IPC Electronics Midwest 2010

Management and Mitigation of Tin Whiskers for Lead-Free Electronics

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Biography

Senior Technologist

Samuel has been with Delphi for the past 24 years, serving in a leadership capacity for more than 17 years. Mr. Platt has broad experience in circuit board manufacturing, and electronic assembly. He has supported the Delphi global enterprise as a development engineer, operations manager, project manager, engineering manager and center of expertise leader. For the past 18 months Mr. Platt has served as the program manager for the global introduction of lead-free technology at Delphi. He is a 1984 graduate of Purdue University with a Bachelor of Science in Chemical Engineering, and a 1991 graduate of Ball State University with a Masters of Business Administration.

Executive Summary

The lead-free directive from the EU has created a number of challenges for high reliability electronic applications. Key among those challenges is the need to address the issue of tin whiskers. While complete elimination of the tin whisker phenomenon on tin finished materials is not possible there are steps that can be taken to manage and mitigate the creation and effect of tin whiskers. Delphi has focused on mitigation steps to reduce the likelihood of tin whisker occurrence and has implemented processing measures to reduce the potential for damage by tin whisker that do occur. Those mitigation steps and findings from validation work and product performance reviews are shared.

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Tin Whiskers in Lead Free Processing

Sam Platt

Delphi Electronics and Safety

Electronics & Safety Division

2004-Present

Delphi Electronics & Safety
Division of Delphi

Markets

Core Automotive Markets


Electrical/Electronic Architecture


Electronics & Safety


Powertrain Systems


Thermal Systems

Adjacent Markets


Commercial Vehicles


Residential/Commercial Heating and Cooling

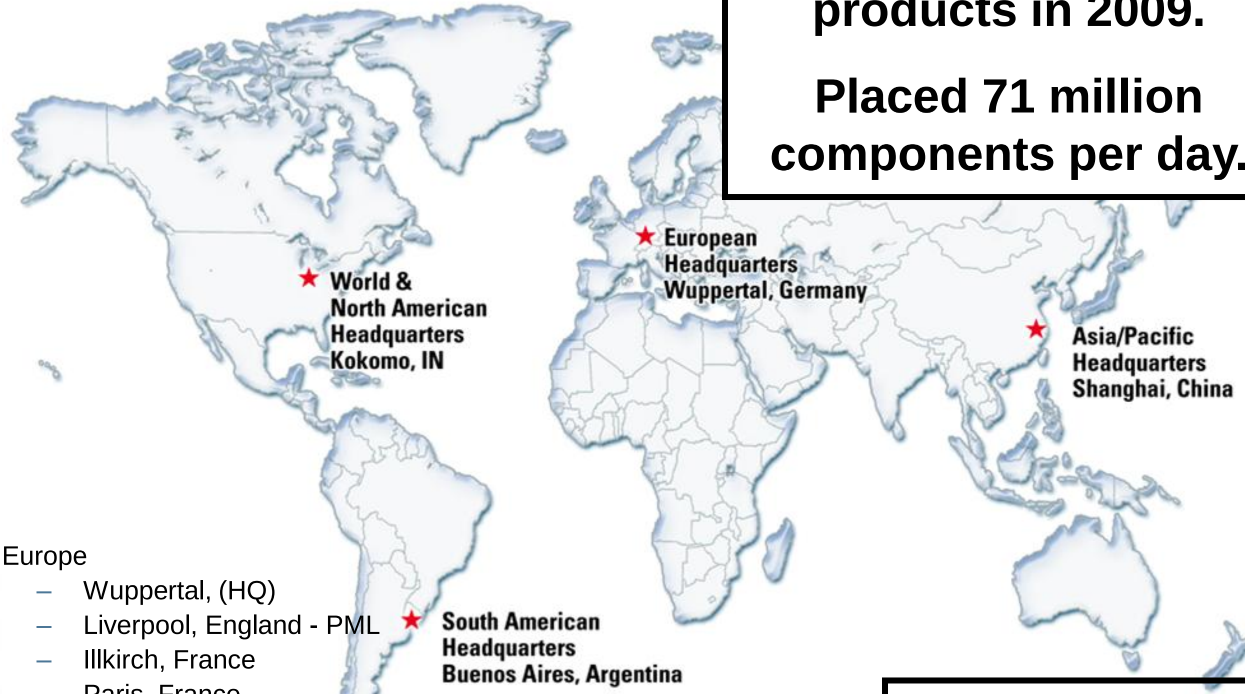

Aftermarket


Military/Aerospace

Electronics & Safety Global Presence

Shipped 179 million products in 2009.

Placed 71 million components per day.



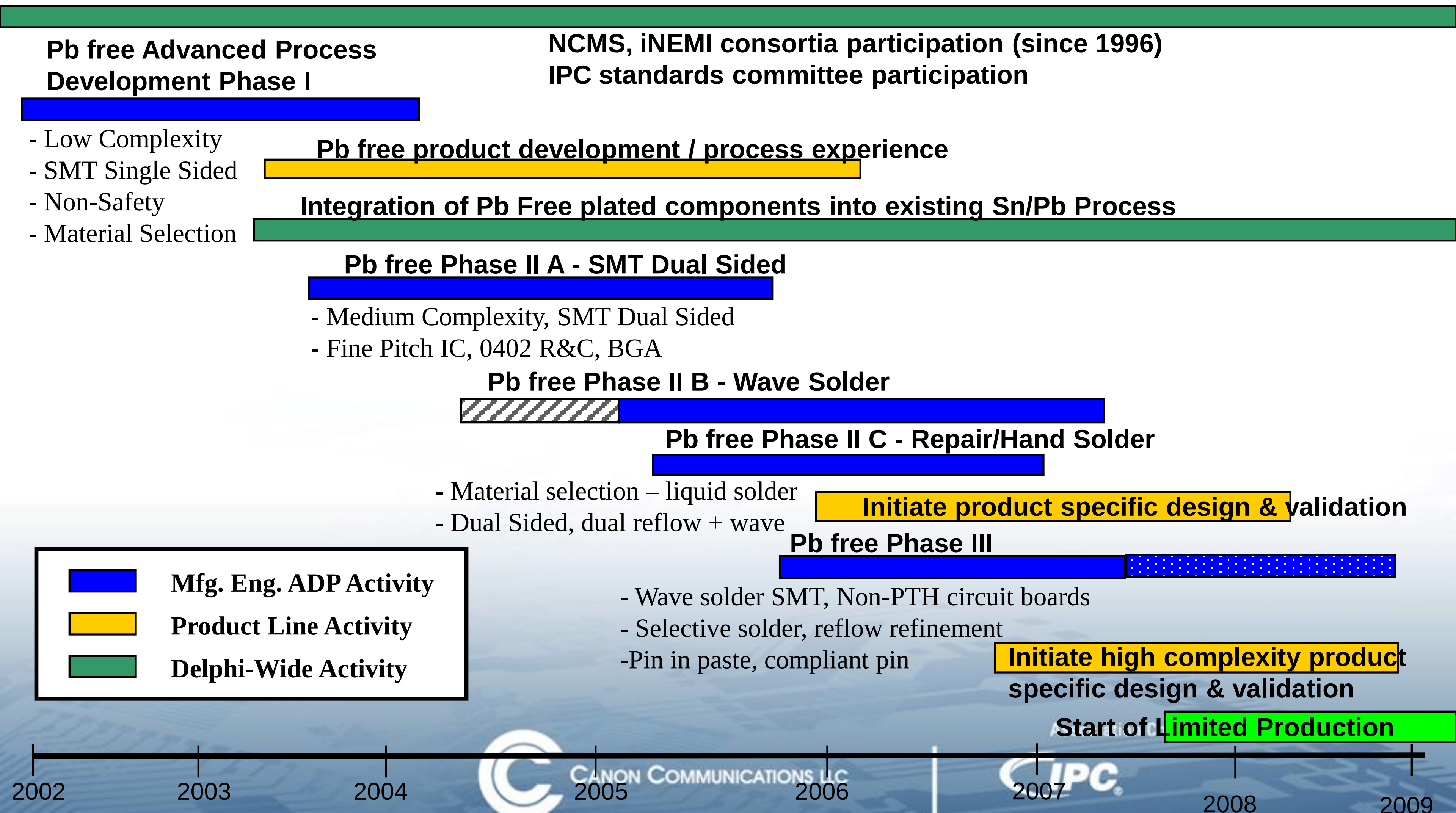
- United States
  - Kokomo, IN (HQ) - PML
  - Montgomery, AL
  - Malibu, CA
  - West Lafayette, IN
  - Auburn Hills, MI
  - Dearborn, MI
  - Flint, MI - PML
  - Troy, MI
  - Vandalia, OH
- Mexico and South America
  - Buenos Aires, Argentina (HQ)
  - Rio Grande, Argentina - PML
  - Sao Paulo, Brazil
  - Juarez, Mexico
  - Matamoros, Mexico - PML
  - Puebla, Mexico
  - Reynosa, Mexico - PML
- Asia Pacific
  - Shanghai, China (HQ)
  - Beijing, China
  - Suzhou, China - PML
  - Bangalore, India
  - Shinjuku, Japan
  - Tokyo, Japan
  - Toyota City, Japan
  - Singapore - PML
  - Munmak, South Korea - PML
  - Yong-in City, South Korea
- Europe
  - Wuppertal, (HQ)
  - Liverpool, England - PML
  - Illkirch, France
  - Paris, France
  - St. Aubin du Cormier, France - PML
  - Bad Salzdefurth, Germany - PML
  - Berlin, Germany
  - Langenlonsheim, Germany - PML
  - Noernberg, Germany
  - Osberghausen, Germany - PML
  - Russelsheim, Germany
  - Stadeln, Germany - PML
  - Stuttgart, Germany
  - Wiehl, Germany
  - Wolfsburg, Germany
  - Szombathely, Hungary - PML
  - Torino, Italy
  - Bascharage, Luxembourg
  - Gdansk, Poland - PML
  - Krakow, Poland
  - Braga, Portugal - PML
  - Ponte de Sor, Portugal
  - Barcelona, Spain - PML
  - Goteborg, Sweden

Global presence

Global coordination

Global logistics

Pb-Free Process Development Timeline



Automotive Performance and Quality

- Product are manufactured to high reliability standards for safety critical applications, in harsh operating environments.
- Automotive electronics products are build with an intended design service life of 15 years, and 6 return parts per million (RPPM) quality performance.
- Typical product operating environment

Temperature: -40 C min. to 125 C max.

Humidity: 95% RH with dew point excursion

Chemical Resistance: Solvents, brine, oxidizers, acids, oils.

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 primary 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 ($$$)

- 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 fail-safe method to prevent whiskers from growing

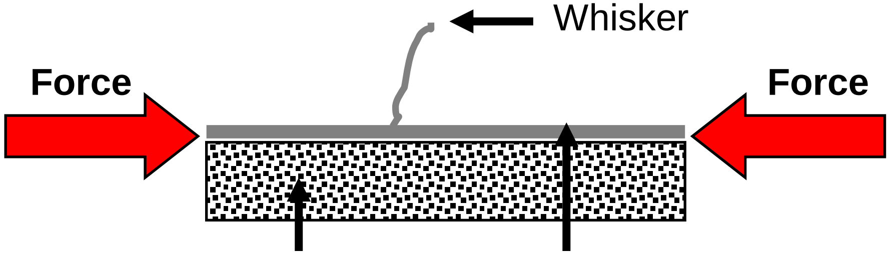
What are “Tin Whiskers”?

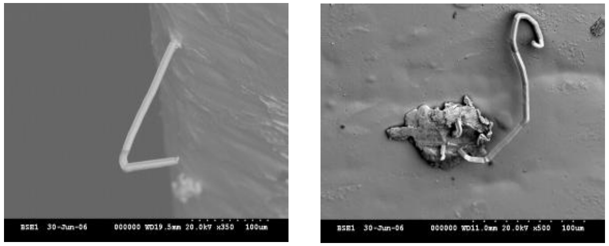
- “Hair-like”, single crystal filament structures, that grow from some tin (Sn) finished surfaces, over time.
- Length: Up to ~10+ mm (typically < 2mm)
- Diameter: from 0.006 μm to 20 μm (typical ~ 1 to 2 μm)
- They grow from their base, not from the tip

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

What are Tin Whiskers?

- 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

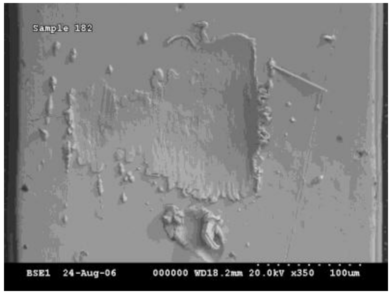
  - Whiskers are ***electrically conductive*** and can lead to ***short circuits*** in the field.
  - The time tested preventive action for Tin Whiskers is to use Tin/Lead alloy. Lead-free requirements drive the removal of lead from tin finishes; this has resulted in the transition to pure tin and zinc finishes which results in an increased risk of Tin whiskers.
  - Both electrical and mechanical parts are at risk.

Cause of Tin Whiskers

- Tin Whiskers
  - The fundamental driving force for whisker formation is stress in the film resulting from a mechanical deformation, diffusion or oxidation reaction.
  - The whisker formation mechanism requires that the metal/plating be in compression (metallurgy, not application compression).
    - Metals highly prone to whiskers are Sn (tin), and Zn (zinc)

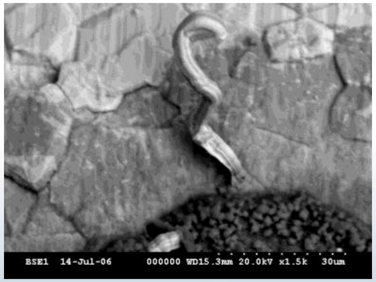
Stress in Sn Platings From:

- 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)



Mechanical Stress

- 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. Corrosion may result in very high stress levels.



Oxide Stress

Where does the Stress in the Sn Come From?

- **Contributors to stress in the Sn film:**
  - Diffusion of the base metal into the tin layer results in intermetallic compound (IMC) formation (e.g., Cu_6Sn_5)
  - CTE stress between base metal and tin layer (e.g., Sn plated alloy42)
  - Externally applied mechanical stress (e.g., torque from a fastener, scratches from handling, stamping, bending, etc.)
  - Environmental stress (thermal, humidity) ➔ Surface oxidation

Where does the Stress in the Sn Come From?

- Sn plating process
  - Plating process parameters (current density, bath chemistry, etc.)
  - Organic additives co-deposited (intentionally added)
  - Contamination of the Sn plating, both organic and inorganic (unintentional)
  - Grain size and crystallographic orientation

Where does the Stress in the Sn Come From?

- Tin Whiskers
  - Compression factors
    - Mechanically induced stress (e.g. bending, stamping, forming, scratched, impacts…)
      - Bending, clamping, stamping, forming, scratching and impact can all cause compressive stress
    - Plating chemistry and plating process
      - Plating process parameters (current density, bath chemistry, etc.)
      - Organic additives co-deposited
      - Unintentional contamination of the Sn plating, both organic and inorganic
      - Grain size and crystallographic orientation

Where does the Stress in the Sn Come From?

- **Multiple stress factors can be present, and be responsible for whisker formation.**

- **These stress factors can change during the life cycle of the component or assembly.**

Other Stresses

- 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.

- Assessment
  - No standard set of tests exist that can accelerate the process of whisker formation and growth relative to field life.
    - Three standard tests have been identified for evaluating the susceptibility to Tin whiskers.

Tin Whisker Mitigation: Electrical Components

– Electrical Part Suppliers are required to do specific tests that evaluate the susceptibility to tin whisker growth

Delphi Spec (C-9024) Tin Whisker Testing Requirements

Whisker Test Method	Test Conditions	Duration	Acceptance Criteria
Ambient Storage	30 °C and 60% RH	4000 hrs min	<40µm or <10% of component terminal spacing, whichever is smaller.
Temperature & Humidity Storage	55 °C and 85% RH	4000 hrs min	<40µm or <10% of component terminal spacing, whichever is smaller.
Temperature Cycle	-55 °C to +85 °C	3000 cycles min	<45µm or <10% of component terminal spacing, whichever is smaller.

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Tin Whisker Mitigation: Electrical Components

- Mitigation plans are in place to address Potential Risks associated with Pb-free Components in the following areas:
  - Have restricted some finishes/materials that are known to be more susceptible to Tin whiskers

Delphi Spec (C-9024) Finish Recommendations

Whisker Risk Level	Surface Finish
None	NiPd NiPdAu
Low	Matte Sn over Barrier underlayer Matte Sn with Anneal (1hr/150°C) Hot Dip SnAgCu Fused Sn Hot Dip Sn Hot Dip SnAg
Medium	Matte Sn (without underlayer or anneal) Hot Dip SnCu
High (Not Acceptable)	Bright Sn Satin Bright Sn SnBi Plated SnCu

Finish Material	Recommended Minimum Thickness
Barrier Layer (e.g., Ni, Ag, etc.)	≥ 2μm
Matte Sn	≥ 5μm
Fused Sn	≥ 5μm
Hot Dip Sn	≥ 5μm
NiPd	Ni ≥ 1.0μm Pd ≥ 0.075μm
NiAu	Ni ≥ 1.0μm Au Flash – 0.05μm to 0.225μm
NiPdAu	Ni ≥ 0.5μm Pd ≥ 0.02μm Au Flash – .003μm to 0.015μm
Hot Dip SnAgCu	≥ 5μm
Hot Dip SnCu	≥ 5μm
Hot Dip SnAg	≥ 5μm

Thermal Requirements: Electrical Components

- Compatibility with higher process temperatures for Pb-free solders
  - Suppliers required to submit evidence that they meet the Delphi specifications for required soldering processes

Delphi Spec (C-9012) Pb-free Solder Process Requirements

Pb-free High Temperature Reflow

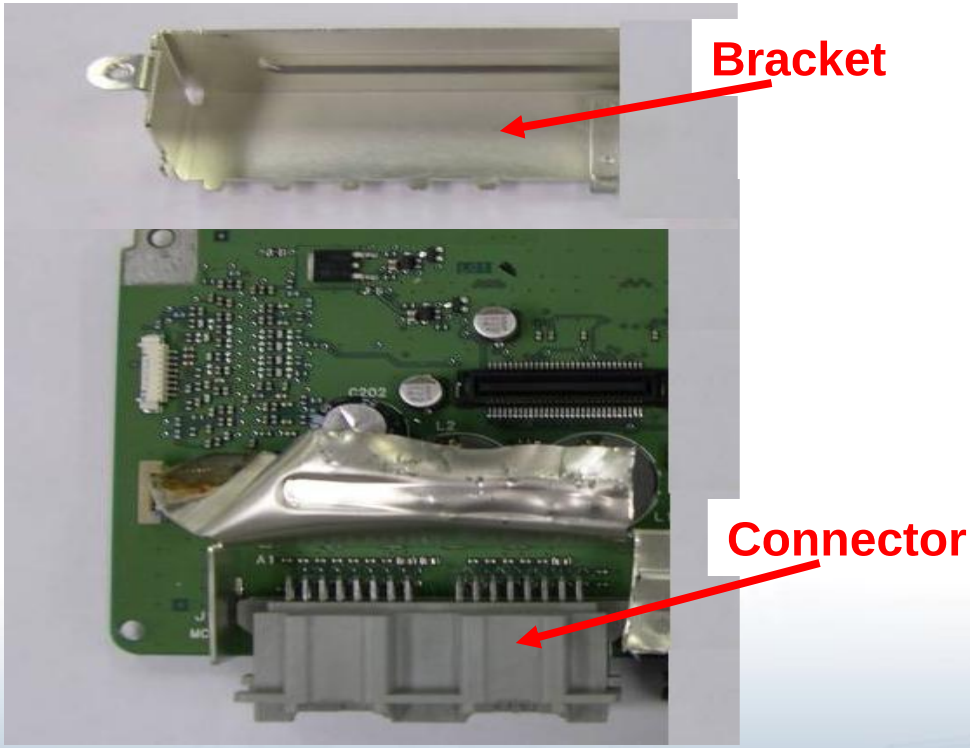
Measurement	Limit
Maximum Temperature	255°C
Maximum Ramp-up rate	3.0°C / sec
Maximum time above liquidus	75 sec
Maximum Ramp-down rate	3°C/sec
Maximum Time to Peak	6 min

Pb-free High Temperature Wave Soldering

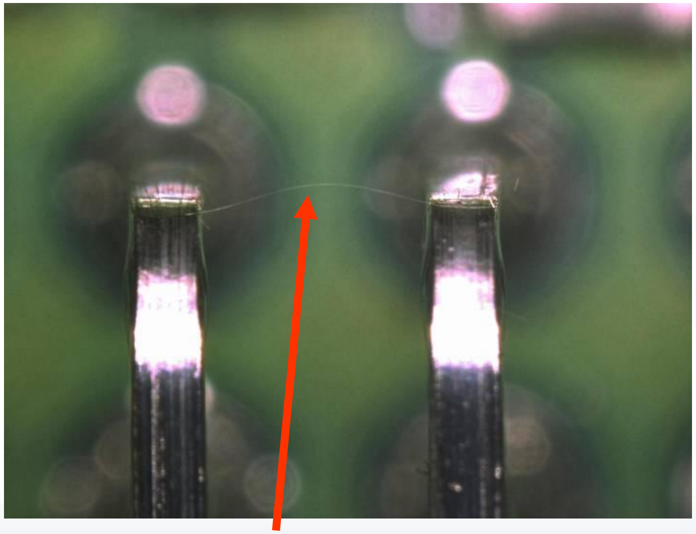
Measurement	Limit
Maximum Ramp Up Rate	3.0°C / sec
Maximum Delta T	140°C
Maximum Solder Pot Temperature	270°C
Pre-Wave Temperature	As required for Delta T
Maximum Dwell Time	5.0 sec
Maximum Ramp Down Rate	12°C / sec max

Tin Whisker Case Study

- RF shield bracket – passenger compartment product



Connector revealed under RF shield bracket

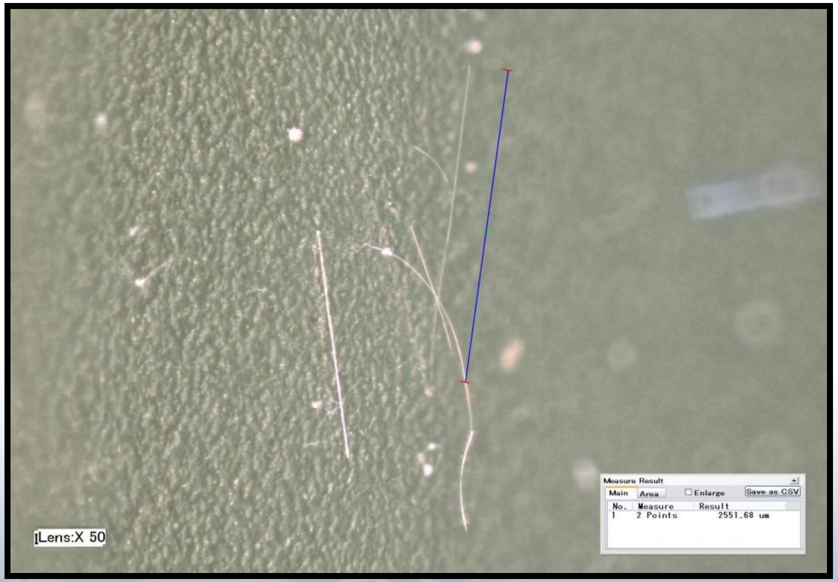


Tin Whisker shorting the connector… where did it come from?

Tin Whisker Case Study

- The connector RF shield is steel with a copper flash and tin plated. The print called out Ni as underlayer plating.
- Vendor changed to a different plating provider which resulted in this problem.
- Assemblies with a shorted connector were caught at test during validation build and units were quarantined.

Entire surface of bracket is covered with tin whiskers



2550 micron whisker

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 to contain whiskers that may form is recommended.**

Changing Organizational Paradigms

- The "current state equals future state" fallacy.
  - Standard validation testing does not accelerate growth of tin whiskers.
  - Stresses change over time in a non-linear fashion.
- Steps must be taken to guard against a condition that cannot reliably be generated in an accelerated test.
  - Mitigation strategies cost money
- Time must be invested to educate the organization on tin whisker risk.

Lessons From the Field

- Lead-free components have been in wide use across product lines since 1995.
  - Nearly all R's and C's have been converted
  - Mix of passive and active components
- Products have cumulatively logged hundreds of millions of miles and service hours.
  - Use environment spans equator to poles
- Observed incidents of tin whisker related failures have been very rare.

Issues with Tin Whisker Identification

- Finding tin whiskers at FA during product tear down can be very difficult
  - Whisker can be destroyed during failure event
  - Whisker can be destroyed, or dislodged during shipping, handling, or disassembly.
  - Whiskers may not be seen by FA technician during inspection.
- Evidence preservation strategies:
  - Develop standard work for sample shipping and teardown
  - Provide training for techniques to be used in identifying possible tin whiskers.

Field Performance