DfR Solutions

reliability designed, reliability delivered

Test Plan Development

Cheryl Tulkoff, ASQ CRE

ctulkoff@dfrsolutions.com

Electronic Equipment Reliability & Testing Seminar
May 24, 2011

Your Partner Throughout the Product Life Cycle

DfR lends a guiding hand on quality, reliability and durability (QRD) issues through our expertise in the emerging science of Reliability Physics, providing crucial insights and solutions early in product design, development and test throughout manufacturing, and even into the field.

Cheryl Tulkoff Biography

- Cheryl Tulkoff has over 20 years of experience in electronics manufacturing with an emphasis on failure analysis and reliability. She has worked throughout the electronics manufacturing life cycle beginning with semiconductor fabrication processes, into printed circuit board fabrication and assembly, through functional and reliability testing, and culminating in the analysis and evaluation of field returns. She has also managed no clean and RoHS-compliant conversion programs and has developed and managed comprehensive reliability programs.

- Cheryl earned her Bachelor of Mechanical Engineering degree from Georgia Tech. She is a published author, experienced public speaker and trainer and a Senior member of both ASQ and IEEE. She holds leadership positions in the IEEE Central Texas Chapter, IEEE WIE (Women In Engineering), and IEEE ASTR (Accelerated Stress Testing and Reliability) sections. She chaired the annual IEEE ASTR workshop for four years and is also an ASQ Certified Reliability Engineer.

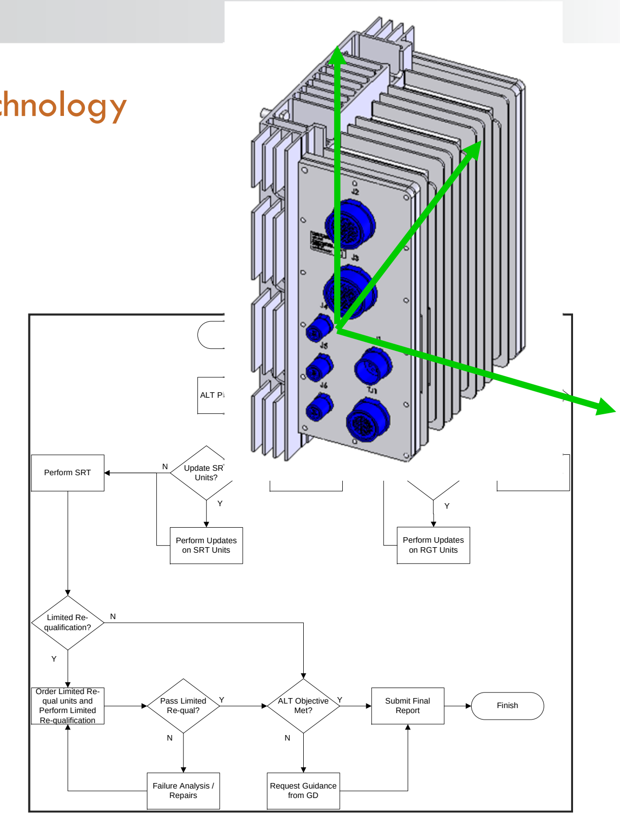
- She has a strong passion for pre-college STEM (Science, Technology, Engineering, and Math) outreach and volunteers with several organizations that specialize in encouraging pre-college students to pursue careers in these fields. In her free time, she competes in various distance endurance activities. She is a Boston Marathon finisher, an Ironman C'oeur D'Alene finisher, and a figure class bodybuilding competitor. She resides in Austin, TX with her husband Mike, son David, and chocolate lab Buddy.

Introduction

- Agenda
  - Introduction to Test Plan Development
    - Testing Examples
  - Introduction to Physics of Failure Methodology for Test Plan Development
    - Examples & Case Studies
  - Initial Reliability Assessment and Virtual Qualification Options

Test Plan Development

- Product test plans are critical to the success of a new product or technology
  - Stressful enough to identify defects
  - Show correlation to a realistic environment
- DfR Solutions approach
  - Industry Standards + Physics of Failure
- Results in an optimized test plan that is acceptable to management and customers
- Experience in product test plans include
  - Industrial controls
  - Process monitoring
  - Consumer appliances
  - Telecom (Class I, II, and III environments)
  - Personal computers
  - Mobile phones and other mobile products
  - Avionics (engine controls, fuselage)
  - Automotive (under-hood, passenger compartment, chassis, and trunk)
  - Down-hole oil-drilling



Month	Cycles/Year	Ramp	Dwell	Max Temp (ºC)	Min Temp (ºC)	ΔT	Cycles per Day	AF
Jan+Feb+Dec	90	6 hrs	6 hrs	30	5	25	1	12.654
Mar+Nov	60	6 hrs	6 hrs	35	10	25	1	11.799
Apr+Oct	60	6 hrs	6 hrs	40	15	25	1	10.944
May+Sep	60	6 hrs	6 hrs	45	20	25	1	10.26
Jun+Jul+Aug	90	6 hrs	6 hrs	50	25	25	1	9.576
Operational	16.6	5 min	3 hrs	25	-40	65	1	2.223

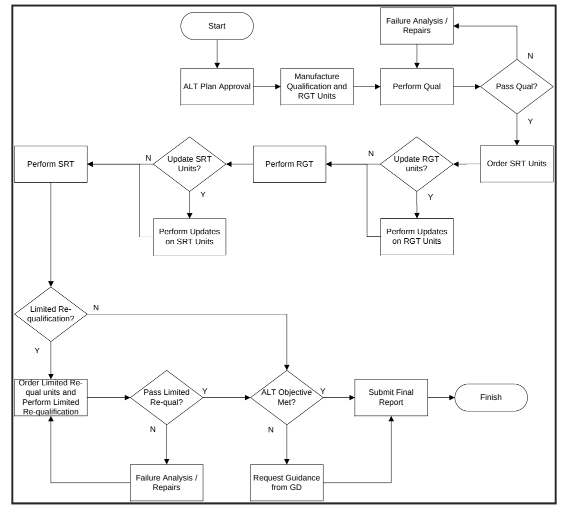
Testing Example: Next Generation Microprocessor

- Selected as the preferred vendor for package qualification testing
  - Reviewed coupon designed, identified deficiencies

- Tests performed
  - Nine point cyclic bend
  - Static bend
  - Drop
  - Mechanical shock
  - Harmonic vibration
  - Random vibration
  - Thermal cycling
  - Temperature / humidity

Testing Example: Intelligent Gas Meter

- Customer transitioning into new product space, concerned about long-term performance
- DfR reviewed potential use environment
  - Identified potential drivers for failure (temperature, humidity, salt spray, sulfur gas, etc.)
- Started with industry standards and best practices
  - Modified based on understanding of Physics of Failure
  - Developed optimized test plan acceptable to management and customers
- Other examples of test plan development
  - Consumer appliances
  - Telecom
  - Avionics (engine controls)
  - Tracked vehicle
  - Automotive
  - Down-hole oil-drilling



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Physics of Failure Definitions

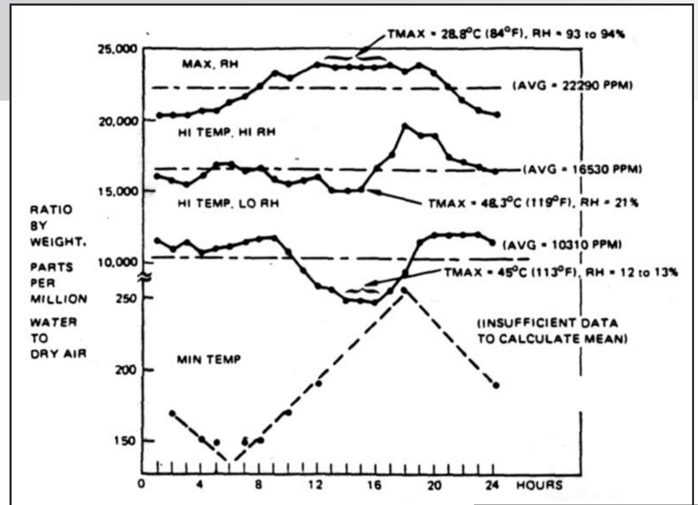
- **Physics of Failure (PoF also known as Reliability Physics)**
  - A Proactive, Science Based Engineering Philosophy.
  - Development and Applied Science of ***Product Assurance Technology*** based on:
    - A Formalized and Structured approach to Failure Analysis/Forensics Engineering that focuses on total learning and not only fixing a current problem.
    - Material Science, Physics & Chemistry.
    - Variation Theory & Probabilistic Mechanics.
    - Up Front Understanding of Failure Mechanisms and Variation Effects.
      - Knowing how & why things fail is equally important to understand how & why things work.
      - Knowledge of how thing fail and the root causes of failures, enables engineers to identify and design out potential failure mechanisms in new products and solve problems faster.
      - Provides scientific basis for evaluating usage life and hazard risks of new materials, structures, and technologies, under actual operating conditions.
    - Applicable to the entire product life cycle
      - Design, Development, Validation, Manufacturing, Usage, Service.

Test Plan Development - Use Environment

- The critical first step is a good understanding of the shipping and use environment for the product.
- Do you really understand the customer and how they use your product (even the corner cases)?
- How well is the product protected during shipping (truck, ship, plane, parachute, storage, etc.)?
- Temp/humidity, thermal cycling, ambient temp/operating temp.
- Salt, sulfur, dust, fluids, etc.
- Mechanical cycles (lid cycling, connector cycling, torsion, etc.)
- Do you have data or are you guessing?

Identify Use Environment

- Approach 1: Use of industry/military specifications
  - MIL-STD-810,
  - MIL-HDBK-310,
  - SAE J1211,
  - IPC-SM-785,
  - Telcordia GR3108,
  - IEC 60721-3, etc.
- Advantages
  - No additional cost!
  - Sometimes very comprehensive
  - Agreement throughout the industry
  - Missing information? Consider standards from other industries
- Disadvantages
  - Most more than 20 years old
  - Always less or greater than actual (by how much, unknown)



MIL HDBK310

USE CATEGORY	WORST-CASE USE ENVIRONMENT Tmin °C	Tmax °C	ΔT(1) °C	t_D hrs	Cycles/ year	Typical Years of Service	Approx. Accept. Failure Risk, %	ACCELERATED TESTING Tmin °C	Tmax °C	ΔT(2) °C	t_D min
1) CONSUMER	0	+60	35	12	365	1-3	1	+25	+100	75	15
2) COMPUTERS	+15	+60	20	2	1460	5	0.1	+25	+100	75	15
3) TELECOM	- 40	+85	35	12	365	7-20	0.01	0	+100	100	15
4) COMMERCIAL AIRCRAFT	-55	+95	20	12	365	20	0.001	0	+100	100	15
5) INDUSTRIAL & AUTOMOTIVE PASSENGER COMPARTMENT	-55	+95	20 &40 &60 &80	12 12 12 12	185 100 60 20	10	0.1	0	+100	100 & COLD(3)	15
6) MILITARY GROUND & SHIP	-55	+95	40 &60	12 12	100 265	10	0.1	0	+100	100 & COLD(3)	15
7) SPACE leo geo	-55	+95	3 to 100	1 12	8760 365	5-30	0.001	0	+100	100 & COLD(3)	15
8) MILITARY AVIONICS a b c	-55	+95	40 60 80 &20	2 2 2 1	365 365 365 365	10	0.01	0	+100	100 & COLD(3)	15
9) AUTOMOTIVE UNDER HOOD	-55	+125	60 &100 &140	1 1 2	1000 300 40	5	0.1	0	+100	100	15

IPC SM785

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Use Environment (cont.)

- Approach 2: Based on actual measurements of similar products in similar environments
  - Determine average and realistic worst-case
  - Identify all failure-inducing loads
  - Include <u>all</u> environments
    - Manufacturing
    - Transportation
    - Storage
    - Field

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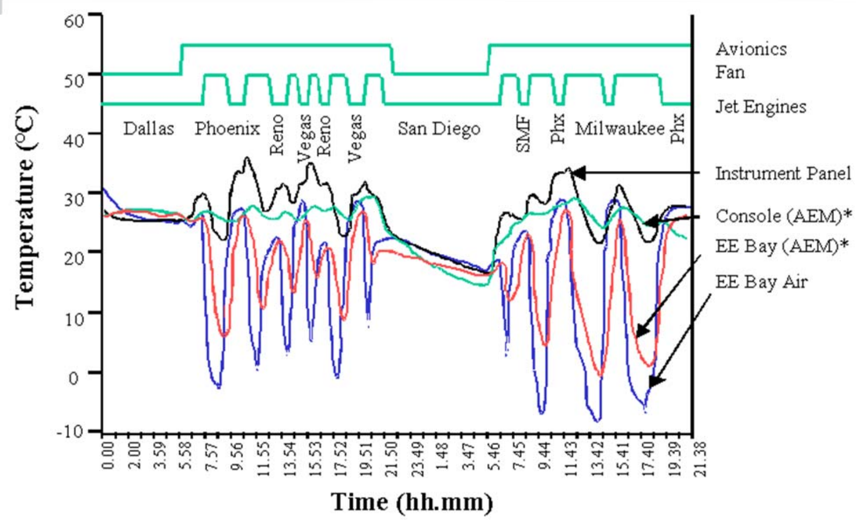
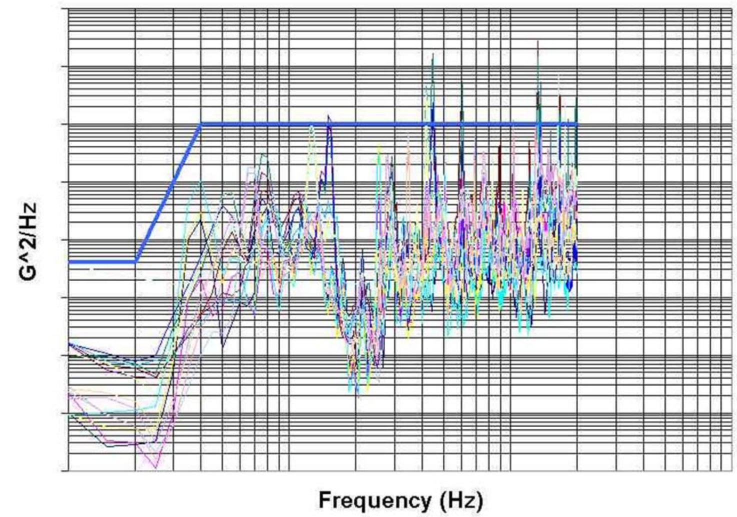
Failure Inducing Loads

- Temperature Cycling
  - Tmax, Tmin, dwell, ramp times
- Sustained Temperature
  - T and exposure time
- Humidity
  - Controlled, condensation
- Corrosion
  - Salt, corrosive gases (Cl_2, etc.)
- Power cycling
  - Duty cycles, power dissipation
- Electrical Loads
  - Voltage, current, current density
  - Static and transient
- Electrical Noise
- Mechanical Bending (Static and Cyclic)
  - Board-level strain
- Random Vibration
  - PSD, exposure time, kurtosis
- Harmonic Vibration
  - G and frequency
- Mechanical shock
  - G, wave form, # of events





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Use Environment (Best Practice)

- Use standards when…
  - Certain aspects of your environment are common
  - No access to use environment
- Measure when…
  - Certain aspects of your environment are unique
  - Strong relationship with customer
- Do not mistake test specifications for the actual use environment
  - Common mistake with vibration loads

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Electrical Environments

- Often very well defined in developed countries
- Introduction into developing countries can sometimes cause surprises
- Rules of thumb
  - China: Can have issues with grounding (connected to rebar?)
  - India: Numerous brownouts (several a day)
  - Mexico: Voltage surges

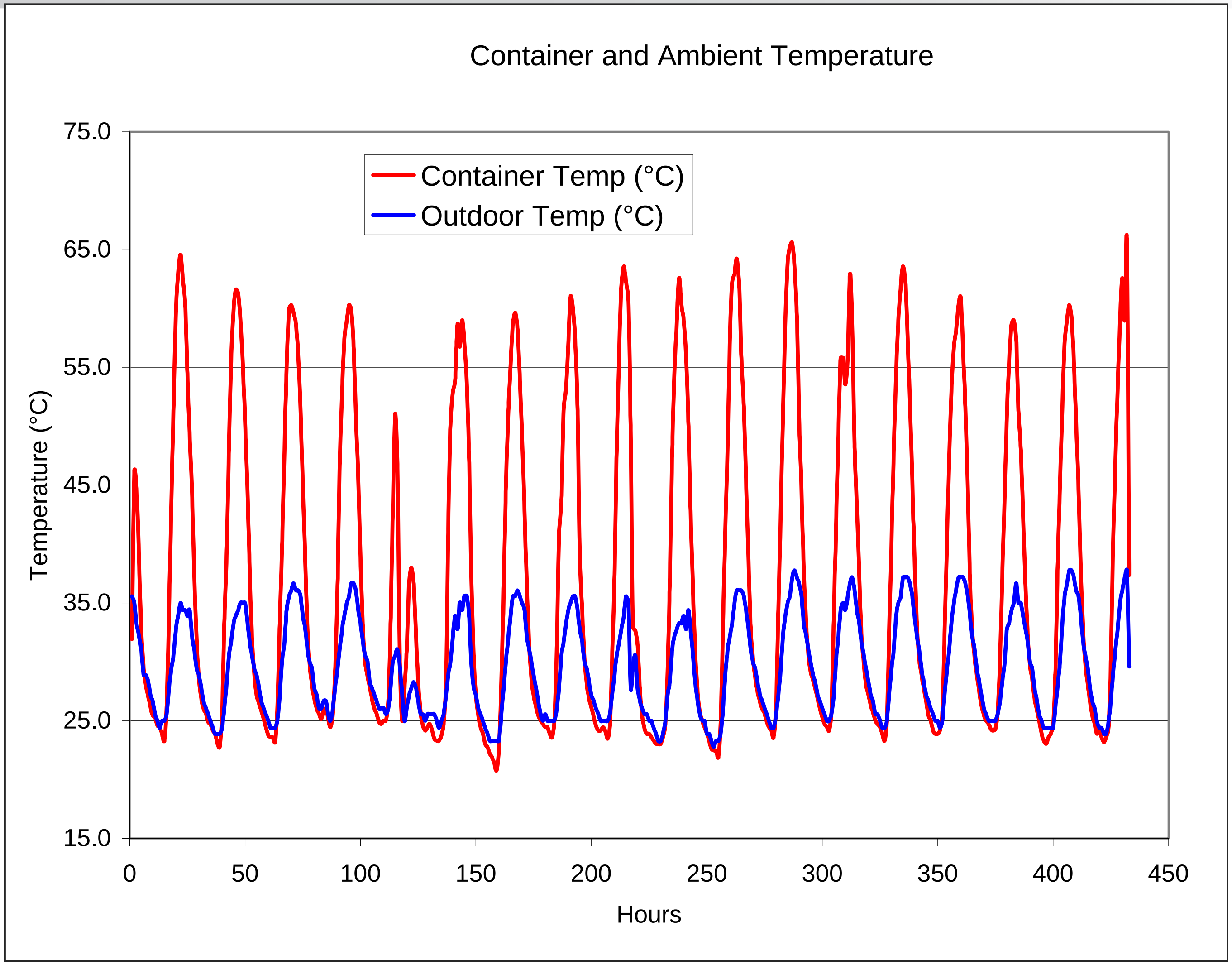
Temperature: Worst-Case (Ambient)

Temperature	Avg. U.S. CLIM Data	Avg. U.S. Weighted by Registration (Source: Confidential)	Phoenix (hrs/yr)	U.S. Worst Case (hrs/yr)
95F (35C)	0.375%	0.650%	11% (948)	13% (1,140)
105F (40.46C)	0.087%	0.050%	2.3% (198)	3.8% (331)
115F (46.11C)	0.008%	0.001%	0.02% (1.4)	0.1% (9)

Temperature: Closed Containers

Temp. Variation

Trucking Container



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Temperature: Long-Term Exposure

- For electronics used outside with minimal power dissipation, the diurnal (daily) temperature cycle provides the primary degradation-inducing load

Phoenix, AZ

Month	Cycles/Year	Ramp	Dwell	Max. Temp (^oC)	Min. Temp. (^oC)
Jan.+Feb.+Dec.	90	6 hrs	6 hrs	20	5
March+November	60	6 hrs	6 hrs	25	10
April+October	60	6 hrs	6 hrs	30	15
May+September	60	6 hrs	6 hrs	35	20
June+July+August	90	6 hrs	6 hrs	40	25

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Humidity / Moisture (Rules of Thumb)

- Non-condensing
  - Standard during operation, even in outdoor applications
  - Due to power dissipation
- Condensing
  - Can occur in sleep mode or non-powered
  - Driven by mounting configuration (attached to something at lower temperature?)
  - Driven by rapid change in environment
  - Can lead to standing water if condensation on housing
- Standing water
  - Indirect spray, dripping water, submersion, etc.
  - Often driven by packaging

Toyota Approach

- Toyota's development engineers are 4X as productive as U.S. counterparts.
- Why?
  - Focus on learning as much as possible
  - Use of that knowledge to develop a stream of excellent products

- **Western engineers**
  - Define several product concepts
  - Select the one that has the most promise
  - Draw up specifications and divide them into subsystems;
  - Subsystems are designed, built and rolled up for system testing.
  - Failures? Rework the specs and the designs accordingly (non-optimized and confusing endeavor)

- **Toyota engineers**
  - Efforts concentrated at lowest possible design level
  - Thorough understanding of the technology of a subsystem so it can be used appropriately in future designs

Toyota Example: Radiators

- Traditional approach: Design radiator for a specific vehicle based on mechanical specifications written for that vehicle
- Toyota considers a range of radiator solutions based on cooling capacities and the cooling demands of various engines that might be used.
  - How the radiator actually fits into a vehicle would be kept loose so that Toyota's knowledge of radiator technology could be used to create the optimum design
- Toyota's system is "test & design" rather than the traditional "design & test."
  - Toyota engineers test at the fundamental knowledge level so they don't have to test at the later, more expensive stages of design and prototyping

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Sorting Out Testing Methods, Brands and Different Approaches

STRIFE
(Stress + Life)

MEOST (Mixed Environment
& Operating Stress Test)

Shock &
Vibration

Test Time
Compression

HALT
(Highly Accelerated Life Test)

Progressive Over
Stress

CERT Combined Environment
Reliability Test)

PoF-ALT
(Physics of Failure based
Accelerated Life Test)

PRD Product Ruggedization
Development)

Shainin's - Step Stress Probe

Dust test

HASS
Highly Accelerated Stress Screen)

Corrosion Testing

MFG, nitric acid test

Salt Spray

Entella's - FMVT
(Failure Mode
Verification Test)

HAST
(Highly Accelerated Stress Test)

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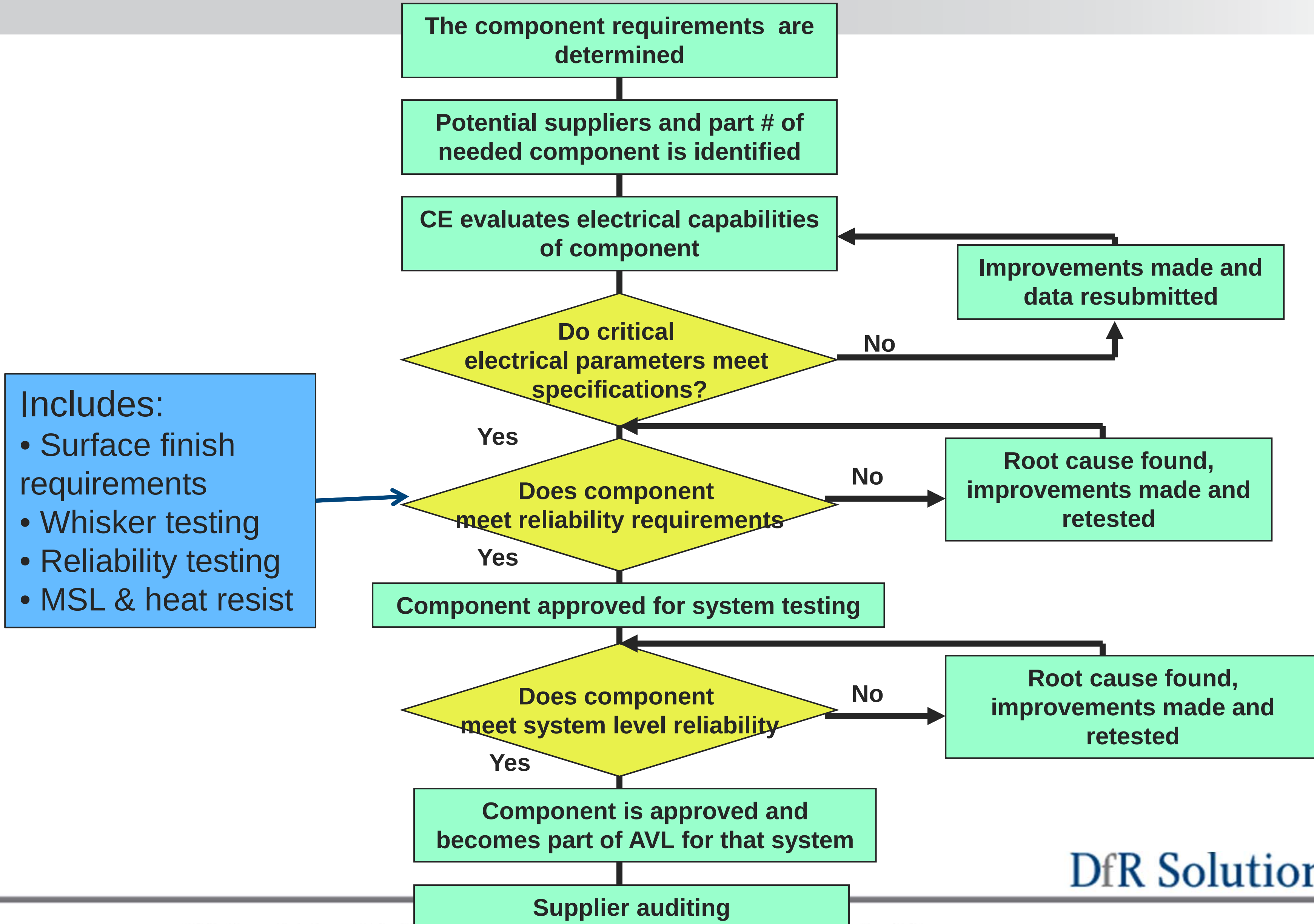
General Test Plan Development Outline – PCBA Example

- Component qualification (with end product in mind)
  - Thermal cycling, high temp, T&H, etc.
- PCBA qualification
  - Thermal cycling
  - HALT/HAST
  - Drop/shock
  - Heat age
- System level qualification
  - Shock and Vibration
  - Dust testing
  - Torsion
  - Etc.

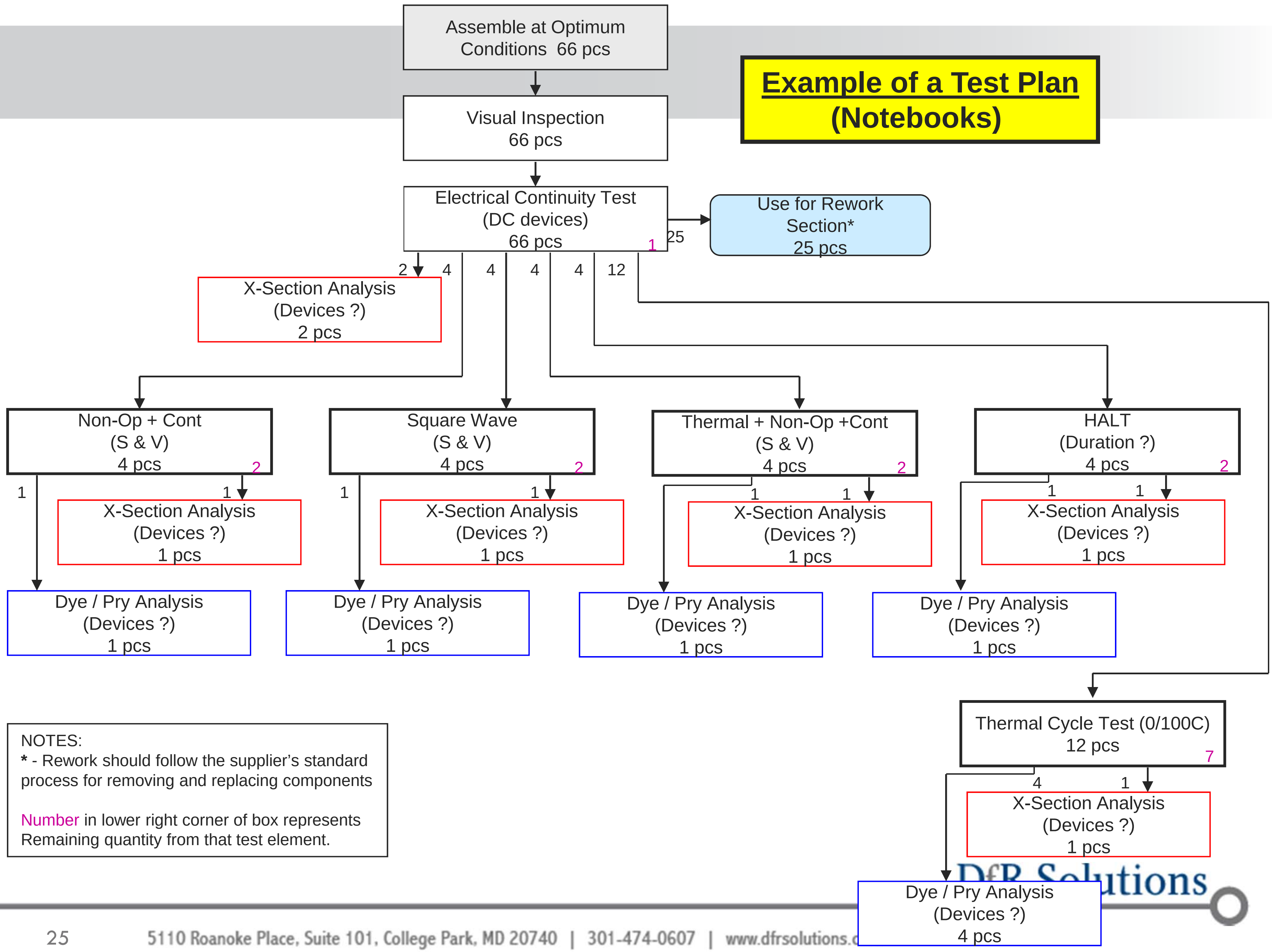
Component Approval Procedure



Test Plan Development – for PWAs

- Develop a comprehensive test plan
- Assemble boards at optimum conditions
- Rework specified components on some boards
- Visually inspect and electrically test
- C-SAM & X-ray inspect critical components on 5 or more boards (+3 reworked for BGAs)
- Use these boards for further reliability testing (TC, HALT, S&V)
- Perform failure analysis
- Compile results and review

Example of a Test Plan (Notebooks)



NOTES:
* - Rework should follow the supplier's standard process for removing and replacing components

Number in lower right corner of box represents Remaining quantity from that test element.

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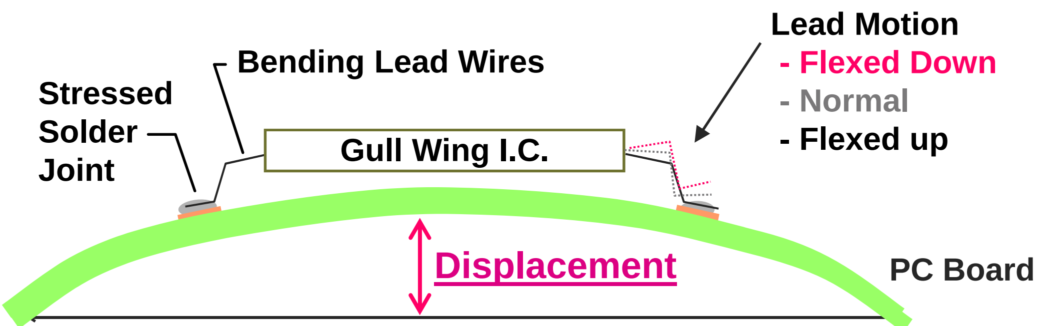
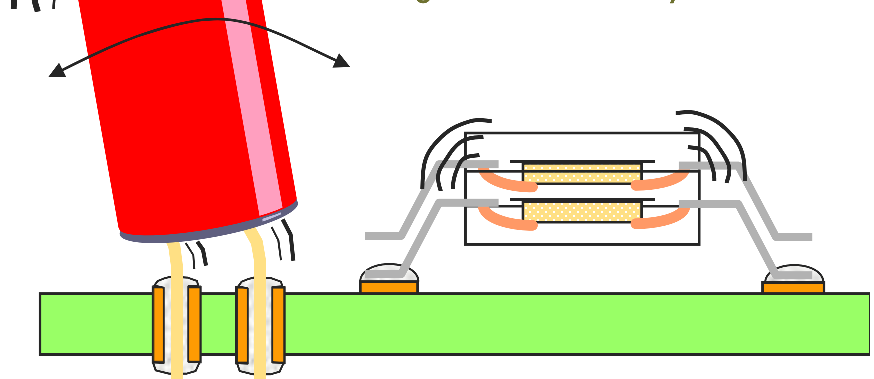
Two Types of Circuit Board Related Vibration Durability Issues

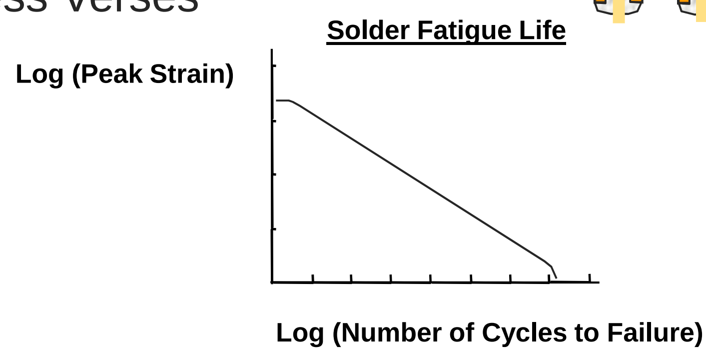
- Board in Resonance
  - Components. Shaken Off/Fatigued by Board Motion.
    - By Flexing Attachment Features



- Components In Resonance.
  - Components Shake/Fatigue themselves apart or off the Board.
  - Especially Large, Tall Cantilever Devices
    3 Med. Sized Alum CAPS
    1 Small Long Leaded Snsr
    1 Hall Effect Sensor.
    1 Large Coil Assembly



- Time to Failure Determine by Intensity/Frequency of Stress Verses Strength of Material



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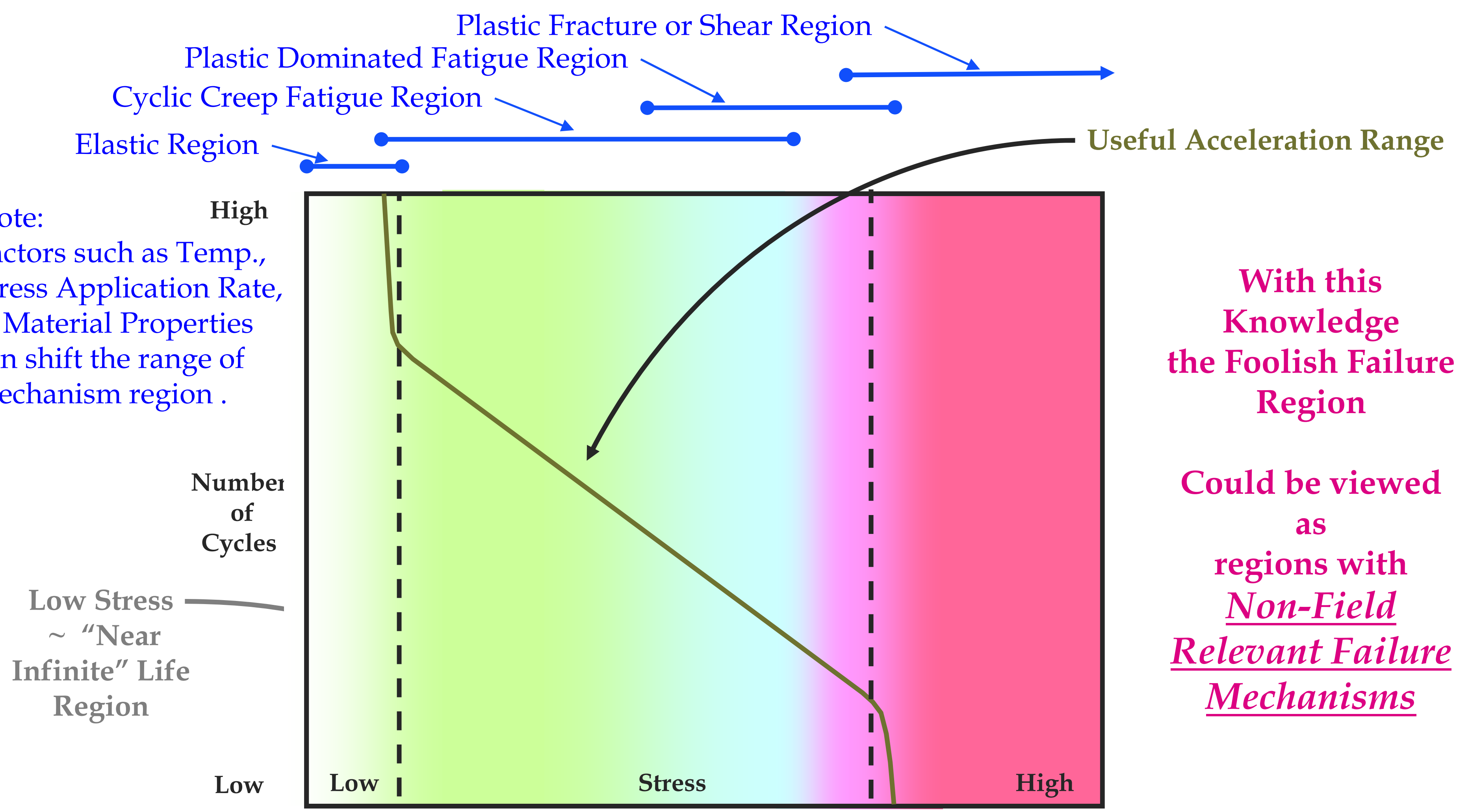
Failure Mechanism Hierarchy (Non Manufacturing Issues)

Relative to the N-S Curve



Note:
Factors such as Temp., Stress Application Rate, & Material Properties can shift the range of mechanism region .

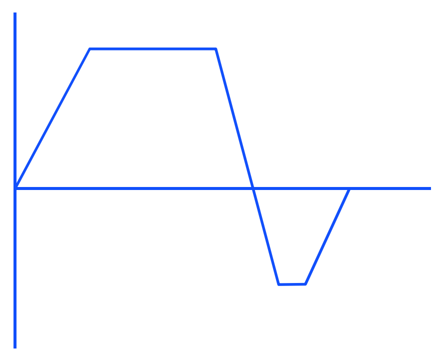
With this Knowledge the Foolish Failure Region

Could be viewed as regions with *Non-Field Relevant Failure Mechanisms*

Thermal Cycle Testing

- From IPC-SM-785 - Guidelines for Accelerated Reliability Testing & Solder Joint Reliability (SJR) Theory & Application - John Lau.
  - **Thermal Cycling Key Parameters:**
    - Thermo-mechanical expansion/contraction is the force that drives material damage accumulation stress aging.
      - Primary Aging Factors are:
        High End Temp., High to Low Temp. Difference & # of Cycles.
        Correlation to Number of Cycles,Not the Time Duration
      - Secondary Aging Factors are:
        Hot Dwell Time & Change Rate.
      - Limit Factors (to Avoid Foolish Failures) are:
        High End Temp., Change Rate & Min. Hot Dwell Time.

Note: PROFILES MUST BE BASED ON Temperatures as are measured at the components on the PCB (Not Chamber Settings) and must include Self heating and Thermal Lag Effects



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- From IPC-SM-785 - Guidelines for Accelerated Reliability Testing & Solder Joint Reliability (SJR) Theory & Application - John Lau.
  - **Temperature Cycling Continued:**
    - **Max Temp.** **MUST NOT EXCEED:**
      - The (Tg - Glass Transition Temp.) of the substrate. Material properties dramatically change above the Tg invalidation the tests. (Tg for FR4 PCB 125-135'C).
      - The Lowest Re-Crystalization Temperature of the Plastics used in the Device.
    - **Temp. Dwell Time** **(MEASURED on the PCB/COMPONENTS IS VERY IMPORTANT.**
      - Hot Dwell is more important than Cold Dwell - needed to realize creep damage.
      - Hot Dwell under a TENSILE LOAD causes faster attachment aging rates then Compressive Load.
        - For FR4 PCB Tensile Loading occurs at Hot Temperatures.)
    - **Practical Min. Temp.** - Cooling Parts below 50% of the Absolute Temp. melting point of a metal is not value added (wasted time and expensive cooling energy)
      - Because Metal becomes a structures (do not creep) < 50% absolute (K) Melting temperature
        - Eutectic Solder Melts at 183°C +> 456°K,
        - 50% = 228°K => - 44°C

Change Control – When to requalify

- Inadequate change control is responsible for many (some would say most) field failures.
- Examples would include
  - Burning Li notebook batteries
  - Electrolytic capacitor leakage
  - Recent flip chip underfill problems
  - Coin cell battery contact failure
  - Heat sink clogging failure
  - DDR2 Memory modules
  - ImAg corrosion
- All changes need to be evaluated carefully (testing to failure recommended).

HALT Testing

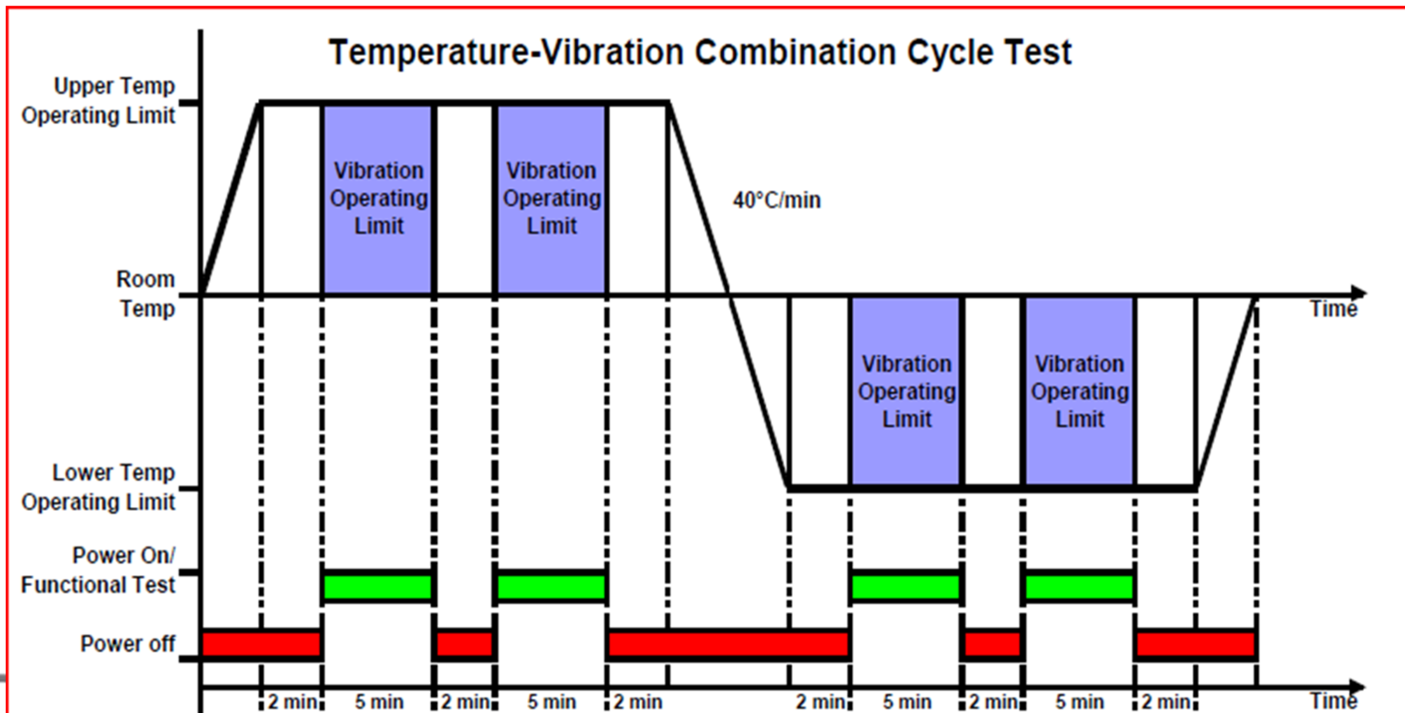
- A typical HALT test exposes the product to simultaneous vibration and thermal cycling. The product is tested in the operational mode while the vibration stress is increased with each thermal cycle.
- The objective of the test is to cause failure of the product thus identifying the weakest link which can be then be improved. The test duration is typically less than a week. On its own, this test is not able to predict the life of a product (acceleration factor is not known). However, it is very useful when a product can be compared side-by-side with a previous generation of product with known reliability.

HALT Testing

- HALT was able to quickly identify the primary failure mechanisms that we found with LF products.
- These included PCB pad cratering, trace fracture, inner plane separation, and poorly formed solder joints. These are all failure mechanisms that would likely occur in the earlier stages of a products life if not corrected.
- Failure mechanisms that HALT did not find were long term thermal fatigue issues such as barrel cracking in vias or high cycle solder joint fatigue failures of resistors and/or capacitors (thermal cycling required for these).

HALT Procedure

- Note that functional testing is performed while the vibration is taking place. This is important since intermittent opens can be found at this condition.
- Vibration should start at 0 Grms and step up by 5 Grms each cycle until failure is detected. Failing units should be removed as the chamber is cycling past room temperature. Failing units shall be analyzed carefully to find root cause failure.



Virtual Qualification (VQ)

- This assessment uses physics-of-failure-based degradation models to predict time-to-failure
- Models include
  - Interconnect fatigue (solder joint and plated-through hole)
  - Capacitor failure (electrolytic and ceramic)
  - Integrated circuit wearout
- Customers develop a degree of assurance that their product will survive for the desired lifetime in the expected use environment

On-Going Reliability Testing

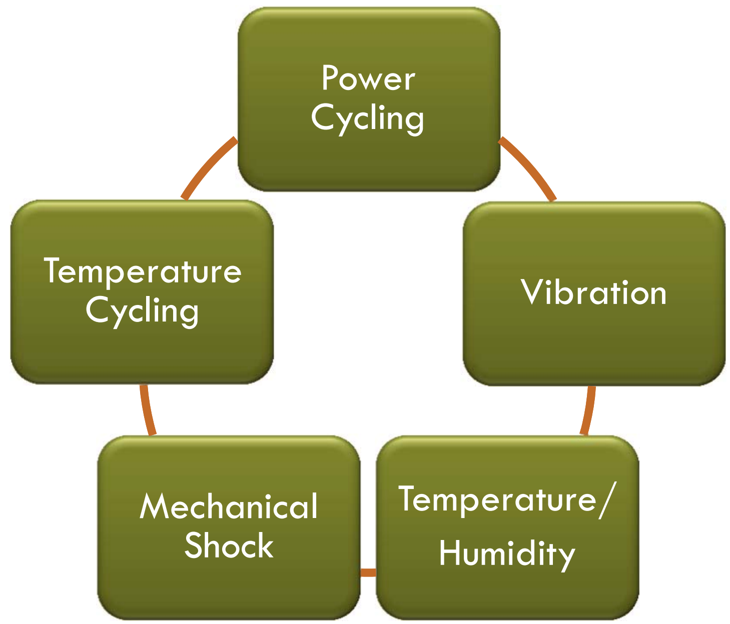
- Qualification shows that a limited number of early manufactured products (maybe even from a pilot line) are reliable.
- It's often not possible to create every permutation of component suppliers in the qual builds.
- How do you know the product will remain reliable as you go to high volume and new component suppliers are introduced?
- There is no perfect answer but an ORT program can help.

Summary

- Product test plans are critical to the success of a new product or technology
  - Stressful enough to identify defects
  - Show correlation to a realistic environment
- PoF Knowledge can be used to develop test plans and profiles that can be correlated to the field.
- Vibration fatigue is easy, as is vibration endurance by design.
- True accelerated wear out thermal cycling is also possible
- True ALT with combined temperature & vibration is still challenging.
- Change control processes and testing should not be overlooked (reliability engineer needs to stay involved in sustaining).
- On-going reliability testing can be a useful (but admittedly imperfect) tool.

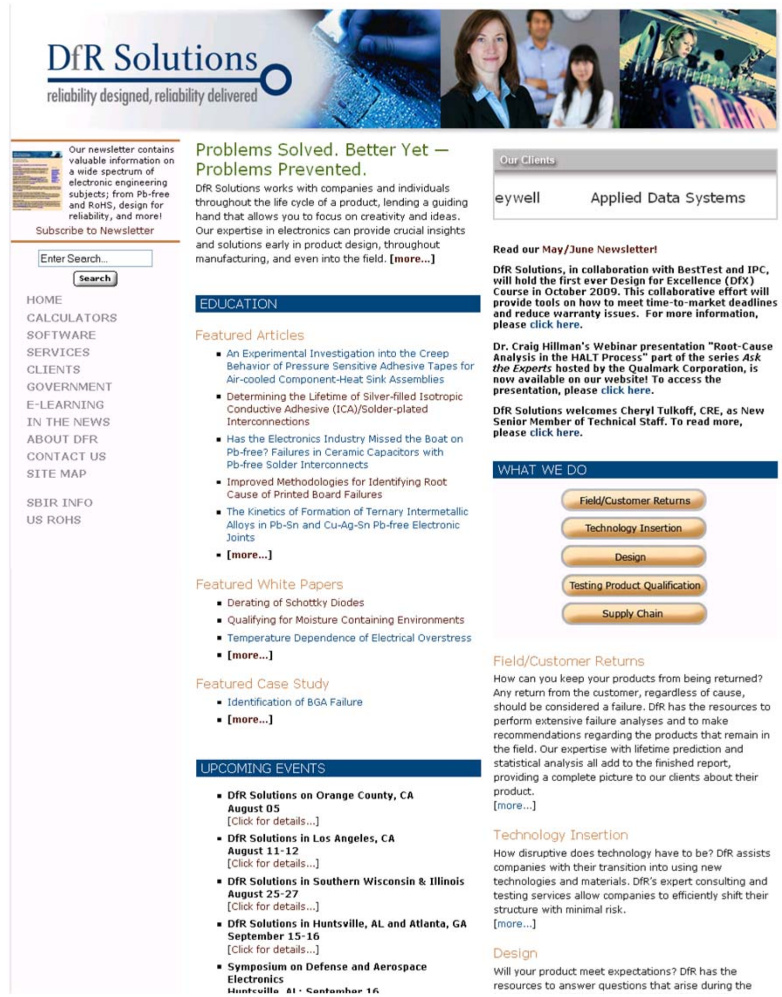
Test Plan Development & Test Plan Performance

- DfR has a unique capability of recommending tests based upon your reliability requirements and customer's use environment AND performing the life testing at DfR



Knowledge and Education (Website)

- Let your staff learn all day / every day



E-LEARNING

- Scholarly articles
- Technical white papers
- Case studies
- Reliability calculators
- Online presentations

Interested?

- Could your next product benefit from DfR's extensive expertise and PoF knowledge base?
  - Bring us in as an independent party during critical design reviews
- Are your concerned with new technologies?
  - DfR's scientists and engineers can provide comprehensive analysis to ensure risk-minimization during these difficult transitions
- Take advantage of our unique Open-Door policy!
  - See how much we already know about your current issues
  - Chances are we have already solved your problem at least once before
  - We work around the clock and around the world
  - Contact us by phone (301-474-0607) or email (askdfr@dfrsolutions.com)