The Who, What, When and Why of WCCA

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Worst Case Circuit Analysis – The Key to Reliability and Product Assurance

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 improve product quality, and avert potential disasters both monetary and political.

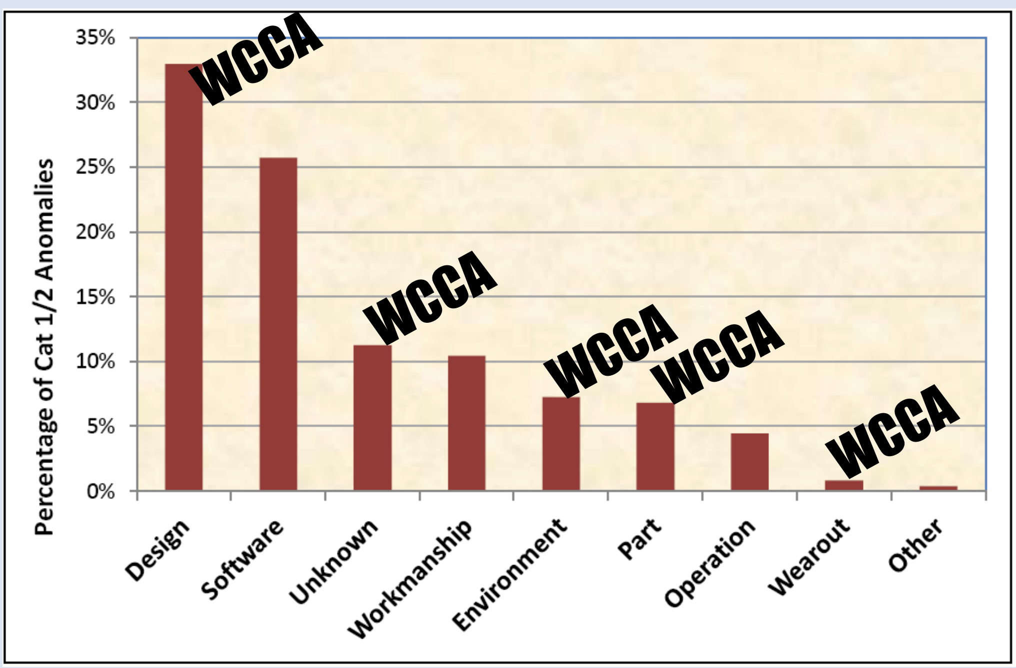
WHAT IS A WCCA?

A WCCA is a quantitative assessment of a circuit or systems FUNCTIONAL performance, accounting for manufacturing, environmental, aging and, in the case of Space applications, radiation tolerances.

Through a worst case analysis many aspects of a design's performance are computed, and the risks and margins of key metrics calculated. It examines the tolerance induced effects on electronic circuits caused by potentially large and unknown magnitudes of variations of electronic piece-parts beyond their initial nominal value. The variations can be the result of manufacturing, 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.

Worst Case Analysis is the KEY to Improving Mission Assurance



Causes of on-orbit anomalies - first 3 years. WCCA attacks key problem areas.

Programs are clearly not doing enough analysis since 32% of early on-orbit failures are design related.

AEi Systems accomplishes WCCA using rigorous mathematical and in-house derived simulation-based models along with hardware correlation. The correlated models are then used to determine stress margins and EOL/BOL performance ranges.

A single over-stressed component can cost your company millions of dollars. **A thorough Worst Case Analysis can eliminate this from happening.**

The methods pioneered by AEi Systems over the last 25 years, for developing part tolerance databases and for performing sensitivity, extreme value (EVA), and Monte Carlo analysis, have become accepted industry standards.

WHY DO A WCCA?

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, whereby the circuit continues to function but with degraded performance, ultimately exceeding the circuit's required specifications. 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 and is the only way to quantitatively assess the possibility and potential impact of out-of-tolerance conditions.

Here are some questions to ask yourself if you are considering <u>not</u> performing a WCCA:

- How much risk can the program accept?
- What is the cost of failure?
- What is the heritage of the circuitry?
- Are you using new technology?

The typical cost of performing a rigorous WCCA is generally less than 1% of the program cost. The cost of not doing the WCCA can cost 100% of the program cost or more. We have seen many program failures, which required at the least, major redesigns AFTER completion of production testing. Not only is money wasted, but schedule and time to market.

So why do we perform a WCCA? There are many reasons.

- **Assure End-Of-Life Specification Compliance**
  - Help to make sure critical requirements are defined
  - Find unacceptable variations early in the program—Before expensive build/test iterations
- **Assure Quality, Robustness, and Reliability**
  - Determine when a given part type doesn’t work well or represents “overkill”
  - Better understand the design, component sensitivity, and areas for improvement

- **Assure components are maintained within acceptable stress limits under all conditions**
  - Evaluate aspects we couldn't easily evaluate otherwise.....tests that are destructive, deadly, catastrophic......
- **Determine Test Program Limits**
  - Without understanding the impact of tolerances, how can you set test limits?
- **Support critical parameters and part requirement definitions**
  - Without understanding the impact of tolerances, how can you evaluate whether a part's min/max limits are acceptable?
- **Allows us to better understand and utilize new parts and technologies**
- **Obtain Insurance – Protection Against Financial, Political, and Legal Disasters**

Given that you can make one of almost anything work in a laboratory environment; the job gets a little harder when:

- You need to build a larger quantity
- It has to work in harsh environments
- It has to work for a long time (high duty cycle)
- It has to interface with someone else's design
- Maintaining Performance throughout the product's lifetime is Critical

<u>Lastly, it should be noted that in the all the WCCAs we have performed, no one has ever passed an analysis without any non-compliances.</u> Some have passed 90% of the analyses, some have passed only 10% (Ouch). But the key point is that WCCA yields a dramatic return on investment both in the short term by vetting competing specifications, reducing design iterations, design changes, and test time; and in the long term by achieving an increase in production efficiency and trouble-free field operation, as well as an increased engineering awareness of the value of good design practices.

Reasons to Perform Worst Case Analysis

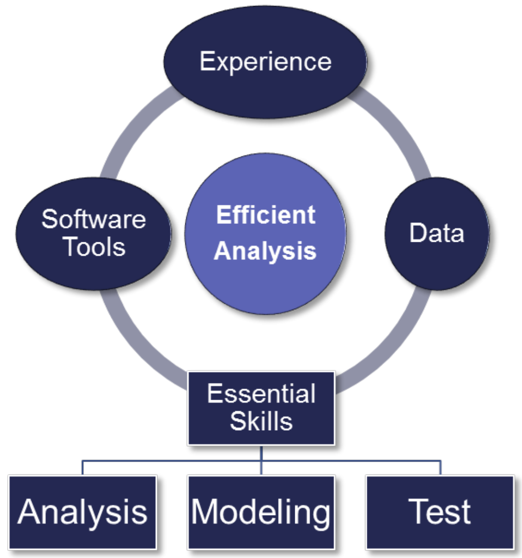
Design Verification and Reliability	To verify circuit operation and quantify the operating margins over part tolerances and operating conditions - Will the circuit perform its functions and meet specifications/To quantify the risk
	To improve performance - to determine the sensitivity of components to certain characteristics or tolerances in order to better optimize/understand a design and what drives performance
	To verify that a circuit interfaces with another design properly
	To determine the impact of part failures or out of tolerance modes
Test Cost Reduction	To evaluate performance aspects that are difficult, expensive or impossible to measure (e.g., determine the impact of input stimulus and output loading so as not to damage hardware)
	To set ATP limits
	To verify SATs/SITs and if they are needed/what their limits should be
	To reduce the amount and scope of testing
Parts Assessment	To determine if a part is suitable (too cheap, too expensive, right characteristics) or if a new technology can be used
	To support/set critical parameters and SCD requirements/screening definition
	To perform Single Event Transient (SET) analyses
Schedule, Cost, or Contractual Risk Reduction	To reduce board spins - determine the impact of late-stage design or part changes
	To verify changes to heritage circuits
	To obtain better insurance rates or reduce contractual liabilities
	To avoid a catastrophic or costly incident

WHO SHOULD PERFORM THE WCCA?

Generally, NOT the circuit designer alone!

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 worst case is not normal for designers. Incorrect assumptions made in the course of the design will generally be repeated in the analysis.

Certainly, the designer has a substantial part to play in the WCCA process including generation of the nominal model, nominal analysis, breadboard testing, and WCCA review. Ideally, however, the analysis should be performed by an <u>independent group</u> of analysts, to remove any bias. Furthermore, the range of skills needed is just not available from one engineer. A team is needed to provide the experience, mathematical skills, component, modeling, test, simulation, reporting and review capabilities necessary to get the analysis right and completed in an efficient amount of time.



Can you perform the analysis?

The project engineer is often under great schedule pressure, the program under budget pressure and the company under political pressure. Consistently, the WCCA performed internally by companies, is not sufficiently rigorous to be acceptable to most prime contractors such as Lockheed-Martin, Ford, Boeing, Aerospace Corporation or NASA and usually does not meet their strict guidelines. The new Aerospace TOR guidelines on WCCA are not tolerant of the normally encountered short-cuts and 'escapes'.

Designers simply believe their design will function based on "experience", bias, or limited breadboard data and not the computed margins. 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.

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

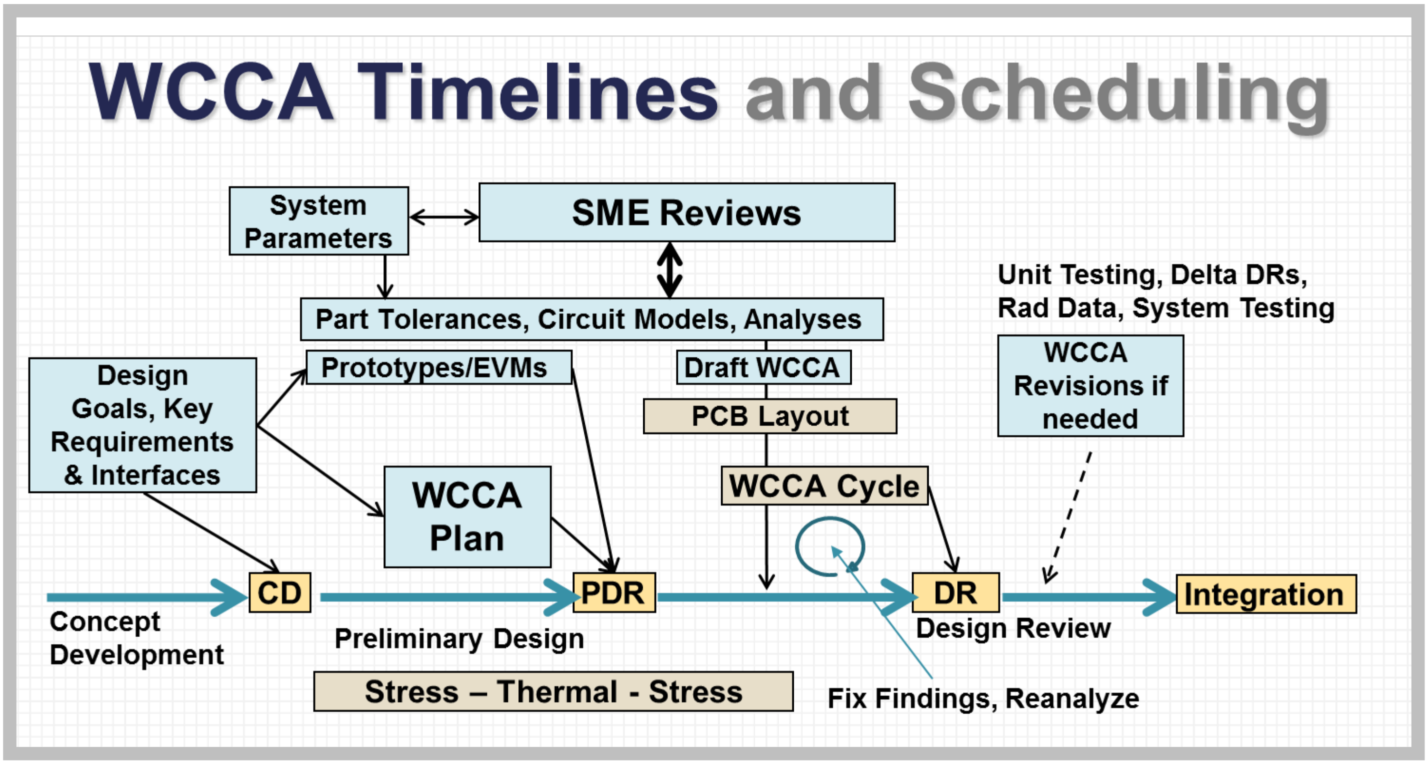
WCCA is the last line of defense for assessing whether the design will perform properly throughout its lifetime. It's just too important. There are just too many biases and we should not let our egos or other external factors drive the analysis if at all possible. To do so can cost us all the savings we derive from the process. Besides having the skills noted above, the analyst(s) should be as independent as possible.

WHEN TO PERFORM A WCCA?

WCCA is often shoe-horned between the end of the design process and the design review. It is also often understaffed. Unfortunately, too many projects find themselves still designing right up until the design review and beyond and there is little or no time to properly perform the WCCA, let alone address the non-compliances found.

This is potentially disastrous. The WCCA, and the other inter-dependent reliability analyses, need time to be completed properly as shown below.

On more than one occasion, AEi Systems has identified serious problems as a direct result of performing a WCCA. In almost all instances we were able to provide simple and inexpensive solutions before the final hardware was delivered. This allowed the issues to be resolved at minimum expense while greatly improving the reliability of the final product.



AEi Systems has also had several unfortunate experiences where significant issues were identified after the hardware was delivered. In the two most extreme cases, the WCCA was preformed after the final hardware was completed and no simple solutions were found. In both of these situations the hardware was not accepted by the end customer resulting in millions of dollars in hardware having to be scrapped.

Some things to note with respect to schedule:

- WCCA should be the major consideration during the design phase
- Models should be developed in parallel with breadboard data – This is Essential!
- It's important not to forget about Stress/Thermal analysis which may need to lead the WCCA effort
    - The temperature range for the WCCA usually comes from the worst case stress analysis where the power dissipation and junction temperatures are computed

- Schedule compression is VERY BAD for WCCA. It increases escapes and reduces the time to fix and reanalyze non-compliances
    - WCCA needs to be performed well before CDR but concurrent with engineering hardware/test data
- Worst-Case Analysis can help you find problems early, when there’s TIME TO CORRECT THEM—COST EFFECTIVELY

CAN’T ELECTRICAL TEST REPLACE WCCA

Can't electrical testing be used as a less expensive alternative to analysis? The answer is generally “No.” Testing normally only determines initial, 25C performance (not even BOL). It usually does not cover EOL tolerances or all operating conditions. 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 costly!

While testing is essential to supporting the WCCA models and conclusions, it comes with the following inherent concerns:

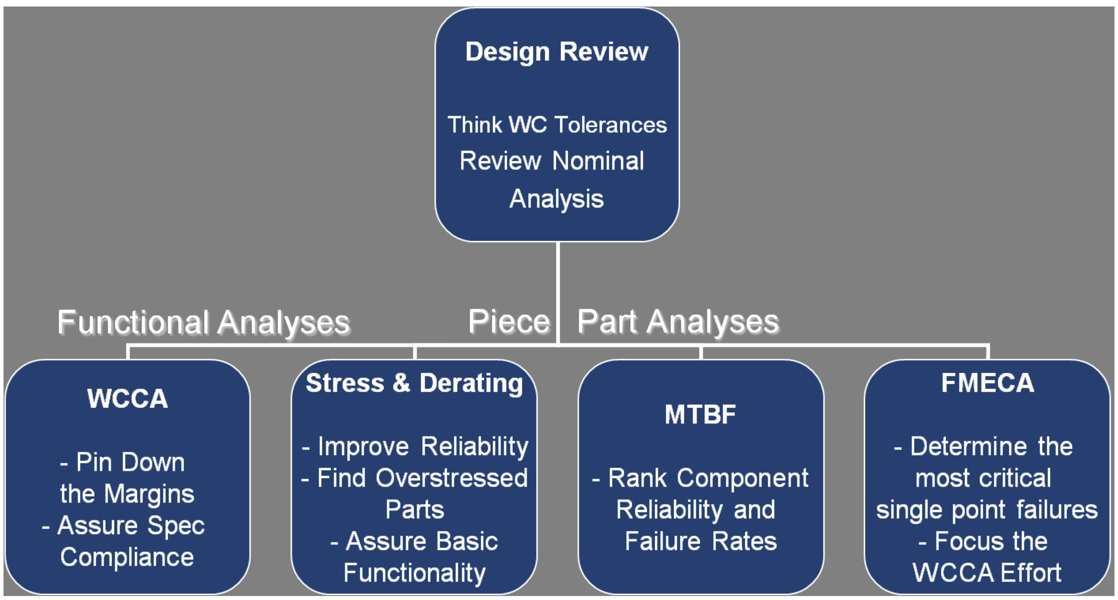
- Testing does not assess key part tolerances. Many circuits are dependent on unspecified parameters. For example, ESR has no minimum specification and is a key factor in power supply stability.
- Testing does not compute margins, risk, or parametric sensitivity; three key outputs of a WCCA. Therefore, it is much harder to improve the design with only test data as the guide
- Testing is fraught with pitfalls
    - Test equipment is often inadequate. Poor test setups often test the setup and not the unit. For instance, today’s POLs, switchers, and digital circuits have edge speeds faster than 1ns. Most applications need an oscilloscope with more than 1GHz of bandwidth and more than 10G Samples/s.
    - Many of the things we need to look at are simply not tested or even testable. Worst case test conditions are often not defined, unattainable, or would over-stress the hardware
    - Test data is often poor in terms of its fidelity or mis-interpreted
    - There is often insufficient knowledge of what to look for
    - Despite reliance by programs with limited budgets, testing isn’t cheap
    - Testing is often limited to the top levels. If an anomaly isn’t seen, probing to lower levels is not performed. Key functional blocks are often not tested. For instance, it is easy for an opamp or power supply with poor stability to hide in a system that appears to be working properly. The poorly performing circuit may be masked and dismissed as increased noise. It is known that stability margins of control loops can change 20-30 degrees over temperature and life. Without knowing where you stand nominally, EOL issues can easily occur.

ISN’T MTBF, FMECA, AND STRESS ANALYSIS SUFFICIENT TO ACHIEVE RELIABLE OPERATION?

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. These analyses increase the chances that the design will meet the identified performance requirements throughout the product's lifetime and particularly at the End-of-Life.

MTBF, FMECA, and Stress & Derating analyses are all part-based analyses and so they do not focus on what WCCA does which is a functional assessment. Performing Stress & Derating analysis on components is not sufficient to insure reliable operation. While it is very valuable, it does not find functional deficiencies in the design.

As shown in the chart figure below, WCCA also cannot be replaced by other Part-based analysis. While critically important, they do not validate and verify the circuit's functional and specification requirements.



The relationship between part based analyses and WCCA.

It should be noted that the tolerances, models, and math needed for a stress & derating analysis greatly overlap with those from the WCCA. Care should be taken so that effort isn't duplicated.

The two analyses are also often interrelated with several worst case analyses such as power supply regulation needed for the stress analysis.

Finally, circuit redundancy doesn't obviate the need for WCCA. Redundancy won't save a bad design.

WHAT IS THE SIGNIFICANCE OF HERITAGE OR PAST PERFORMANCE?

"I HAVE 10 UNITS FLYING IN SPACE AND SOLID TEST DATA. DO I STILL NEED TO DO A WCCA?"

WCCA does not, in large part, determine whether the design will work. Likely, in the typical case the design does. The worst case analysis process is about quantifying the performance boundaries, the margins, and assessing the risk probabilities.

Unless there is a statistically significant amount of data, it doesn't matter what kind of heritage the unit has, that is simply irrelevant to computing the margins and confidence levels.

A good portion of WCCA non-compliances are in the 3-4 sigma range. That is where a WCCA provides visibility. You might see those results with one in a hundred units; you might or might not be happy with that percent failure rate.

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 really is not does the unit work, the problem is how do you prove it without an analysis?

Here are some examples of WCCA outcomes and lessons learned:

- **Security System**
  - Found a power supply negative spike issue that was resetting a PWM causing intermittent failing control chips
  - Result: Improved Circuit Understanding – Saved Design Iterations – Helped Evaluate thermal concerns
- **Motor – Encoder Circuit**
  - Predicted the jitter at EOL, Revealed flaw in optical sensor,
  - Result: Provided the need and data for tighter SCD requirement
- **High Reliability Power Supply – Can it be salvaged?**
  - WCCA helped repaired and quantify 13 key requirements failures before a 2 year "button-up" phase
  - Result: Able to refurbish the power supply rather than replace it
- **Power Plant**
  - Snubber Cap Failure – Saved loss of production over 18-month production phase
  - Result: WCCA helped guide and define the needed component selection
- **Satellite Power Supply**
  - Found UVLO problem one week before Major CDR,
  - Result: WCCA enabled easy fix
- **Medical Device**
  - Expensive Zener diode testing did not reveal range of tolerances unit was seeing
  - Result: WCCA able to replace expensive testing saving tremendous legal and replacement costs
- **Power Supply Works at Low Temperature, Fails at High (> 200C)**
  - Analysis helped understand the impact of tolerances for characteristics that couldn't be probed/tested
  - WCCA helped build confidence in the control loop redesign
  - Result: Failure anomalies were better understood and quantified

IP PROTECTION

AEi Systems has had the pleasure of supporting many projects for many customers. We have analyzed projects that resided from 5 miles below sea level to deep space. We have supported commercial projects, as well as special secret projects. AEi Systems is currently entrusted with the component radiation and aging databases for almost every satellite manufacturer. We have not had a security or disclosure related issue in the 20 years since the company was founded in 1995.

AEi Systems is involved with the SPICE modeling of many integrated circuits from major manufacturers such as Linear Technology, ON Semiconductor, Analog Devices, Texas Instruments, Intersil and others. In each case, AEi Systems has been trusted to receive, store, and keep in confidentiality, transistor level schematics containing the core circuitry and IP for the ICs we model.

Thorough documentation, exhaustive attention to accuracy, and the use of multiple methods of analysis to verify conclusions are the hallmarks of an AEi Systems' WCCA

A Partial List of AEi Systems WCCA Clients

- Aerojet/Rocketdyne
- Aerospace Corporation
- Aitech Defense Systems
- Allied Signal
- Anaren
- Amway
- Argon
- Babcock
- BAE Systems
- Ball Aerospace
- Blue Canyon
- Blue Origin
- Boeing Space Systems
- BOSCH
- Brookhaven National Labs
- Canadian Space Agency
- Cobham/Aeroflex
- Comdev
- Continental Automotive
- Crane/Interpoint
- DELL
- EB Aerospace
- ESI Motion
- Excelitas/Perkin-Elmer
- Florida Power and Light
- Ford
- Frequency Electronics (FEI)
- General Dynamics
- Gentex
- Gurley
- Hamilton Standard
- Honeywell
- Hughes Space and Comm
- International Rectifier
- ITT Industries/Exelis
- Interpoint/CRANE
- Johnson Controls
- JPL
- L3
- Linear Technology
- Lockheed Martin
- Luminar
- Lucix
- Medtronic
- Micrel
- Micropac
- Microsemi
- MIT Lincoln Labs
- MOOG
- Motiv Space Systems
- M.S. Kennedy
- Northrop Grumman
- Pratt & Whitney
- Raytheon
- SEAKR
- Signal Technology
- Sierra Space
- Siemens
- Smith & Nephew
- Smith's Interconnect
- Stellant
- SWRI
- Space Systems Loral
- Spinnaker Microwave
- SSDI
- Symmetricom
- Taber Industries
- Tavis
- Telephonics
- Teledyne
- Toyota
- Yardney