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reliability designed, reliability delivered

Test Plan Development using Physics of Failure: The DfR Solutions Approach

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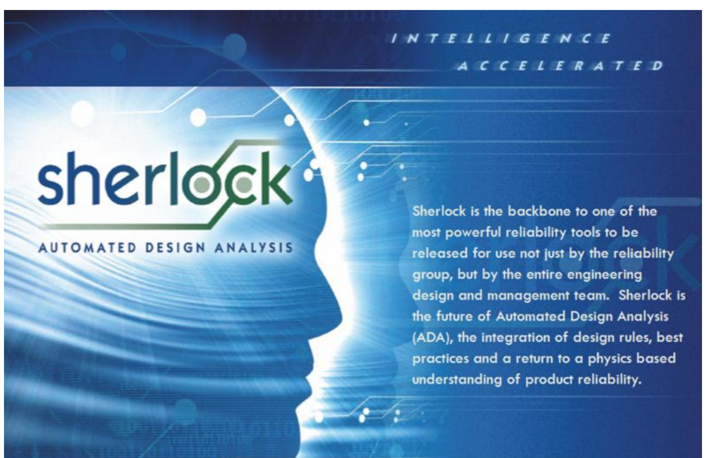
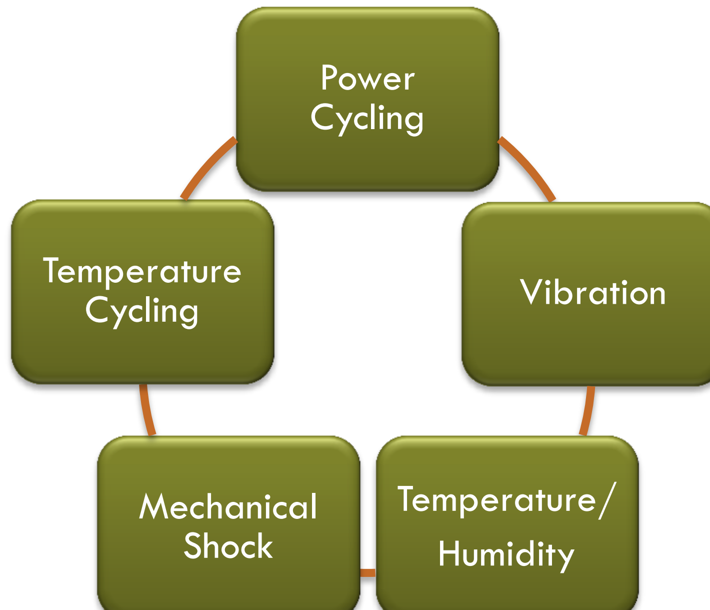
Introduction

- Agenda
  - Introduction to Test Plan Development
  - Introduction to Physics of Failure Methodology for Test Plan Development
  - Virtual Qualification Option
  - After Release
  - Case Study





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Test Plan Development

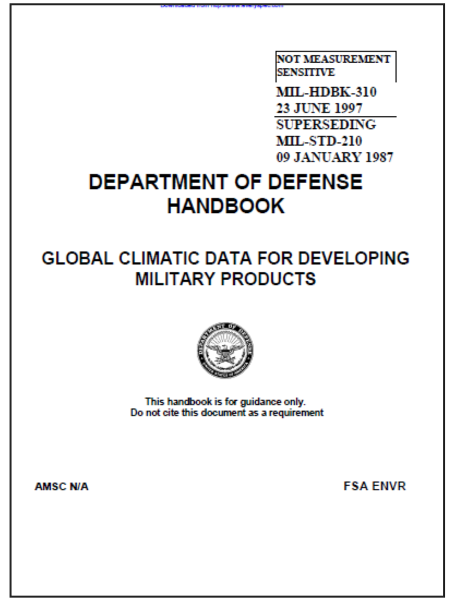
- How can you be sure that you have the best test plans for your specific need?
- DfR Solutions has worked closely with over 500 OEMs in multiple industries developing hundreds (thousands??) of test plans.
  - DfR Solutions experts have written product specs for these organizations.
- Through close collaboration with industry leading electronics manufacturers and deep industry knowledge, DfR Solutions delivers the right test for the right product every time!

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

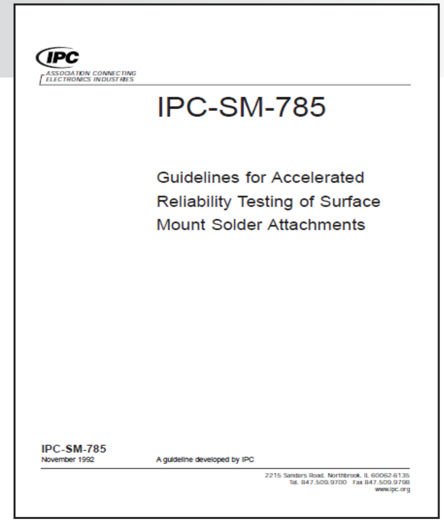

NOT MEASUREMENT SENSITIVE
MIL-HDBK-310
23 JUNE 1997
SUPERSEDING
MIL-STD-210
09 JANUARY 1987

DEPARTMENT OF DEFENSE
HANDBOOK

GLOBAL CLIMATIC DATA FOR DEVELOPING MILITARY PRODUCTS

This handbook is for guidance only.
Do not cite this document as a requirement

AMSC N/A FSA ENVR


IPC
ASSOCIATION CONNECTING ELECTRONICS INDUSTRIES

IPC-SM-785

Guidelines for Accelerated Reliability Testing of Surface Mount Solder Attachments

IPC-SM-785
November 1992

A guideline developed by IPC

2215 Sanders Road, Northbrook, IL 60062-6135
Tel. 847.509.9700 Fax 847.509.9798
www.ipc.org

- MIL-STD-810,
- MIL-HDBK-310,
- SAE J1211,
- IPC-SM-785,
- Telcordia GR3108,
- IEC 60721-3, etc.
- PoF!

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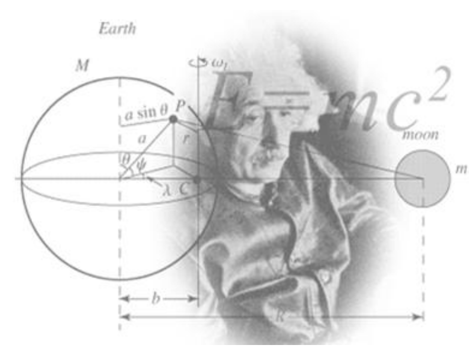
Physics of Failure (PoF)

- 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

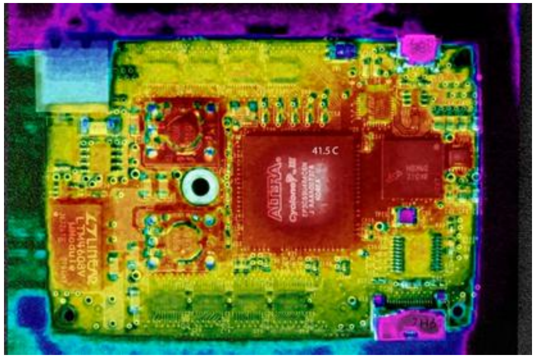
- Limited degree of mechanism-appropriate testing
  - Only at transition to new technology nodes
  - Mechanism-specific coupons (not real devices)
  - Test data is hidden from end-users

- 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

Physics of Failure Definitions

- 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



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Critical Elements for Developing Robust Test Plans

- Test Objectives!
  - Comparison
  - Qualification
  - Validation
  - Research
  - Compliance
  - Regulatory
  - Failure analysis

- Elements
  - Reliability Goals
  - Design
  - Materials
  - Use Environment
  - Budget
  - Schedule
  - Sample availability
  - Practicality
  - Risk

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Define Reliability Goals

- Identify and document two key metrics
  - *Desired lifetime*
    - Defined as time the *customer* is satisfied with
    - Should be actively used in development of part and product qualification
  - *Product performance*
    - Returns during the warranty period
    - Survivability over lifetime at a set confidence level
    - MTBF or MTTF (try to avoid unless required by customer)

Test Plan Development – Define 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.)?
- Do you have data or are you guessing?
  - Temp/humidity, thermal cycling, ambient temp/operating temp.
  - Salt, sulfur, dust, fluids, etc.
  - Mechanical cycles (lid cycling, connector cycling, torsion, etc.)

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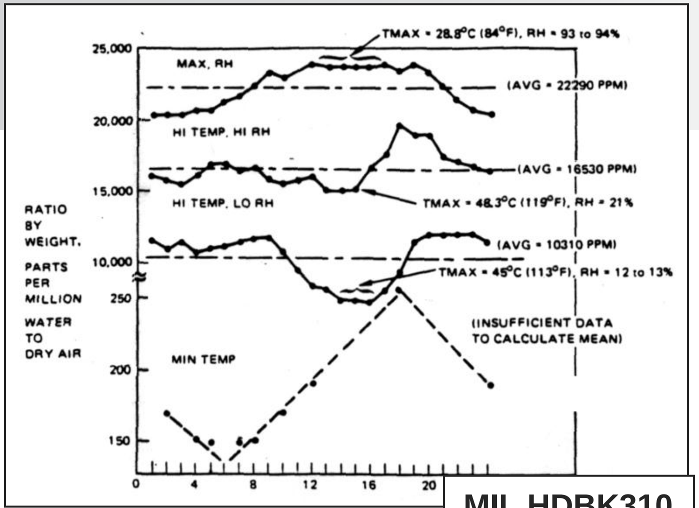
Identify Use Environment

- Old School Approach: Use of industry/military specifications
  - Military, IPC, Telcordia, ASTM…..
- 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.)

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

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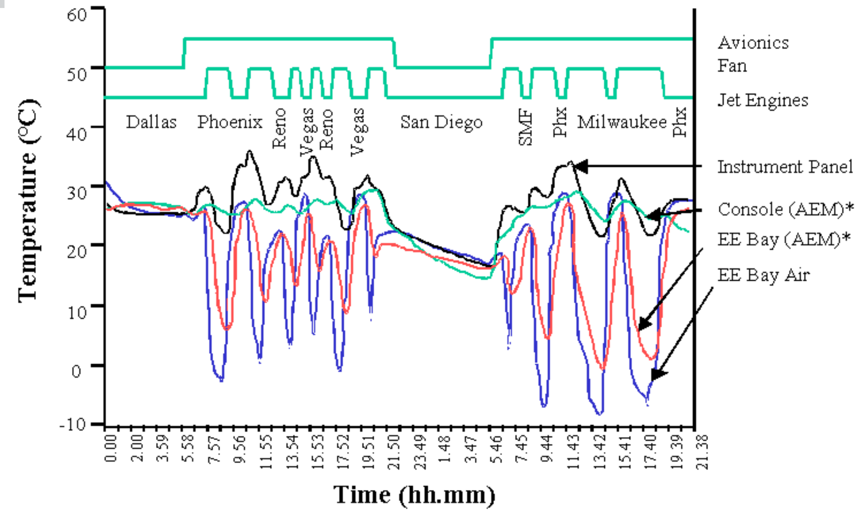
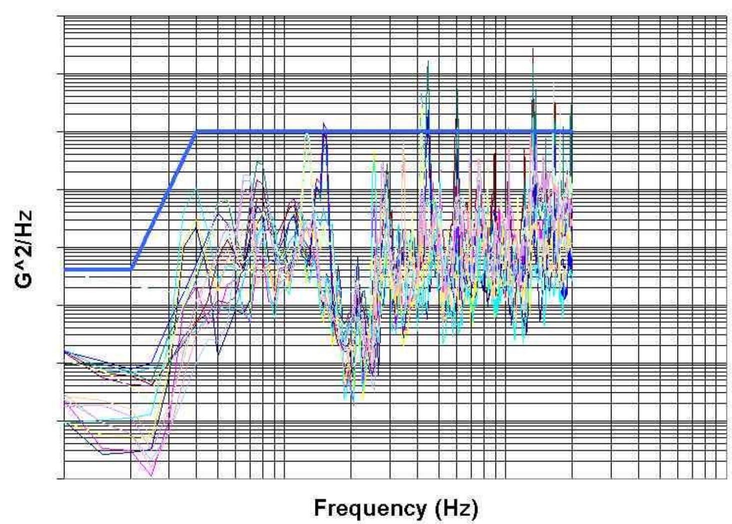
Examples of Failure Inducing Loads

- 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 real 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

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Failure-Inducing Load Example: 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

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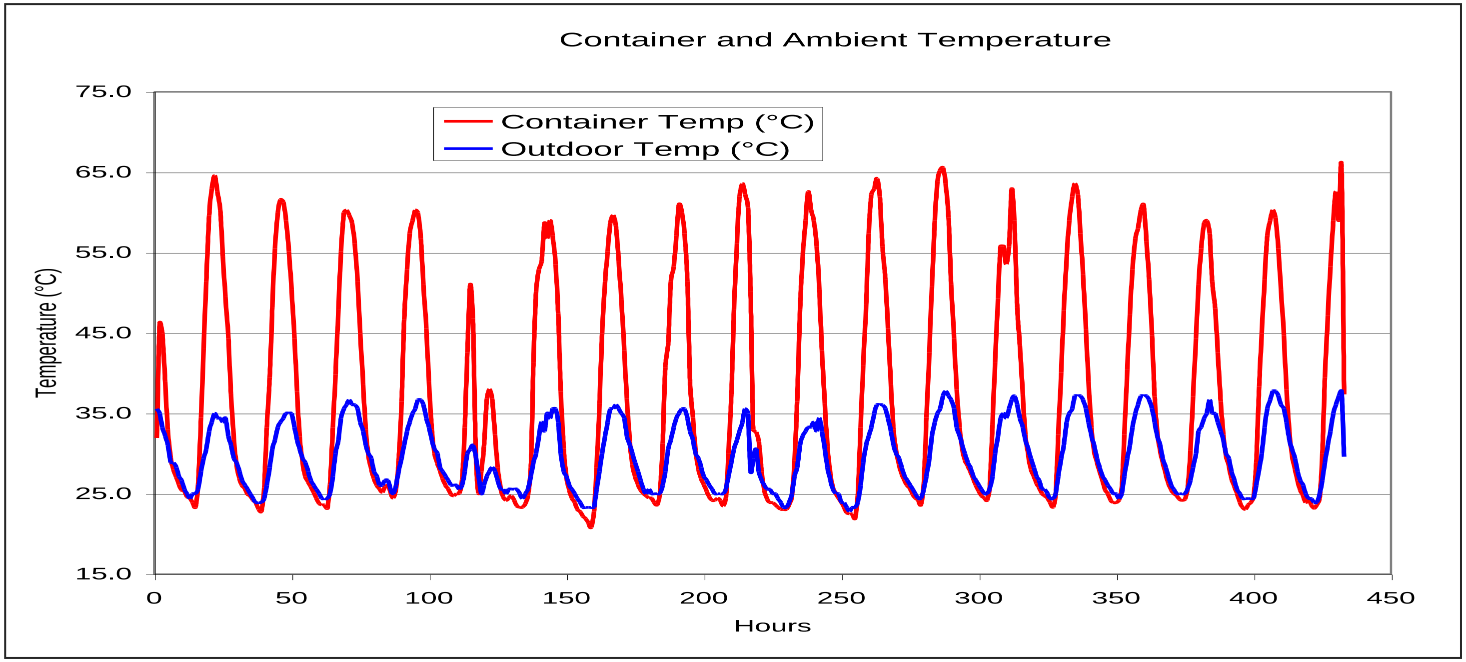
Failure Inducing Temperature: Transport & Storage

Temp. Variation In a Trucking Container



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: 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 (^{o}C)	Min. Temp. (^{o}C)
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

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

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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.

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Test Plan Development – for PCBAs continued…

- 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

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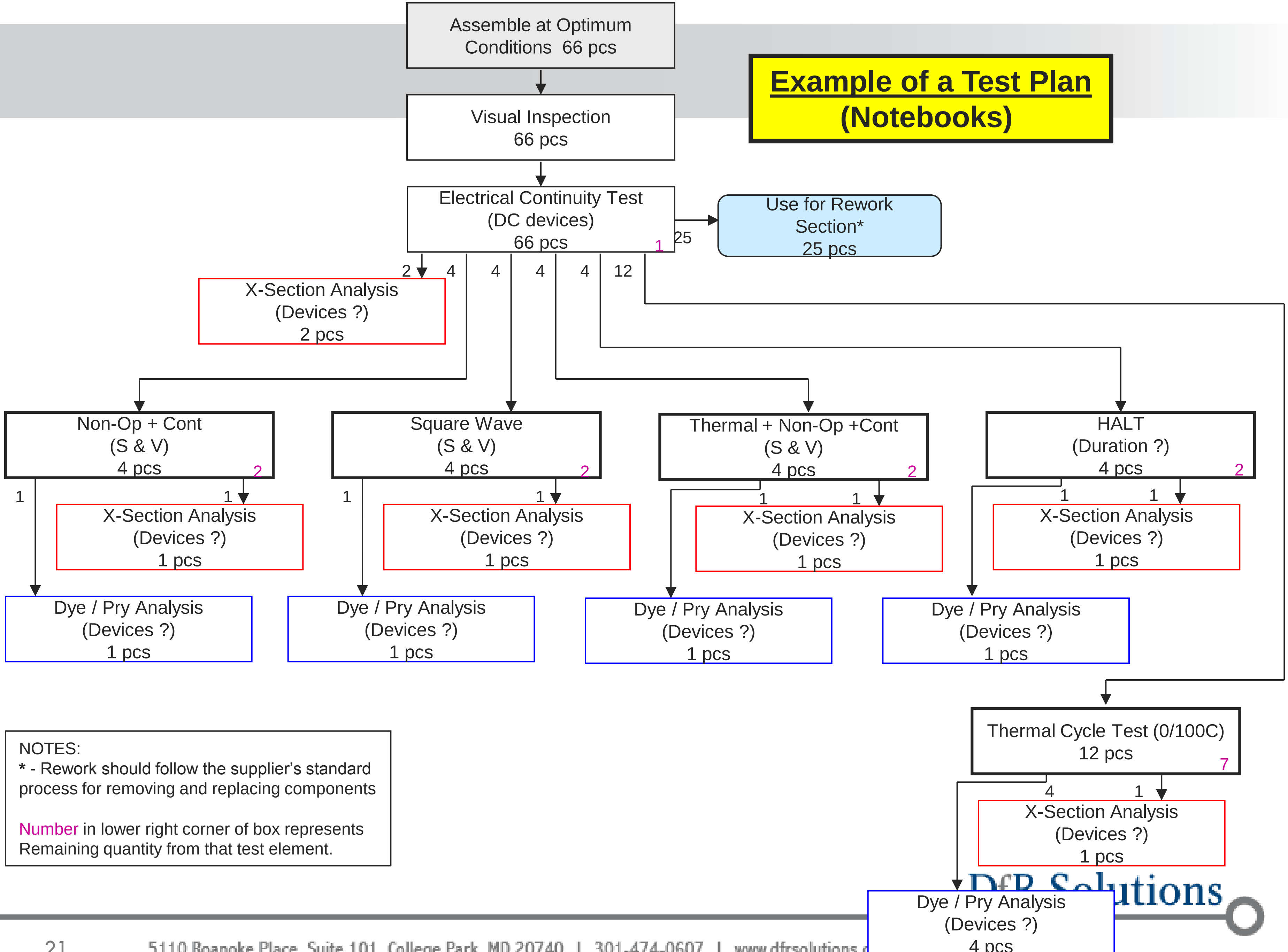
Example of a Test Plan (Notebooks)



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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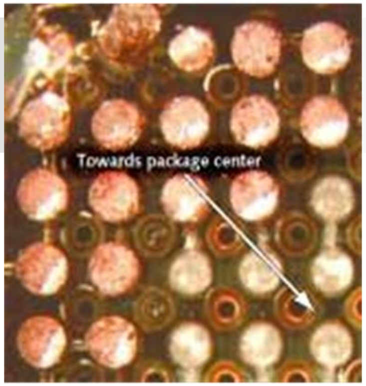
Don't Overlook Failure Analysis!



- Effective failure analysis is critical to reliability!
- Without identifying the root causes of failure, true corrective action cannot be implemented
  - Risk of repeat occurrence increases
- Use a systematic approach to failure analysis
  - Proceed from non-destructive to destructive methods until all root causes are identified.
- Techniques based upon the failure information specific to the problem.
  - Failure history, failure mode, failure site, failure mechanism

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Virtual Qualification (VQ, Modeling)

- 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

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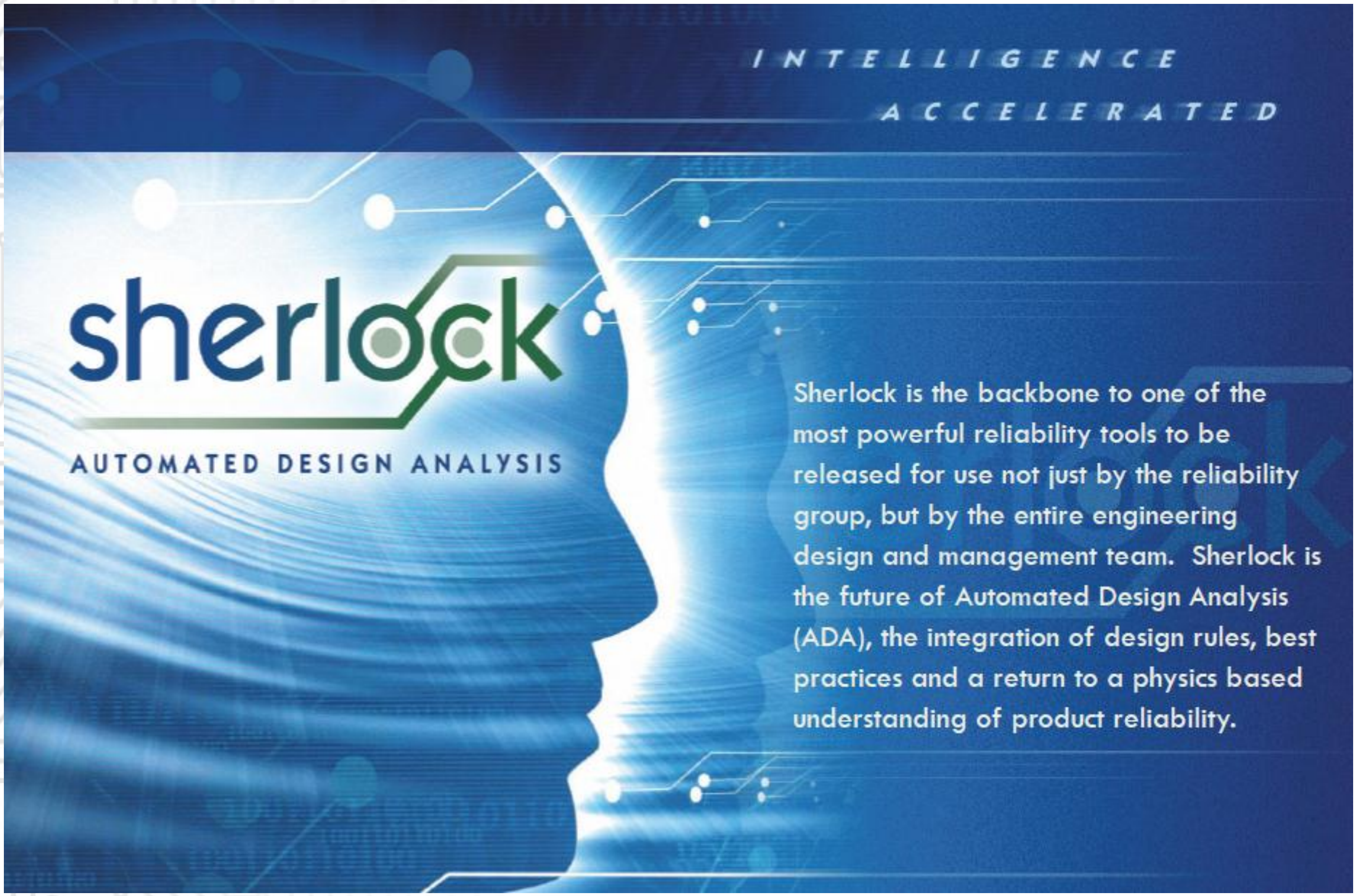
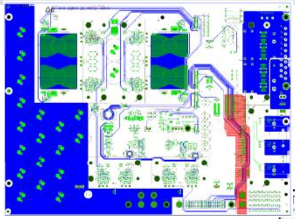
sherlock
AUTOMATED DESIGN ANALYSIS

Sherlock ADA – A Reliability Assurance CAE Tool Suite - the Physics of Failure App.

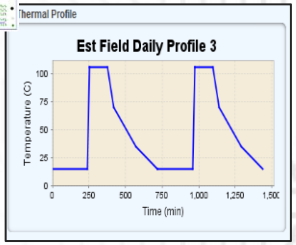


It is not at the Iphone or Droid App store. But yes there is now a Physics of Failure Durability Simulation App

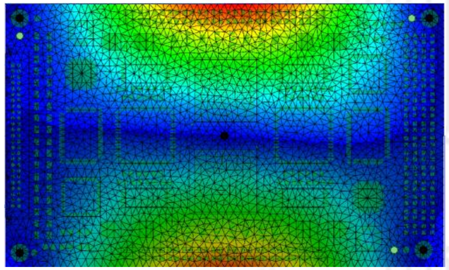
The 4 Parts of a Sherlock PoF Analysis



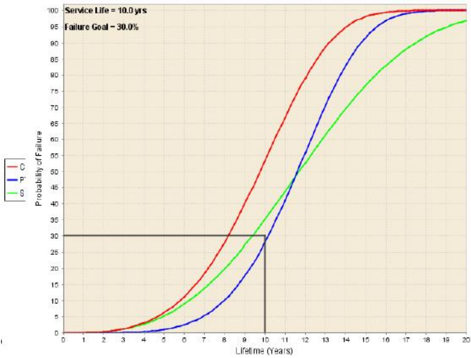
1) **Design Capture** - provide industry standard inputs to the modeling software and calculation tools



2) **Life-Cycle Characterization** - define the reliability/durability objectives and expected environmental & usage conditions (Field or Test) under which the device is required to operate

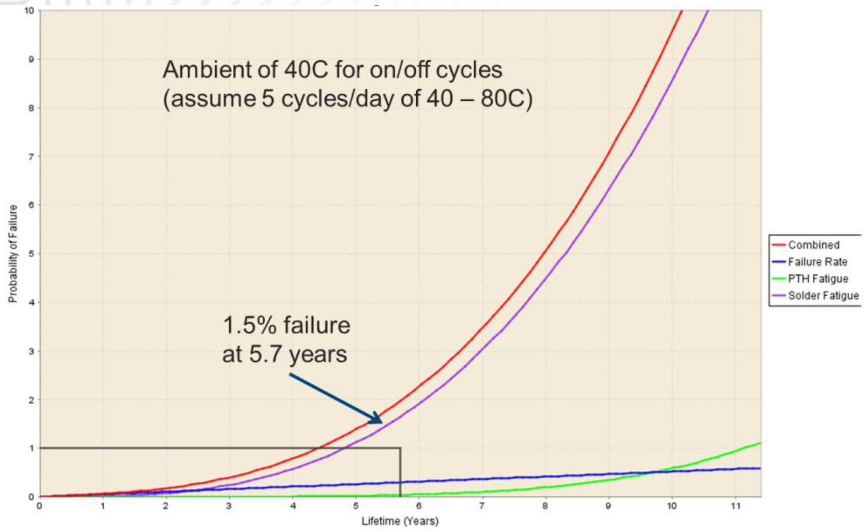


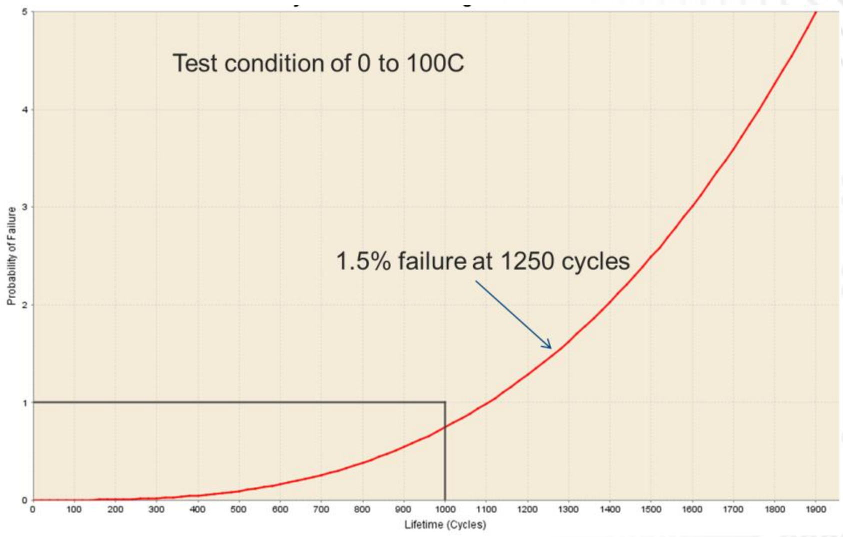
3) **Load Transformation –** automated calculations that translates and distributes the environmental and operational loads across a circuit board to the individual parts



4) **PoF Durability Simulation/Reliability Analysis & Risk Assessment –** Performs a design and application specific durability simulation to calculates life expectations, reliability distributions & prioritizes risks by applying PoF algorithms to the PCBA model

PoF Modeling & Test Plan Development





- Lighting products customer was attempting to develop a product qualification plan
- Sherlock identified appropriate test time and test condition based on field environment and likely failure mechanism

When to Repeat Testing: Change Control

- 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).

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.

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Case Study: Solar Micro-Inverter Reliability

- The electronic components used in a micro-inverter are commercial off-the-shelf (COTS)
  - Parts designed for consumer electronics but need to survive 25 years in solar installations
    - Outdoor/Partially Protected & Temp Not Controlled
  - Lack of industry standards for testing

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What can be done?

- How can a micro-inverter supplier design the product to meet the requirements AND convince the customer of this?
- One new method: model the reliability of an electronic assembly in a variety of conditions based on the design (before building anything).
- Design for Reliability (DfR) concepts and Physics of Failure (PoF) are used.

Are there Methods to Model these Failure Mechanisms?

- Yes!
- Algorithms exist to estimate the failure rate from solder joint fatigue for different types of components.
- IPC TR-579 models PTH reliability
- Risk for CAF can be determined
- Finite Element Analysis can be used for Shock & Vibration risk.
- MTBF calculations can be performed to estimate component failure rates.

Micro-Inverter Environment

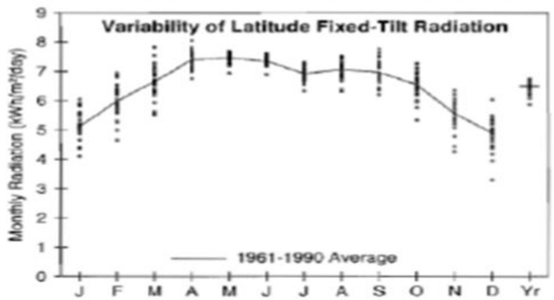
- Extreme hot and cold locations (AZ to AK)
- Possible exposure to moisture/humidity
- Large diurnal thermal cycle events (daily)
- Largest temp swings occur in desert locations where it can reach 64C in the direct sun down to 23C at night (Δ41C)

Phoenix, AZ

WBAN NO. 23183

LATITUDE: 33.43° N
LONGITUDE: 112.02° W
ELEVATION: 339 meters
MEAN PRESSURE: 974 millibars

STATION TYPE: Primary



Min/Max	3.5/6.5	3.7/7.5	4.5/8.6	6.7/10.3	7.1/9.9	8.0/10.1	5.8/9.0	5.7/8.6	5.5/8.7	4.4/7.9	3.1/7.1	2.8/6.8	5.8/7.4

Temperature (°C)	12.0	14.3	16.8	21.1	26.0	31.2	34.2	33.1	29.8	23.6	16.6	12.3	22.6
Daily Minimum Temp	5.1	7.1	9.3	12.9	17.7	22.7	27.2	26.2	22.7	16.0	9.4	5.4	15.2
Daily Maximum Temp	18.8	21.5	24.2	29.2	34.2	39.7	41.1	39.8	36.8	31.2	23.8	19.0	29.9
Record Minimum Temp	-8.3	-5.6	-3.9	0.0	4.4	10.0	16.1	15.6	8.3	1.1	-3.9	-5.6	-8.3
Record Maximum Temp	31.1	33.3	37.8	40.6	45.0	50.0	47.8	46.7	47.8	41.7	33.9	31.1	50.0
HDD, Base 18.3°C	201	126	101	42	4	0	0	0	0	9	74	192	750
CDD, Base 18.3°C	4	12	53	123	242	387	491	457	343	173	23	4	2312
Relative Humidity (%)	51	44	39	28	22	19	32	36	36	37	44	52	37
Wind Speed (m/s)	2.5	2.8	3.2	3.4	3.4	3.2	3.4	3.2	3.0	2.8	2.6	2.5	3.0

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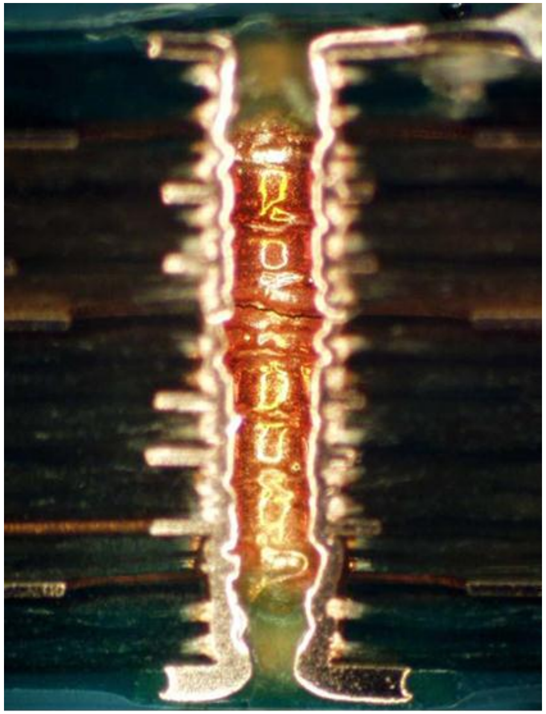
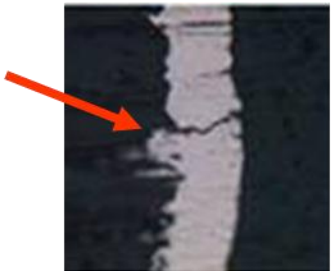
Potential Inverter Failure Mechanisms

- Solder joint fatigue failure
- Plated through hole fatigue failure
- Conductive anodic filament formation (CAF)
- Shock or Vibration (during shipping)
- Component wear out





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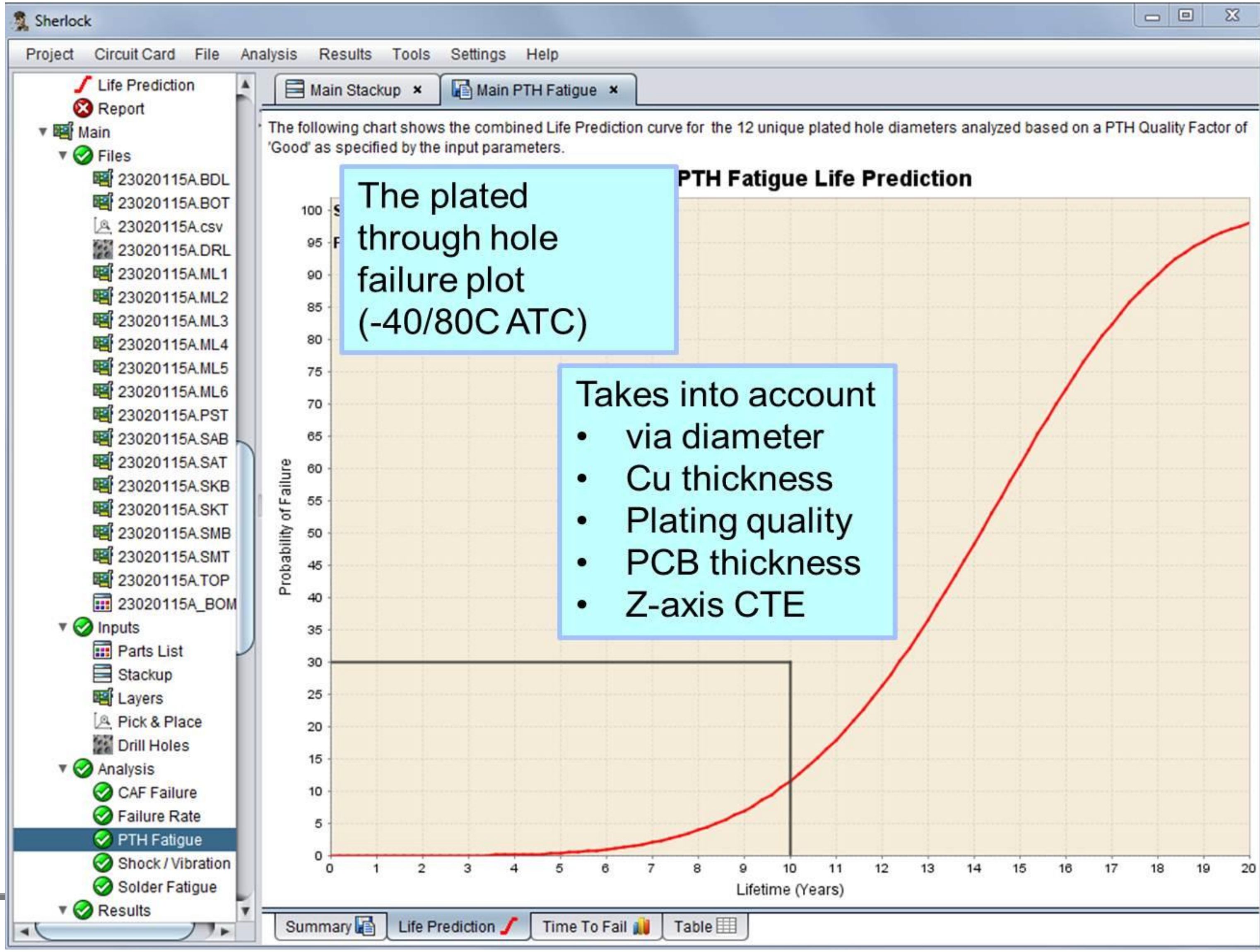
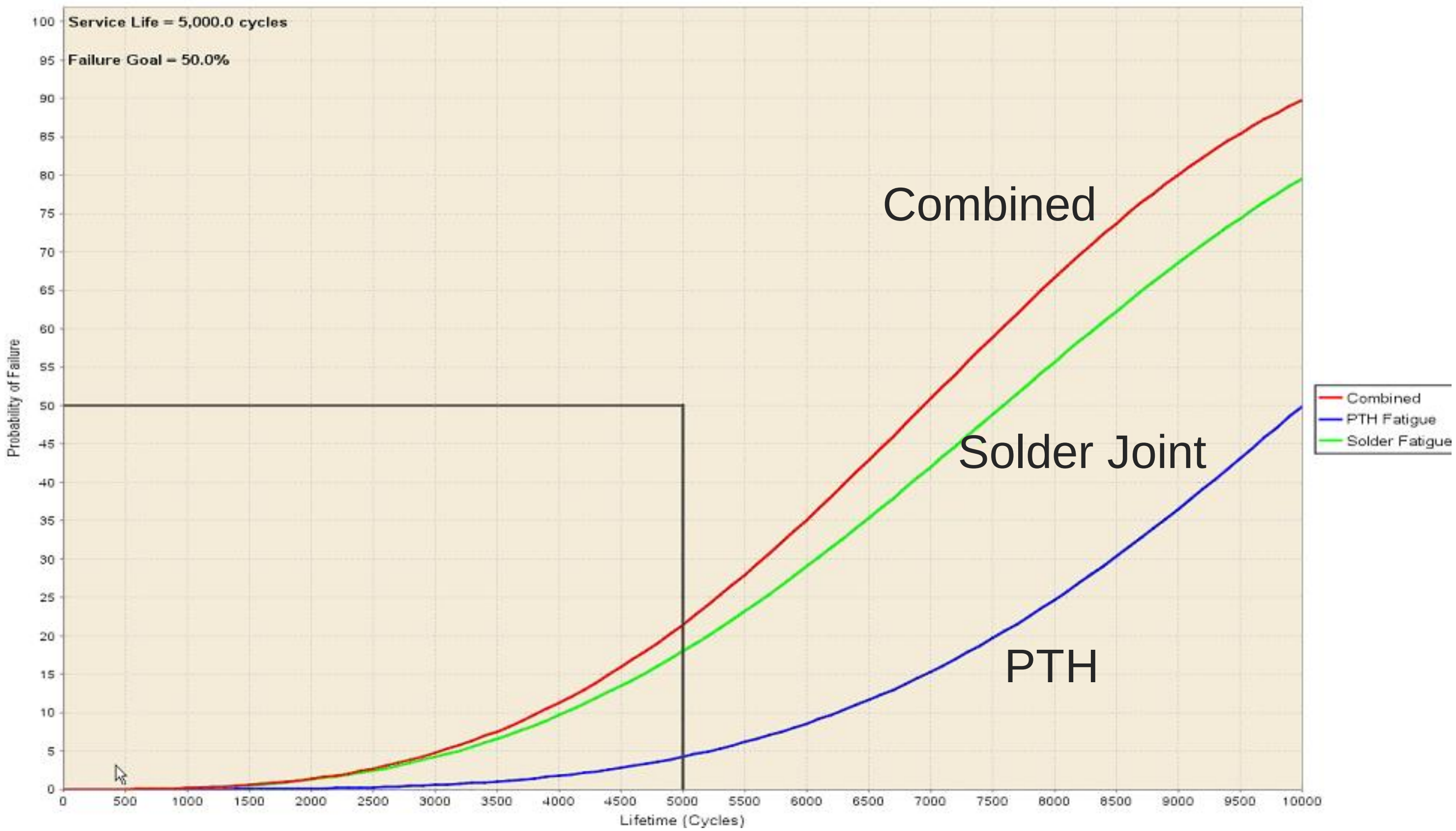
PTH Fatigue Results - Example



Combined (SJ & PTH) Lifetime Prediction



- Combines analysis results into overall failure prediction curve

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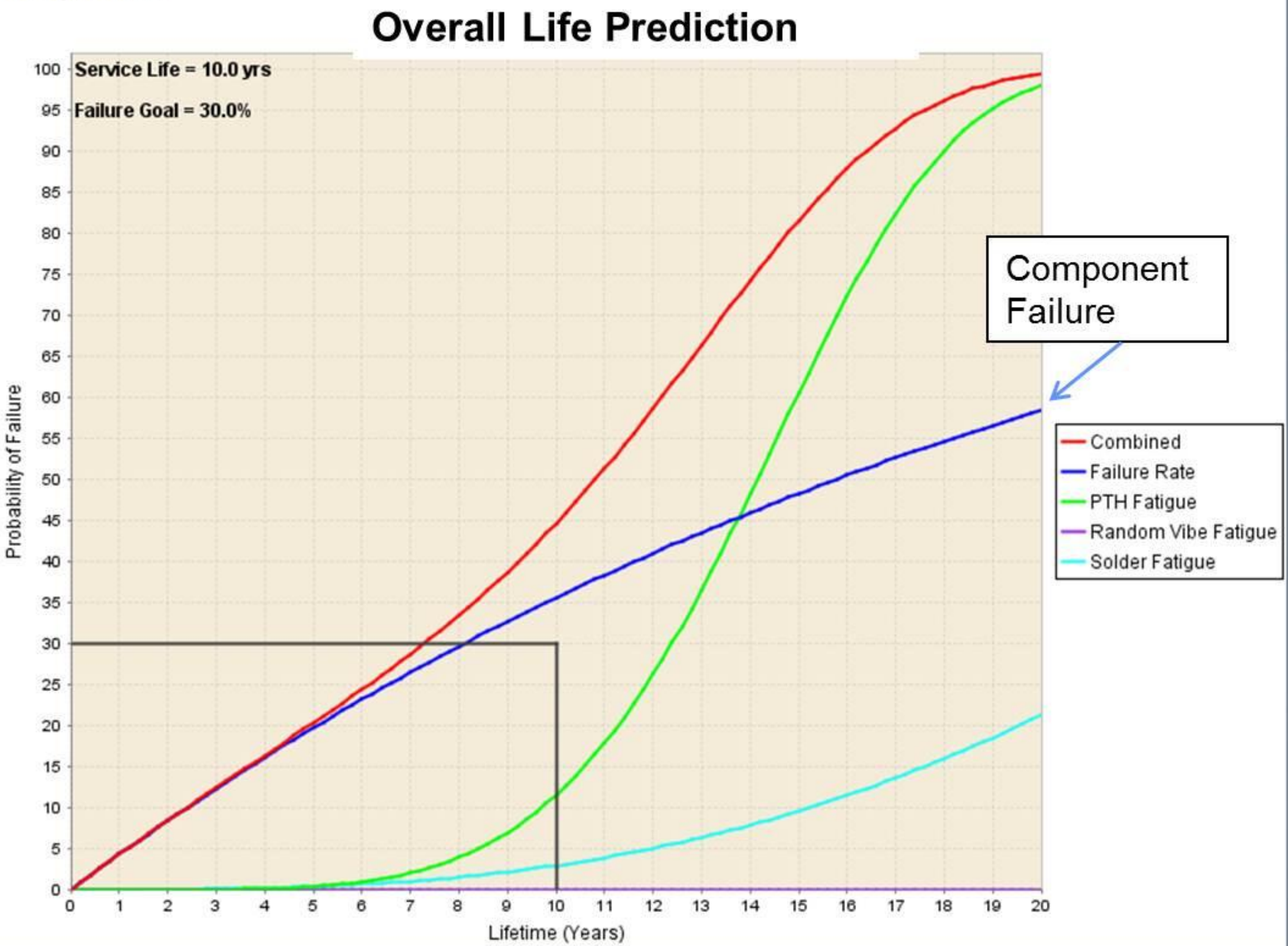
Combined Failure Rate is Provided

The following chart shows the individual Life Prediction curves generated by all analysis modules and a combined Life Prediction curve based on all the analysis results.



Additional Uses for Modeling

- Use Sherlock to determine thermal cycle test requirements.
- Use to modify mount point locations
- Use to determine ESS conditions
- Component Replacement
- Determine impact of changing to Pb-free solder
- Determine expected warranty costs

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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.
- 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.
- PoF Modeling is an excellent tool to help tailor & optimize physical testing plans

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