Test Plan Development: How to do it – Sherlock

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Speaker Bio:

- Research focus:
  - Mechanical reliability of electronic systems and components
  - Multidisciplinary reliability of complex electro mechanical systems
  - Characterization and modeling of material behavior
  - Physics of failure of electromechanical and MEMS system
  - Mechanical performance of flip chip packages
- Doctoral research
  - Solder reliability
  - MEMS structures characterization
  - Embedded components failure analysis
  - Particle beam accelerator mechanical fatigue.
- Experience at Amkor technology
  - Advanced product development group as senior engineer
  - Analysis of chip-package interactions
- Ph.D, Mechanical Engineering (University of Maryland)

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Question Everything

"I want you to remember that everything I am saying may be wrong and I want you to question everything that I'm saying."

-Nathan Myhrvold

Formerly Chief Technology Officer at Microsoft

Agenda

- What is a test plan
  - Test plan strategies
- Physics of failure
  - Field failures
- Test plan elements
- Reliability goals
- Wear out and overstress
- Use environment
- Choosing a test board
- Test methods
  - Temperature cycling
  - Plated through hole fatigue
  - Mechanical vibration
  - Mechanical Shock
  - CAF resistance
- Failure analysis
- Summary and questions
  - But feel free to ask questions in the middle

What Is A Test Plan?

- Test plans are a central part of implementing any new technology
- Test plan is the strategy used to identify the board's ability to succeed
  - For the intended use environment
  - For a specified reliability goal
  - Known failure modes
- Trade off between:
  - Cost of test and simulation
  - Risk
- There are many specifications

JEDEC

IPC®

IEC

MIL-STD 810G

IP65

INTERNATIONAL CERTIFICATIONS ISO 9001

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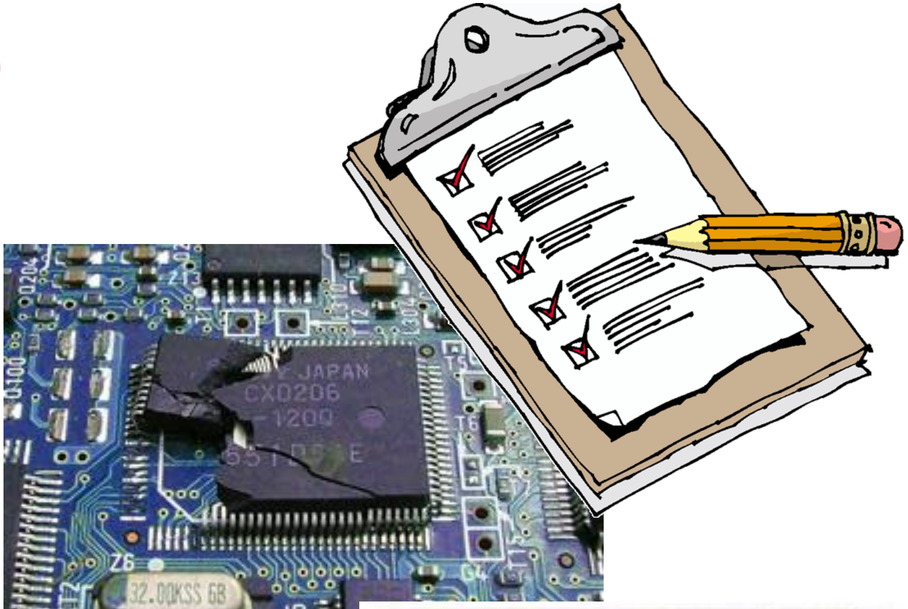
Test Plan Strategies

- Test to "Spec" (Industry standards)
  - Pass/Fail: Clipboard engineering
  - Uses best practices and previous success
  - Design by similarity
  - Different requirements for every manufacturer or industry
- Physics of failure (POF) testing
  - Test to failure
  - Failure analysis for failure mode verification
  - One test per failure mode
  - Creates prediction models that feed back to industry standards
- Combined approach
  - Physics of failure prediction
  - Industry standards



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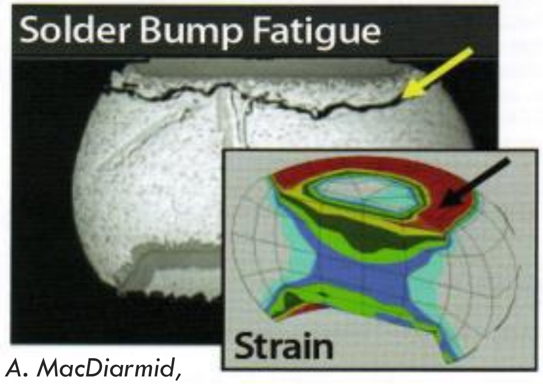

Source: A. MacDiarmid, "Thermal Cycling Failures", RIAC Journal, Jan., 2011.

Physics of Failure

- 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 individual board design and materials
  - Consider the use environment and reliability needs

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Clipboard Engineering Is Not Enough

- Limited failure mechanism specific testing
  - Only performed at transition to new technology nodes
  - Mechanism-specific coupons (not real boards)
  - Test data is hidden from end-users

- Questionable JEDEC tests are promoted to OEMs
  - Limited duration (1,000 hrs) hides wearout behavior
  - Use of simple activation energy
    - Incorrect assumption that all mechanisms are thermally activated
    - Constant failure rate calculation is outdated

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Field Failure of Devices

- Field failures rates of hardware
  - Gradual material degradation
  - Rapid or immediate failures
- Environment stressors
  - Thermal, Chemical, Moisture, Electrical, Shock…ETC
  - Combination of stresses
  - Probabilistic vs. deterministic
- Premature failures
  - Shipping, manufacturing, installation, test …
- Gradual failures
  - Long product life, high cycle count, long term storage…
- Erratic failures
  - Mechanical shock, accidental misuse, electrical overstress …

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Test Plan Elements

- Type of test objective
  - Comparison test
    - Option A,B,C …
  - Qualification
    - Pass/ Fail
  - Validation
    - Sanity check
  - Research
  - Compliance and regulatory
  - Failure analysis
    - Verify failure mode
    - Can be difficult
- A test without an objective is doomed before it even started

- Justification checklist
  - Define reliability goals
  - Experiment design
  - Materials availability
  - Defined use environment
  - Budget
    - Time and money
  - Sample availability
  - Practicality of test
  - Risk
- Every test has a risk associated with it
- Have a plan for failure

Reliability Goals

- Lifetime
  - How long does the customer expect the device to perform?
  - How long is the warranty? Extended warranty?
  - Cost of replacement.
  - Should be used in all phases of product qualification
- Performance
  - Define the probability of failure during product life
  - Actively monitor field returns: perform failure analysis
    - Feedback to refurbishing/redesign
  - MTBF and MTTF
    - Only if customer requirement
    - Do not use for design

Examples of Product Lifetimes

- Low-End Consumer Products (Toys, pedometers, gadgets etc.)
  - Do they ever work?
- Consumer electronics
  - Cell Phones: 18 to 36 months
  - Laptop Computers: 24 to 36 months
  - Desktop Computers: 24 to 60 months
  - Home appliances: 7 to 15 years
- Commercial electronics
  - Medical (External): 5 to 10 years
  - Medical (Internal): 7 years
  - High-End Servers: 7 to 10 years
  - Industrial Controls: 7 to 15 years
- Highly regulated
  - Automotive: 10 to 15 years (warranty)
  - Avionics (Civil): 10 to 20 years
  - Avionics (Military): 10 to 30 years
- Telecommunications: 10 to 30 years
- Solar 25 years (warranty)

- Can we really define a “standard” use case for an entire industry?
  - Or product?
  - Or board?

Wear Out and Overstress

- Wear out mechanisms are the usual culprit for failures
  - Fatigue and creep are hard to test for correctly
  - Perform failure analysis to verify failure mode
  - We are getting much better at doing this but you can’t rush physics

- What if an overstress failure is detected
  - Audit suppliers
  - Reevaluate field environments
  - Combined stresses can have an unexpected effect
  - Redesign the test
    - Must be effective for desired failure mode
    - Must be effective for expected use environment

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Defining the Use Environment

- Shipping
  - How well is the product protected during shipping?
- Assembly, test, manufacturing, storage …
  - All the things that happen before the product is even turned on
- Do you have a good understanding of how your customer uses the product?
  - What about the corner cases?
- Opinioneering: Engineering without data
  - Measured temperatures. Thermal simulation. Previous experience.
  - Mechanical loads: Accelerometer data. Strain gauge. Extensometer
  - Cycle rate data: Software and hardware interaction

Test Plan Development

- Develop a comprehensive test plan
  - Have specific goals in mind
- Assemble boards at optimum conditions
  - Manufacture test boards in similar environment as production boards
- Visually inspect and electrically test
  - Per lot ?
  - 100% inspection ?
  - Per product line ?
- Non destructive inspection of critical components
  - C-SAM, X-ray
- Destructive reliability testing
  - Test to failure: No failure = no data
- Perform failure analysis
- Compile results and review
- Recommended actions

The test or analysis is worthless without a recommendation based on the result

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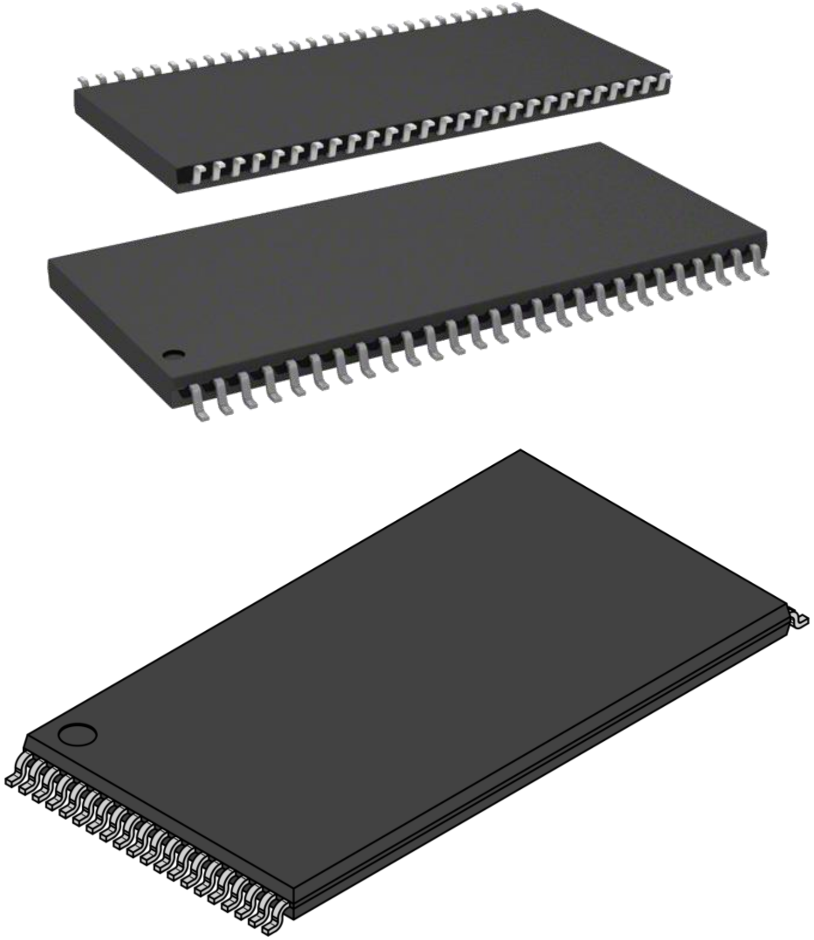
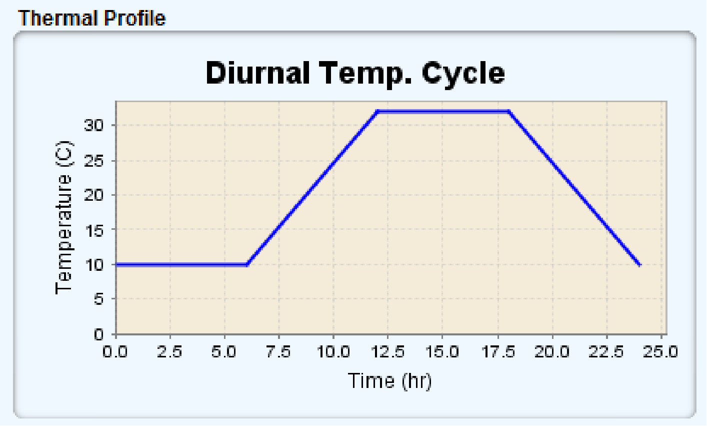
The Test Board: Case study

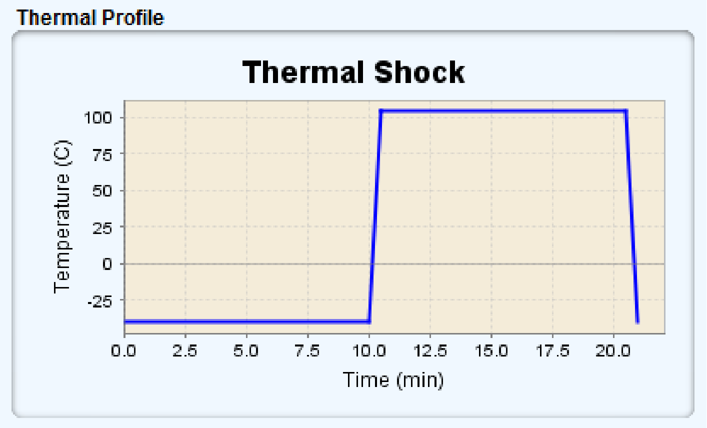
- Comparing two different components
  - TSOP-I and TSOP-II
  - Both are surface mounted
  - Similar size
- Do we really need a production board?
  - Expensive materials
  - Similar failure mode
- Cheaper board with dummy components
  - Failure analysis to verify failure mode



Test Methods: Temperature Cycling

- Key parameters:
  - Number of cycles
    - Qual vs. test to failure
  - High and low temperatures
    - Glass transition temperature (Tg)
  - Dwell time
    - Critical dwell time can be different for different solders
  - Ramp rates
    - Thermal shock vs. Thermal cycling
- Monitoring during test
  - Most desirable: in situ monitoring with event detector
  - Usual: Spot check every number of cycles
  - Least desirable: Functional check at beginning and end
  - Thermocouple data
    - Temperature should be measured on components
    - Chamber settings do not include self heating or thermal lag effects
- Verify failure mode
  - The whole test can be worthless





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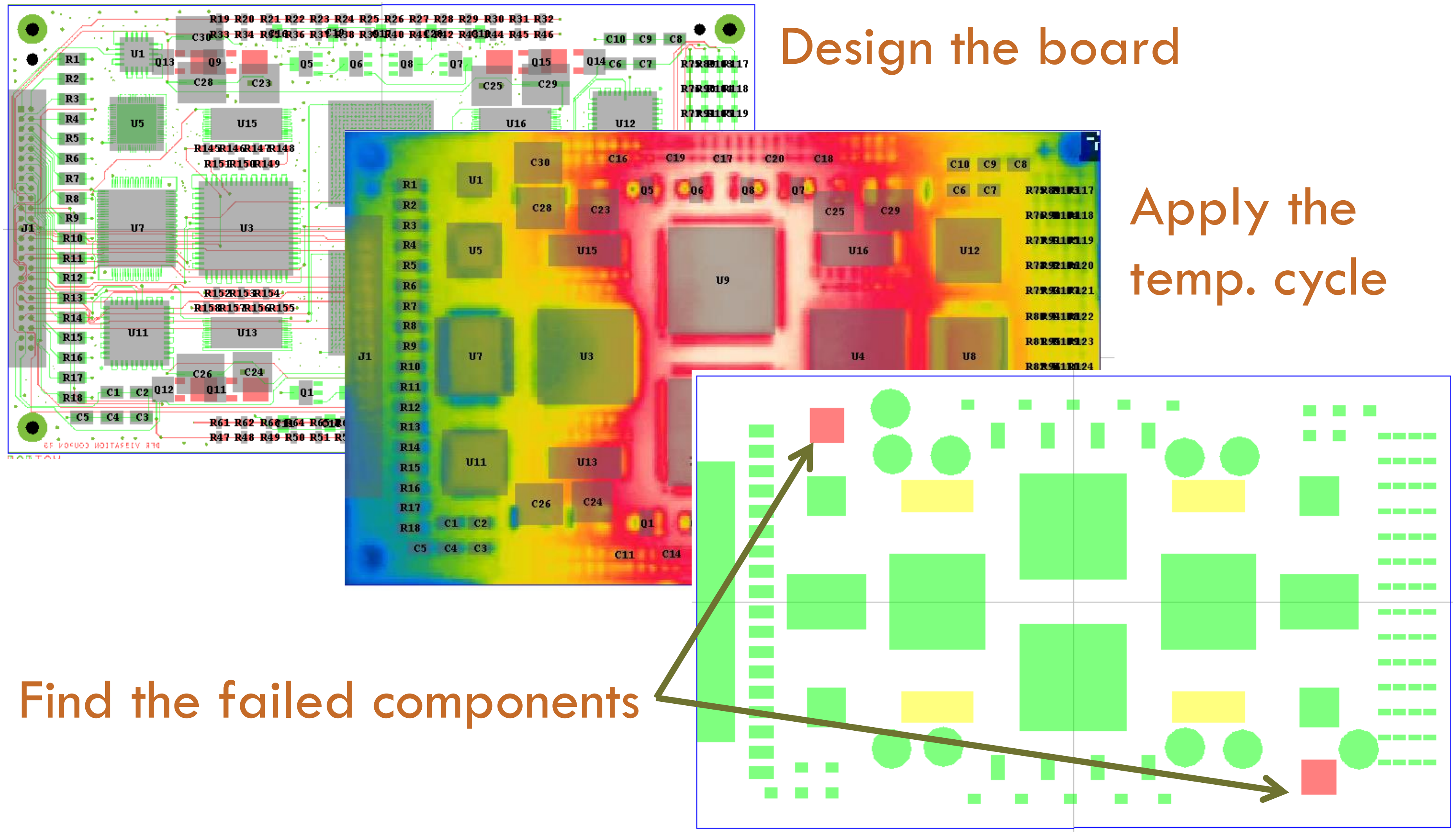
Temp. Cycling: Reliability Prediction Software



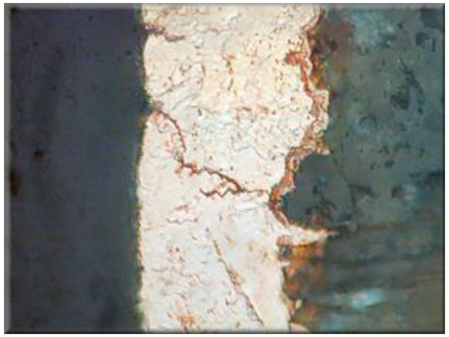
Design the board

Apply the temp. cycle

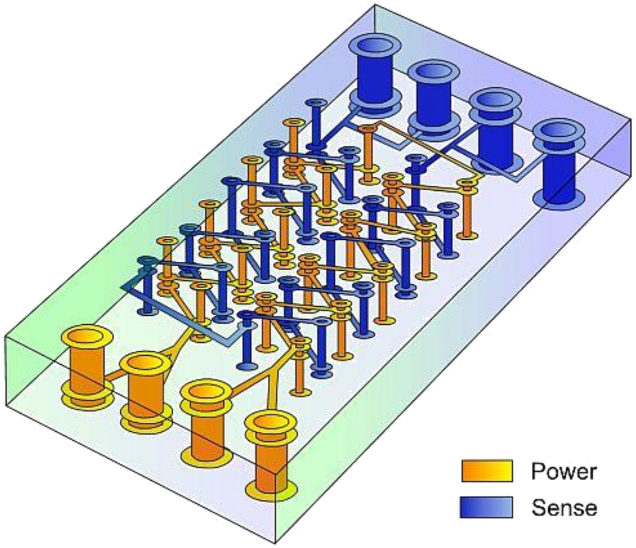
Find the failed components

Test Method: Plated Through Hole Fatigue

- Expansion/contraction in the z-direction is higher than that in the x-y plane.
  - The glass fibers constrain the board in the x-y plane
- Smaller holes fail faster
  - Higher aspect ratio
- More plating is better
  - Up to a point
- Lower CTE of PCB is better
  - Hard to do in reality

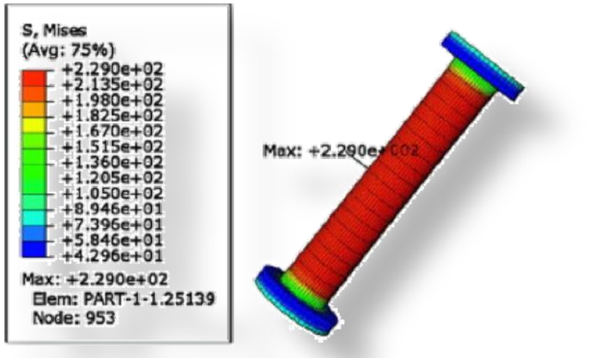


Source: Paul Reid, "The Impact of Lead-Free Processing on Interconnect Reliability" , Printed Circuit Design & Fab,

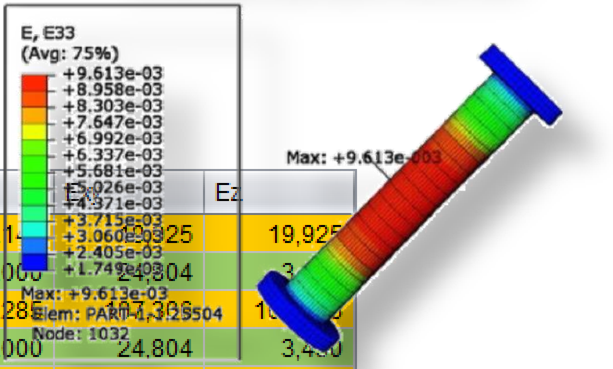


Plated Hole Fatigue: Reliability Prediction Software

- Use the same temperature map from the solder fatigue input
- Calculate barrel stress
  - Use board stackup in the calculation
  - Modify calculations to account for qualification tests and quality control



(a) The Mises stress field of PTH at 150ºC



(b) The residual strain field of PTH after 3 cycles

Layer	Type	Material	Thickness	Density	CTExy	CTEz	Exy	Ez
1	SIGNAL	COPPER (15.0%) / COPPER-RESIN	0.5 oz	2.8650	45.140	45.14	19,925	19,925
2	Laminate	Generic FR-4	51.26 mil	1.9000	17.000	70.000	24,804	[illegible]
3	SIGNAL	COPPER (94.8%) / COPPER-RESIN	0.5 oz	8.5308	19.285	19.285	107,306	[illegible]
4	Laminate	Generic FR-4	51.26 mil	1.9000	17.000	70.000	24,804	3,450
5	SIGNAL	COPPER (1.7%) / COPPER-RESIN	0.5 oz	1.9207	49.449	49.449	5,262	5,262
6	Laminate	Generic FR-4	51.26 mil	1.9000	17.000	70.000	24,804	3,450
7	SIGNAL	COPPER (1.6%) / COPPER-RESIN	0.5 oz	1.9136	49.482	49.482	5,252	5,252
8	Laminate	Generic FR-4	51.26 mil	1.9000	17.000	70.000	24,804	3,450
9	SIGNAL	COPPER (94.8%) / COPPER-RESIN	0.5 oz	8.5308	19.285	19.285	107,306	107,306
10	Laminate	Generic FR-4	51.26 mil	1.9000	17.000	70.000	24,804	3,450
11	SIGNAL	COPPER (9.9%) / COPPER-RESIN	0.5 oz	2.5029	46.792	46.792	14,340	14,340

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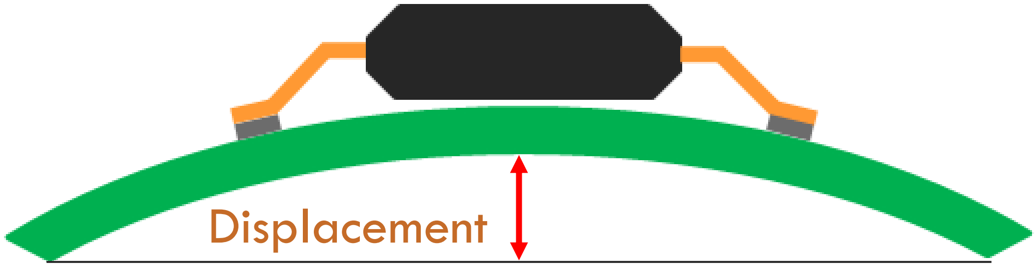
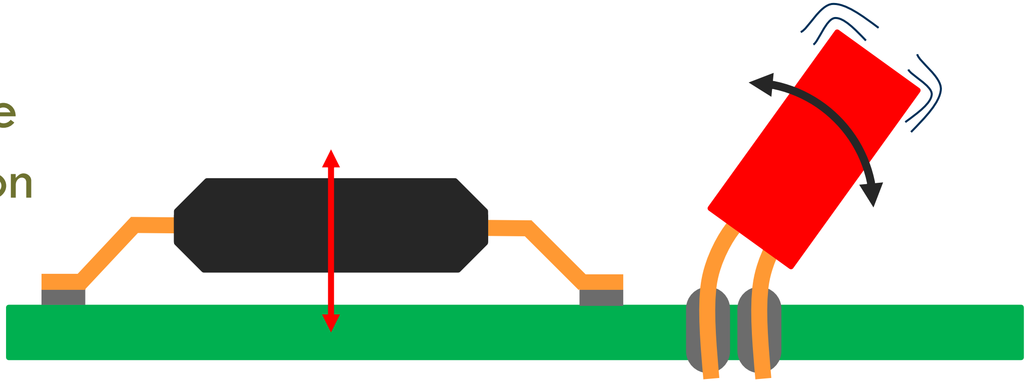
Test Method: Vibration

- Board close to resonance
  - Components can shake off due to fatigue in leads or solder

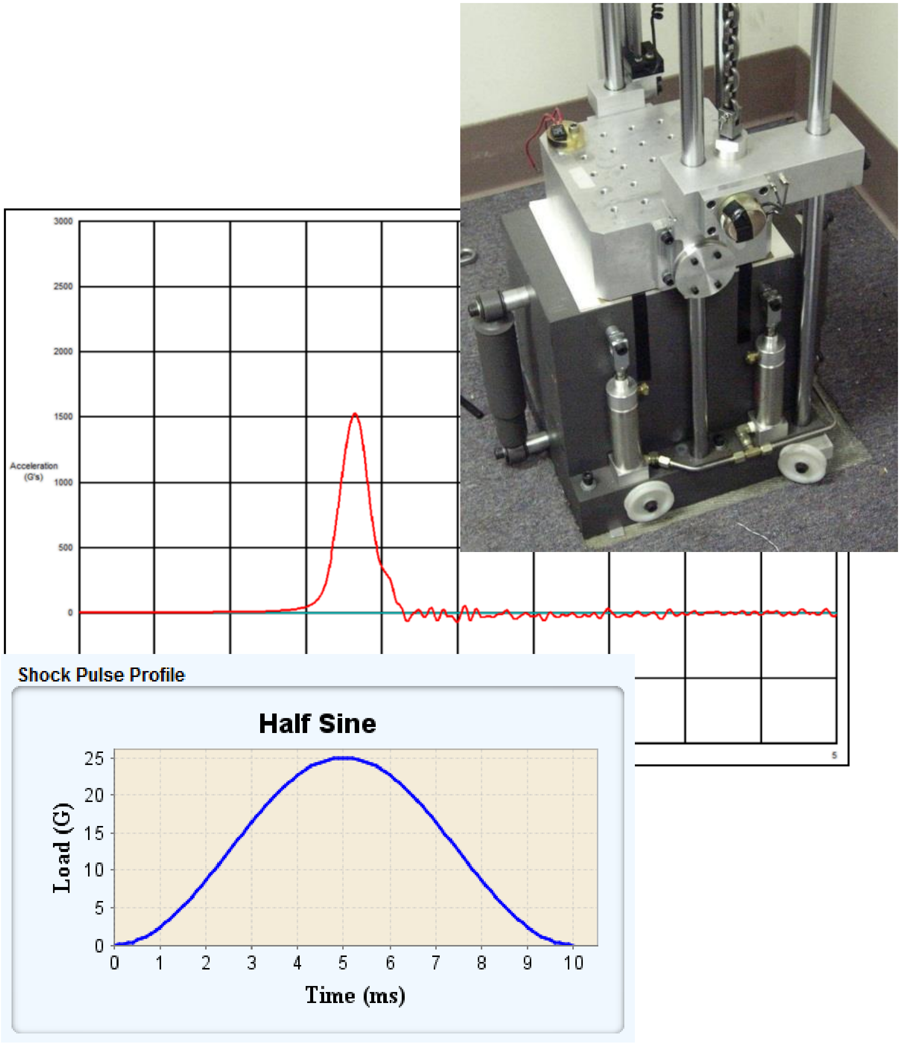


  - Time to failure is determined by intensity and frequency of stress
- Component resonance
  - Lead and solder fatigue due to component motion



Test Method: Mechanical Shock

- Happens as random events
- Failure mechanism
    - Sensitive to intermetallic layer thickness
    - Brittle failure
- Board failures
    - Pad cracking
- Lead failures
- Probabilistic
    - Equally likely to fail at event #20 as event #200
    - Stress to probability of failure

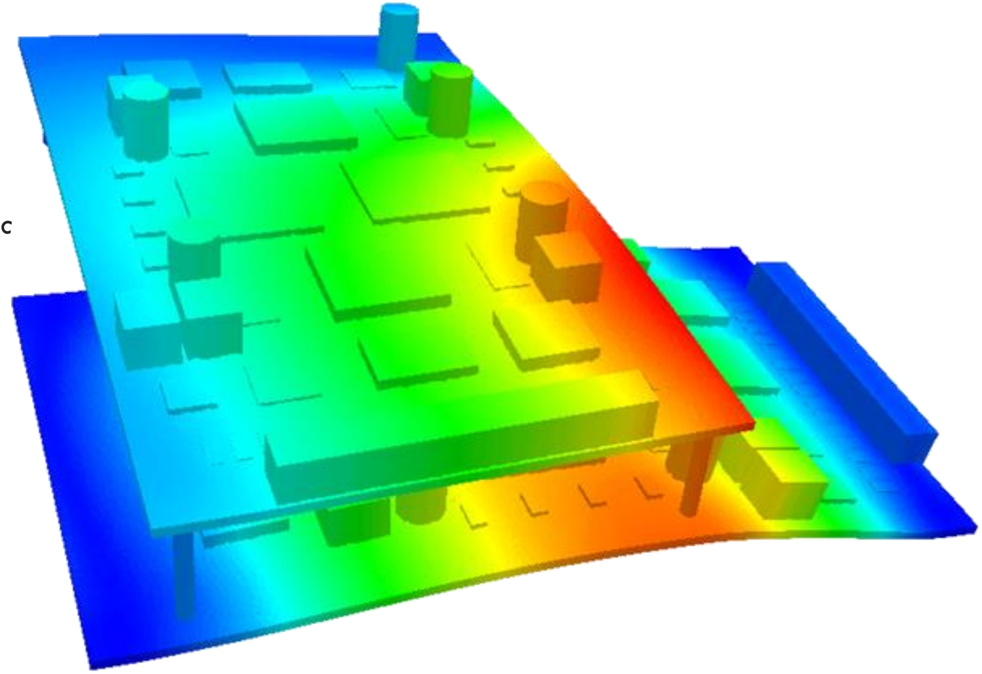


Shock and Vibration: Reliability Prediction Software

- Calculate board strain during mechanical shock or vibration
- Use the strain to predict probability of failure

$$Z_0 = \frac{9.8 \times G_{in} \times Q}{f_n^2}$$

Source: Steinberg D.S. "Vibration analysis for electronic equipment". John Wiley & Sons, 2000.



Test Method: CAF Resistance Test

- CAF: Conductive Anodic Filament
- Inadequate dielectric for the applied voltage
- Exceeding the maximum operating temperature of the laminate
- Manufacturing process

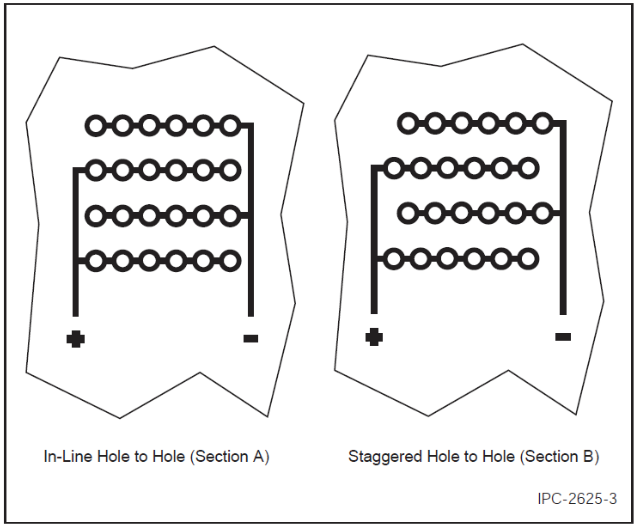
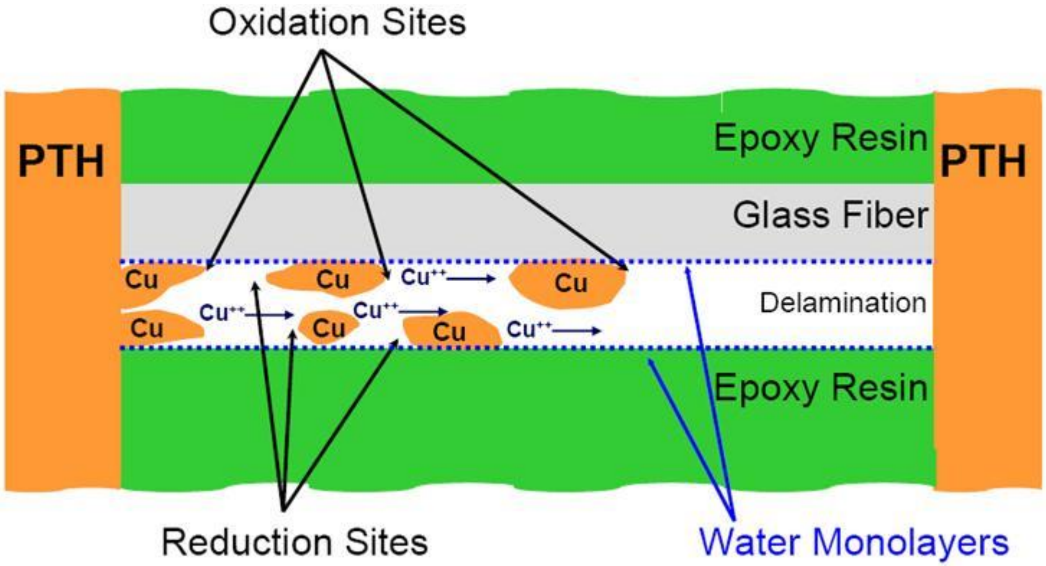


Figure 3 CAF Test Board PTH-PTH Spacing Design



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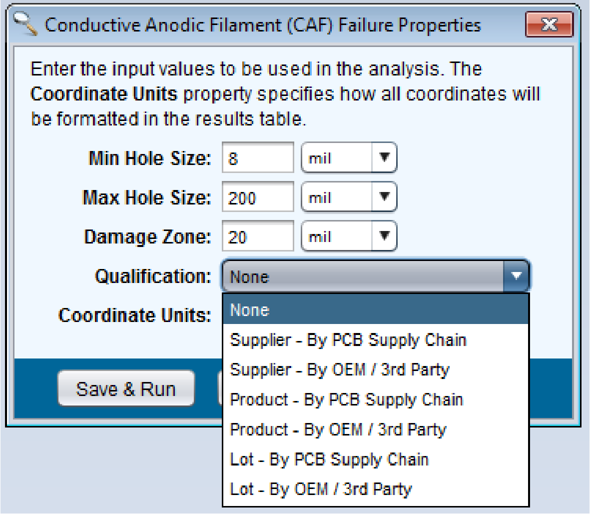
CAF: Reliability Prediction Software

- Input the drill hole locations and diameters
  - From drill files
- Set the “Damage zone”
  - Maximum distance between a pair of holes to be considered for analysis
- Qualification process
  - Better qualification process will decrease the number of failures
- Filter by hole size



Enter the input values to be used in the analysis. The **Coordinate Units** property specifies how all coordinates will be formatted in the results table.

Min Hole Size: 8 mil

Max Hole Size: 200 mil

Damage Zone: 20 mil

Qualification: None

Coordinate Units:


Highlighted CAF Results

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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Summary

- If you remember nothing else:
    - A test plan without an objective is doomed before it even started
    - Testing to pass has no failure data
    - Root cause failure analysis is worth it
- Some tests can be simulated in software
    - Solder fatigue
    - Plated Through Hole fatigue
    - Mechanical shock and vibration
    - Conductive anodic filament resistance
- Every test or analysis must have a recommended action as a result
    - And every recommended action should have test data or analysis as justification

Questions?

Test Plan Development

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