

# Design for Reliability of Electronics in Automotive Applications

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# DfR Solutions

reliability designed, reliability delivered



- DfR Solutions is the leading provider of quality, reliability, and safety software and services for the electronics industry.
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  - Consulting services
  - Reliability software
- Advanced Accelerated Testing
- E/E Component Robustness & Supply-Chain Selection and Management

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# Nathan Myhrvold

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

# Let's Talk Reliability

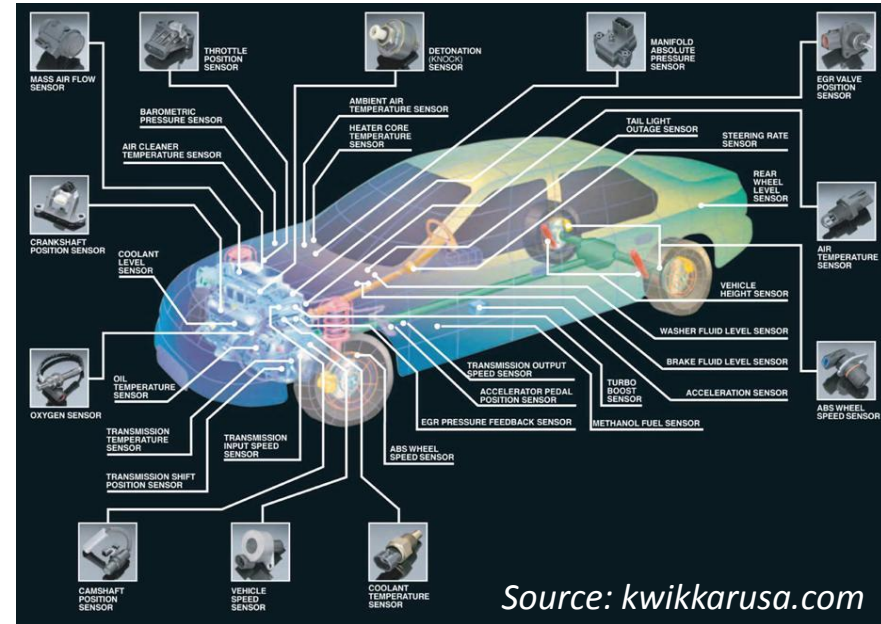
- What is reliability?
  - Is this really a problem?
- Temperature cycling
  - Solder Fatigue
  - Plated Through Hole (PTH) fatigue
- Shock and Vibration solder fatigue
- Moisture and Contamination
- Field failures
- What do we do about it?

# What is reliability?

- Simple reliability
  - System or component
  - What is the function
  - Usage conditions
  - Operation time
- Single failure mode
  - Complex systems have several failure modes
  - Dominant failure mode
- Known or knowable failure rate
  - Complex systems don't have simple failure rates

# Complex Systems in Automobiles

- Sensors
  - Air–fuel ratio meter, Blind spot monitor, Crankshaft position sensor, Tire-pressure monitoring sensor, Wheel speed sensor...and many more
- Actuators
  - HVAC, Grill shutters, Headlamps, Coolant...and many more
- Feedback controls
  - Cruise control, A/C temp
- Touchscreens
  - Nav. System, Dashboard
- And all of these are only inside the vehicle!
  - Test equipment
  - Maintenance gear



# We Have Some Problems

*Source: nhtsa.gov*

- August 16: 1,540 BMW X5 xDrive35d vehicles with a diesel engine from 2009-2010, Recalled for potential loss of battery power and vehicle fire.
- August 14: 1,989 Jaguar XK convertible vehicles from 2011-2014, Recalled for failing to comply with federal standards for power operated windows, increasing the risk of injury.
- August 12: 6,308 Ford Focus vehicles from 2012-2013, Recalled for side marker lamps that may not function, resulting in less visibility and increasing the risk of a crash.
- August 12: 549 Cequent Performance electric trailer brake controllers for Dodge Ram 1500 trucks, recalled for incorrect wiring, increasing the risk of a crash.
- August 6: 652 Honda Trailer Hitch Harness Kits for 2014 Acura MDX vehicles, Recalled for incorrect wiring of the trailer brake controller, causing loss of power to the brakes and increasing the risk of a crash.
- July 19: 3,900 Yamaha XVS950CU (Bolt) motorcycles from 2014, Recalled for engine stalling from melting wiring harnesses.
- Mitsubishi Motors North America, Inc. (Mitsubishi) is recalling certain replacement lithium-ion batteries installed on 2012 Mitsubishi i-MiEV vehicles.
- Stoneridge Inc. (Stoneridge) is recalling ignition switches
- Sutrak USA (Sutrak) is recalling certain HVAC Systems manufactured May 2012 through May 2013 used in DART 39000 buses manufactured by North American Bus Industries, Inc. The fuse holder inside the HVAC may allow voltage spikes, which may damage electrical components.
- Mercedes-Benz (Mercedes) is recalling certain model year 2013 SLK250 and SLK350 that are equipped with an occupant classification system (OCS) that may not correctly differentiate between a child seat or a very light person being in the front passenger seat.
- Chrysler is recalling certain model year 2013 Ram 1500, 2500, and 3500 trucks equipped with optional premium tail lamps. The turn signal indicator may not flash at a double rate to give a notification to the driver of a turn signal malfunction against requirements of Federal Motor Vehicle Safety Standard (FMVSS)

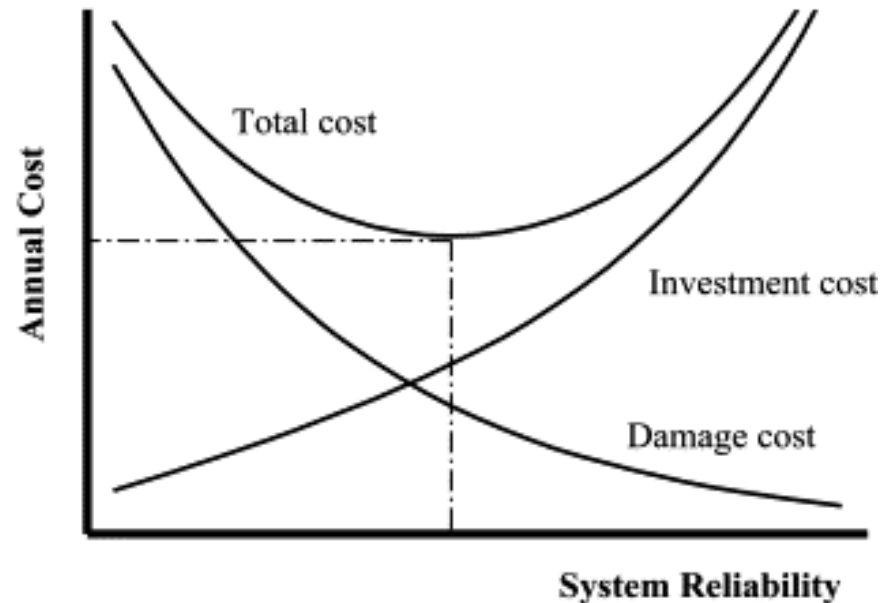
# Load Conditions of Electronics in the Automotive Industry

- Under hood
  - Sensors, Controllers
  - High temperatures
  - Heavy vibration, High cycle count
  - Some shock events possible
- Dashboard (Static mounting)
  - Displays, Communications, Controls
  - Temperature controlled environment (can get hot in Summer)
  - Mild vibration
- Doors and Panels (Dynamic mounting)
  - Controls, Sensors, Actuators
  - Temperatures exposed to the environment
  - Shock and vibration loads



# Reliability by design

- Trade-off
  - Cost vs. reliability
  - How good is good enough?
  - Planning for the unknowable
- Design for test
  - In line nondestructive testing
  - Lot qualifications



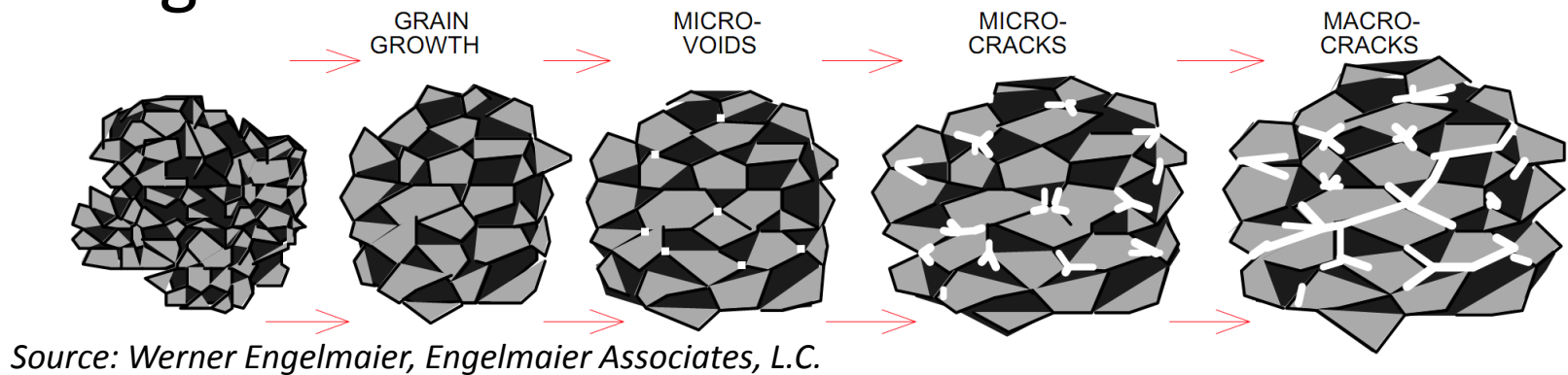
Source: R. Billinton, W. Zhang. "Cost related reliability evaluation of bulk power systems" *International Journal of Electrical Power & Energy Systems* Volume 23, Issue 2, 1 February 2001, Pages 99–112

# Maintainability is Part of Reliability

- Downtime
  - How long does the maintenance take?
  - How much does it cost to maintain? (Labor hours)
  - How often is the maintenance task performed?
- Corrective maintenance
  - Fix something that broke
- Preventive maintenance
  - Adjust something so that it does not break
- Unplanned maintenance
  - This will happen to you
- Tradeoff between reliability and maintainability
  - Built in diagnostics are expensive
  - Making a system easier to maintain may decrease reliability

# Temperature cycling: The solder fatigue mechanism

- Grain growth in solder is an indicator of fatigue



- Textbook calculation of solder fatigue
  - Lead-free and Tin-Lead

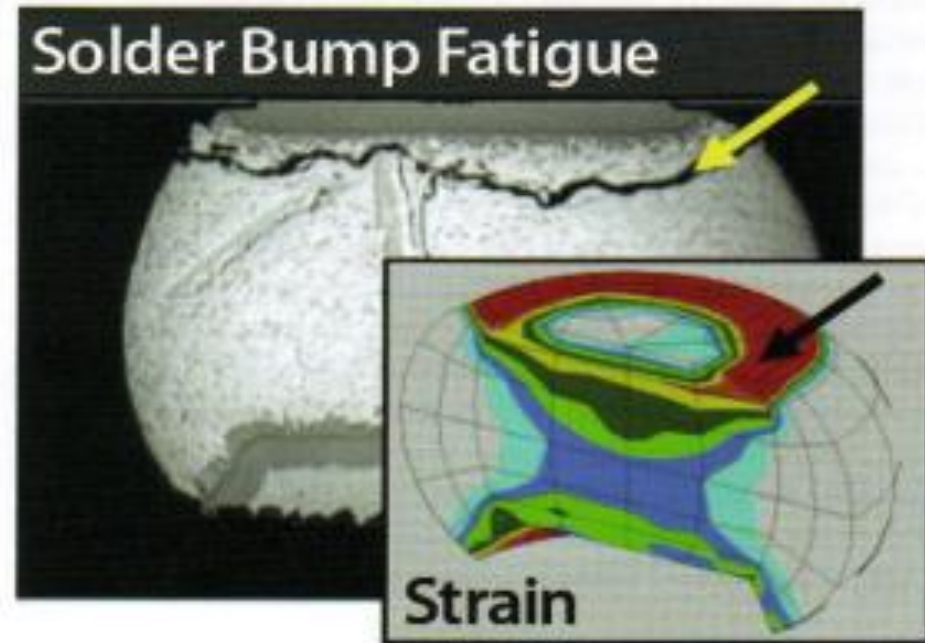
$$N_f = (0.0019 \cdot \Delta W)^{-1}$$

$$N_f = (0.0006061 \cdot \Delta W)^{-1}$$

Source: Ahmer Syed, Amkor technology

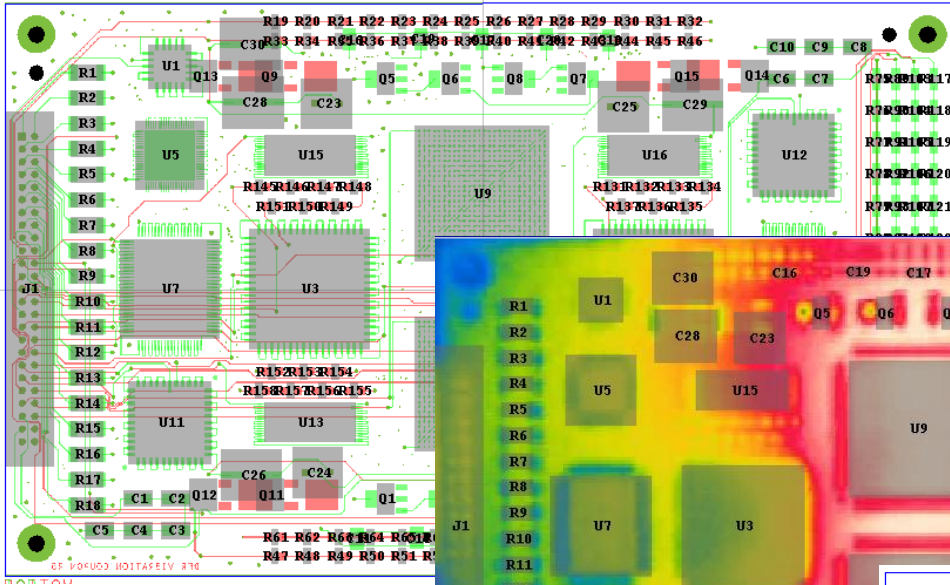
# Temperature Cycling: Automated solder fatigue prediction

- Using software
  - Predict probability of failure
  - Component by component calculation
  - Cumulative probability
- Apply thermal maps
  - IR camera
  - Thermal analysis software

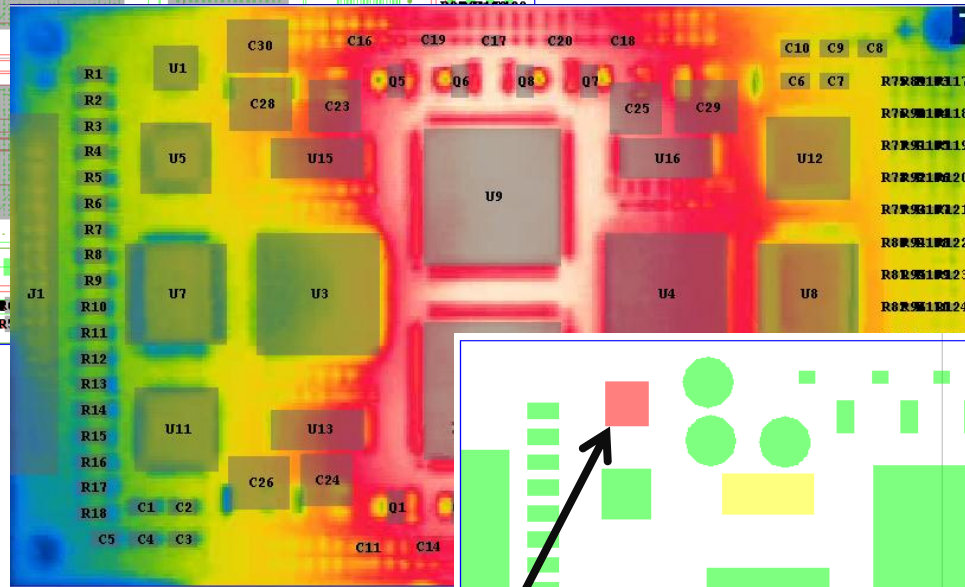


Source: A. MacDiarmid, "Thermal Cycling Failures", RIAC Journal, Jan., 2011.

# Reliability Prediction Software

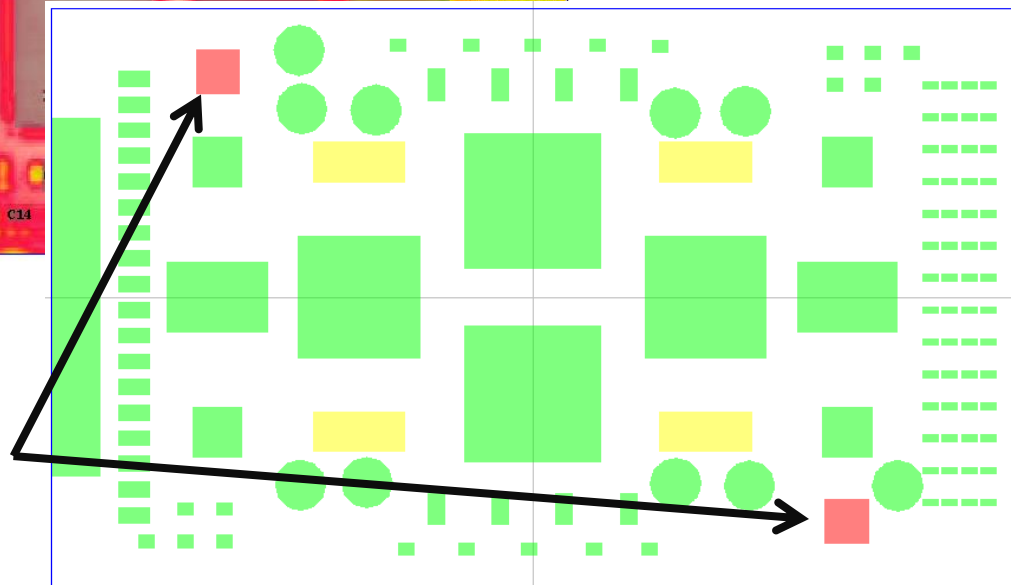


Design the board



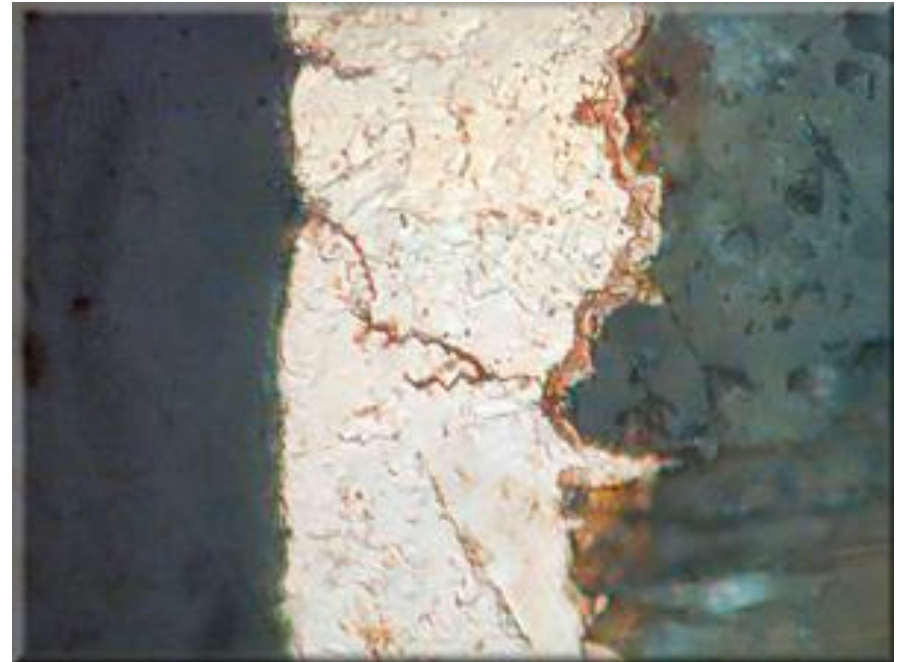
Apply the temp. cycle

Find the failed components



# Temperature cycling: Plated through holes

- 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,*



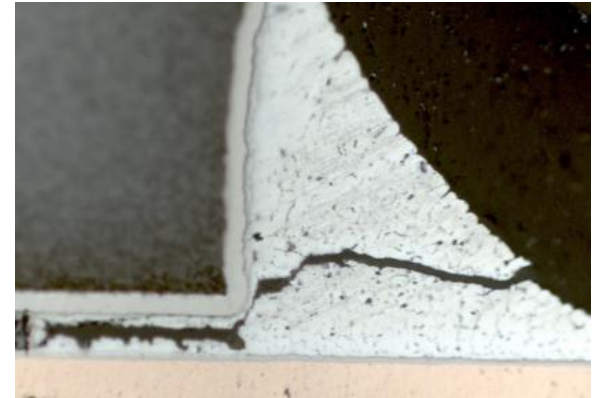
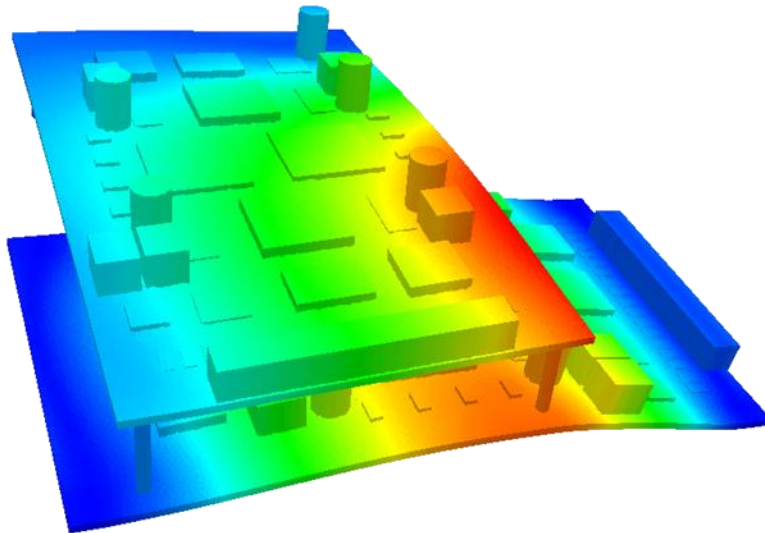
# Shock and Vibration: Solder fatigue

- Similar to temperature cycling
  - But so much different
  - Textbook solution

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

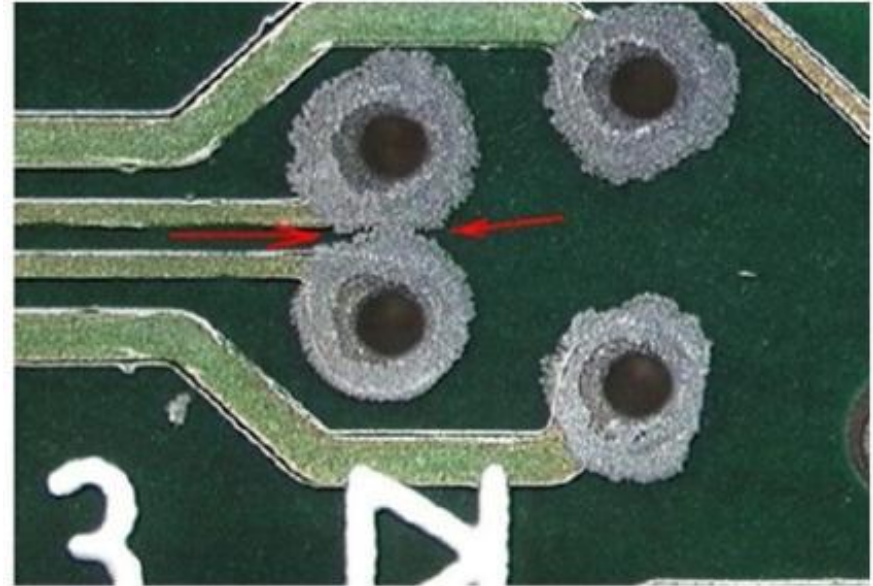
Source: Steinberg D.S. "Vibration analysis for electronic equipment". John Wiley & Sons, 2000.

- Predicting Solder fatigue
  - Experimental data
  - Simulation



# Moisture and Contamination

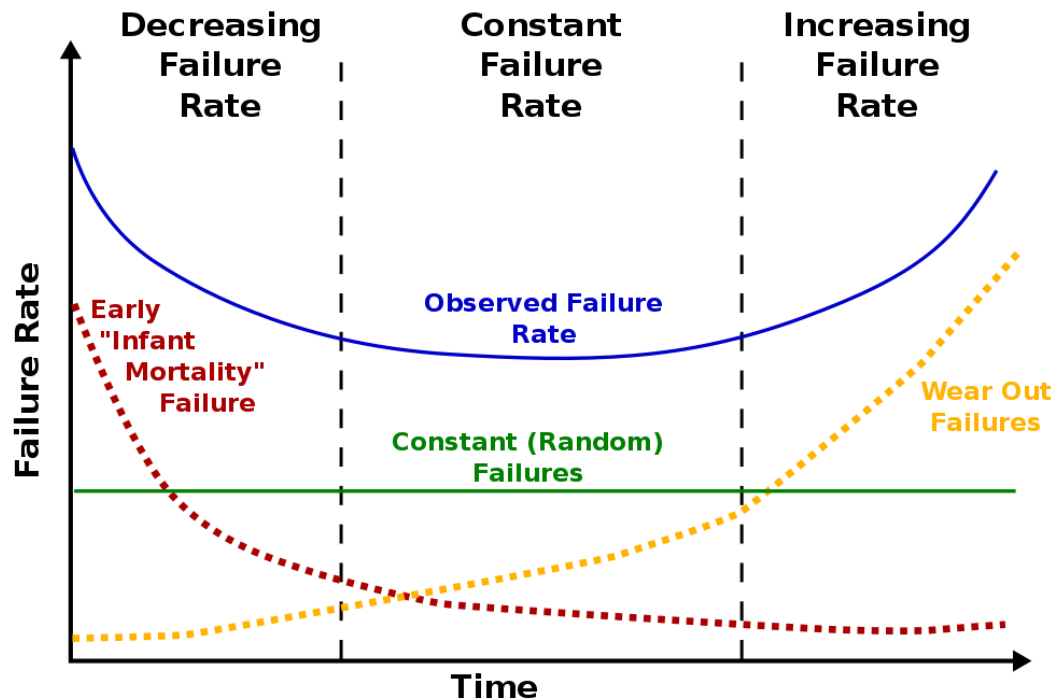
- Shorting
  - Condensation
  - "No fault found"
- Corrosion
  - Incompatibility of materials (Etching)
  - Oxidation
  - Galvanic cells
- Environmental contamination
  - Dust
  - Metal filaments
  - Fibers





# Field Failures

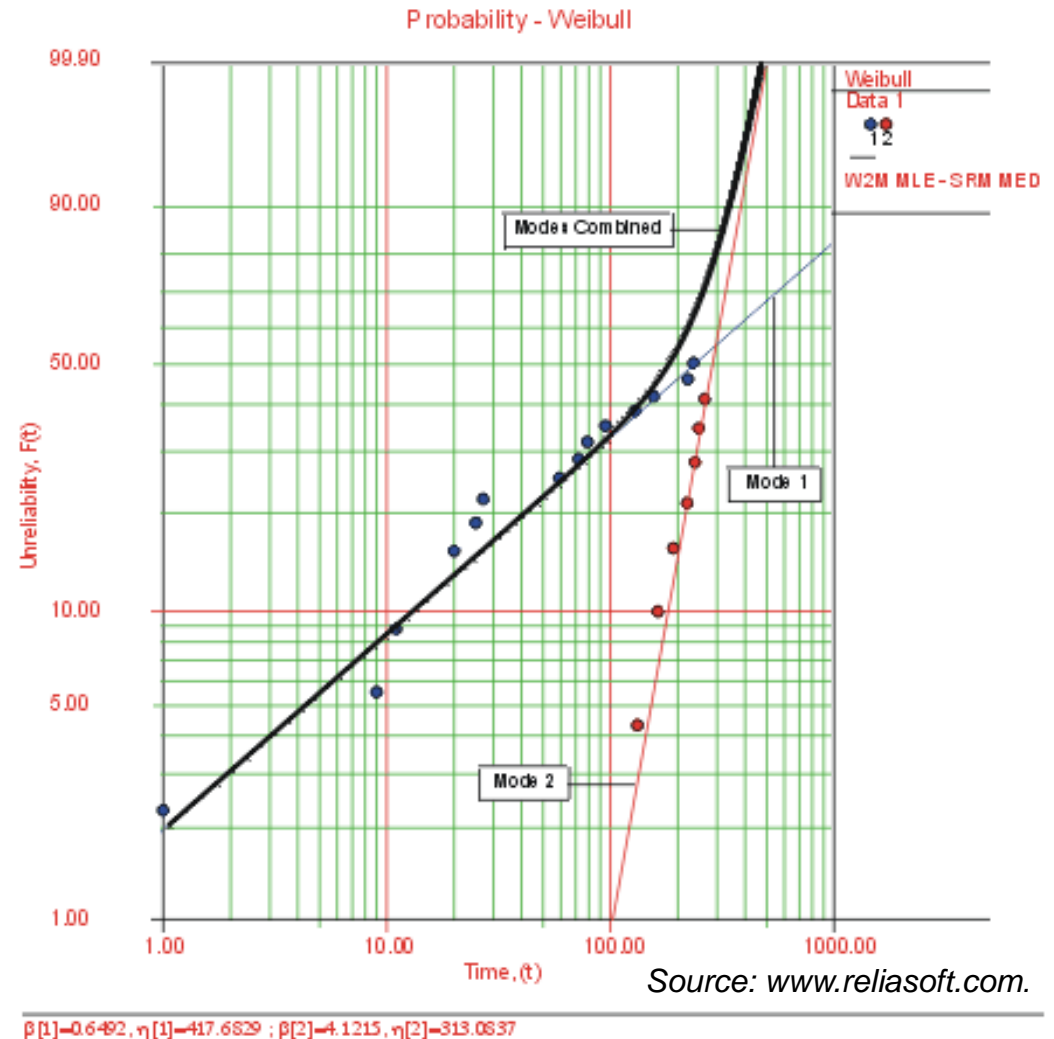
- Initial failures are not always indicative of characteristic life



- Valid for a single component
- Complex systems are different

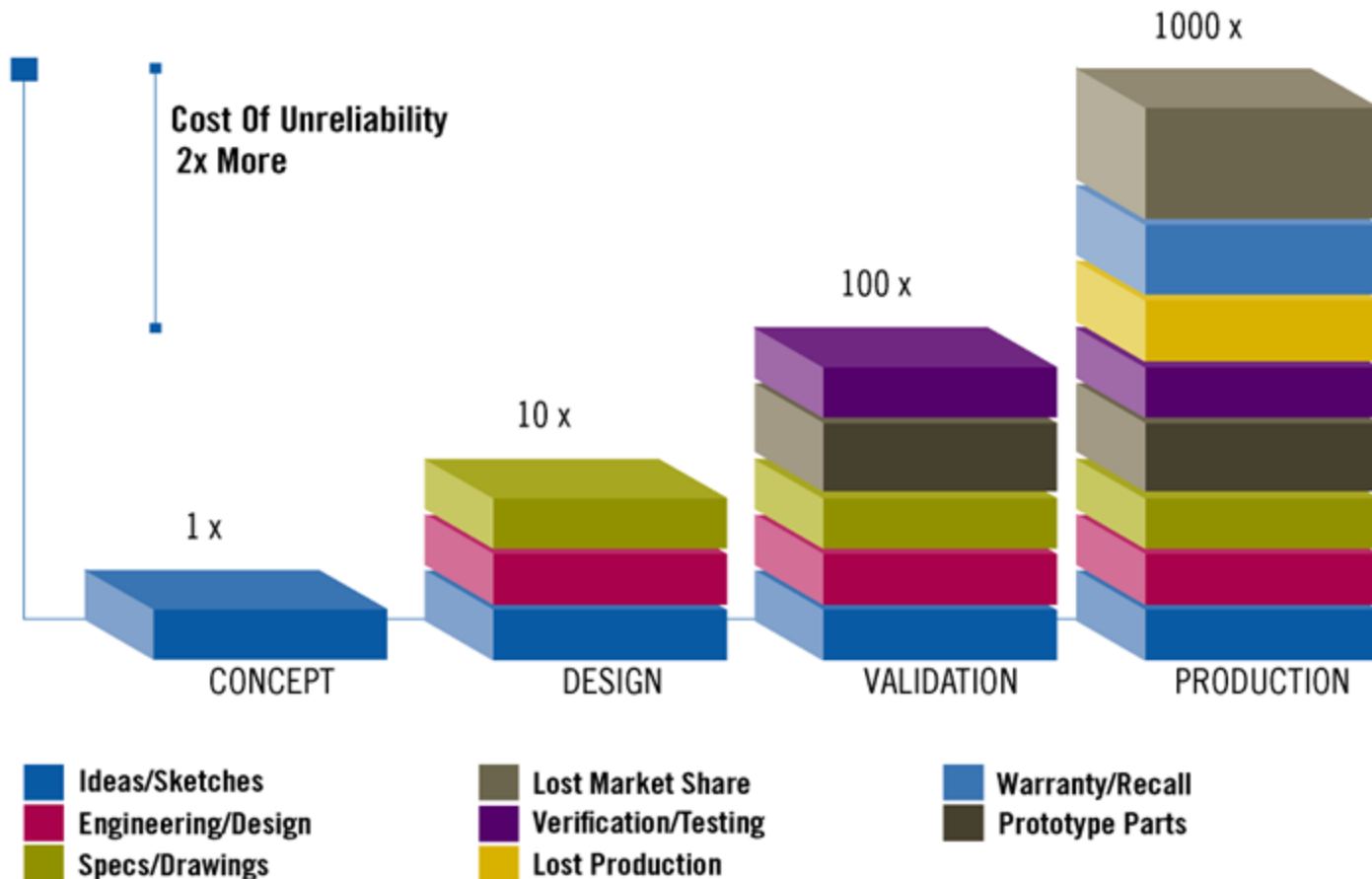
# Field failures

- Competing failure modes
  - Complex systems have multiple failure modes
- Rapid diagnostics
  - On board diagnostics for failure modes



# Design for Reliability

- Reduce cost by improving quality



# What to do?

- Reliability starts in the design phase
  - Redundancy
  - Robust design
  - Accelerated life tests
- Who packed your parachute?
  - Audit your electronic suppliers
  - Lot qualification tests
  - Counterfeit electronics
- Don't destroy your products during transportation and assembly
- Monitor performance for the life of the product
  - Be involved
  - Communicate



Source: [www.army.mil](http://www.army.mil), Photo by Donna Dixon.

# If you Remember Nothing else...Remember This:

- Complex systems fail in complex ways
  - Competing failure modes
  - Can be predicted with models
- Thermal fatigue is a real killer
  - Solder Fatigue
  - Plated Through Hole (PTH) fatigue
- Keep your boards clean (contamination) and dry (moisture)
- Field failures will happen
  - Have a plan
- Cost of unreliability