Pb-Free Development & Implementation

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Why Lead Free?

- Lead is one of the few natural substances that serves no purpose in the human body. Once lead enters the body it is absorbed and distributed throughout.

- Lead typically enters the body through breathing and ingestion (swallowing) and once in the blood stream will be deposited in the soft tissue, including the brain.
  - Lead in the developing brain of small children can impact the ability to use vitamin D and calcium leading to developmental disorders.
  - Lead in the bodies of adults can create a host of disorders including infertility.

- Lead leached from the electronics materials discarded in landfills into the water table is a potential mechanism of human and wildlife exposure.

- In order to reduce the amount of potentially hazardous lead containing electronics in landfills the EU pasted legislation to remove all lead from electronics manufactured, and sold in EU member countries.

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What is driving Lead-Free?

- The European Union enacted legislation requiring all ***consumer electronics*** products sold after July 1, 2006 to meet the lead-free requirement.
- Lead-Free is defined per RoHS (Restriction of Hazardous Substances) requirements as having less than 0.1% Lead in a homogeneous material.
- ***Automotive electronics*** were exempt until the **EU End of Life Vehicle (ELV) Annex II Directive 2000/53/EC was inadvertently opened for review in June of 2008.**
  - Modified language for section 8(a), Pb in Electronics, introduced a deadline for Pb removal for automotive electronics of 12/31 2010.
- The revised document included the statement, “Technical impossibility is not a excuse for non-compliance”.
- There is no drop in replacement for some high temperature components. Discussion with the EU regarding ongoing exemptions continues.

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Pb-Free Development Strategy

Develop Totally Pb-Free Manufacturing Processes and Designs for full range of Delphi E&S products

- Utilize Delphi **A**dvance **D**evelopment **P**rocess
  - Demand technical rigor in development activities
  - Document development project outputs
  - Insure that 'production-ready' processes are available for use in new product programs
  - Reduce risk associated with new technology introduction
- Utilize Phased Development Approach
  - Phase I – Single Sided Reflow
  - Phase II – Double Sided Reflow & Liquid Soldering
  - Phase III – Additional Reflow & Liquid Soldering
- Utilize Taguchi & Robust Engineering Methodologies
  - Optimization Of Process Parameters
  - Optimization Of Material Selection
  - Optimization Of Product Design Standards

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Delphi E&S Pb-Free Implementation

- Delphi development roadmap calls for production volumes of lead free product to be manufactured beginning in 2009.

- Delphi plans to be completely lead free by approximately 2016.
  - Safety products and absence of a breakthrough in high temp. solders cause a delay.

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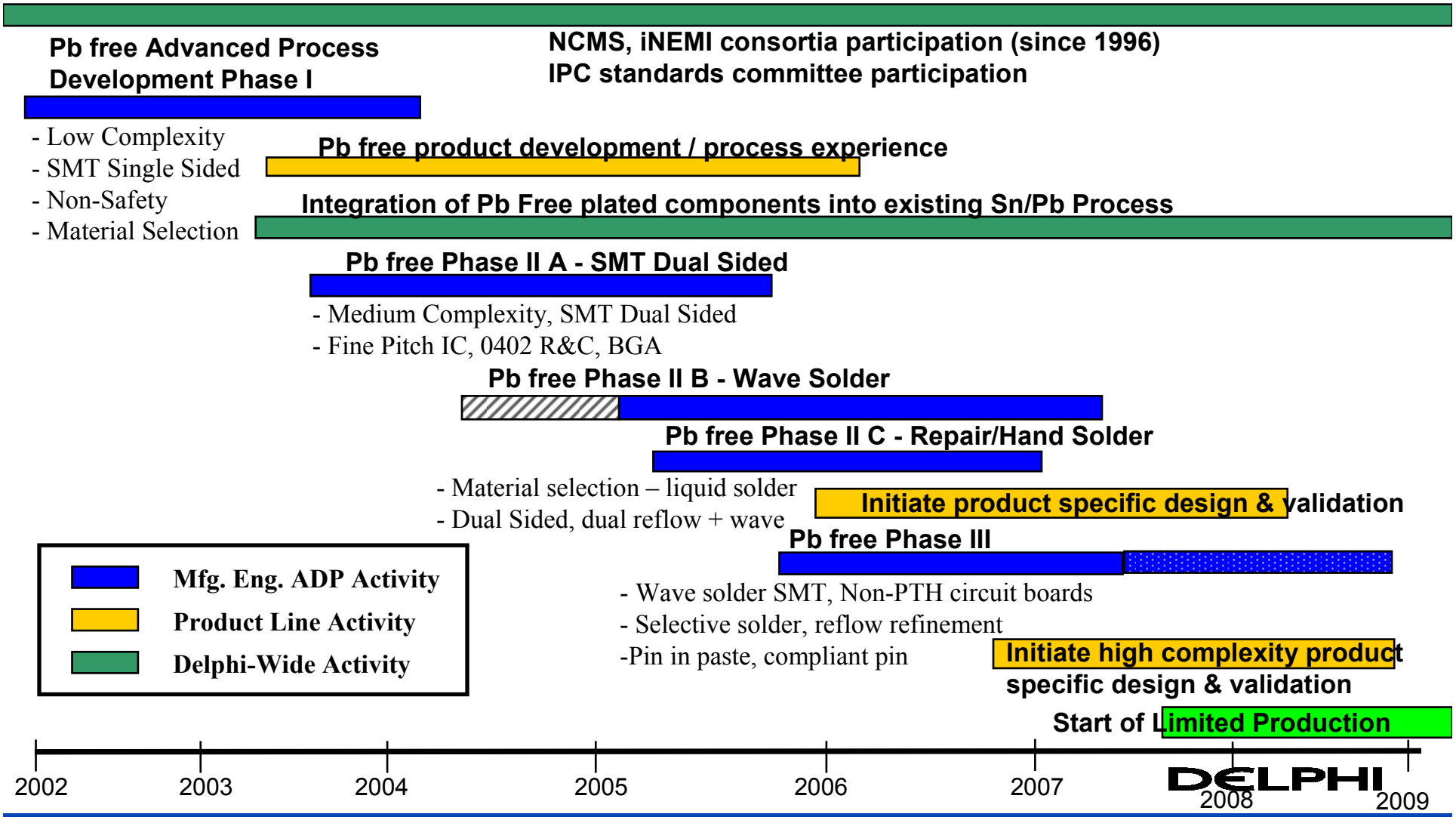
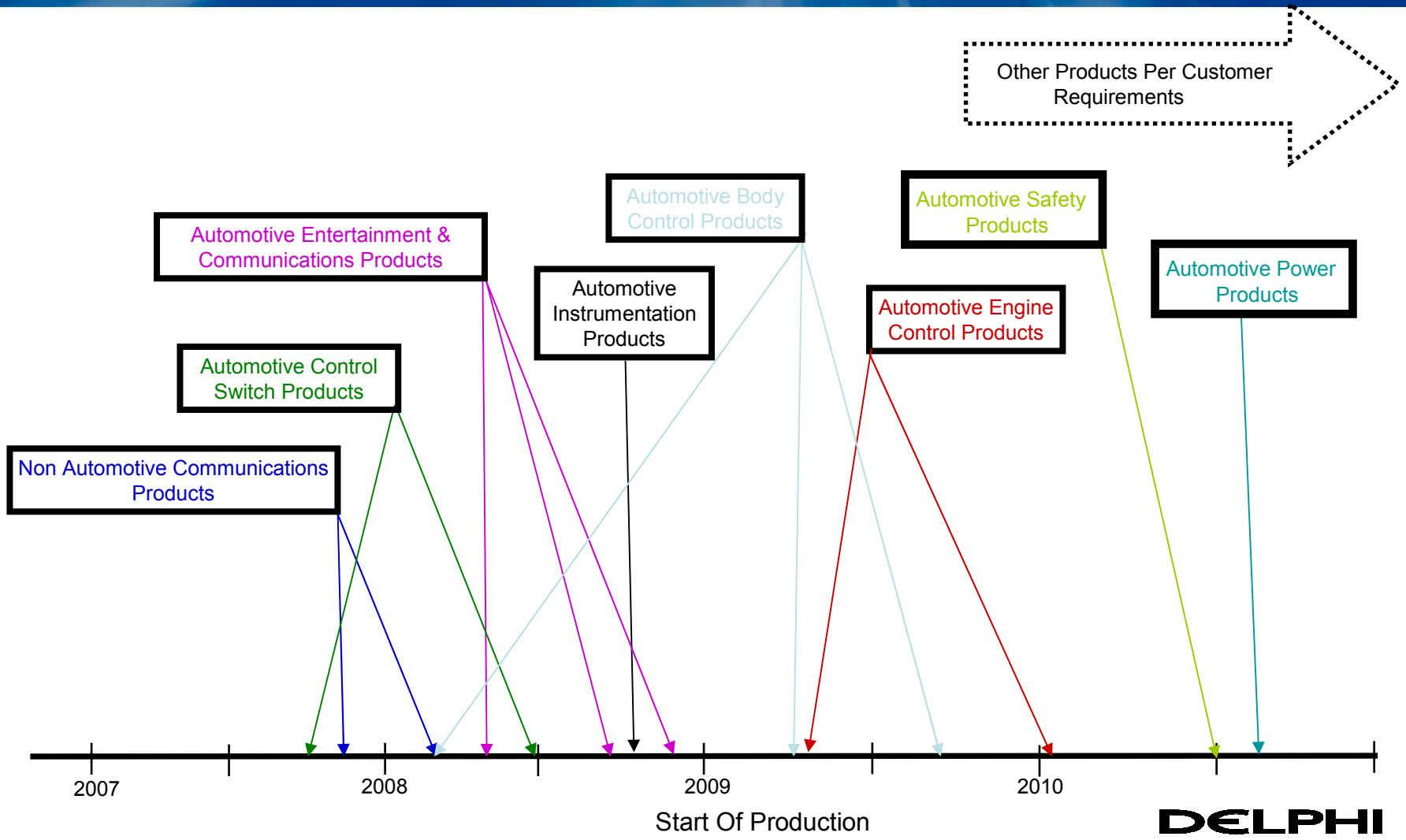
Delphi Pb-Free Process Development Timeline



Delphi E&S Pb-Free Product Implementation



Impact Of Pb-Free Soldering on Processing

Materials

- Solder Alloy Change
  - 63%Sn - 37%Pb → 96.5%Sn - 3.0%Ag - 0.5%Cu
- Flux Formulation Changes
  - Higher Activity Levels With Higher Thermal Stability
  - Must Continue To Meet Current **S**urface **I**nsulation **R**esistance (SIR) Requirements

Processes

- Higher Solder Reflow Temperatures Required For SMT
  - 220°C peak → 250°C peak
- Higher Pre-heat and Solder Bath Temperatures Required For Liquid Soldering
  - 240°C - 260°C → 260°C - 270°C (Solder Bath)
- Nitrogen Inerting Required
  - Reflow Oven Atmosphere Controlled
  - Liquid Solder Bath Atmosphere Controlled

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Impact Of Pb-Free Soldering on Processing

Equipment

- Some Solder Reflow Ovens Must Be Upgraded To Support Process Requirements
  - Higher Peak Temperature Profile and Nitrogen Atmosphere Capability
- Liquid Soldering Equipment Must Be Upgraded To Support Process Requirements
  - Must Be Constructed With Materials Capable Of Withstanding Sn Corrosion
  - Nitrogen Atmosphere Capability
- Liquid Solder Bath Chemistry Monitoring and Control Equipment Will Be Required At Each Manufacturing Site

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Impact Of Pb-Free Soldering

Cost

- Material Cost Increase From Solder Alloy Metal Content
  - Approximately 30% Increase
- Manufacturing Cost Increase From Increased Temperature Requirements
  - Approximately 25% Increase In Utility Costs
- Manufacturing Cost Increase From Nitrogen Inerting Requirements
  - Approximately $22 K / Yr. / Machine
- Potential Cost Increase For Components Capable Of Higher Soldering Temperatures
- Capital Equipment Expenditures Required
  - Reflow Oven Nitrogen Capability
  - Liquid Solder Equipment Upgrades
  - Liquid Solder Bath Chemistry Monitoring and Control Equipment

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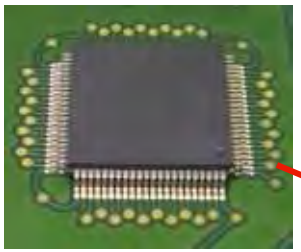
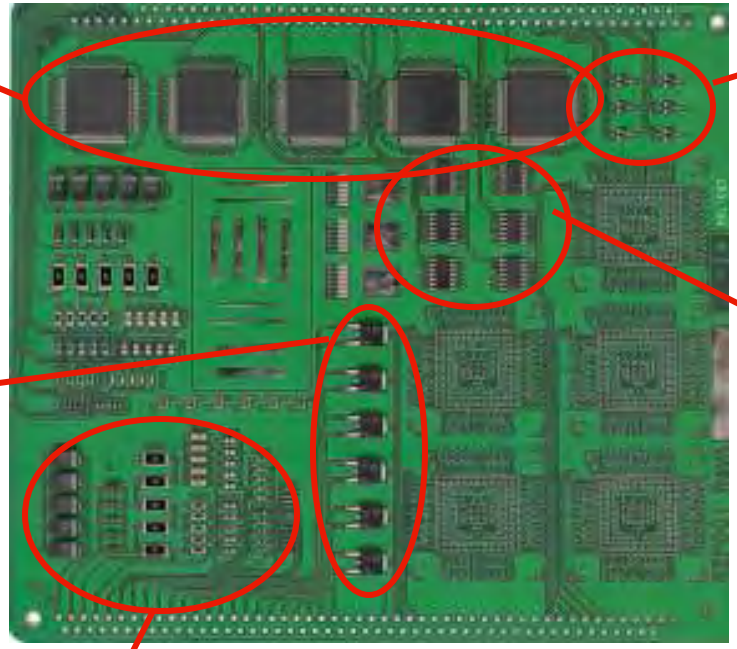
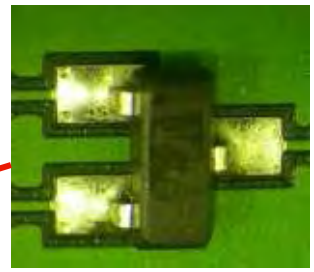
Pb-Free Test Board Thermal Cycle Reliability Evaluation -40 to +125C (80 min.)



QFP: no fails @ 5500 cycles
SnPb or Pb Free





SOT23: no fails @ 5500 cycles
SnPb or Pb Free

DPAK: no fails @ 5500 cycles
SnPb or Pb Free

SO14: no fails @ 5500 cycles
SnPb or Pb Free

0402 through 2512 resistors
(1005 through 6332)

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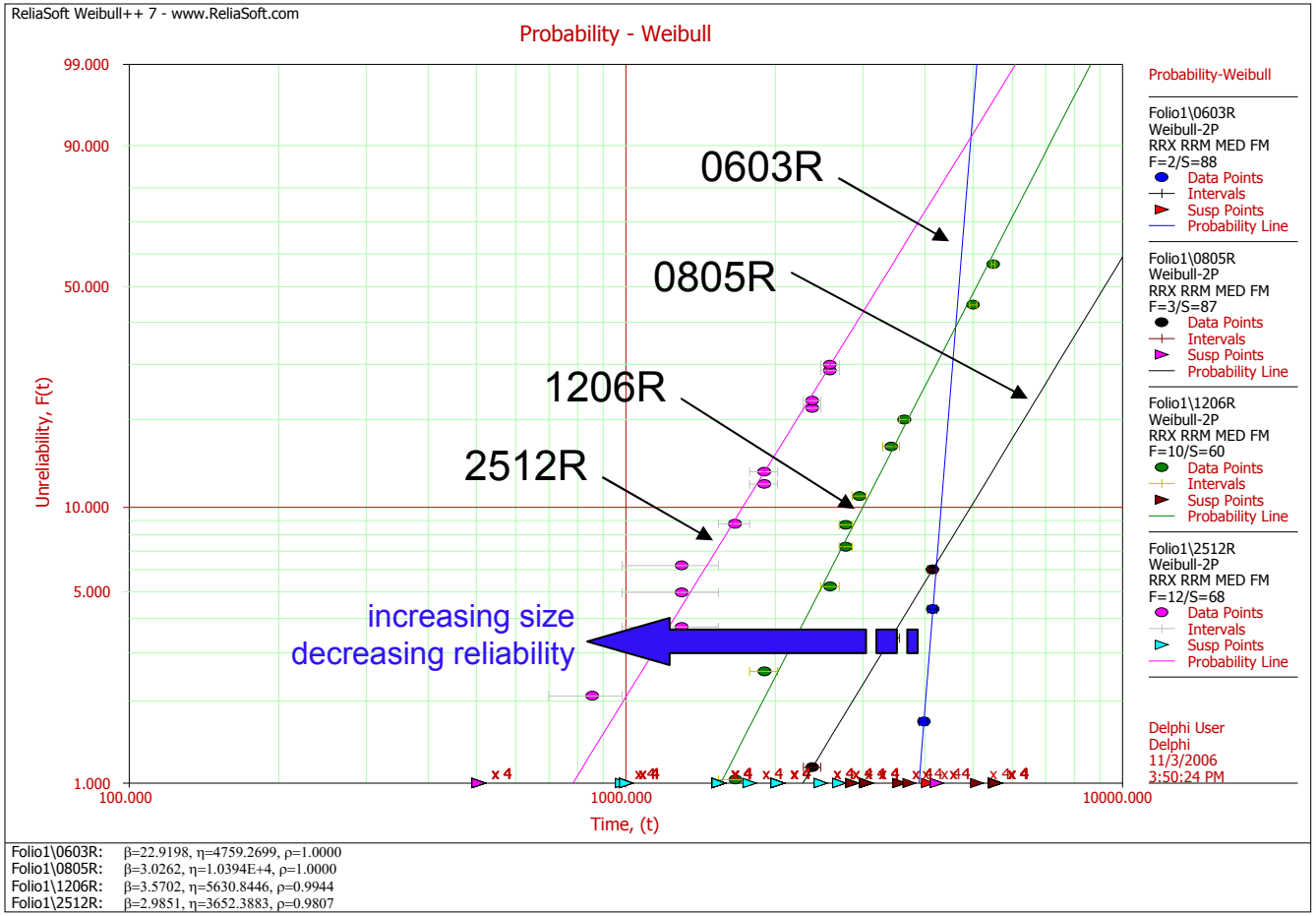
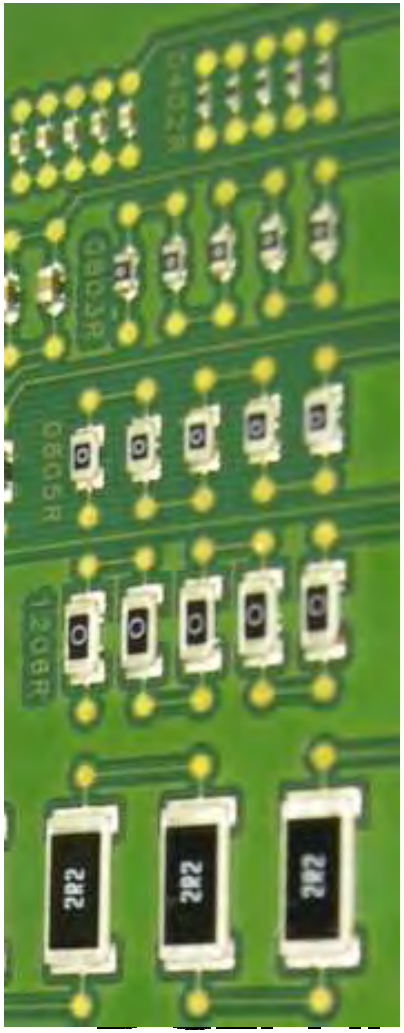
Pb-Free Test Board Thermal Cycle Reliability Evaluation -40 to +125C (SMT Resistors)

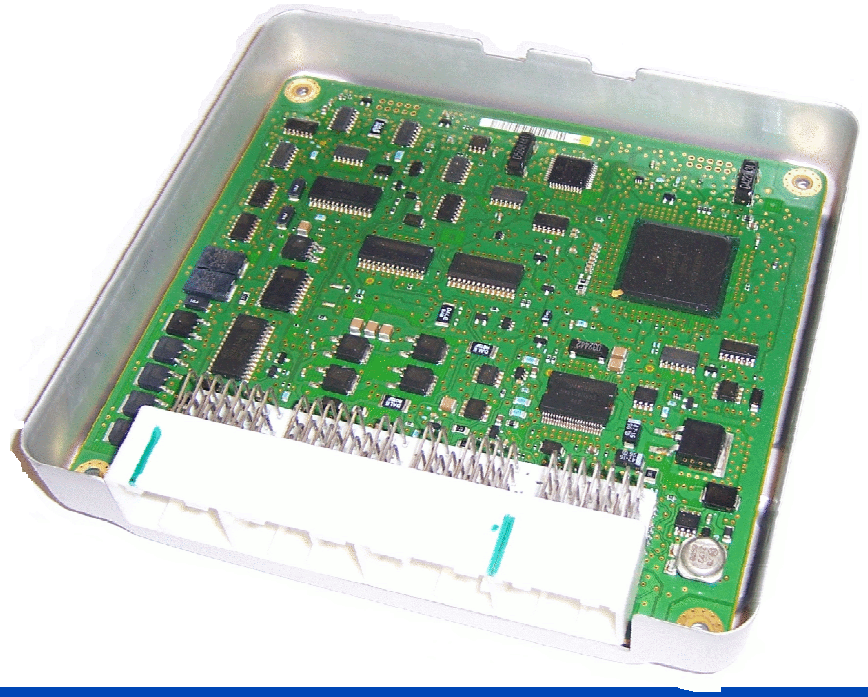
- Reliability decreases with increasing size
- No failures of 0402 at 5500 cycles





Automotive Pb-Free ECU Reliability Evaluation

- Dual sided SMT + wave solder
- Passed validation requirements
  - 192 hr condensation conduction test
  - 85/85 temp/humidity: passed 1000 hours
  - Vibration
  - 3000 cycles (60 min.) -30/+85°C



After 3000 Thermal Shock

SnPb	Pb Free	
		0603
		0805
		connector
		HSOP

The Sn Whisker Conundrum

- Sn finish was chosen by the electronics industry to replace the SnPb finish on component terminations.
  - Plating process compatibility and cost were the big drivers
  - Virtually all components use a Sn finish now.
    - » There are options for a Ni-Au finish on some specialty components but these are reserved for the military, medical, and space applications. (Higher cost…)
- Sn whiskers are a risk to reliability for Pb-free & SnPb soldered electronics.
  - Sn whiskers can cause an electrical short circuit
  - They grow over the life of the electronic product (months to +20 years)
  - They respond to environmental stresses
  - There is no know method to prevent whiskers from growing
- What are Sn whiskers?

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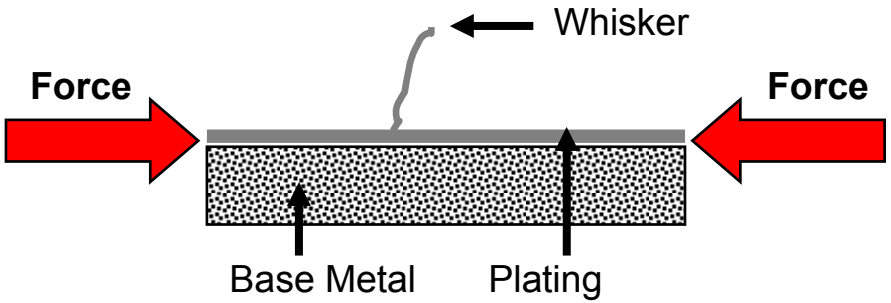
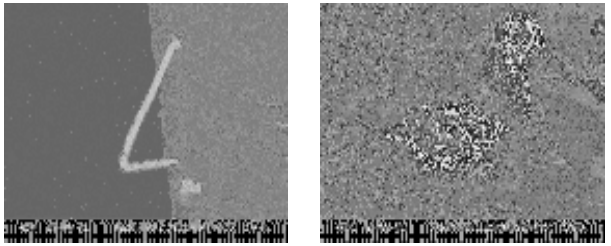
Risks Associated with Lead-free Conversion

- Tin Whiskers
  - Some metals (platings) can form “hair-like” single crystal metallic filaments called “whiskers” under compressive loads.





Antenna socket built 1-12-05
Identified June 2006

  - Whiskers are ***electrically conductive*** and can lead to ***short circuits*** in the field.
  - The historical corrective action for Tin Whiskers is to use Tin/Lead finishes. Lead-free requirements drive the removal of lead from tin finishes; this has resulted in the transition to pure tin and zinc finishes and is expected to result in an increased occurrence of Tin and Zinc whiskers.
  - We need to raise the overall awareness of this issue for both mechanical and electrical parts.

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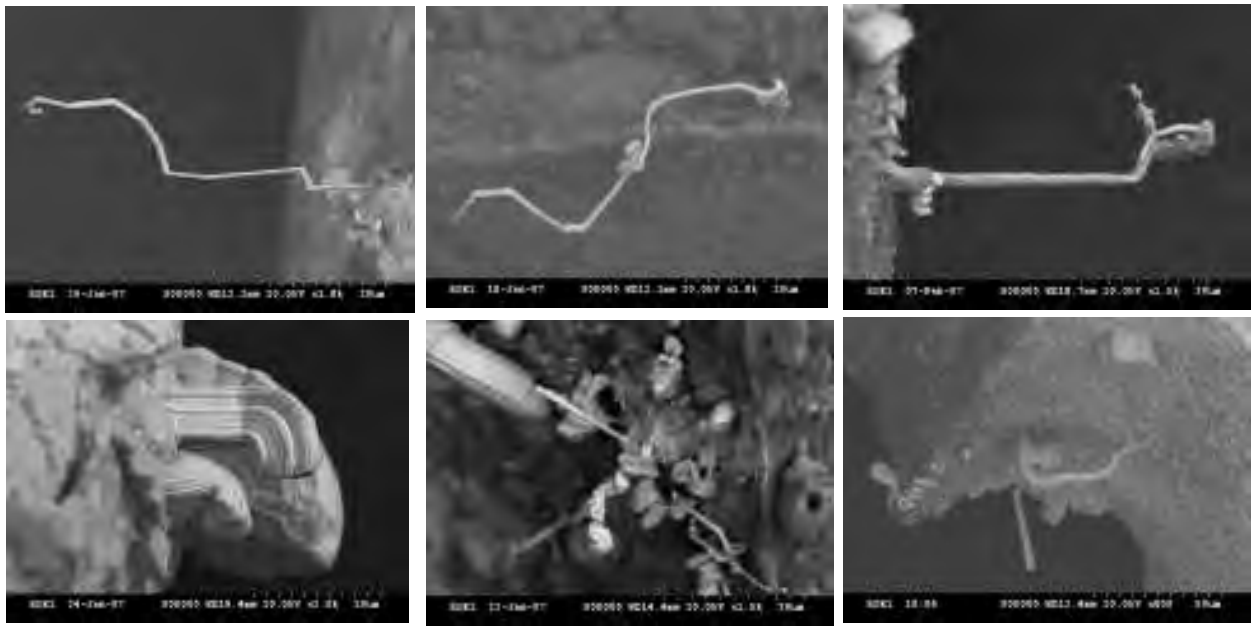
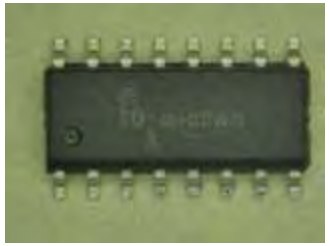
What are “Tin Whiskers”?

- “Hair-like”, single crystal filament structures, that grow from some tin (Sn) finished surfaces, over time.
  - They are electrically conductive and can cause short circuits.
- Length: Up to ~10+ mm (typically < 2mm)
- Diameter: from 0.006 μm to 20 μm (typical ~ 1 to 2 μm)
- They grow from their base, not from the tip





Photos by M. Tanner, Delphi
iNEMI DOE5 100c 60%RH

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Big Sources of Stress in Sn Platings From:

Oxide Stress

Mechanical Stress

- Intermetallic formation
  - If the molar volume of the intermetallic is larger than the Sn it displaces, compressive stress will develop. (Cu_6Sn_5 formation)
  - If the molar volume of the intermetallic is smaller than the Sn it displaces, tensile stress will develop. (Ni_3Sn_4 formation)
- Oxide growth
  - When oxides form on Sn (SnO & SnO_2), the molar volume is greater than the Sn it replaces and a compressive stress develops. Severe corrosion results in very high stress levels.
- Thermal Cycles
  - CTE difference between Sn and the base metal results in compressive or tensile stress, depending on which way the temperature swings. The impact is larger with alloy 42 materials than with copper.
- Compressive Mechanical Stress
  - Bending, clamping, and scratching can all cause compressive stress

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Mitigation of Whisker Risks

- To reduce risk of problems from Sn whisker growth, a method of reducing or mitigating the effects of stress in the Sn finish is needed.
  - Use non-Sn platings
  - Use underlayer plating
  - Anneal Sn after plating
  - Use alloy elements with Sn
  - Use of matte Sn (instead of bright Sn)
  - Use hot dipped Sn alloys (instead of plated Sn)
  - Fuse (reflow above 232^{o}C) Sn plating
  - Maintain good process control of Sn plating process
  - All of these methods are controlled by the component manufacturer
- Conformal Coating of selected areas to contain whiskers that form

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