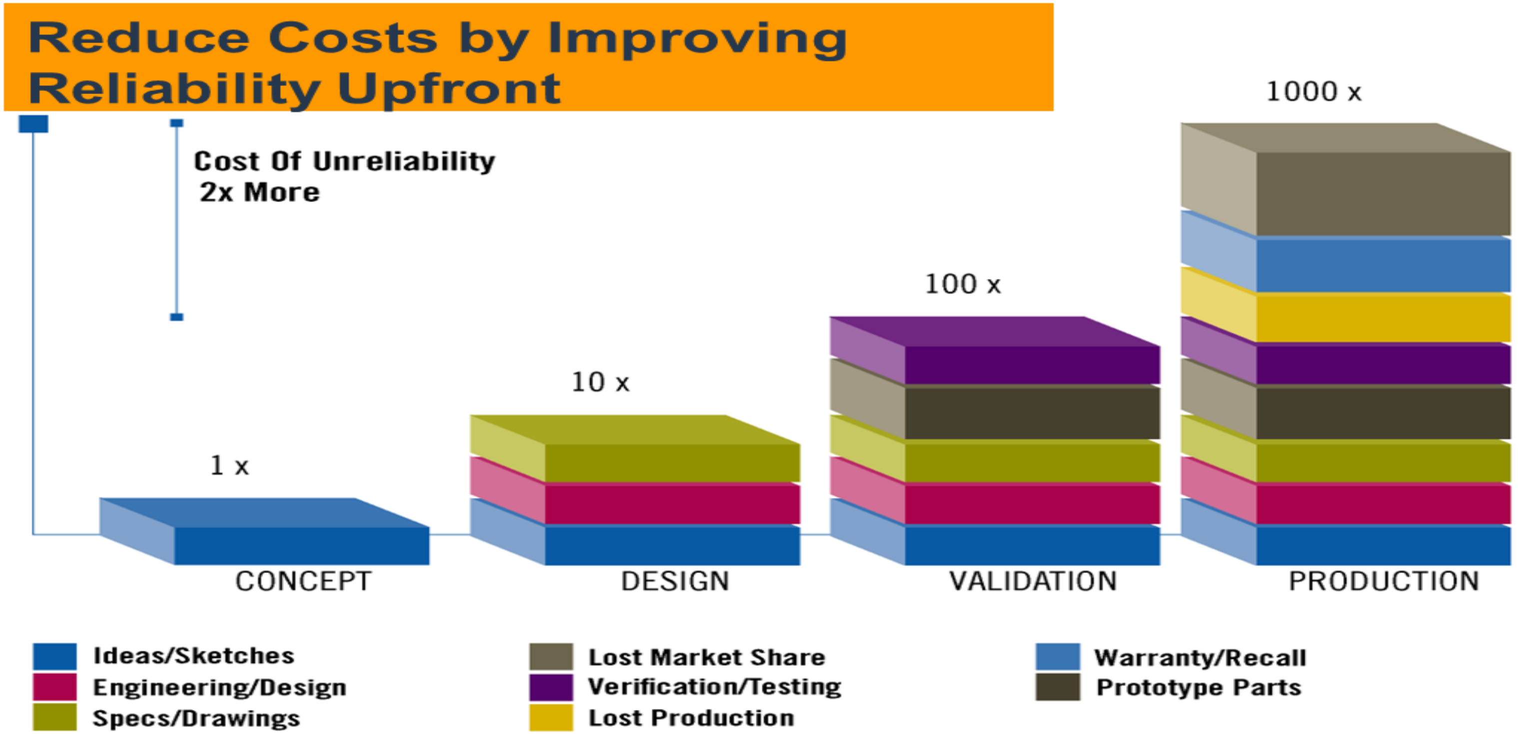
Reliability 360: How to Verify Design Robustness Early in the Process

DfR Open House

March 16, 2014

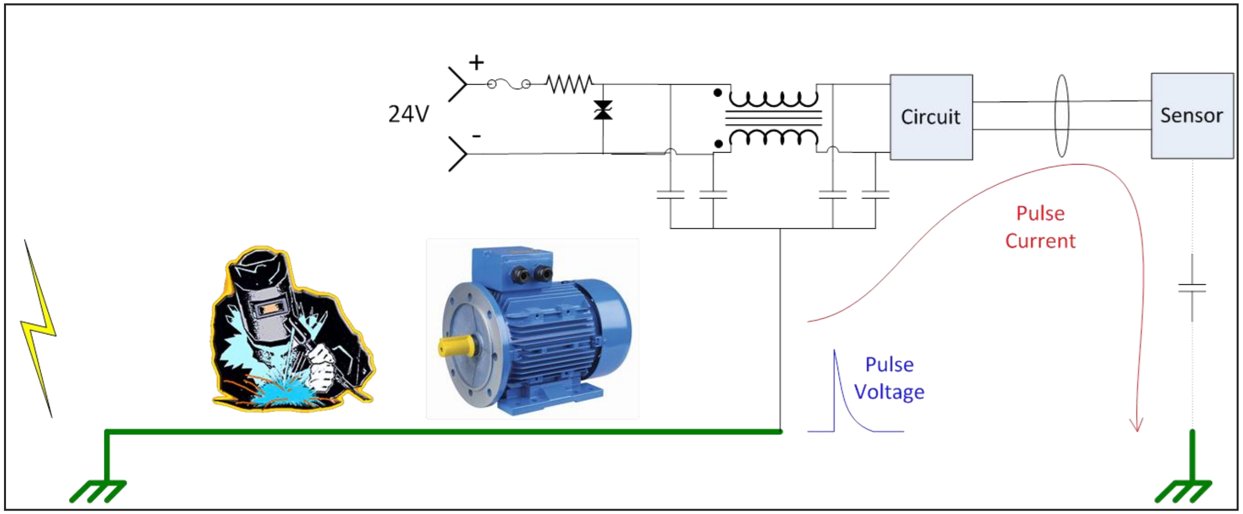
Reliability 360

- Producing reliable products is critical to a company's success.
- Performing comprehensive design reviews during product development is the only proven method for ensuring a reliable product.



9000 Virginia Manor Rd Ste 290, Beltsville MD 20705 | 301-474-0607 | www.dfrsolutions.com

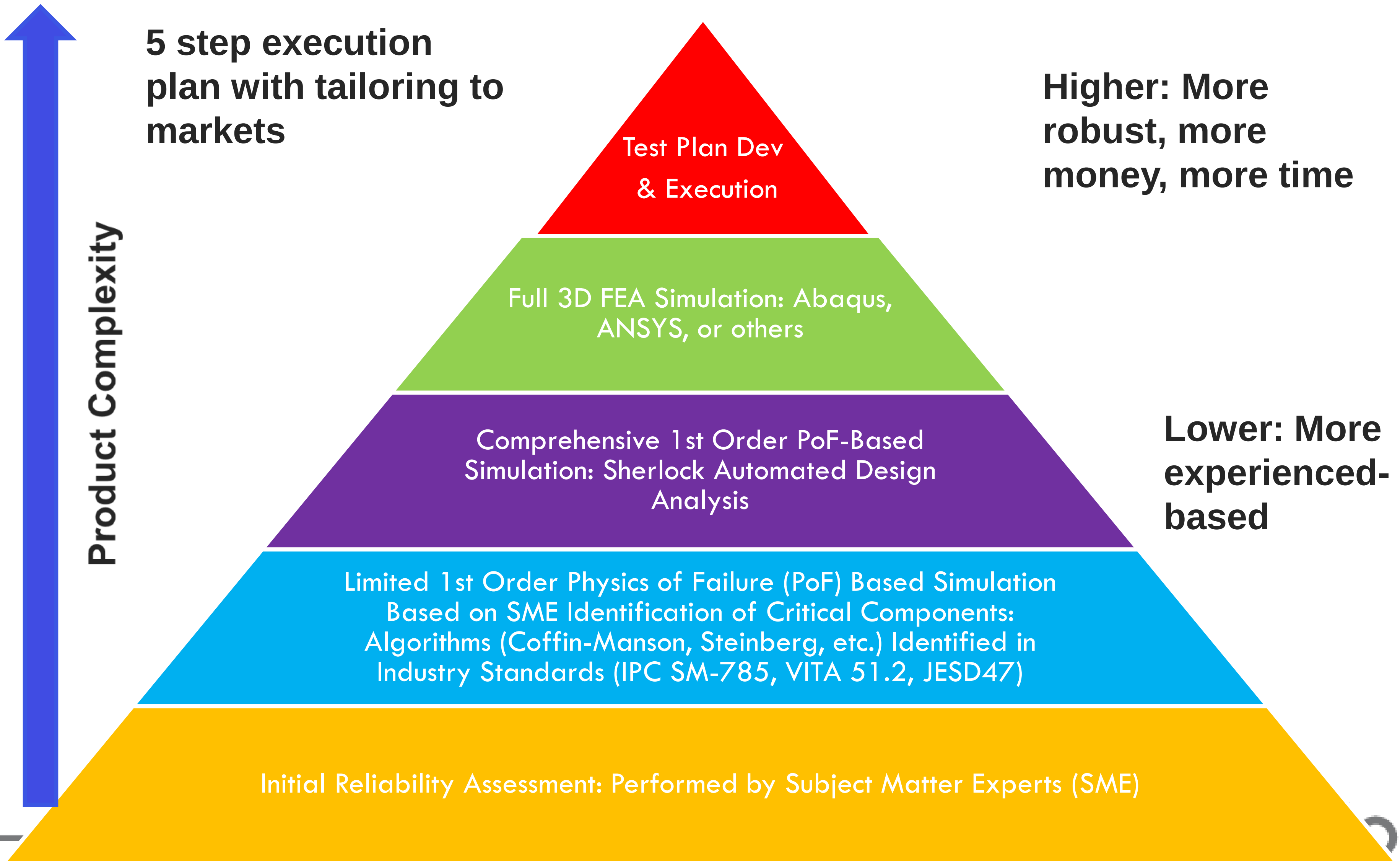
- At DfR, we review products from electrical, thermal, mechanical, manufacturability, reliability, and component selection perspectives to give you the full 360 degree picture.
- Example: IEC61000-4-5 covers surges on the input lines. However, there have been discussions and DfR has seen this effect where a surge is conducted on the earth ground going to the device.



Example Ground Surge

The figure shows where ground surge can affect the circuit yet the product passes IEC61000-4-5 surge.

Our Design for Reliability (DfR) Methodology



Design for Reliability

SME – Experienced, cross functional reliability dream team

> 500 Failure Analysis projects per year covering all things from die level to system level

DfR Solutions:

Your Partner Throughout the Product Life Cycle

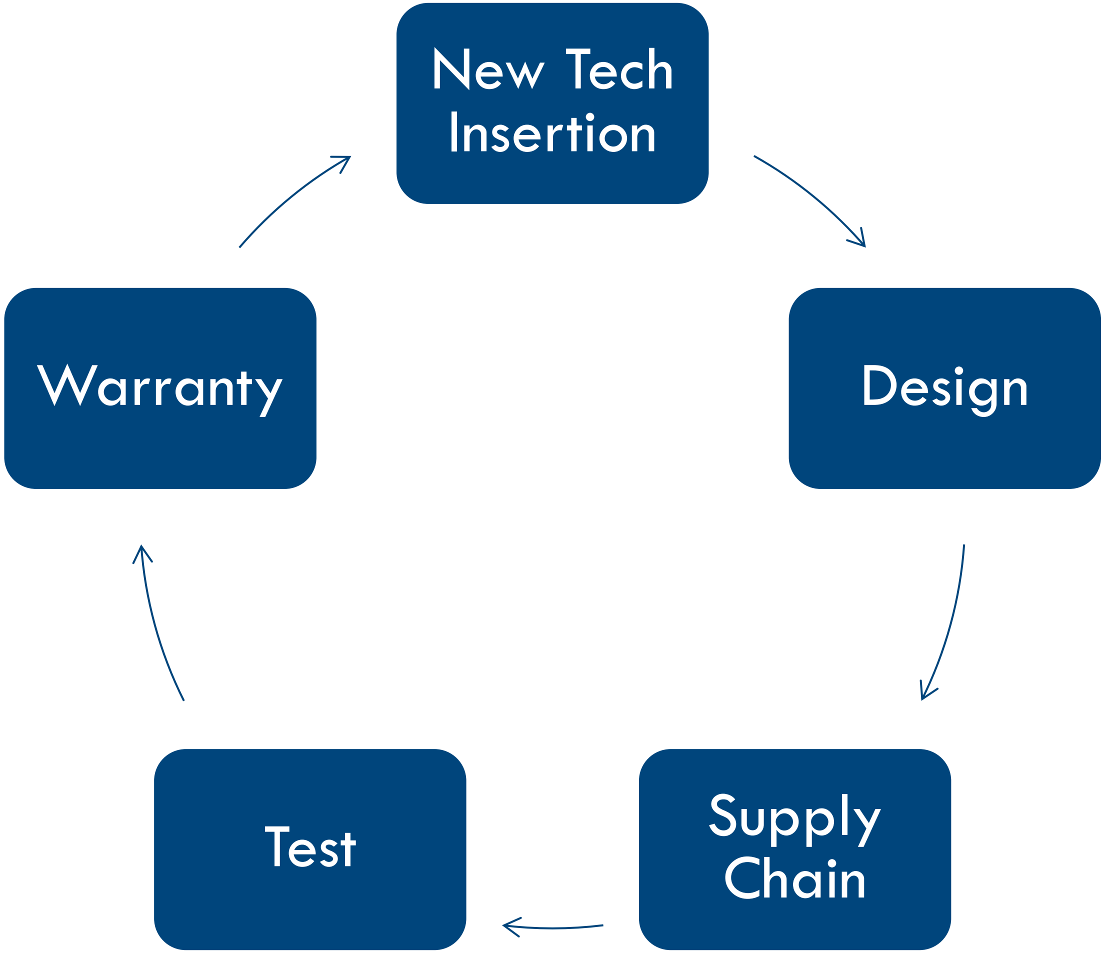
Comprehensive PoF: Design, predict, perform, and interpret the results of accelerated life tests starting at design stage, continuing throughout the lifecycle of the product

Test Plan Dev – 100's of plans developed & executed in our state of the art lab. Through close collaboration with industry leading electronics manufacturers & deep industry knowledge, we deliver the right test for the right product every time!

FEA - Excellent reputation in FEA-based simulation & modeling of electronic components, products & systems. Team of five FEA experts

DfR Solutions

Working with Customers Throughout the Product Life Cycle

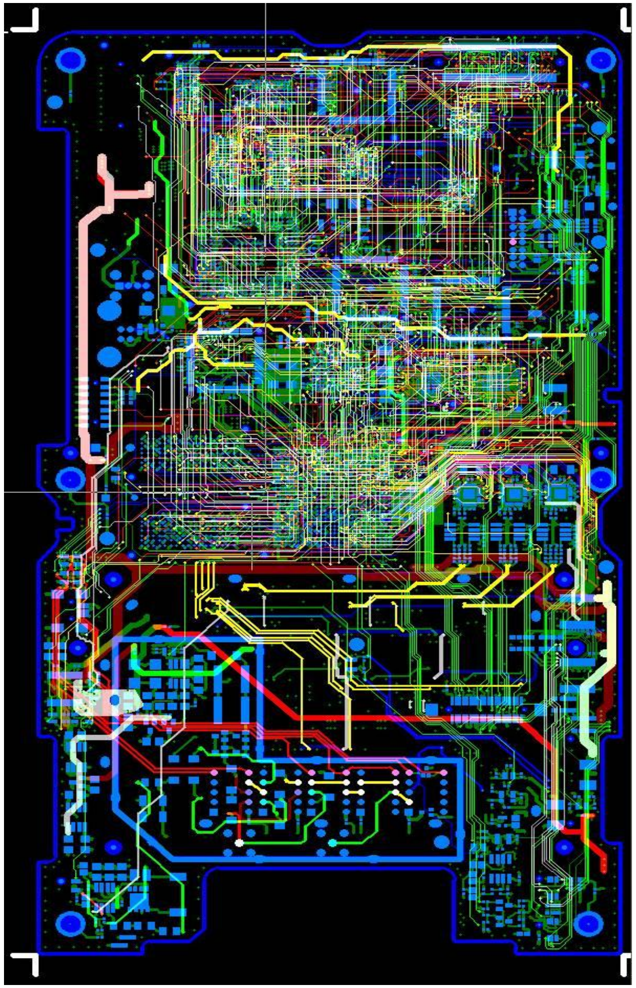


- Applied Research
- Simulation and Modeling
- 'ilities' (DfR, DfM, DfT, … DfX)
- Supplier Audits
- Qualification
- Test Plan Development
- Root-Cause Analysis

DfR Solutions

Reality of Design for Reliability (DfR)

- Ensuring reliability of electronic designs is becoming increasingly difficult
  - Increasing complexity of electronic circuits
  - Increasing power requirements
  - Introduction of new component and material technologies
  - Introduction of less robust components
- Results in multiple potential drivers for failure



DfR Solutions

Electrical

- Turning an idea into a functional circuit board is a complex and time consuming process that can prove to be error-prone.
- The procedure of creating the schematics includes both the circuit design and the component selection.
- Then the board has to be laid out in CAD.
- Next, the board design is sent out to board manufacturers
- After all these steps are complete, testing can finally begin. During the test phase, issues are discovered requiring hardware or software changes.

Electrical

- Given that schematic design is complicated and mistakes are costly, the more systematic the design and test process the more reliably products will be delivered to schedule.
- Actual DfR Design Review Example:
  - "Theoretically, an unstable circuit will not oscillate unless there is a disturbance. For example, an unstable power supply in some cases can power up and its output voltages appear to be regulating. As soon as a load step is applied, the output of the power supply breaks out in an oscillation.
  - It may be possible that the linear regulator is breaking into an oscillation with a disturbance in the right condition (the surge shape and level). This will also vary significantly from part to part. It is possible that some parts are more prone to oscillating (lower phase margin) than others and the temperature in the field will have an effect on how sensitive they will be to oscillation. Therefore, it's possible that the output oscillates in some cases in the field but not on the lab bench. This could be directly related to the issue client has with replicating the failures.
  - If VCCO oscillated, the only circuit that would be affected is X on page 2. If it did oscillate, it would affect the voltage reading only and not the current so it is unlikely this is the cause of the issue. "

What is Thermo/Mechanical Reliability?

- Describes the potential for product failure when subjected to periodic changes in environmental stress or an overstress event that are thermal or mechanical in nature

- What types of thermal or mechanical stress could cause failure in today's electronics?

DfR Solutions

Why Care About Thermal/Mechanical Reliability?

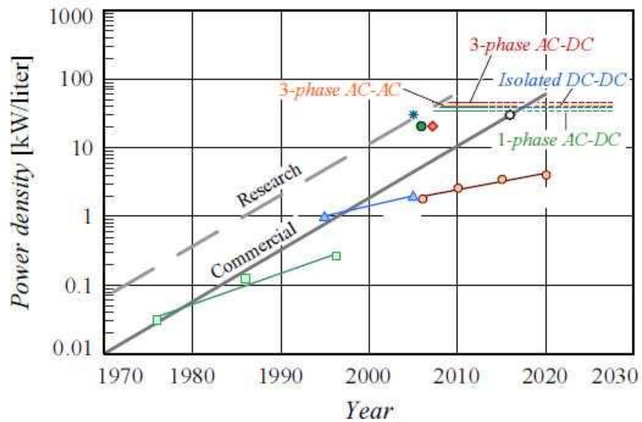
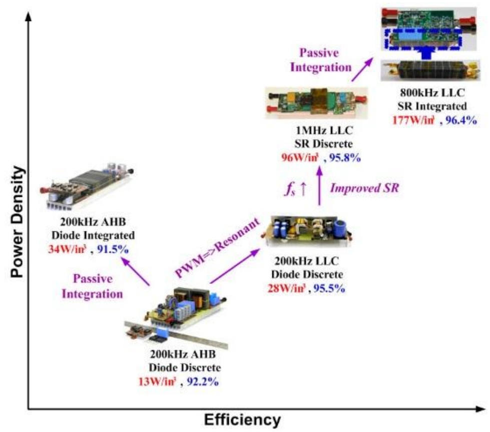


Figure 2. Power density trends of commercial and research systems and the Power Density Barriers.

Everything is Hot



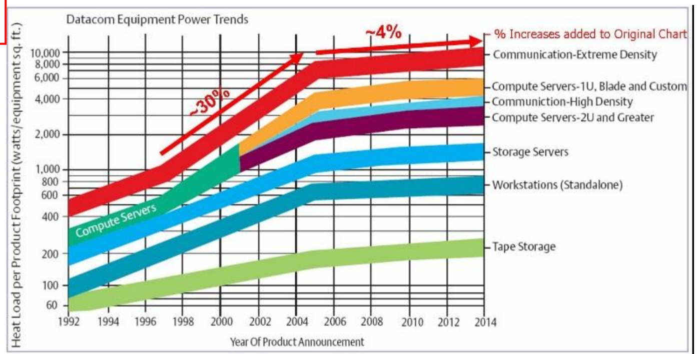


Figure 1. Equipment densities are rising even faster than once predicted.
© 2005 ASHRAE TC 9.9 Datacom Equipment Power Trends & Cooling Applications

Everything is Mobile

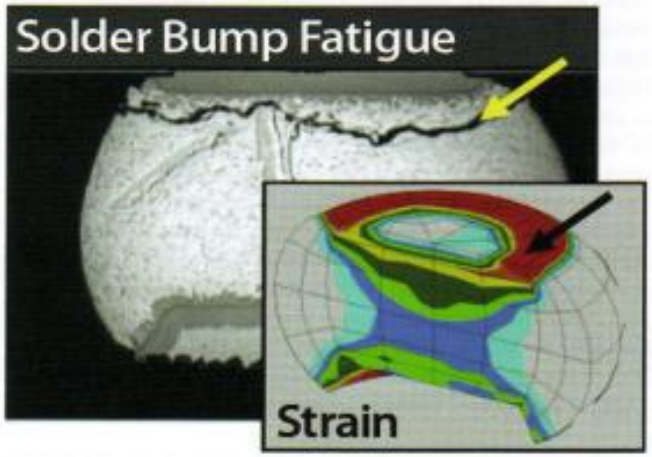
Everything is Everywhere

DfR Solutions

Why Care About Thermal/Mechanical Reliability? (cont.)

- Failures are not always about electrical overstress (EOS)!
- Recent studies suggest that the majority of electronic failures are thermo-mechanically related*

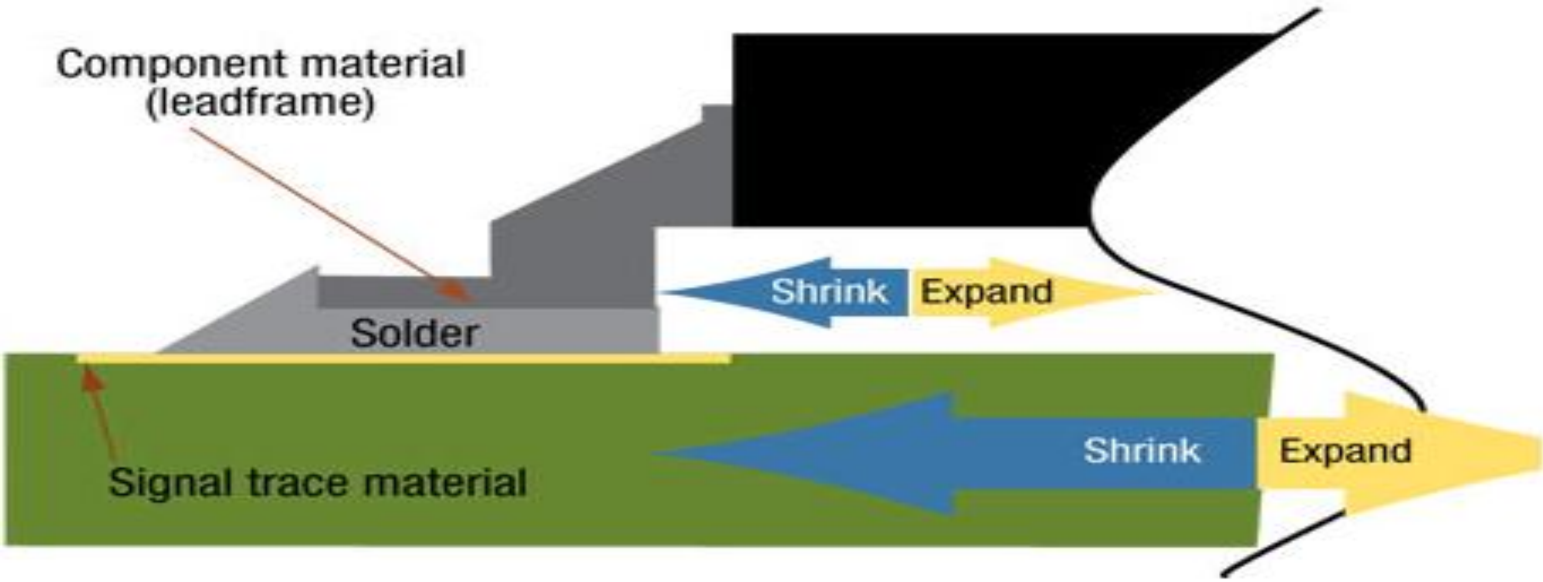
*Wunderle, B. and B. Michel, "Progress in Reliability Research in Micro and Nano Region", Microelectronics and Reliability, V46, Issue 9-11, 2006.



A. MacDiarmid, "Thermal Cycling Failures", RIAC Journal, Jan., 2011.

Why Do Electronics Fail Under Thermal Cycling? (cont.)

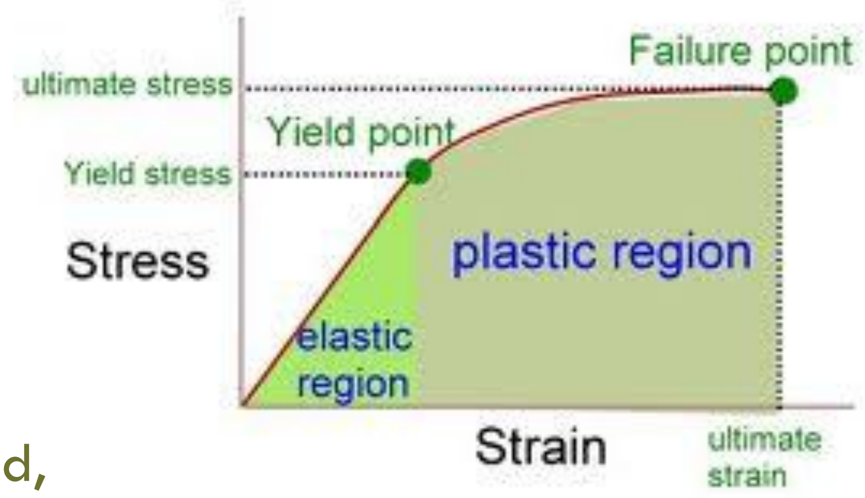
- Two different expansion/contraction behaviors
  - Because solder is connecting two materials that are expanding / contracting at different rates (GLOBAL)
  - Because solder is expanding / contracting at a different rate than the material to which it is connected (LOCAL)



How Do Electronics Fail Under Thermal Cycling? (cont.)

- This differential expansion and contraction introduces stress into the solder joint
  - This stress causes the solder to deform (aka, elastic and plastic strain)

- The extent of this strain (that is, strain range or strain energy) tells us the lifetime of the solder joint
  - The higher the strain, the more the solder joint is damaged, the shorter the lifetime



DfR Solutions

Thermo-Mechanical Design Rules

- Knowing the drivers and how to predict provides powerful insight to the design process
- Identify which designs and environments are at potential risk of solder joint fatigue
- Quantitatively benchmark material changes
- Develop accurate accelerated life tests

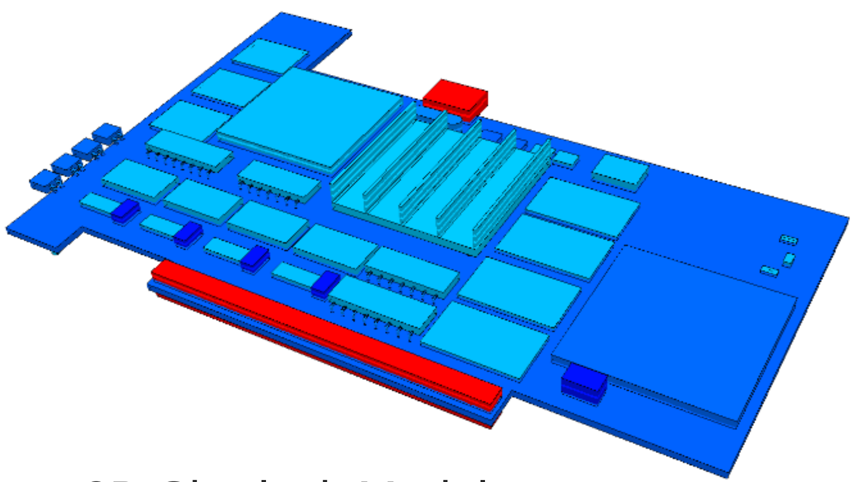
DfR Solutions

Thermo-Mechanical Design Rules - Environment

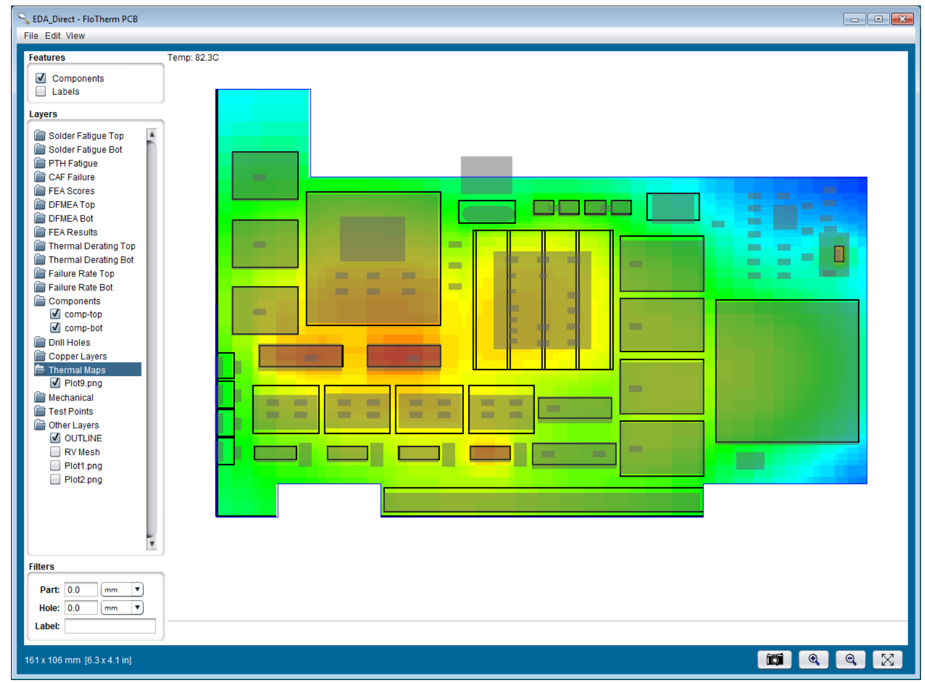
- Environments of No Concern
  - Home/Office Environments with no power cycling
- Environments of Less Concern
  - Diurnal with low power dissipation (ΔT of 25C, 1 cycle/day)
  - Lifetime of less than 10 years
- Environments of Higher Concern
  - Diurnal heat sources with sufficient fluctuation (Δ40C)
  - Diurnal power dissipation of Δ40C and greater
  - Power cycling greater than 4 cycles/day (mini-cycling)
  - Long lifetimes (>15 years)

Thermo-Mechanical Design Rules Through Prediction

More specific design rules requires performing a higher level of analysis (especially for power cycling)



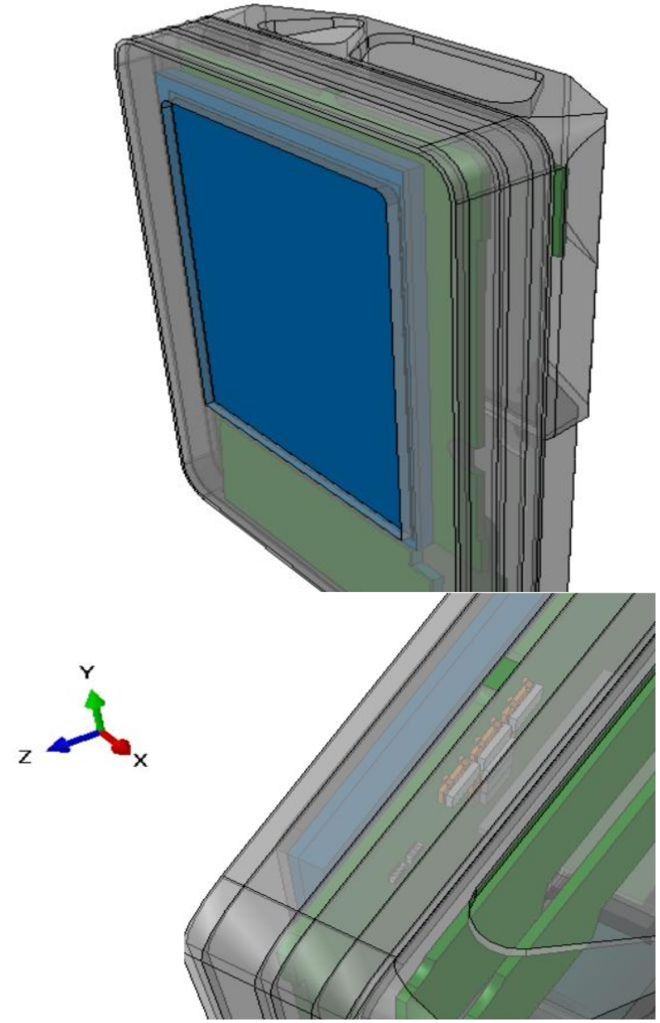
3D Sherlock Model



Thermal Analysis Results

3D Model

- Transient thermal analysis
- Thermal conduction model
- Body heat flux applied to critical components
  - Power dissipation / volume
- Power applied for 15 minutes
- Temperature rise predicted
- Three major sections
  - Battery pack
  - Base unit
  - Small module



Discussion – Materials

- Due to housing requirements (dust, water spray) the dominate heat transfer is due to conduction
  - Component -> PCB -> Standoffs -> Housing
- The use of metal to increase conductivity of board mounting can have dramatic effects on temperature rise during a failure event with minor weight penalty
- Potting may be reduced to just a conformal coat
- Power dissipating components could be placed closer to conduction points (standoffs).

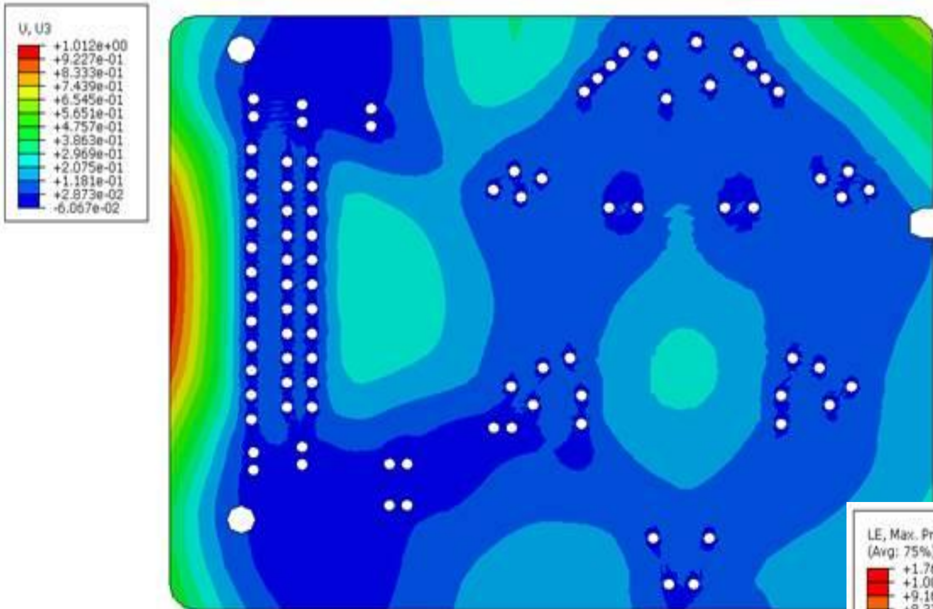
Mechanical – Background

- There are three mechanical loading conditions of concern to modern electronics

- **Mechanical Shock / Drop**
- **Bending (Cyclic or Overstress)**
- **Vibration**

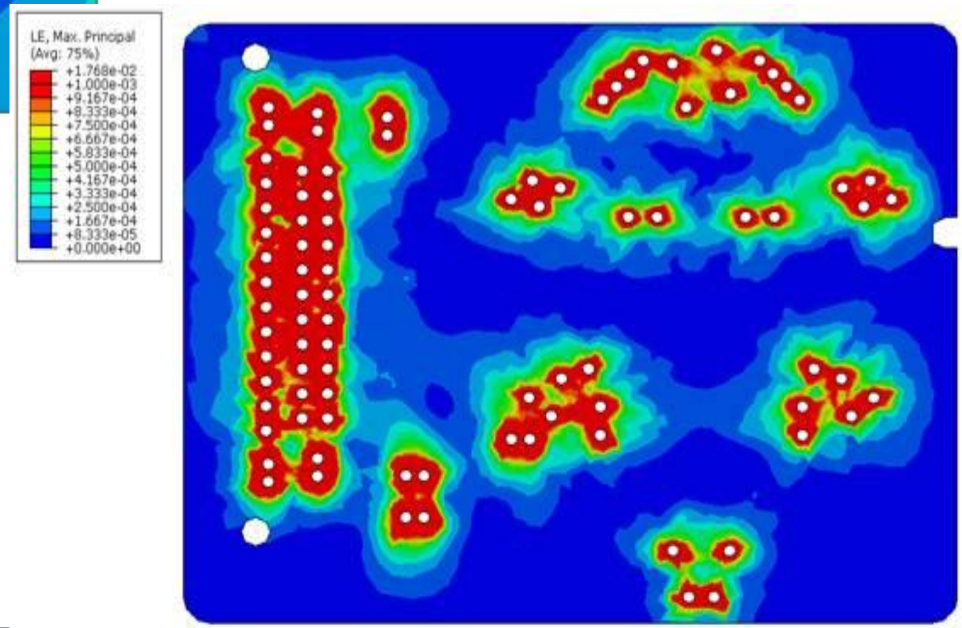
- Mechanical failures occur due to either overstress/low cycle/high amplitude events (shock/bending) and high cycle/low amplitude events (vibration/bending)

Mechanical – Press Fit Connector Analysis



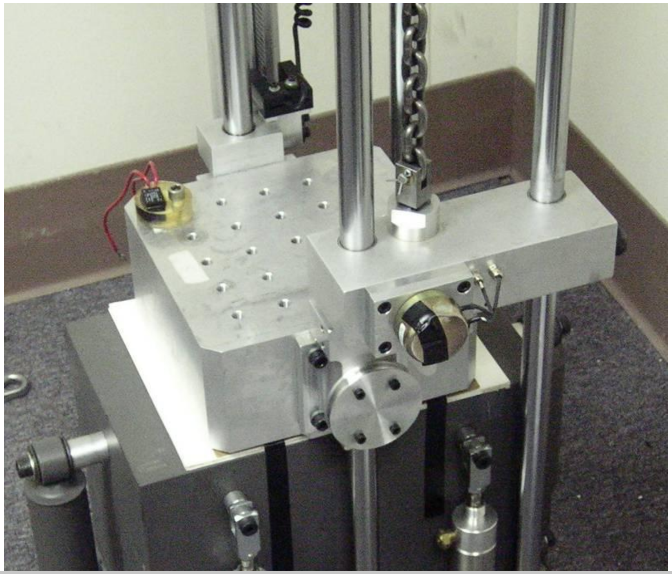
Deflections (mm)

Surface strains (0 – 1000 ue)



Mechanical Shock / Drop

- Initially driven by experiences during shipping and transportation
- Increasing importance with use of portable electronic devices
  - A surprising concern for portable medical devices
  - Floor transitions (1 to 5 inch 'drop')
- Environmental definitions
  - Height or G levels
  - Surface (e.g., concrete)
  - Orientation (corner or face)
  - Number of drops



DfR Solutions

When Does Vibration Occur?

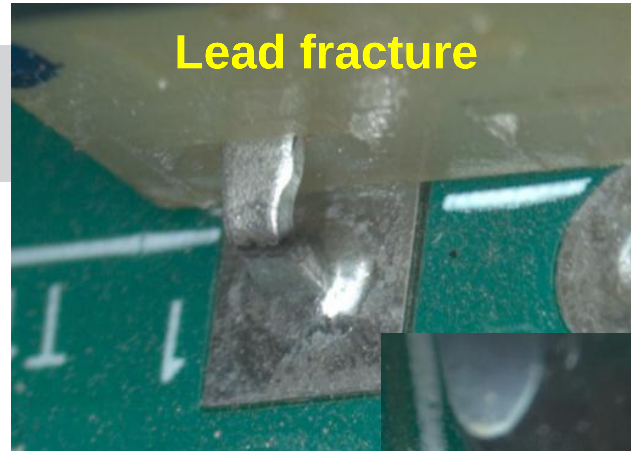
- Primarily affiliated with transportation
  - Shipping (very short part of the life cycle)
  - Automotive, trains, avionics, etc.

- Also a concern with rotating machinery (motors)
  - Transportation, appliances, HVAC, pipelines

- The two environments produce two very different forms of vibration
  - Harmonic (sinusoidal) and Random

Vibration Failure Sites

- Failure sites may occur in the lead or solder (or even PCB traces)
  - Lead failures often affiliated with tall components and in-plane vibration
- Crack propagation usually in the bulk material
  - Cracks along the interface, typically either indicate a much higher stress application (such as shock) or manufacturing defect



Thermal / Mechanical

- Understanding and mitigating thermal and mechanical is just as important as electrical for ensuring reliability

- There are very robust methods for predicting the performance of electronics under a variety of thermo-mechanical and mechanical environments
  - Automation can accelerate and improve the accuracy of these calculations

- Design rules are a good start, but not the way to win!

Manufacturability

- The best design is only reliable if it can be manufactured without defects.
- While the burden for defect-free manufacturing is often placed on the component suppliers and contract manufacturers, designing your product to be manufacturable is a critical step in the process & often overlooked.
  - Is the component manufacturable?
  - Is the component in the right location?
  - Is the component in the right orientation?
  - Is the board layout compatible with manufacturing processes and reliability expectations?

Manufacturability: Potential Layout/ Spacing Issues

- Components located close to board edge
  - Vulnerable to damage at depanel
  - Risk of exposed copper by depanel
- Components close to nylon standoffs at risk for cracking
  - What insertion force required?

Reliability & Physics of Failure (PoF)

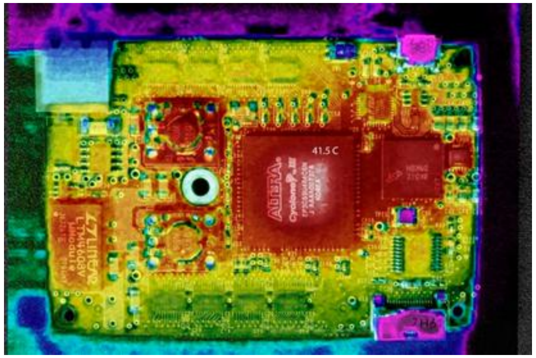
- PoF Definition: The use of science (physics, chemistry, etc.) to capture an understanding of failure mechanisms and evaluate useful life under actual operating conditions
- Using PoF, design, perform, and interpret the results of *accelerated* life tests
  - Starting at design stage
  - Continuing throughout the lifecycle of the product
- Start with standard industry specifications
  - Modify or exceed them
  - Tailor test strategies specifically for the individual product design and materials, the use environment, and reliability needs

Industry Testing Falls Short

- Limited degree of mechanism-appropriate testing
  - Only at transition to new technology nodes
  - Mechanism-specific coupons (not real devices)
  - Test data is hidden from end-users
- Questionable JEDEC tests are promoted to OEMs
  - Limited duration (1000 hrs) hides wearout behavior
  - Use of simple activation energy, with incorrect assumption that all mechanisms are thermally activated, can result in overestimation of FIT by 100X or more

9000 Virginia Manor Rd Ste 290, Beltsville MD 20705 | 301-474-0607 | www.dfrsolutions.com

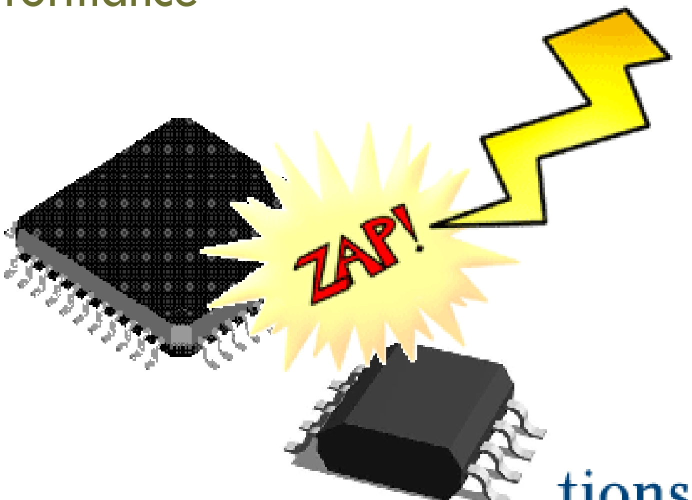
- Failure of a physical device or structure (i.e. hardware) can be attributed to the gradual or rapid degradation of the material(s) in the device in response to the stress or combination of stresses the device is exposed to, such as:
  - Thermal, Electrical, Chemical, Moisture, Vibration, Shock, Mechanical Loads . . .



- Failures May Occur:
  - Prematurely
  - Gradually
  - Erratically

Critical Components

- Most small to mid-size organizations do not have the resources to perform a thorough part selection assessment on every part
  - Does not excuse performing this activity
  - Requires focusing on components critical to the design
- Critical Components: A narrowed list of components of most concern to the OEM
  - Sensitivity of the circuit to component performance
  - Number of components within the circuit
  - Output from FMEA / FTA
  - Past experiences
  - Complexity of the component
  - Industry-wide experiences



Critical Components (Industry Experience)

- Optoelectronics
  - High volume controls not always in place
  - Wearout can initiate far before 20 years
- Low volume or custom parts
  - Part is no longer a commodity item
- Memory devices
  - Non-volatile memory has limited data retention time and write cycles
- Parts with mechanical movements (switches, relays, potentiostats, fans)
  - Depending on environment, wear out can initiate far before 20 years
- Surface mount ceramic capacitors
  - Assembly issues

9000 Virginia Manor Rd Ste 290, Beltsville MD 20705 | 301-474-0607 | www.dfrsolutions.com

Critical Components (cont.)

- New technologies or state-of-the-art
  - At the limit of the manufacturer's capabilities
  - MEMS, 45-nm technology, green materials, etc.
- Electronic modules
  - Part is a miniature assembly (no longer a commodity item)
- Power components
- Fuses
  - Susceptible to quality issues
- Electrolytic capacitors
  - Depending on environment, wear out can initiate far before 20 years

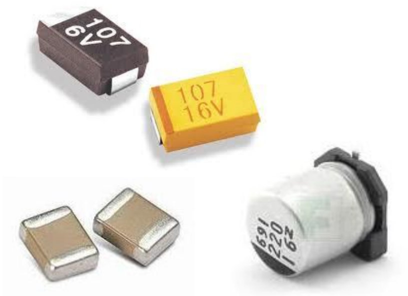
Testing: Component Center of Excellence (CCE)

- To provide the electronics industry a source of knowledge and turn-key test capability for *"Critical Components"*

- Critical Components, Definition:
  - Those discrete items that tend to have a disproportionate influence on quality / reliability of electronic products and systems

DfR Solutions

CCE: Focus Areas



Capacitors
(Ceramic/Tantalum/Electrolytic)

Fans

Power Supplies
(Converters/Inverters)

Microprocessors

Memory
(Flash, SRAM, DRAM)

Drive Technology
(Platter and Solid State)

DfR Solutions

CCE: Success Stories

- Investigating performance of ‘off-the-shelf’ microprocessors and memory over a range of temperatures
  - Beyond manufacturer’s specifications
  - Range of technology nodes

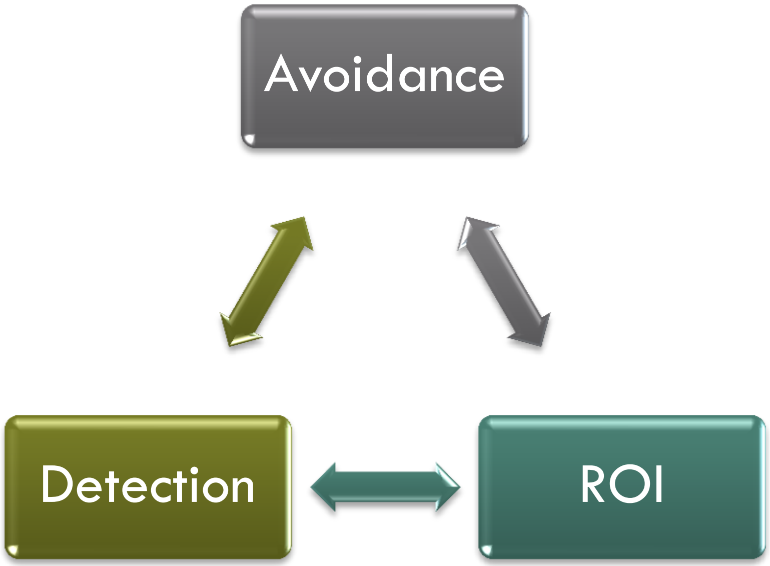
- Provide high-temperature customers with better selection and prediction capabilities for commercial components

DfR Solutions

Counterfeit Detection / Counterfeit Strategy

- Leaders in Counterfeit Detection
  - Familiar and compliant with all major industry standards (SAE AS5553, SPOC419, etc.)
  - One of only four preferred providers of counterfeit detection for Honeywell

- Provide guidance and implementation of internal Counterfeit Strategies
  - Only organization to address the complete process



DfR Solutions

Design for the Environment

- Environmental Compliance Legislation
  - Challenges of new materials (2nd gen Pb-free solder, halogen-free, etc.), RoHS, REACH and more….
- Energy Consumption and Efficiency Requirements
  - Challenges of new environments (free air cooling, power down, etc.)
- Environmental Packaging (minimize, reuse, recycle)
- Disposal Planning
  - Design for disassembly, design for serviceability

REACH: Registration, Evaluation, Authorisation and Restriction of Chemicals

European Commission

Conclusions

- Design for Reliability is a valuable process for lowering cost, reducing time-to-market, and improving customer satisfaction
- PoF is a powerful tool that can leverage the value of DfR activities
- Successful DfR / PoF implementation requires the right combination of personnel and tools and time limitations
- Design reliability in by practicing Reliability 360!