined
- To more easily address requirements creep/changes in objectives, parts substitutions/radiation requirements changes
- Find unacceptable variations early—Before expensive build/test iterations
- 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 <u>process</u> of WCCA (and not the effort) improves designs and catches many of the issues before they make it to the product.



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.

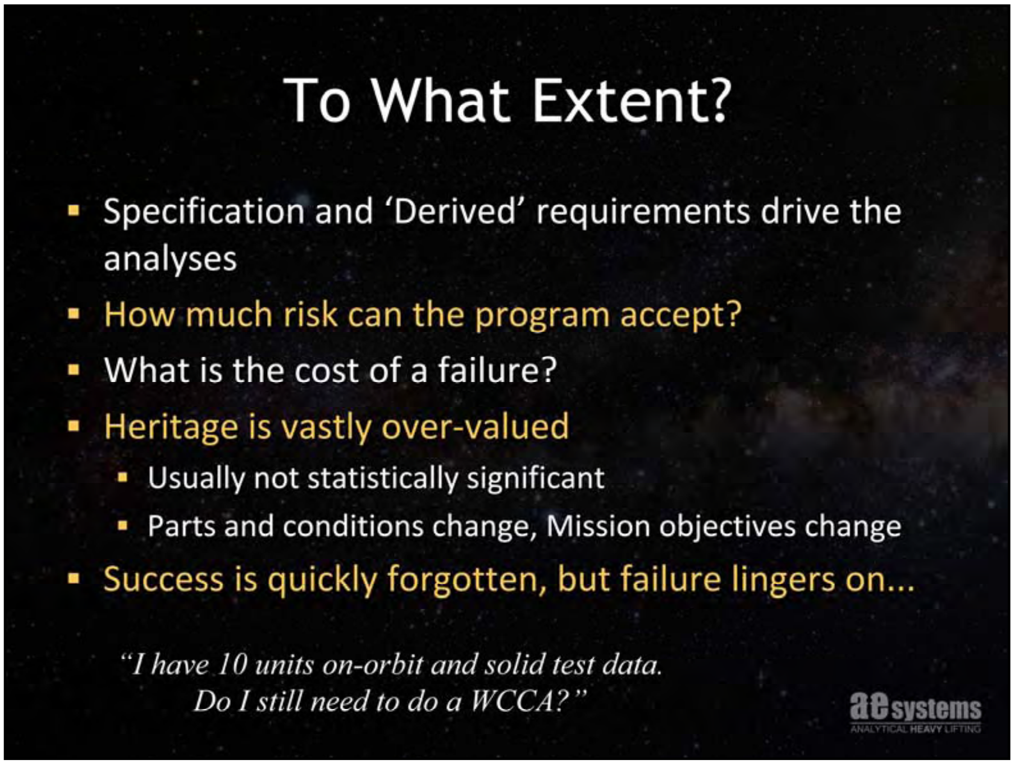
This is potentially disastrous. The WCCA needs time to be completed properly and outages need to be addressed.



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 is 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.



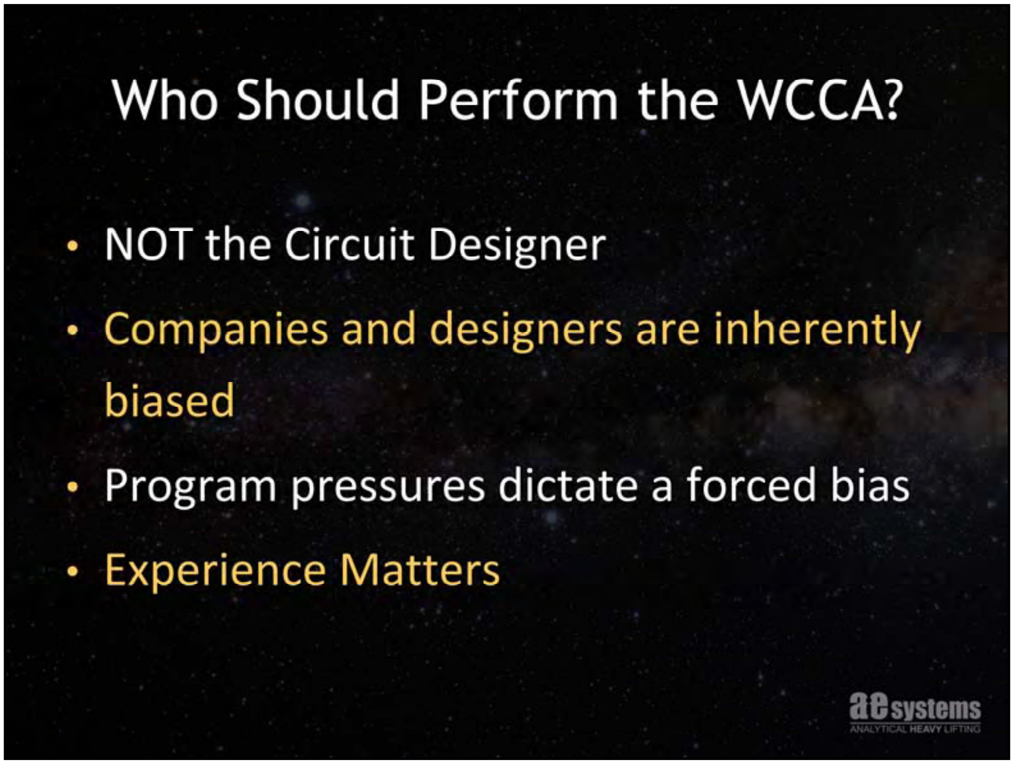
The extent to what is analyzed is often the first casualty of limited time, limited budget, or limited man-power. Deciding on which items are low or high risk must be done with caution and not solely by the designer.

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?**



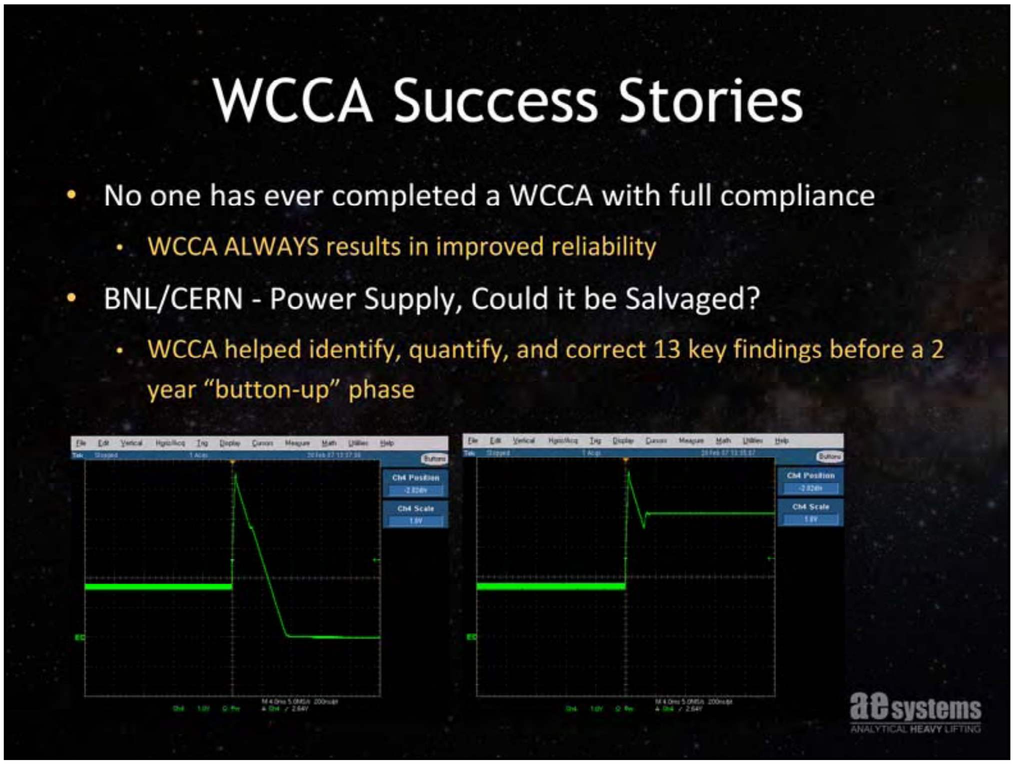
When was the last time you walked into your boss's office and said, "wow, look how I can bring my circuit to its knees." Thinking WC is not normal for designers. Incorrect assumptions made in the course of the design will generally be repeated in the analysis.

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.

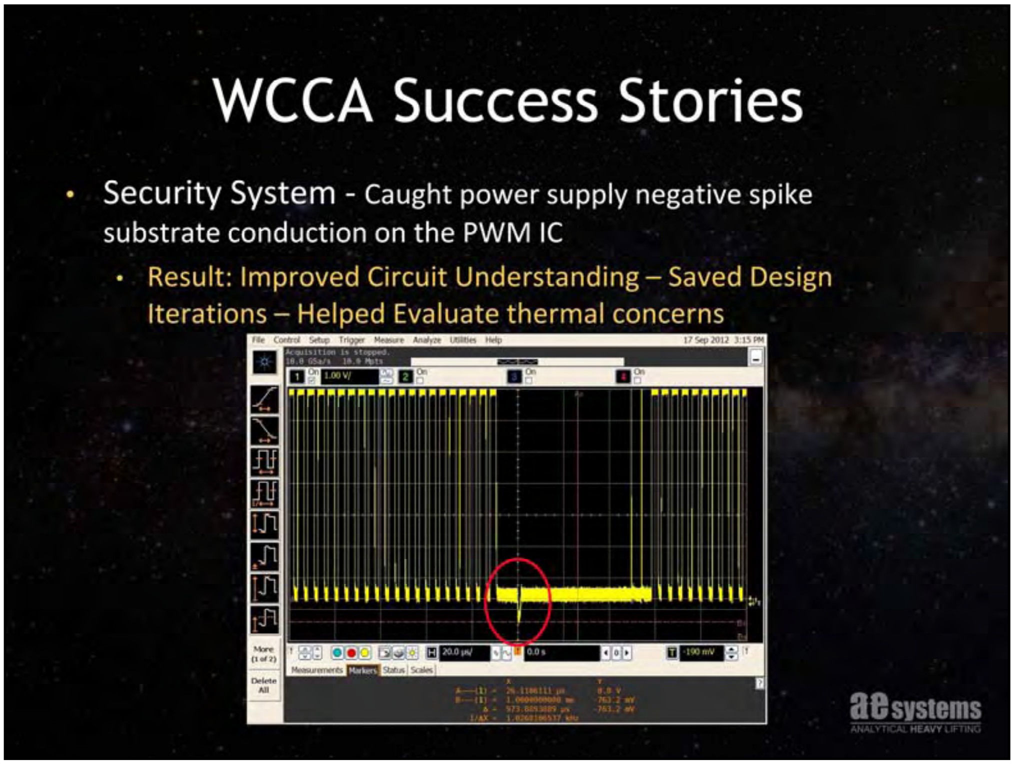
The selection of personnel is also a significant factor. It's one thing to have a junior engineer working along side a seasoned veteran, but it's not enough to simply have the review done by senior engineers. It must be performed by experienced personnel.

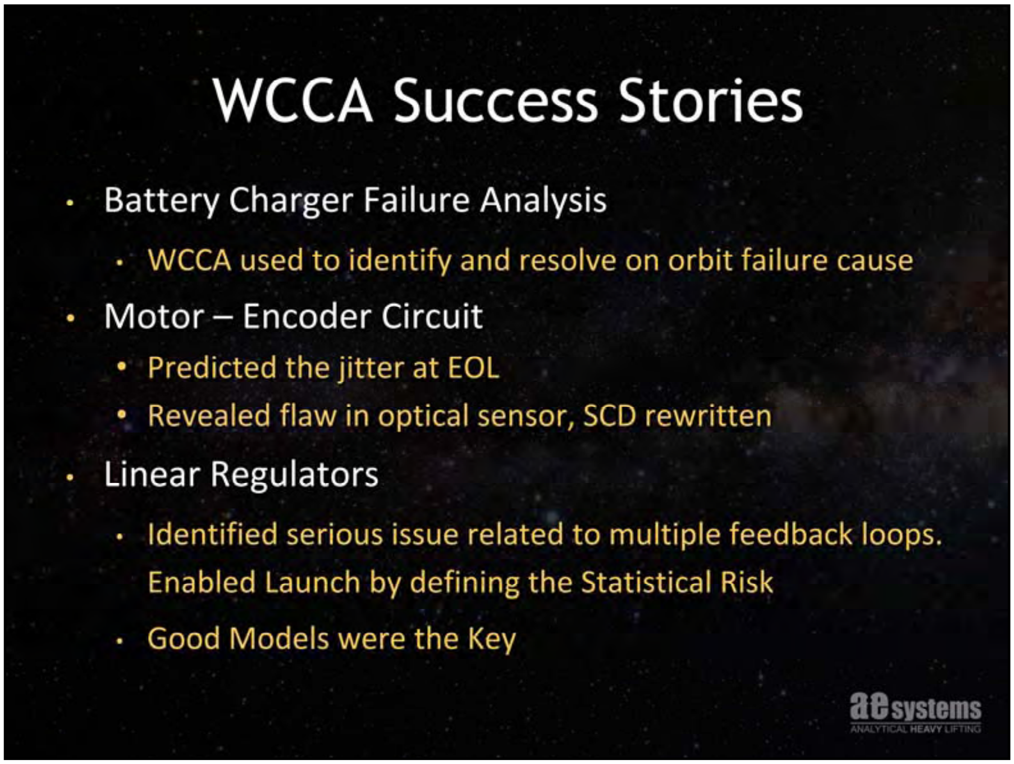


WCCA is a powerful tool for troubleshooting, failure analysis, and optimizing design performance.

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


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
aesystems
ANALYTICAL HEAVY LIFTING


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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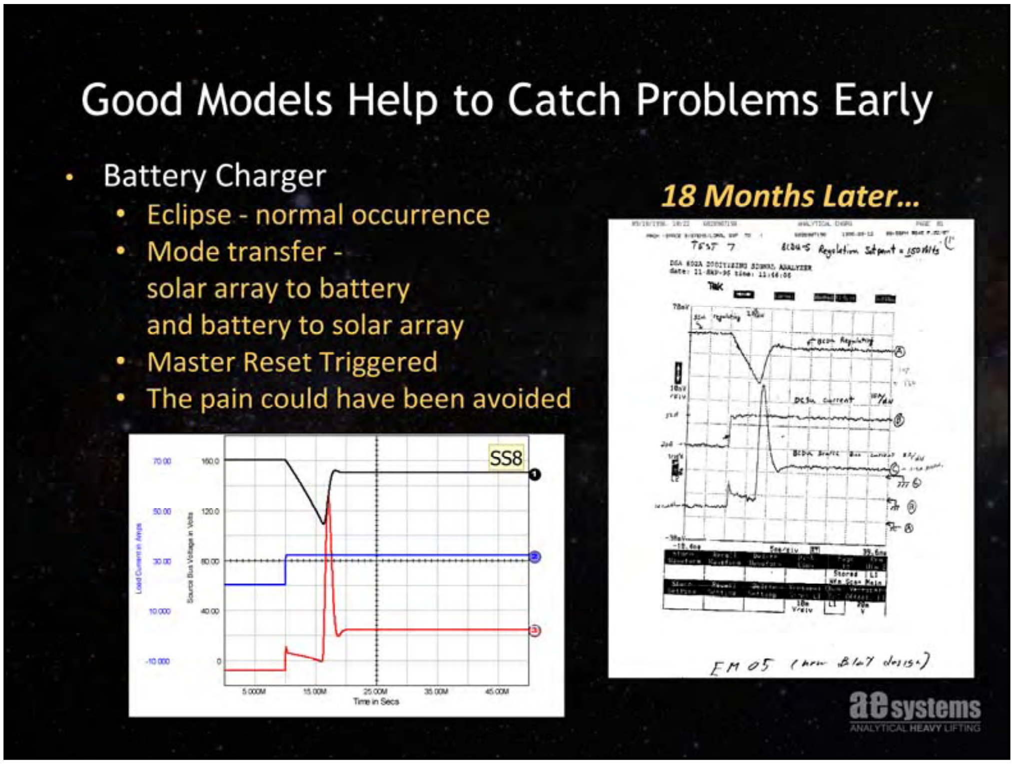
ANALYTICAL HEAVY LIFTING

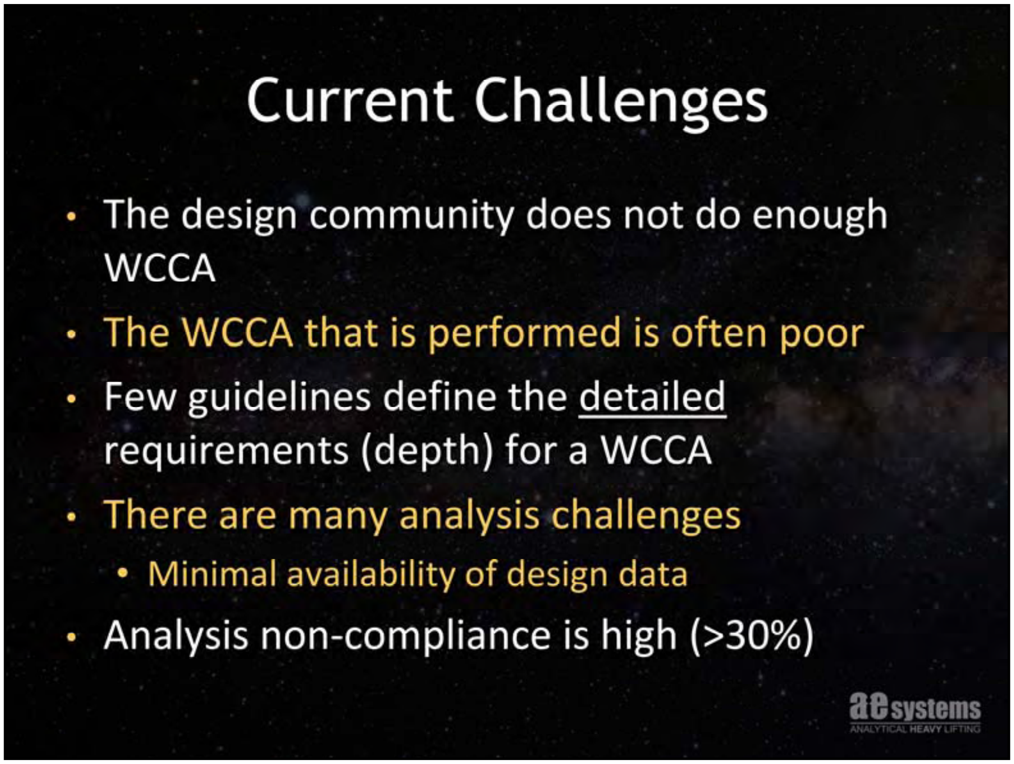


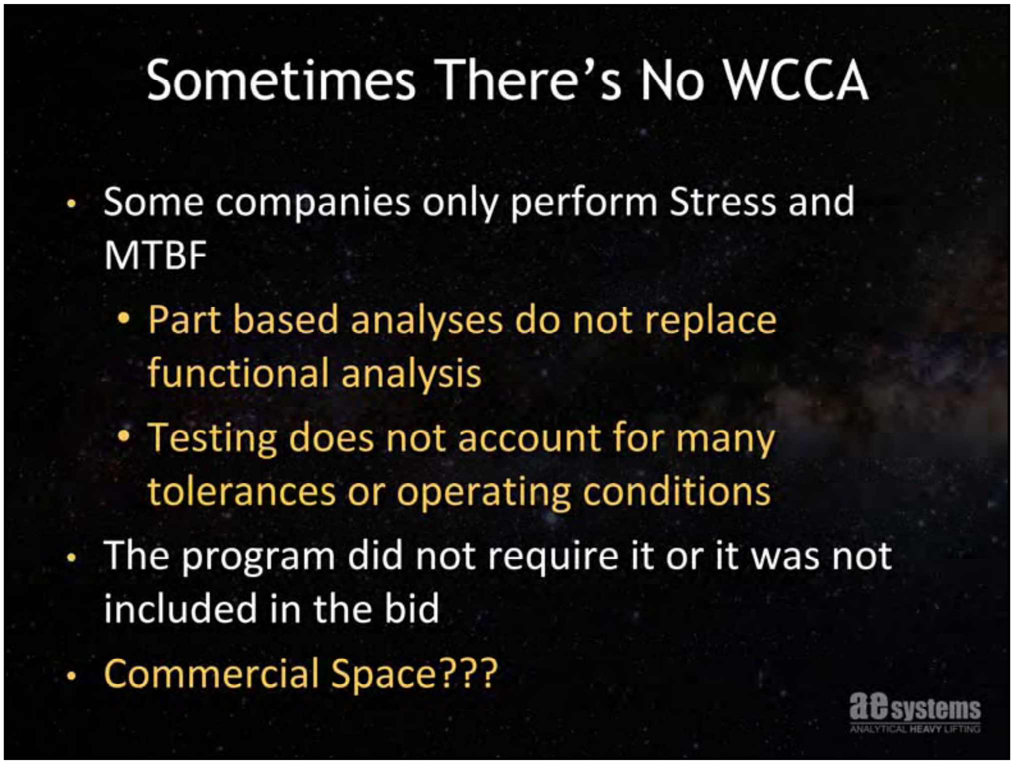
Yes, it’s true. With SPICE it’s garbage in, garbage out. But with high quality/high fidelity models in, the results can be dead on accurate.

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%)
aei systems
ANALYTICAL HEAVY LIFTING


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???
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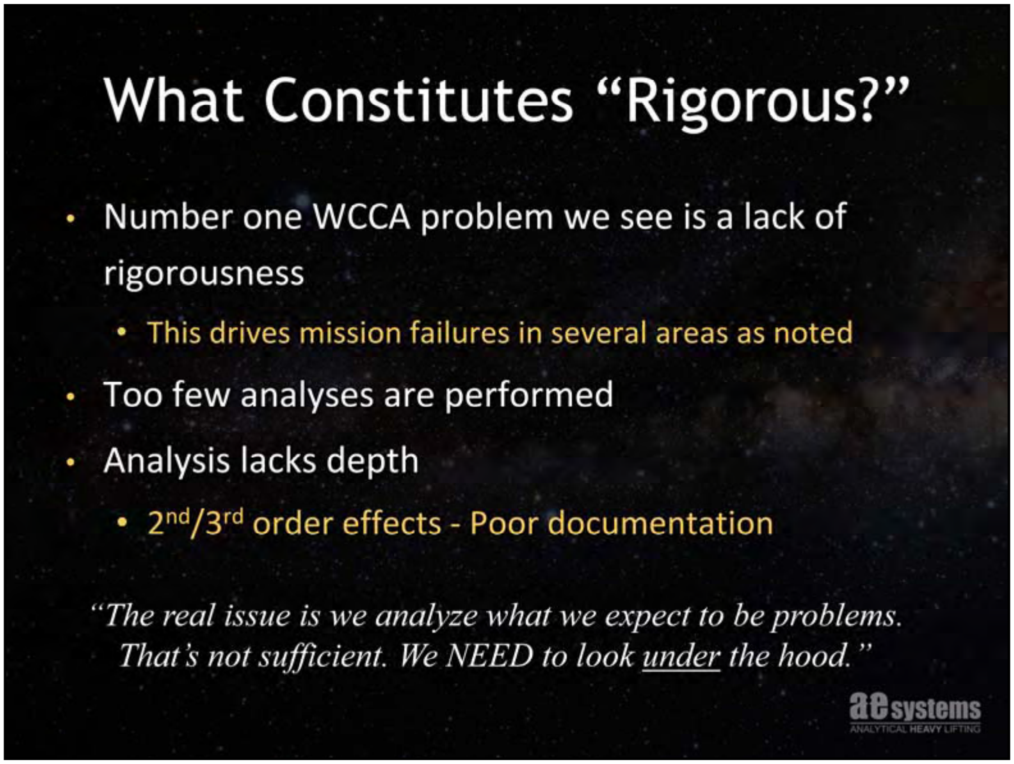


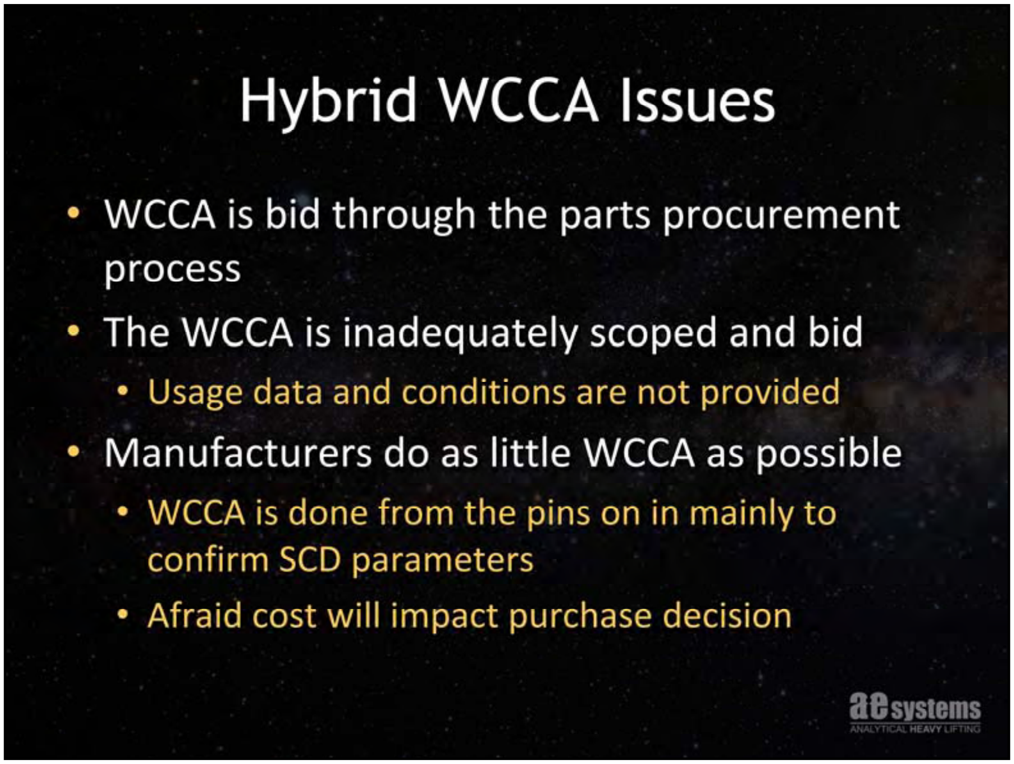
Analysis 'Escapes' are driven by:

- Time compression, usually due to a pending milestone payment (CDR)
- Poor or non-existent <u>design</u> 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?



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.

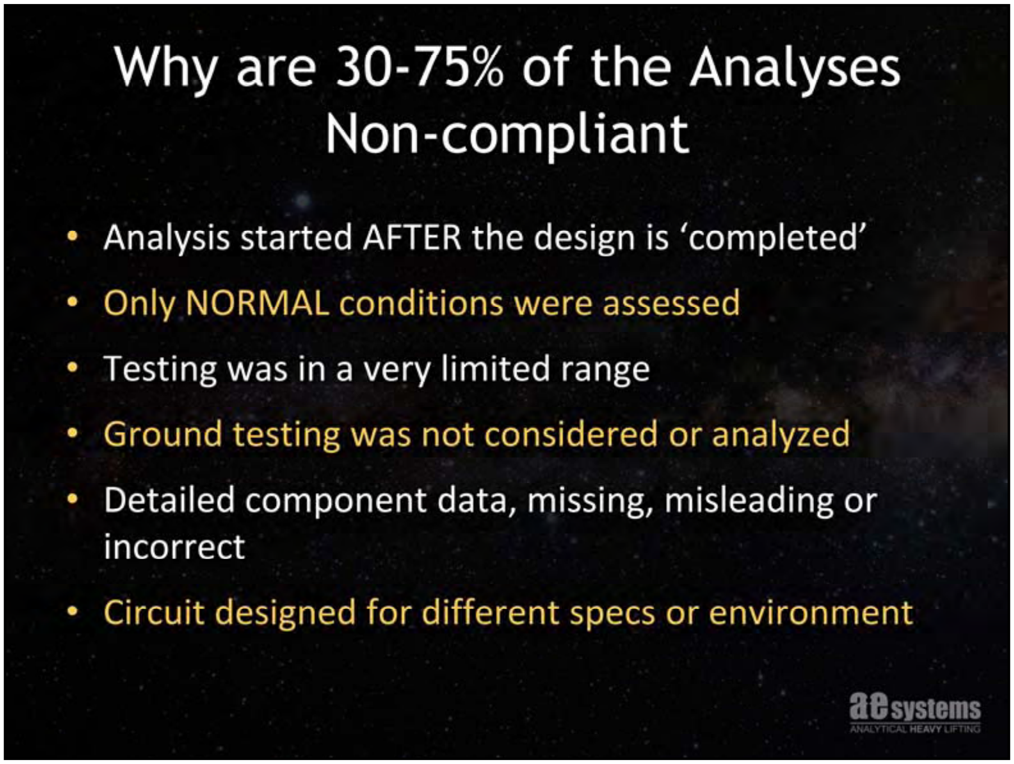
This means that the WCCA bid and scope will not be accurate. The WCCA can not even be performed if the circuit is not defined. Often hybrid manufacturers and the part's procurement people they deal with don't even know the correct questions to ask one another. After all neither are usually WCCA experts.

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.

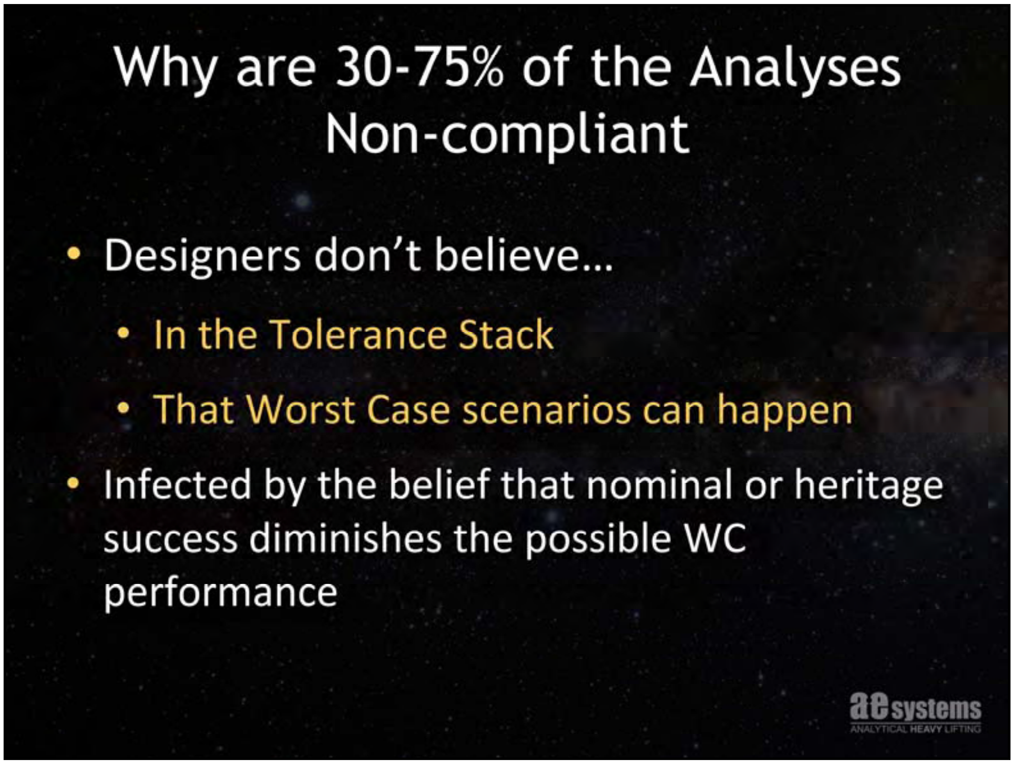
The WCCA (or Stress analysis for that matter) can not be delivered (let alone bid properly) until the circuit the part is used in (all source and loading, specifications, functional usage, etc.) is fully defined.

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.



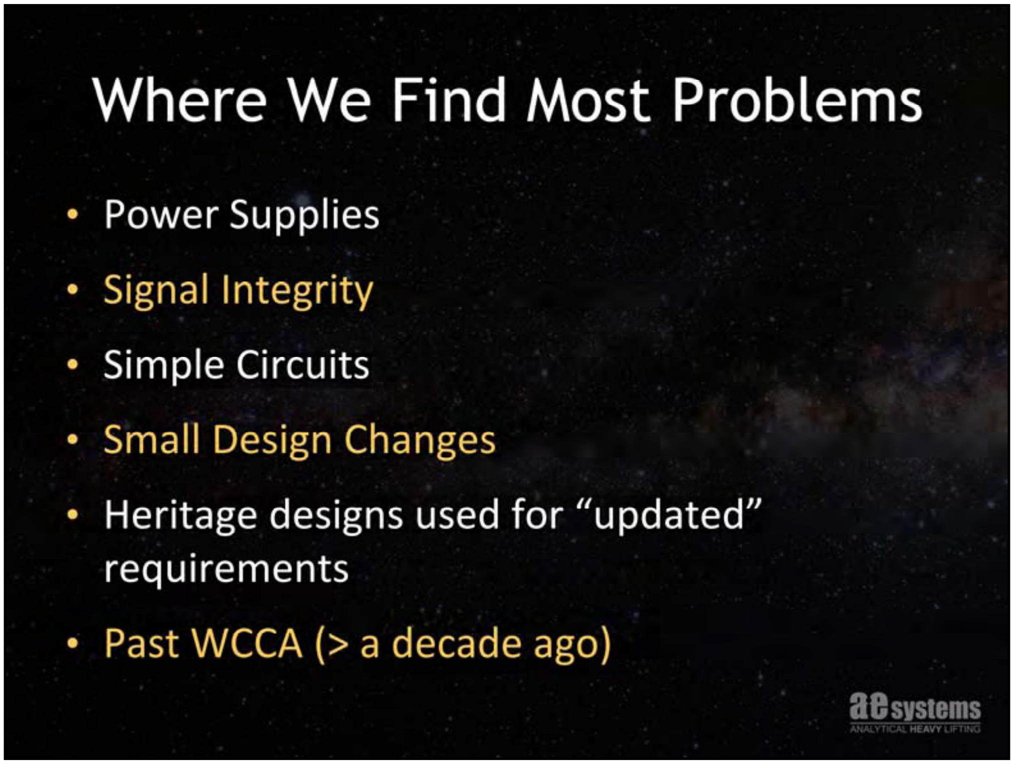
AEi Systems has performed hundreds of WCCAs since its inception in 1995.

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



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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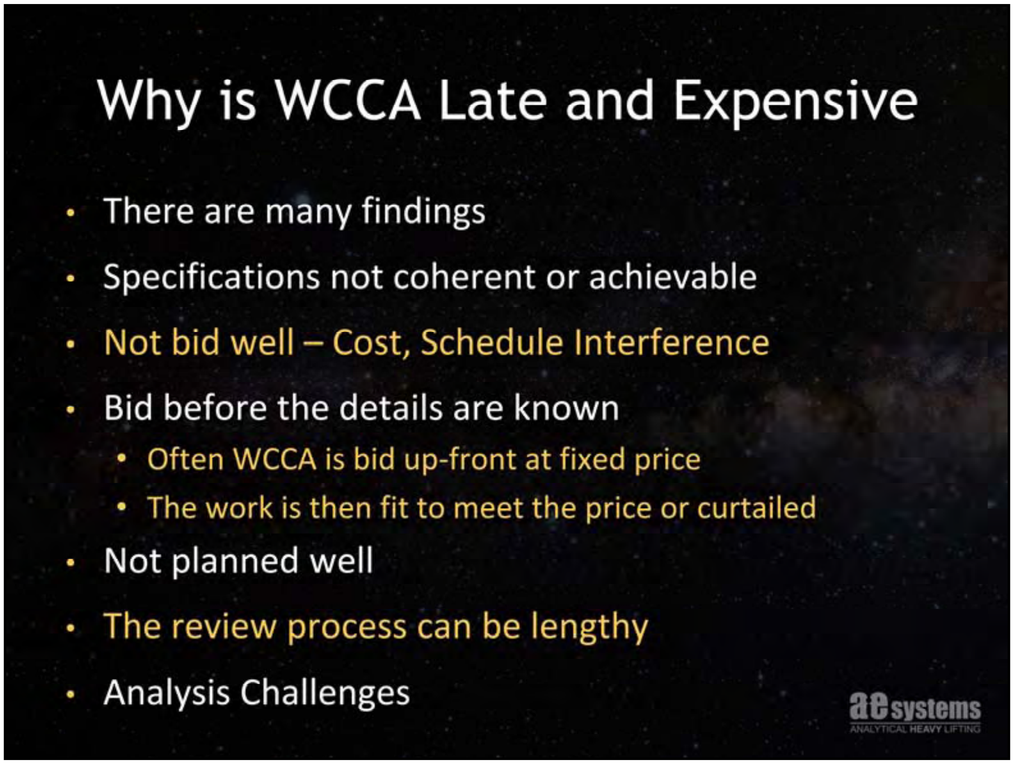
Why is WCCA Late and Expensive
• There are many findings
• Specifications not coherent or achievable
• Not bid well – Cost, Schedule Interference
• Bid before the details are known
• Often WCCA is bid up-front at fixed price
• The work is then fit to meet the price or curtailed
• Not planned well
• The review process can be lengthy
• Analysis Challenges
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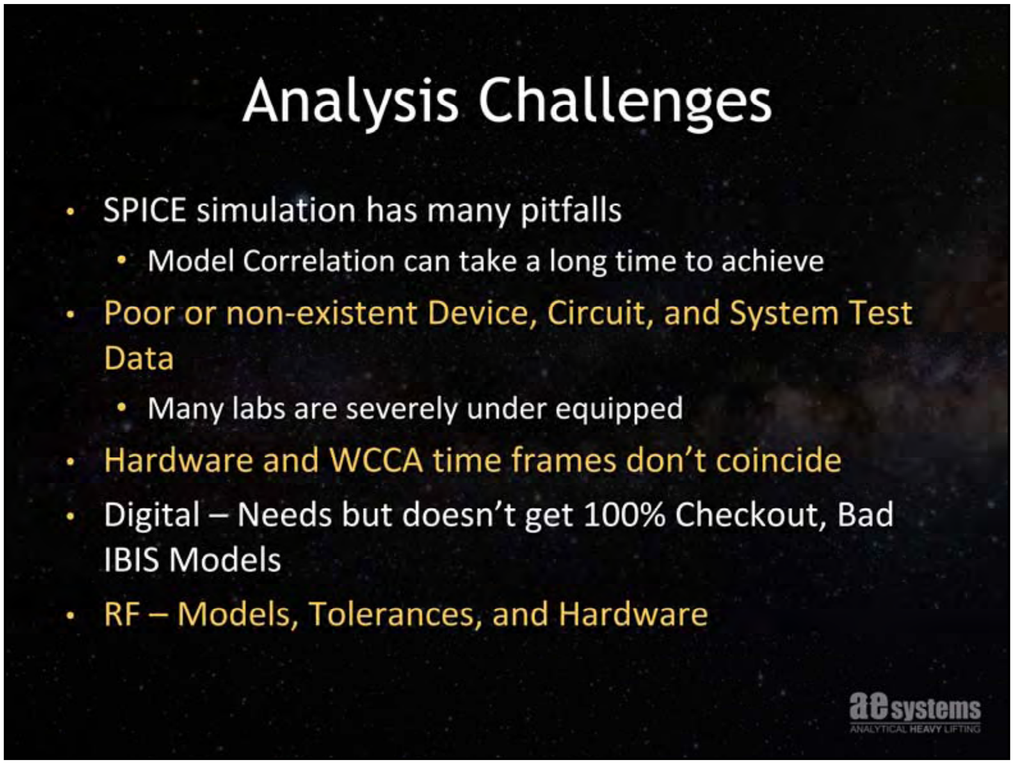
Analysis Challenges
• SPICE simulation has many pitfalls
• Model Correlation can take a long time to achieve
• Poor or non-existent Device, Circuit, and System Test Data
• Many labs are severely under equipped
• Hardware and WCCA time frames don't coincide
• Digital – Needs but doesn't get 100% Checkout, Bad IBIS Models
• RF – Models, Tolerances, and Hardware
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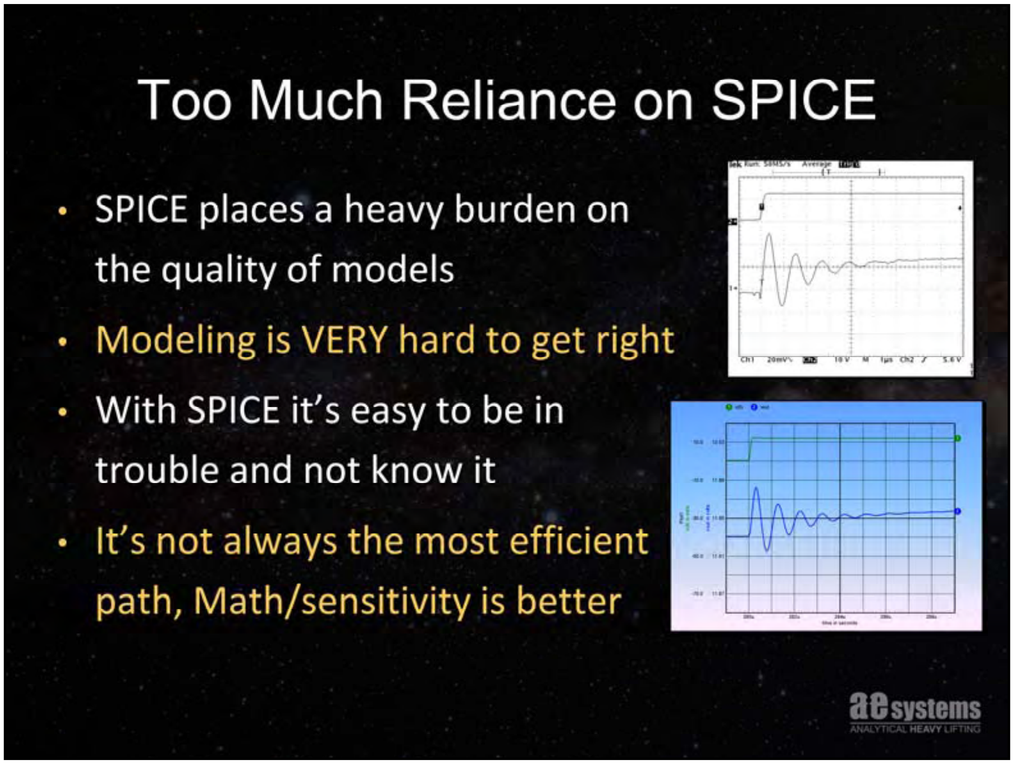

Modeling is VERY hard to get right

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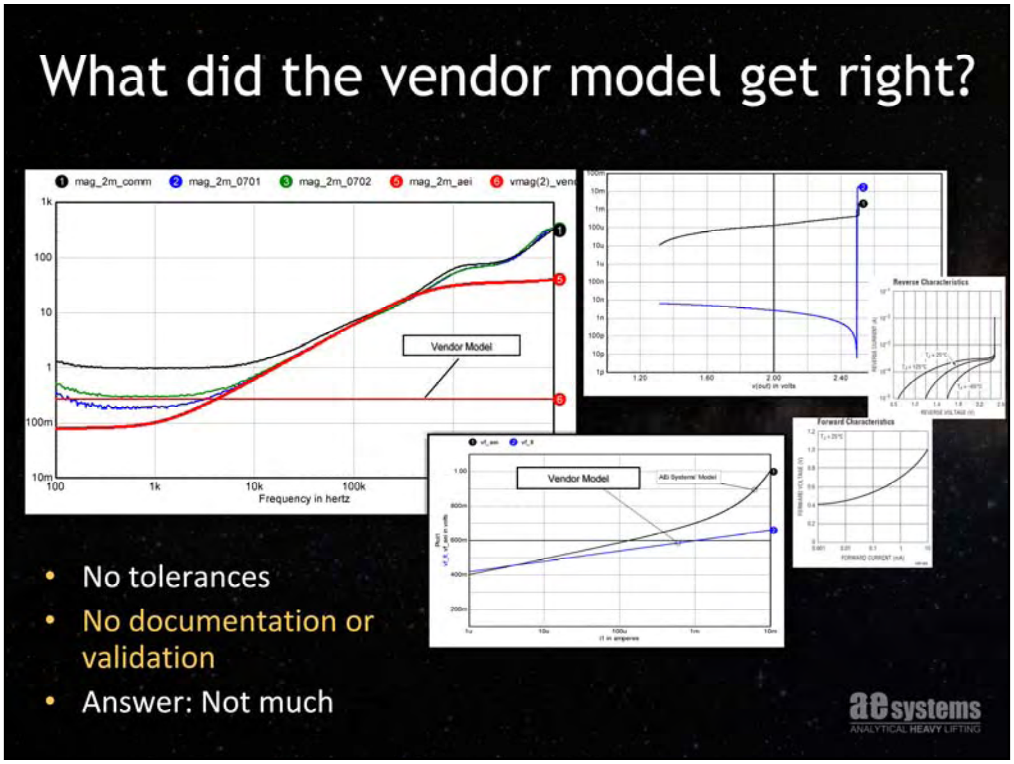
Accurate WCCA relies to a large degree on accurate SPICE models and modeling capabilities. This is why it is a core competency for AEi Systems. We are the number one source in the world for custom SPICE modeling.

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.

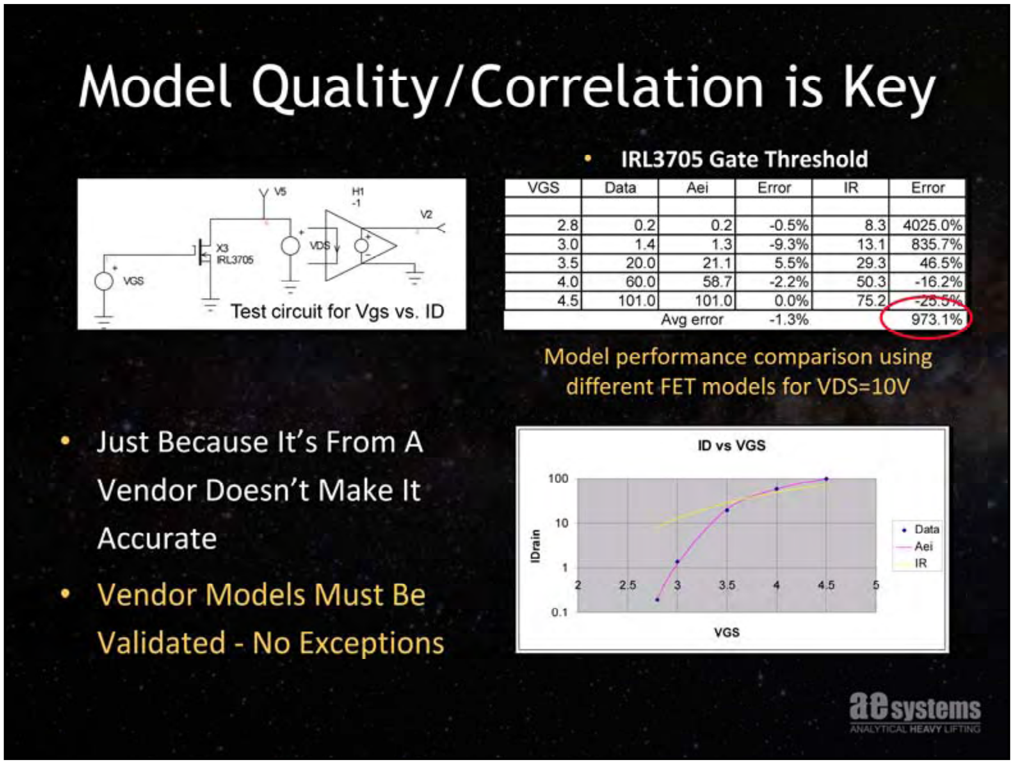


It’s sad, but vendors rarely (if ever) test the models they post on their web site against real hardware. Talk about “garbage in, garbage out!”

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.

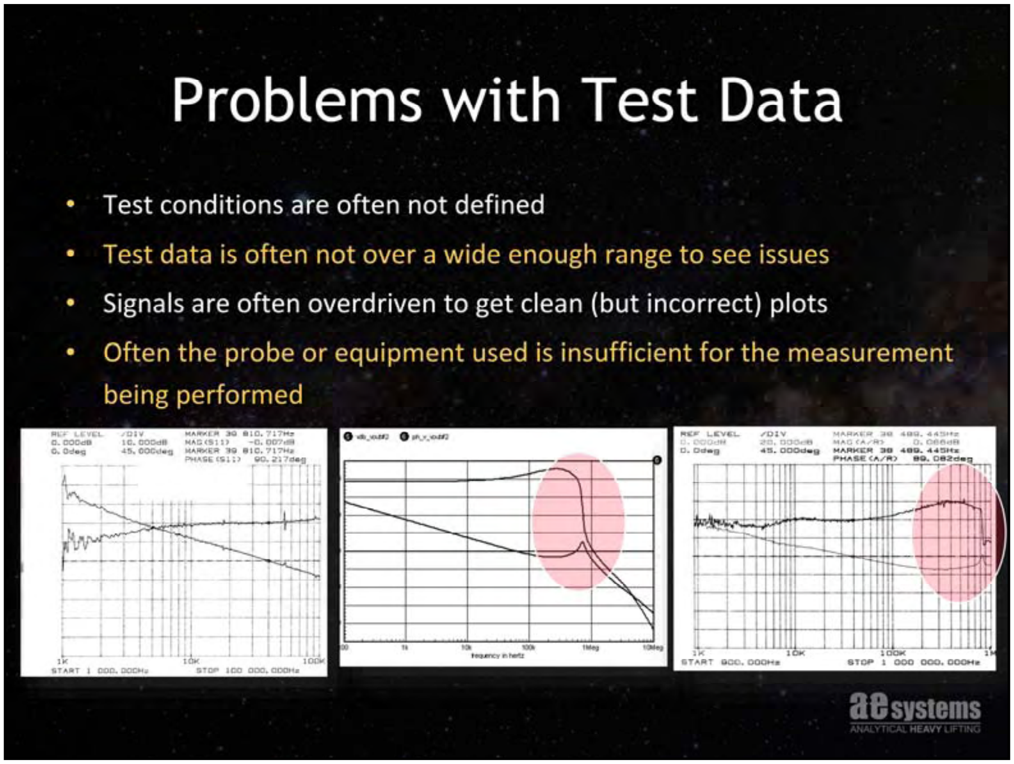
That means to do WCCA well, you need to be able to make and validate your own models – or use specially verified models such as those produced by AEi Systems. (We are not aware of any other truly reliable source – please let us know who is out there.)



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.



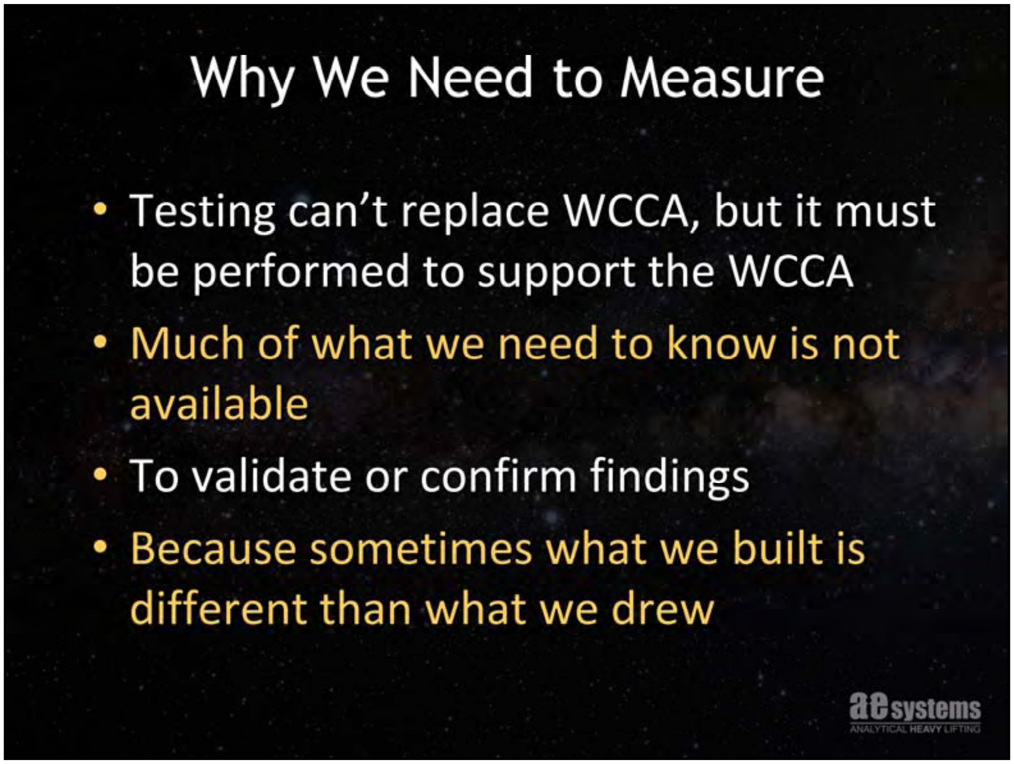
In order to perform a WCCA you need to be able to get reliable test data. Correlation of hardware to test data is essential for a successful and reliable WCCA.

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.

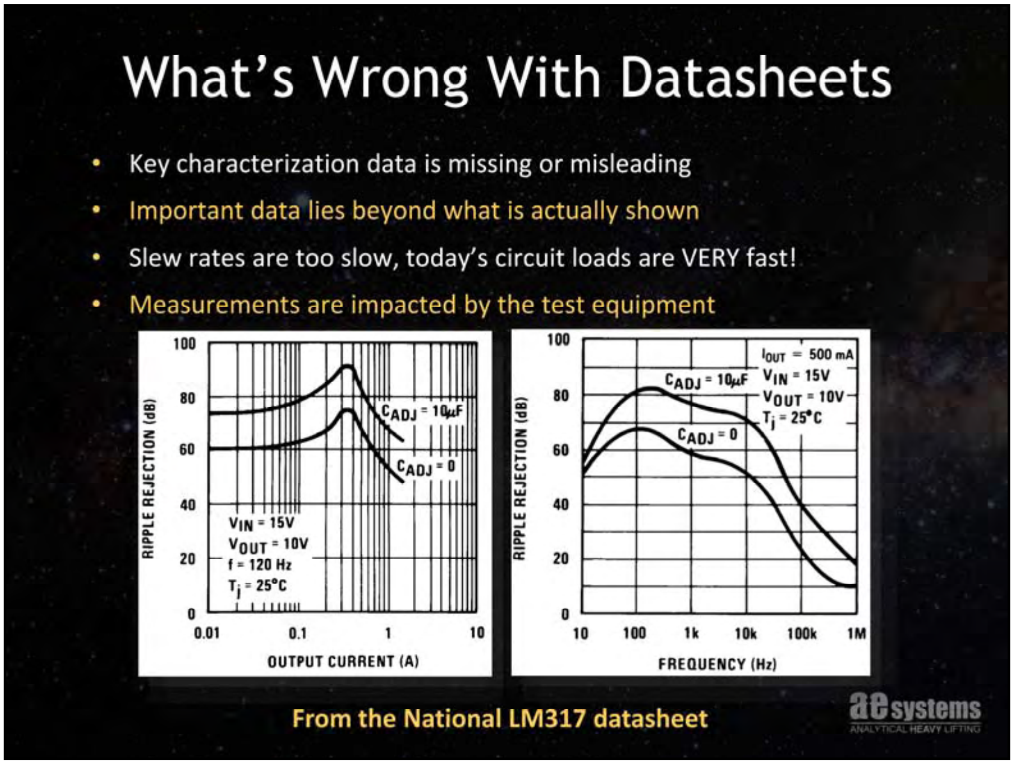
Test corrals leaps of faith and assumptions made during the analysis process. The process of correlating part and circuit models to test data is really critical and its usually one of the efforts that gets cut short due to schedule, cost, people, or equipment.



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.



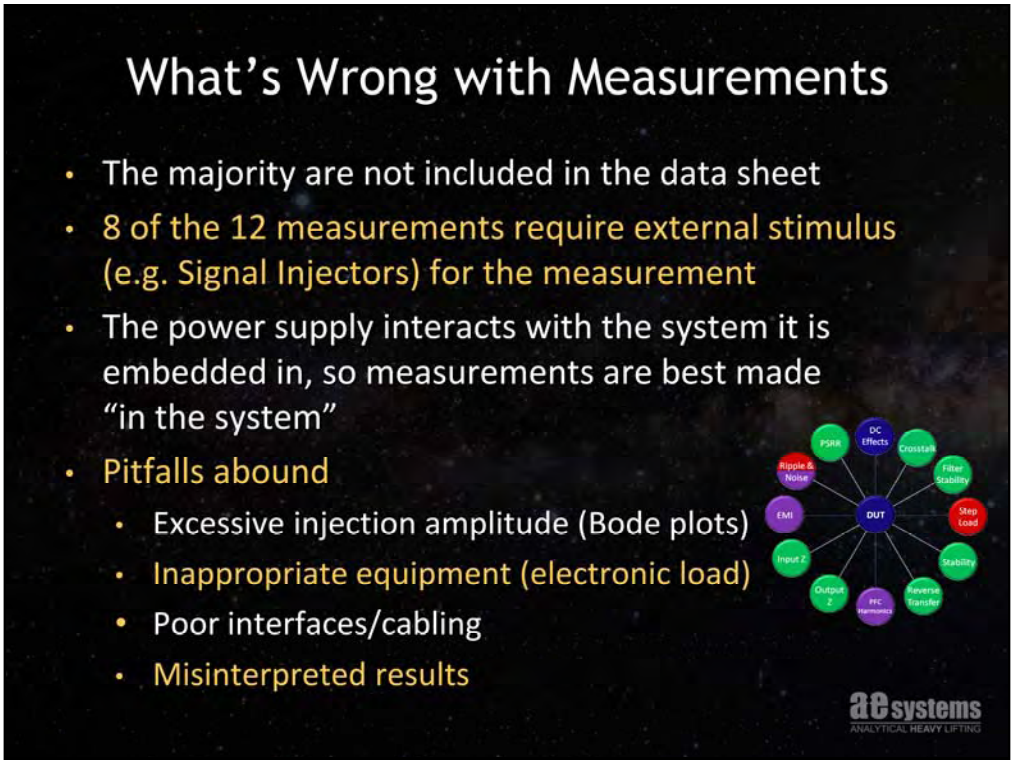
In the figure above, note that PSRR is specified at the optimum current/frequency and with larger Vi-Vo then other tests.

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.



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
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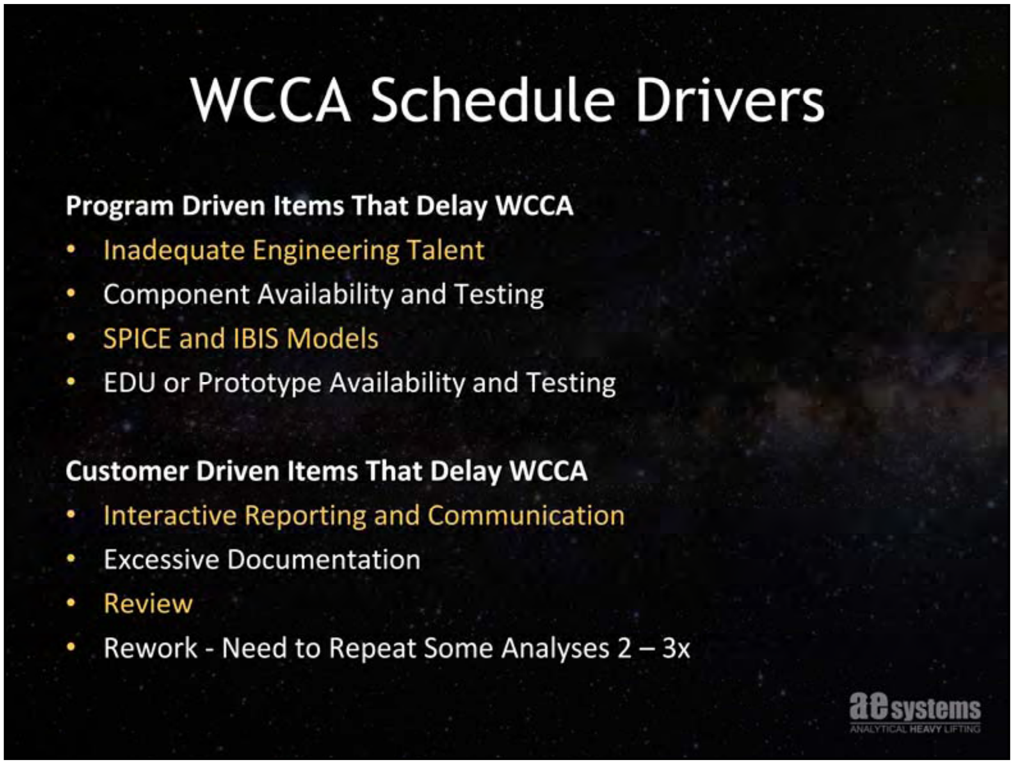
WCCA Schedule Drivers
Program Driven Items That Delay WCCA
Inadequate Engineering Talent
Component Availability and Testing
SPICE and IBIS Models
EDU or Prototype Availability and Testing
Customer Driven Items That Delay WCCA
Interactive Reporting and Communication
Excessive Documentation
Review
Rework - Need to Repeat Some Analyses 2 – 3x
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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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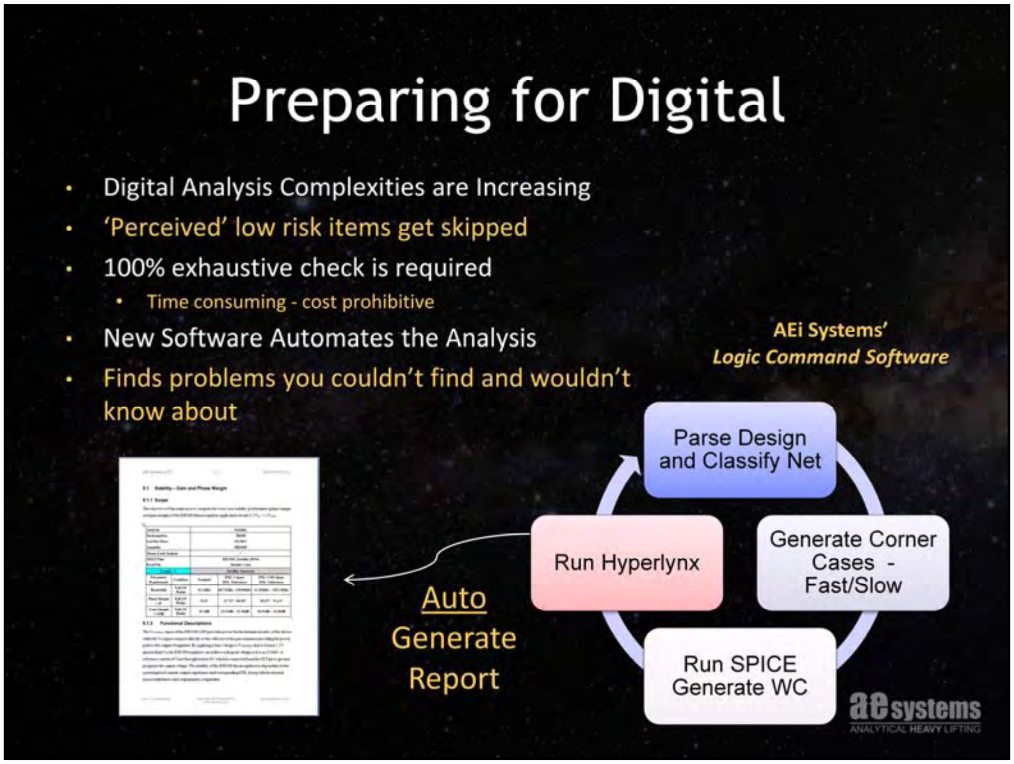


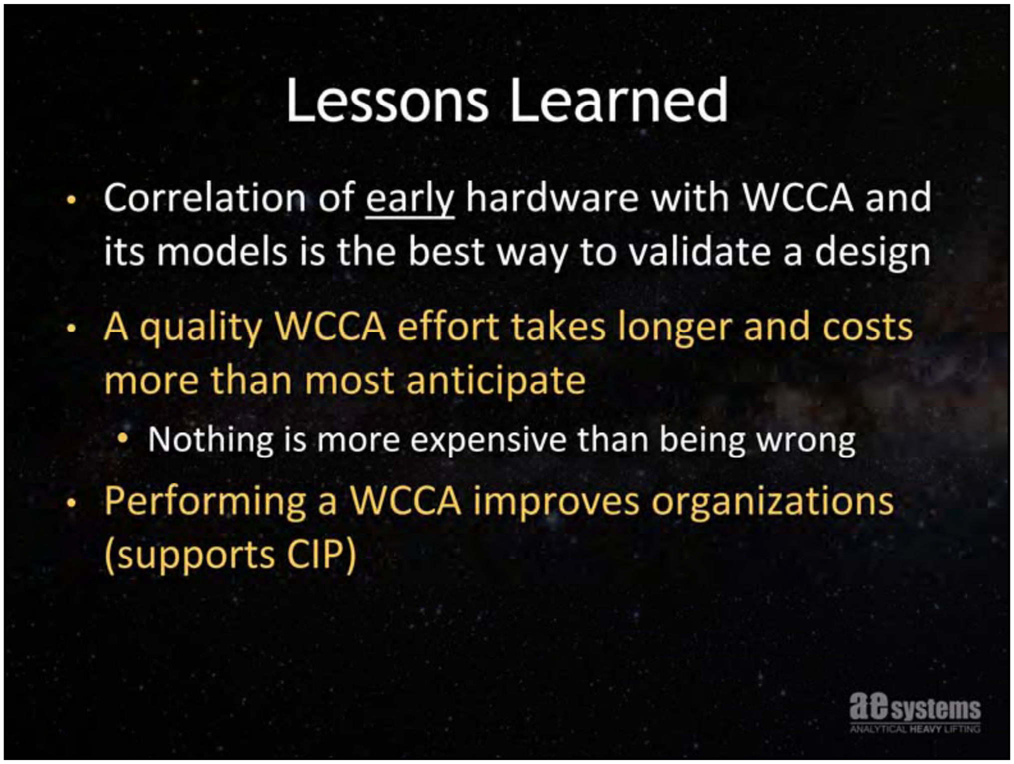
Digital analysis complexities are increasing. Designs can have 100s – 1000s of nets Each net can have 2-15 analysis cases. Net extraction can be complex and it's not always obvious what direction the WC parameters should be moved in. Manual analysis is prohibitive. Traditionally this means only analyzing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

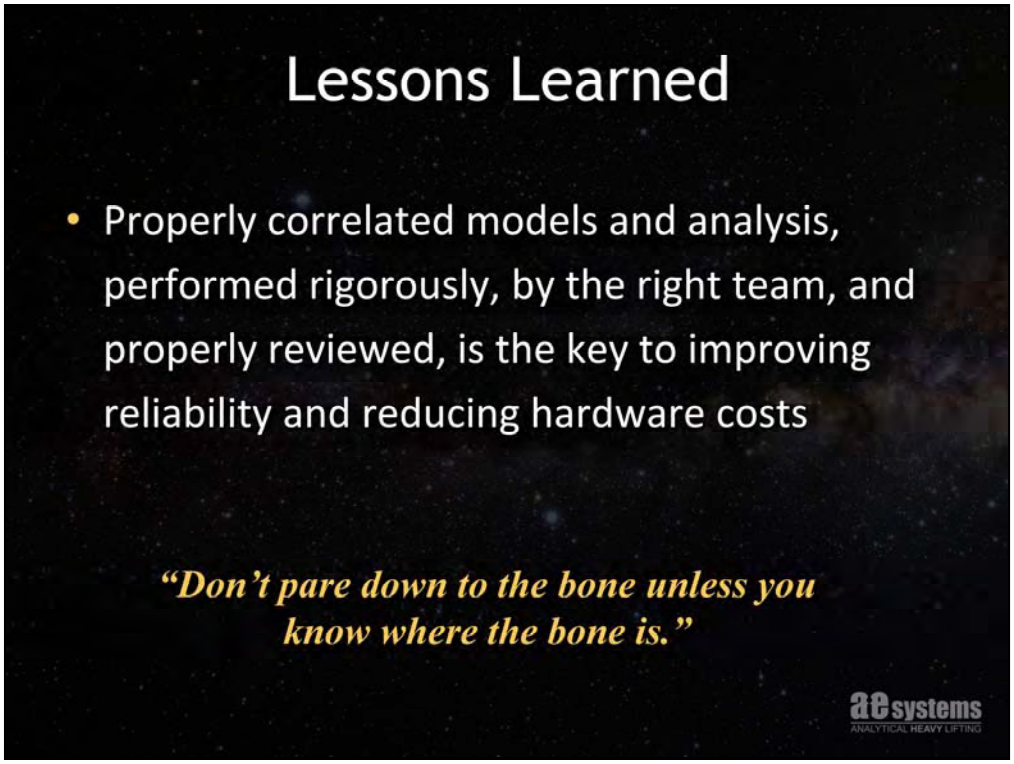
Findings such as inappropriate pull-up/pull down resistors, improperly terminated test interfaces and undocumented features in parts that are not even in datasheet (because models are created using measured data), are often uncovered by the software.

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



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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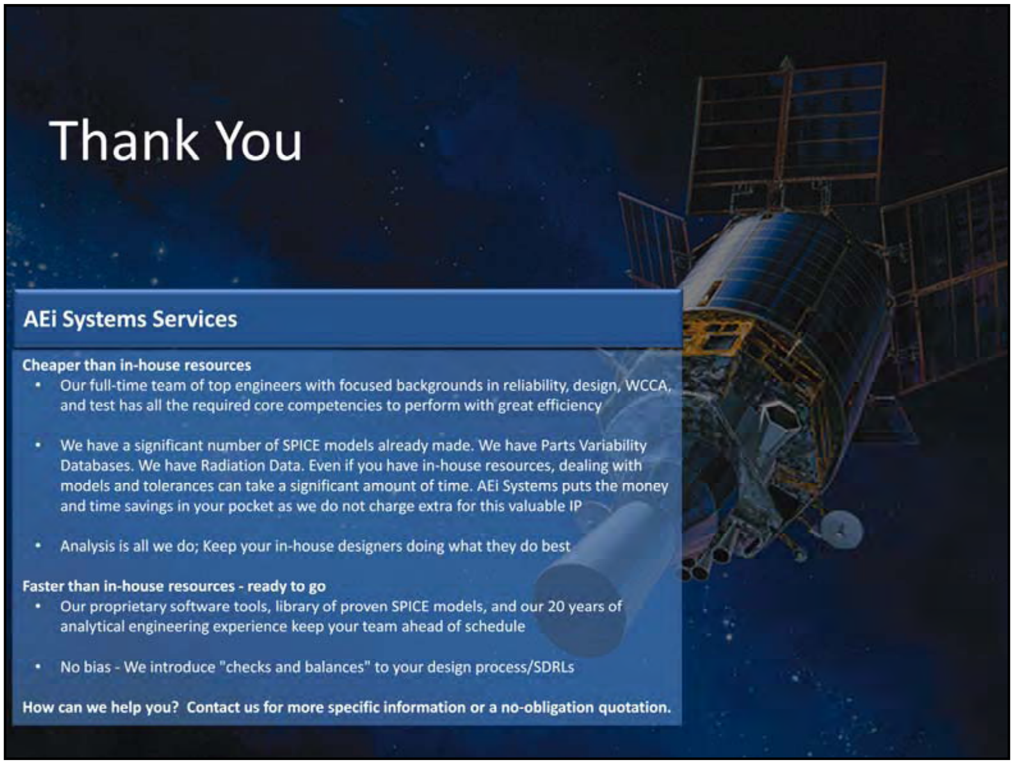
ANALYTICAL HEAVY LIFTING



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