DoD Lead-free Electronics Risk Mitigation: Tin Whisker Basics for Systems Engineers

SERDP/ESTCP Webinar hosted by CALCE

Dr. Michael Osterman, CALCE/University of Maryland
Dr. Stephan Meschter, BAE Systems
Dr. Peter Borgesen, Binghamton University
Dr. Indranath Dutta, Washington State University

Strategic Environmental Research and Development Program (SERDP)
Environmental Security Technology Certification Program (ESTCP)

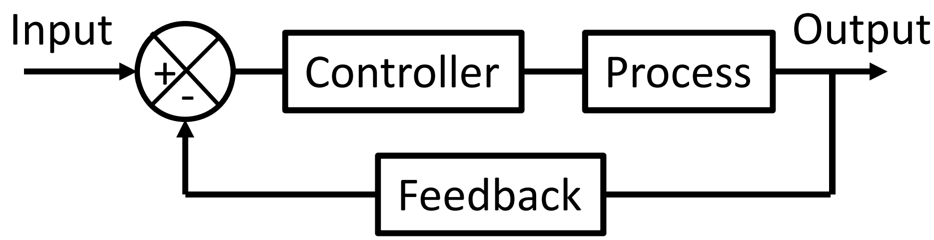
SERDP/ESTCP lead-free projects

- **Prior DoD Lead-free Electronics Risk Mitigation Webinars**
  - **Understanding and Mitigating the Risks Associated with Lead-Free Electronics March 2015**
    - https://serdp-estcp.org/content/download/32643/318678/file/Lead%20Free%20Webinar%20Slides.pdf
  - **Program Management and Systems Engineering Overview Oct. 2016**
    - http://www.calce.umd.edu/seminars/PM-LF-Webinar-2016-10-12.htm
  - **Lead-free Solder Basics for Systems Engineers March 2017**
    - http://www.calce.umd.edu/seminars/SR-LF-Webinar-2017-03-14.htm
- **Active projects**
  - **Novel Whisker Mitigating Composite Conformal Coat Assessment**
    - **SERDP WP-2213 Dr. Stephan Meschter, BAE Systems, May 2012-Present**
    - https://www.serdp-estcp.org/Program-Areas/Weapons-Systems-and-Platforms/Lead-Free-Electronics/WP-2213
  - **Enabling Lead-free Interconnects in Weapon Systems**
    - **ESTCP WP-201573-T2 Dr. S. Meschter**
- **Complete projects**
  - **The Role of Trace Elements in Tin Whisker Growth**
    - **SERDP WP-1751 Dr. Jean Nielsen, The Boeing Company, Sept. 2013**
    - https://www.serdp-estcp.org/Program-Areas/Weapons-Systems-and-Platforms/Lead-Free-Electronics/WP-1751
  - **Microstructurally Adaptive Constitutive Relations and Reliability Assessment Protocols for Lead Free Solder**
    - **SERDP WP-1752 Dr. Peter Borgesen, Binghamton University, May 2015**
    - https://www.serdp-estcp.org/Program-Areas/Weapons-Systems-and-Platforms/Lead-Free-Electronics/WP-1752
  - **Tin Whisker Testing and Modeling**
    - **SERDP WP-1753 Dr. Stephan Meschter, BAE Systems, Dec 2015**
    - https://www.serdp-estcp.org/Program-Areas/Weapons-Systems-and-Platforms/Lead-Free-Electronics/WP-1753
  - **Contributions of Stress and Oxidation on the Formation of Whiskers in Lead-Free Solders**
    - **SERDP WP-1754 Dr. Elizabeth Hoffman, Savannah River National Laboratory, Jan 2016**
    - https://www.serdp-estcp.org/Program-Areas/Weapons-Systems-and-Platforms/Lead-Free-Electronics/WP-1754
  - **Tin Whiskers Inorganic Coatings Evaluation (TWICE)**
    - **SERDP WP-2212 Mr. David Hillman, Rockwell Collins, Inc., Jan. 2015**
    - https://www.serdp-estcp.org/Program-Areas/Weapons-Systems-and-Platforms/Lead-Free-Electronics/WP-2212

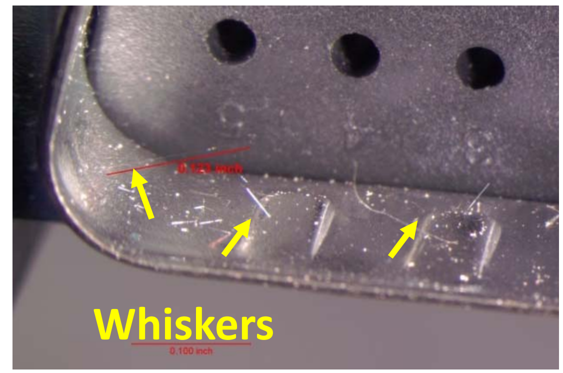
Overview

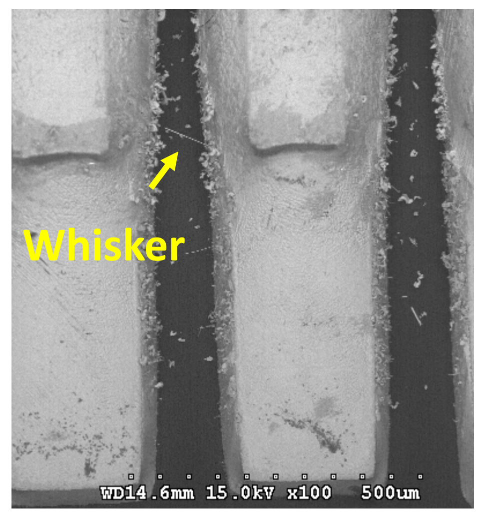
- Tin whisker description
- Factors influencing whisker growth
- Whisker events in industry
- Failure risk
  - Inspection
  - Electrical characteristics
  - Whisker movement
  - Metal vapor arcing
- Systems engineering
  - Systems design considerations
  - Role in contracting
  - System requirement details
  - Sub-tier supply chain flow down
  - Commercial – off – the shelf (COTS) electronics
  - Selecting a control level
  - Mitigating whiskers
    - Circuit considerations
    - Solder coverage
    - Conformal coating
    - Solder dipping
- Tin whisker risk assessment tools
- Case studies
  - Toyota accelerator pedal assembly
  - NASA Space Shuttle
- Summary
- Your every day tasks
- Back-up slides

System function

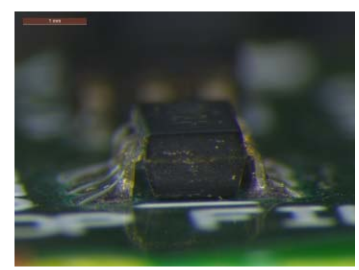


Connector shell





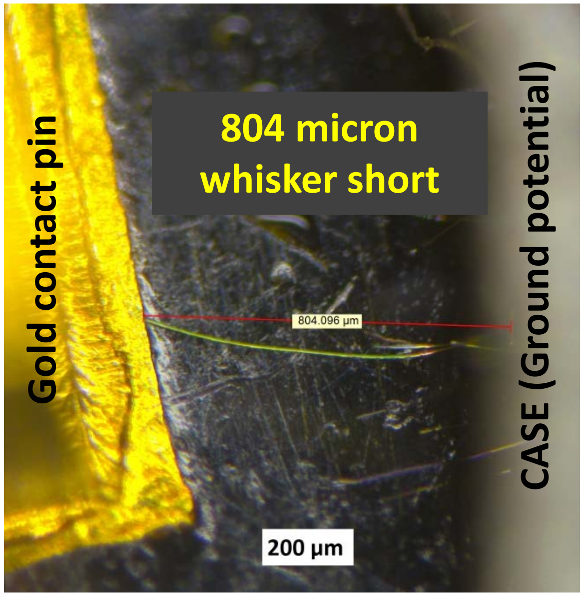
Sn-3Ag-0.5Cu Soldered assembly



Electronic assembly

Take away

- Tin whisker growth
  - Even if you are soldering with tin-lead assembly solder, there is still a significant tin whisker risk
  - Industry JESD-201 tin whisker testing is insufficient for long term DoD verification
  - Watch for tin (and zinc) plated electrical part bodies and mechanical items
- Failure modes
  - Intermittent, soft and hard shorts can occur
  - Metal vapor arcing possible in power circuits
- Whisker mitigations
  - Conformal coating is under DoD supply chain control
  - Tin lead solder mitigates whisker growth
  - Thick lead-free solder regions retard whisker growth
  - Hot solder dip
- Systems Engineering best practice
  - Lead-free control plan (LFCP) requirements in SEMP and SSP
    - GEIA-STD-0005-1 & GEIA-STD-0005-2
  - Subcontracting
    - Include LFCP in "Request for Proposal", contracts or engineering specifications
    - Review COTS and sub-tier supply chain for lead-free content



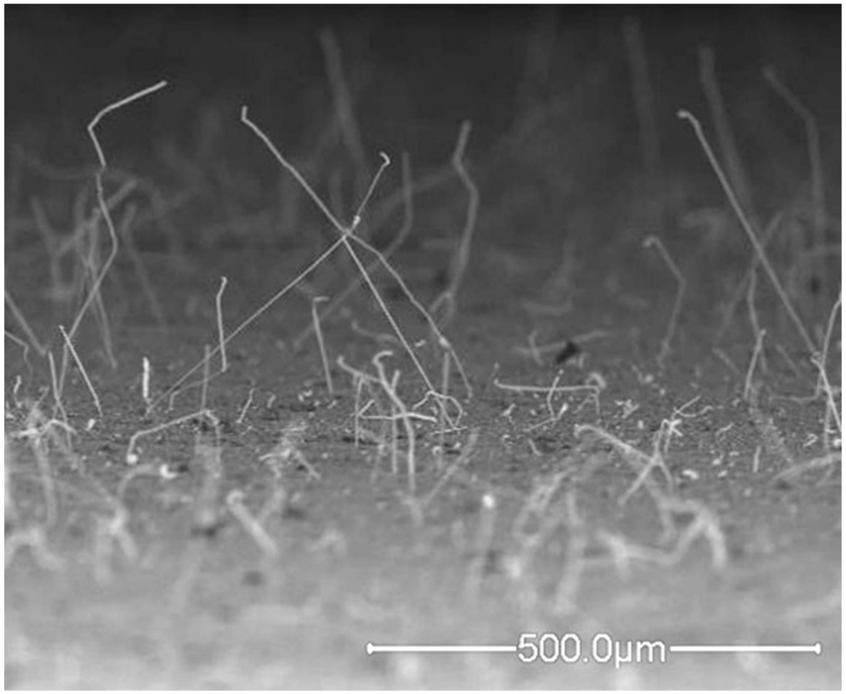
2007 switch inspected in 2015

SEMP = Systems engineering management plan
SSP = Systems safety plan
COTS = Commercial – off – the shelf

Unintended use of lead-free tin is detrimental to electronics reliability

Tin whiskers: Introduction

- Tin Whisker - conductive crystalline structure of tin growing from tin rich surfaces
- Whiskers are formed through addition of atoms at the base, not the tip
- Shape can be straight, kinked, or curled
- Typically 1 to 10 micron diameter
- In accordance with JEDEC/IEC standards:
  - Aspect ratio (length/width) greater than 2
  - Length greater than 10 µm, although smaller whiskers may be important for research



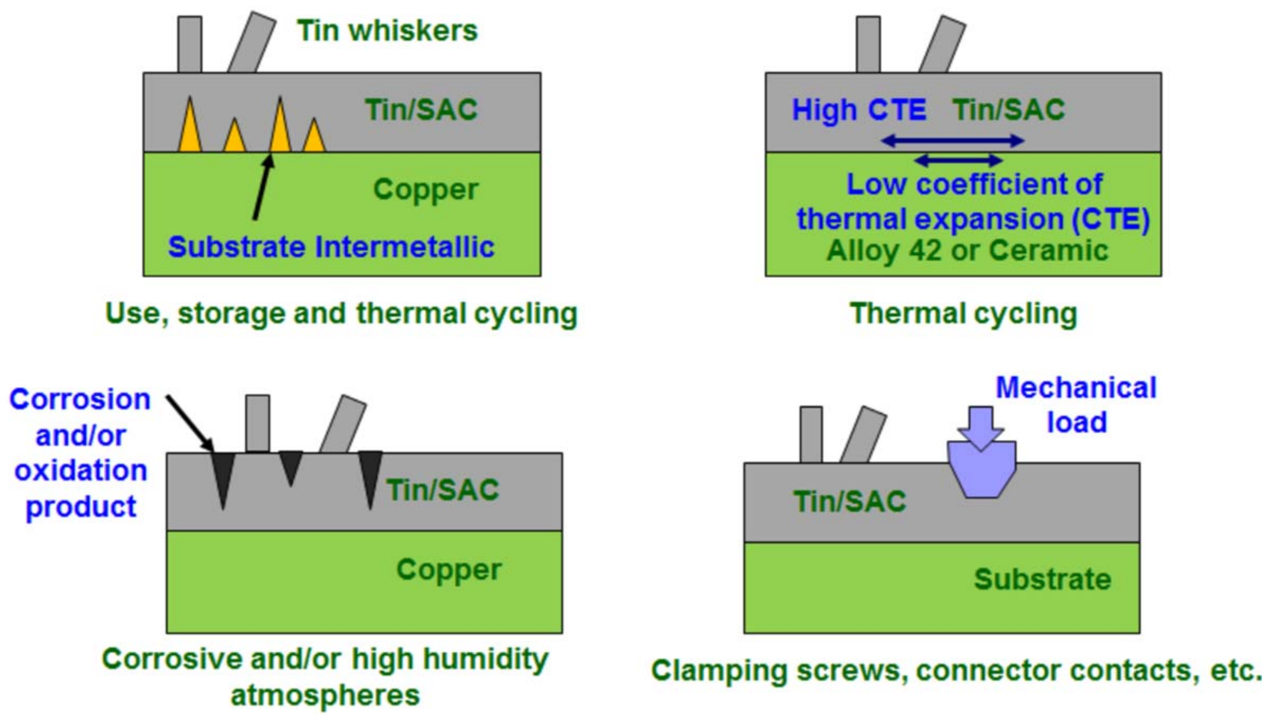
Whiskers can have long incubation times and lengths vary greatly

Factors contributing to whiskering

Compressive stress believed to promote whisker growth

Whisker growth pronounced in *thin* tin and lead-free solder films up to 50-75 microns

Bulk lead-free solder e.g. 300 micron BGA balls do not grow whiskers
Small flip chip solder balls may grow whiskers, but parts are usually are epoxy under filled



No voltage required for whisker growth

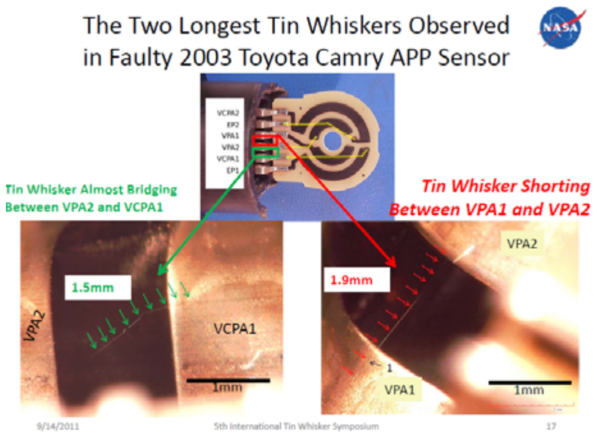
Whisker growth clock starts after plating or restarted after lead-free reflow

Many DoD applications have all four whisker stress sources

SAC = Sn-Ag-Cu solder

Whisker events in industry

- I heard tin whisker issue was solved
  … but still seem to persist (Ref: https://nepp.nasa.gov/whisker)
  - **2005 Tin whisker causing shutdown of Millstone nuclear power station in Connecticut**
  - 2012 Press-in connector tin whiskers Continental AG
  - **Toyota accelerator position sensor whiskers**
  - GIDEP alerts
- Consumer JESD-201 short term test
  - Stated goal – No whiskers longer than 50 microns in two years (25% of fine pitch lead spacing)
  - But, whiskers are unpredictable
    - **CALCE: Tin samples dormant for 4 years, then grew phenomenal whiskers**
- Proactive programs and robust DoD suppliers
  - **Using SAE GEIA-STD-0005-2 whisker mitigation**
    - Conformal coating, material and circuit analysis, …
    - Need more research to improve validation



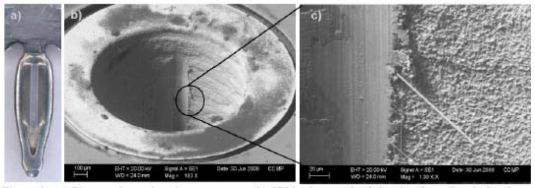


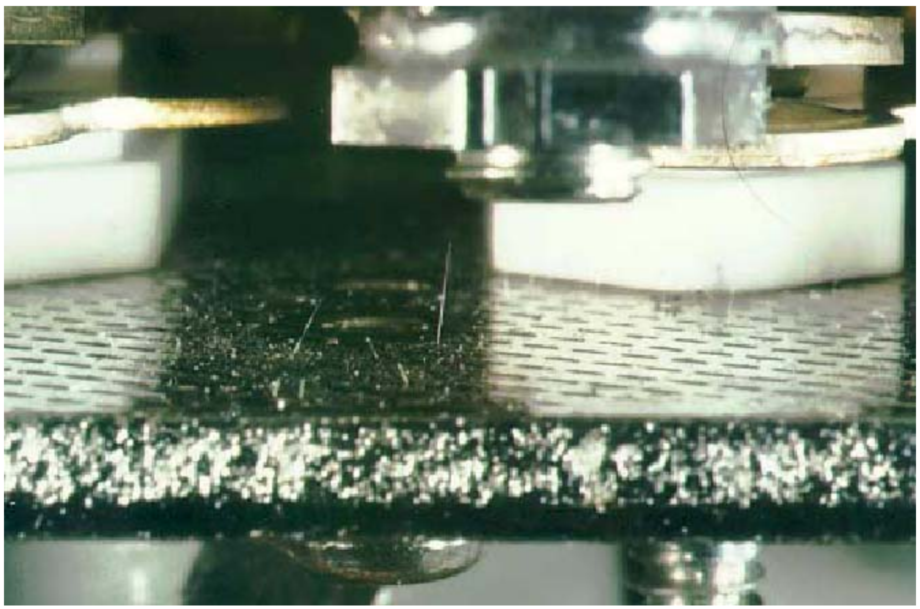
Figure 6 – a) Picture of a spring shape zone type, b) SEM micrograph of the via where the pin has been removed, c) magnified section showing the deformation line and whiskers.

Continental 2012

Watch items: Whisker test complacency & cost reduction initiatives

Failed relay due to tin vapor arcing

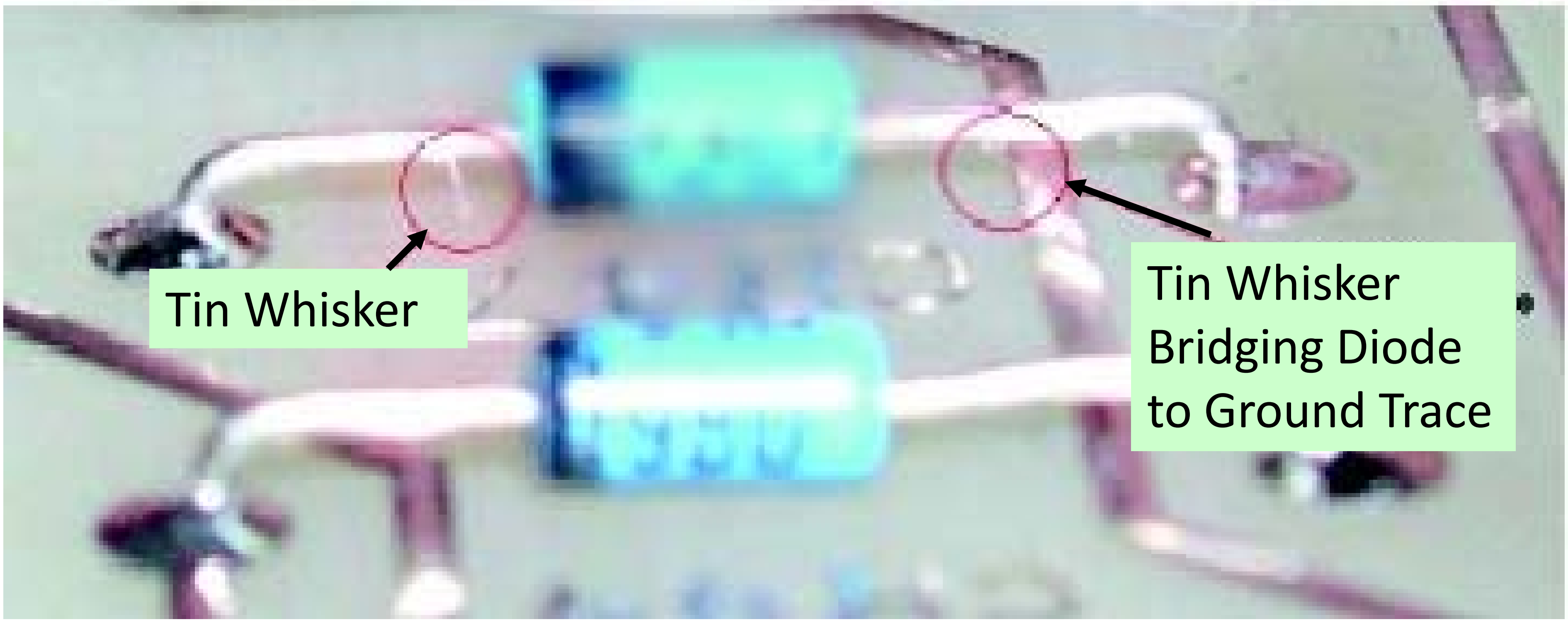
Whiskers on the Armature of the Relay



Failed Relay Due to Tin Vapor Arcing

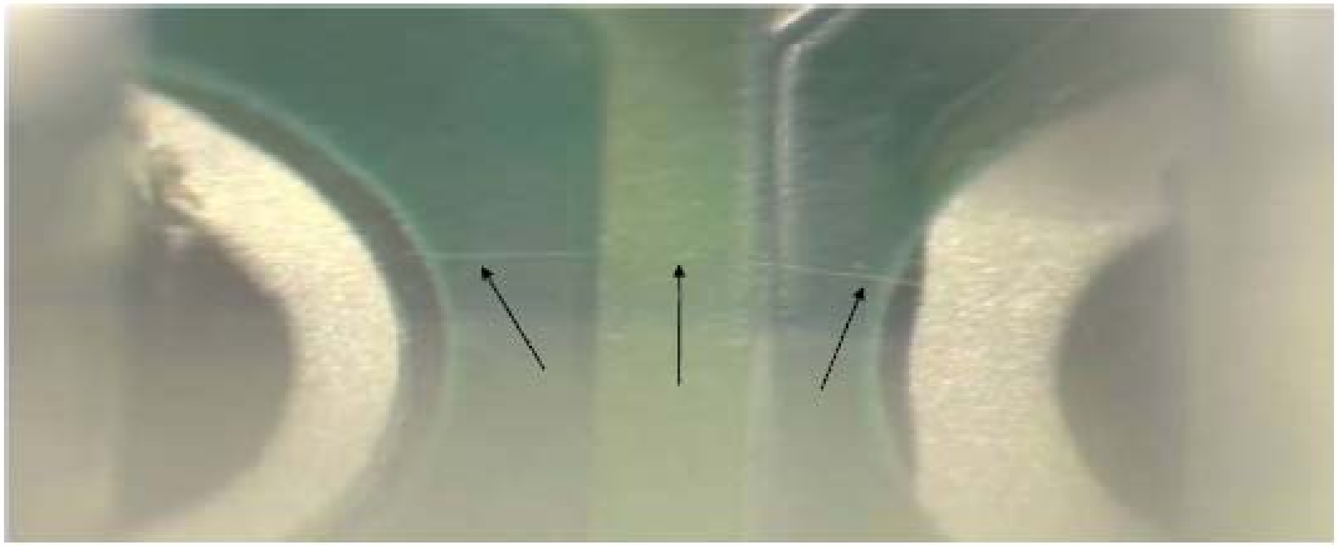
- Davy, G., (Northrop Grumman Electronic Systems), “Relay Failure Caused by Tin Whiskers,” http://nepp.nasa.gov/whisker/reference/tech_papers/davy2002-relay-failure-caused-by-tin-whiskers.pdf, June 10, 2004.

Tin whisker bridging a diode and trace: Millstone 3 Nuclear Power Plant Failure



H. Leidecker, J. Brusse, "Tin Whiskers: A History of Documented Electrical System Failures", Technical Presentation to Space Shuttle Program Office, NASA, April 2006

Press-fit connector pin failure



- Some 0-km and field returns identified at a body controller 2007
- Whiskers create direct parasitary signal path at sensor exits (very low current flow)
- Whisker length > 2 mm within 2-6 weeks after insertion in this case

Direct bridging of low signal electrical contacts

Central Electronic Plants – Manufacturing Technology – Advanced Technologies

Continental

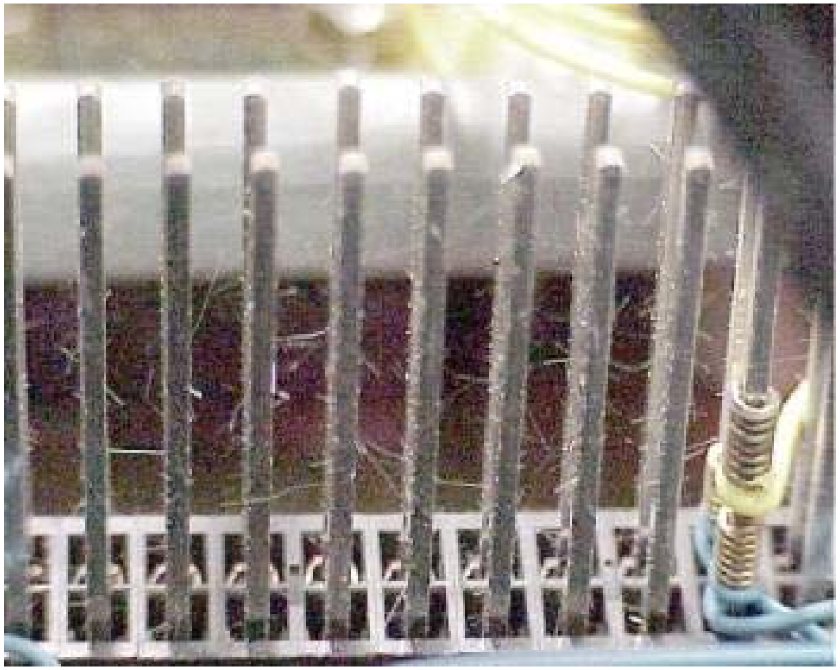
Hans-Peter Tranitz, Pressure-induced Whisker Growth in Press-in Connections of PCB Through-Holes, IPC Whisker Conference, Dec. 2010

Failure risks from tin whiskers

- Major failure modes and mechanism of tin whiskers are:
  - Electrical short: permanent (typically <10mA), intermittent (typically >10mA)
    - Range of resistances e.g. "soft" shorts
  - Metal vapor (plasma) arcing in vacuum and low pressure
    - Systems with high available current
  - Contamination

- Various sectors of the electronics industry, including military, medical, telecommunications and commercial applications, have experienced field failures induced by tin whiskers.

Pure tin plated connector pins

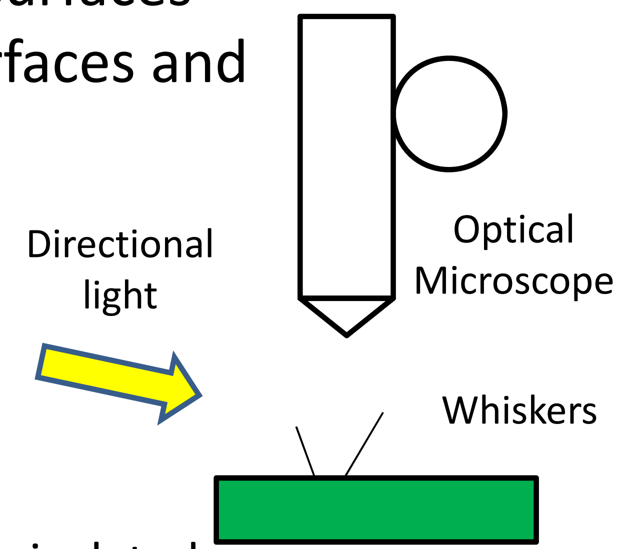


10 years in the field (reported in 2000)

[Courtesy of NASA Goddard]

Inspecting for Whisker Growth

- Identify tin, zinc, and cadmium finished surfaces
- Identify distances between identified surfaces and active electronic devices.
- Use directional light source
  - Looking for a whisker glint
    - Low angle almost horizontal light
  - Whiskers are difficult to see
    - Small diameters
    - Small lengths
  - Magnification should be sufficient to examine isolated conductors



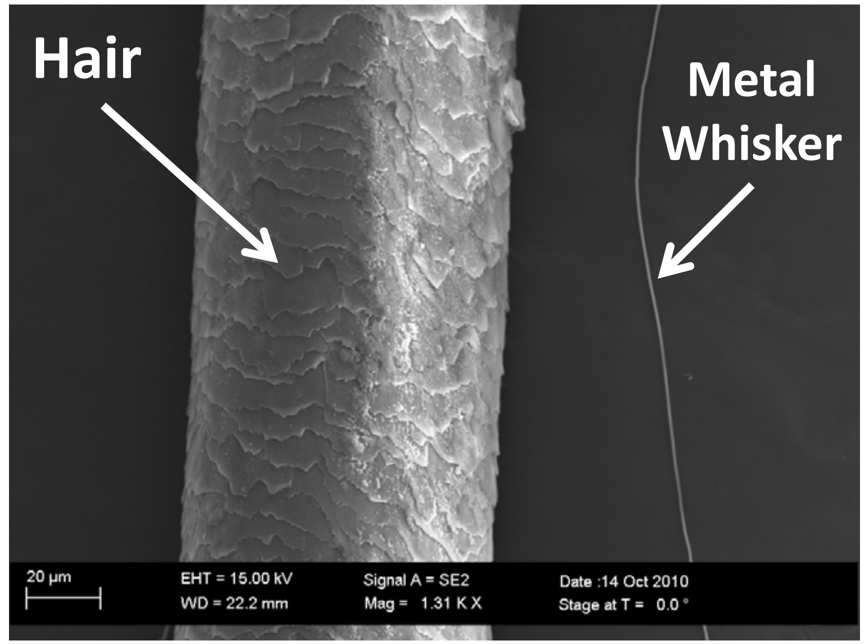
- Scanning electron microscope useful for validation
  - Large depth of field
  - Differentiate metal whiskers from non-conductive organic and glass fiber debris
  - Can not be used on electrostatic sensitive assemblies

Whisker can be very difficult to see

Human hair vs. Metal whisker

Optical comparison of Human Hair vs. Tin Whisker

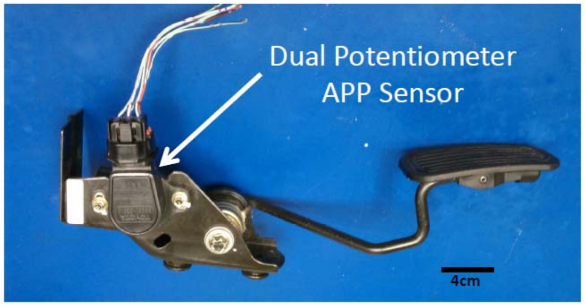
SEM comparison of Human Hair vs. Metal Whisker



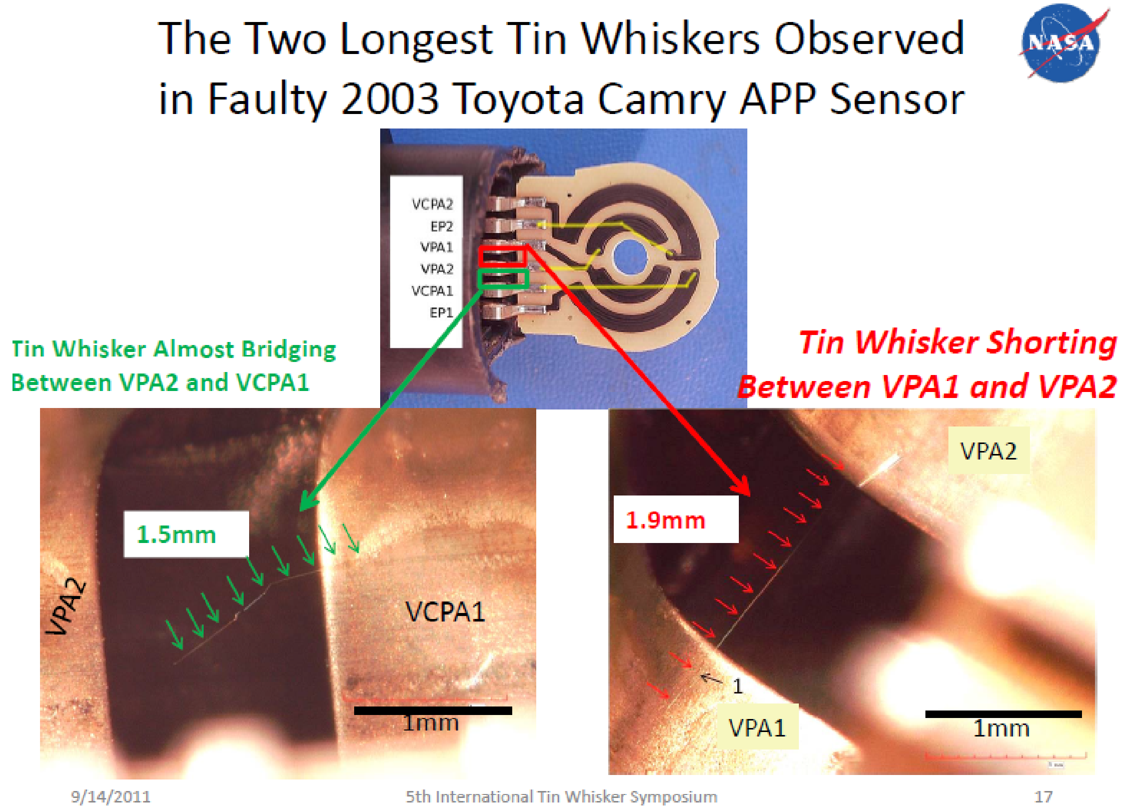
Courtesy of NASA

Metal Whiskers are commonly 1/10 to <1/100 the thickness of a human hair

Electrical detection issue: Tin whiskers in accelerometer pedal position sensor failure



Digital volt meter test

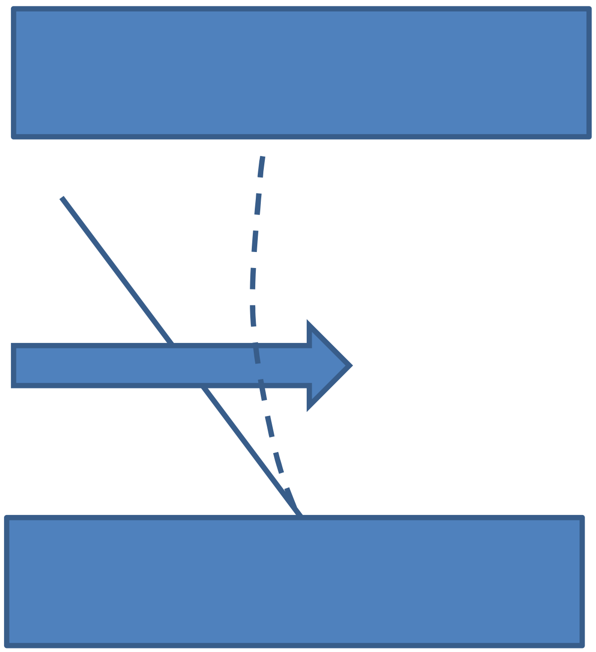


Digital volt meter can fuse whisker in less than a millisecond
Test result: No – fault found

https://nepp.nasa.gov/WHISKER/reference/tech_papers/2011-NASA-GSFC-whisker-failure-app-sensor.pdf

Whisker movement

- Long thin whiskers are very flexible
- Without breaking can bend, flex through very large angles under the influence of air, vibration, shock or electrostatic forces.
- After significant movement, whisker tip may be caught by the irregular surface of tin plating on an adjacent conductor.
  - Mechanical shock or air movement may dislodge the whisker tip



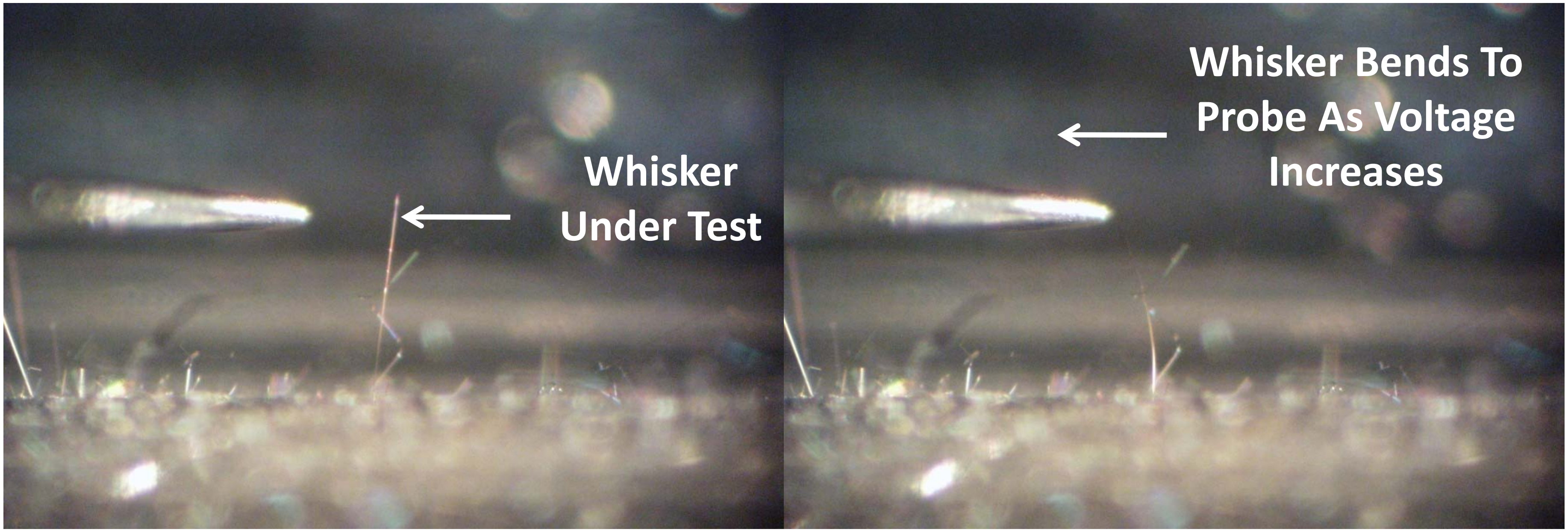
See also:

H. Leidecker, L. Panashchenko, J. Brusse, NASA Goddard, Electrical Failure of an Accelerator Pedal Position Sensor Caused by a Tin Whisker and Discussion of Investigative Techniques used for Whisker Detection, 5th Tin whisker Symposium CALCE University of Maryland 2011

V. G. Karpov, Understanding the movements of metal whiskers, Journal of Applied Physics **117**, 235303 (2015)

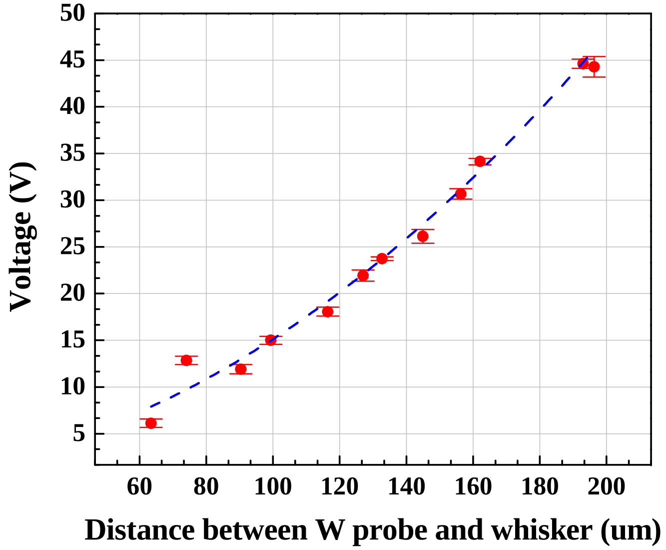
Movement of whisker tip against adjacent surface could reduce breakdown voltage by altering the oxide layer

Electrostatic force can attract whiskers



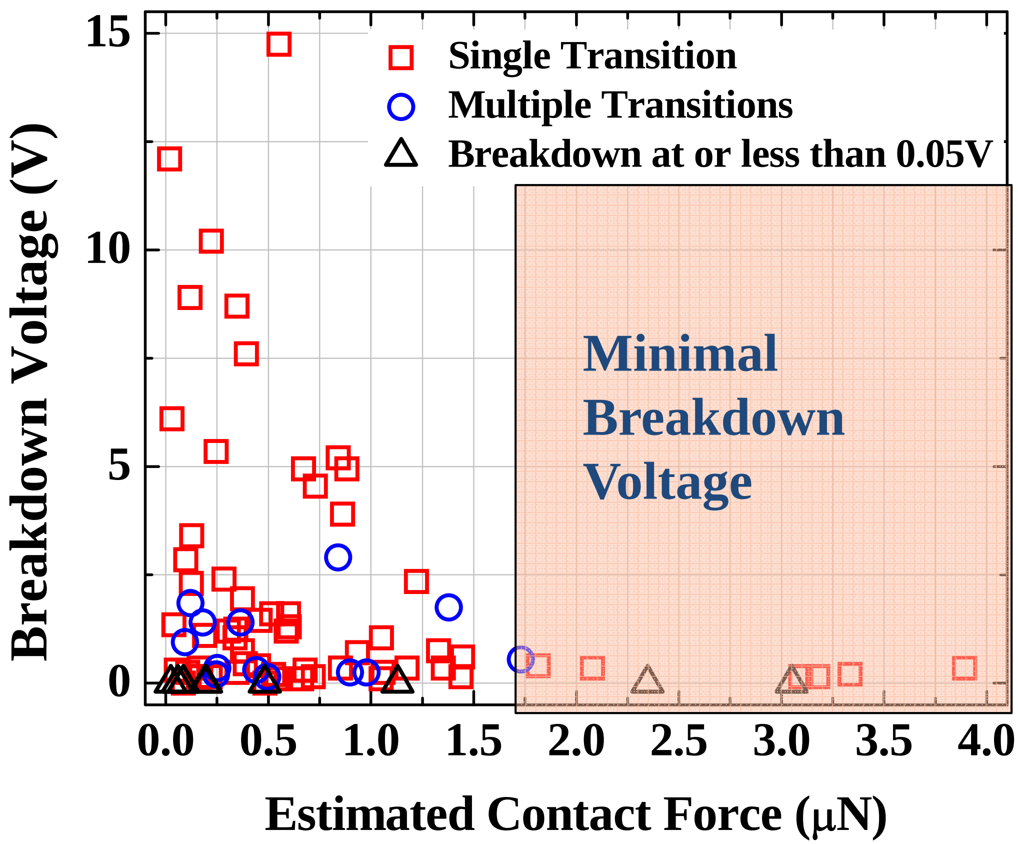
Tin whiskers are effected by electrostatic forces. As expected, the amount of deflection is related to the voltage potential existing between the whisker and adjacent conductor.

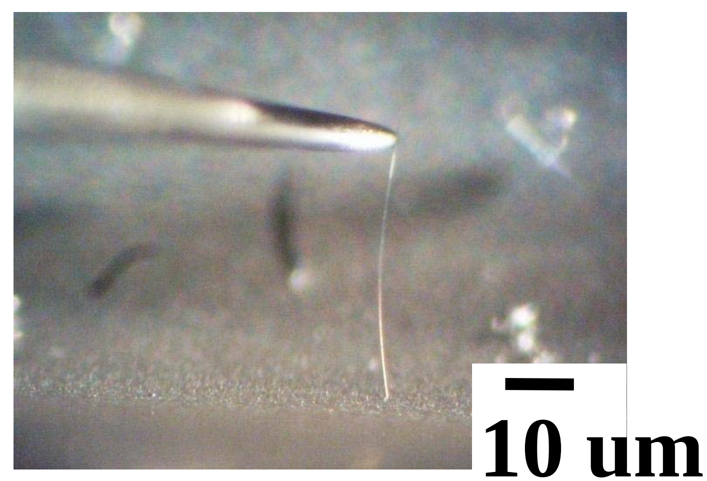
Whiskers can be drawn to opposite potential lead increasing shorting likelihood



Effects of contact force on breakdown voltage

- The both single and multiple transitions occurred at breakdown voltages between 0 to 15 V, when the estimated contact force was less than 1.5 µN. While, the breakdown voltage was less than 0.5 V when the estimated contact force exceed 1.5 µN.



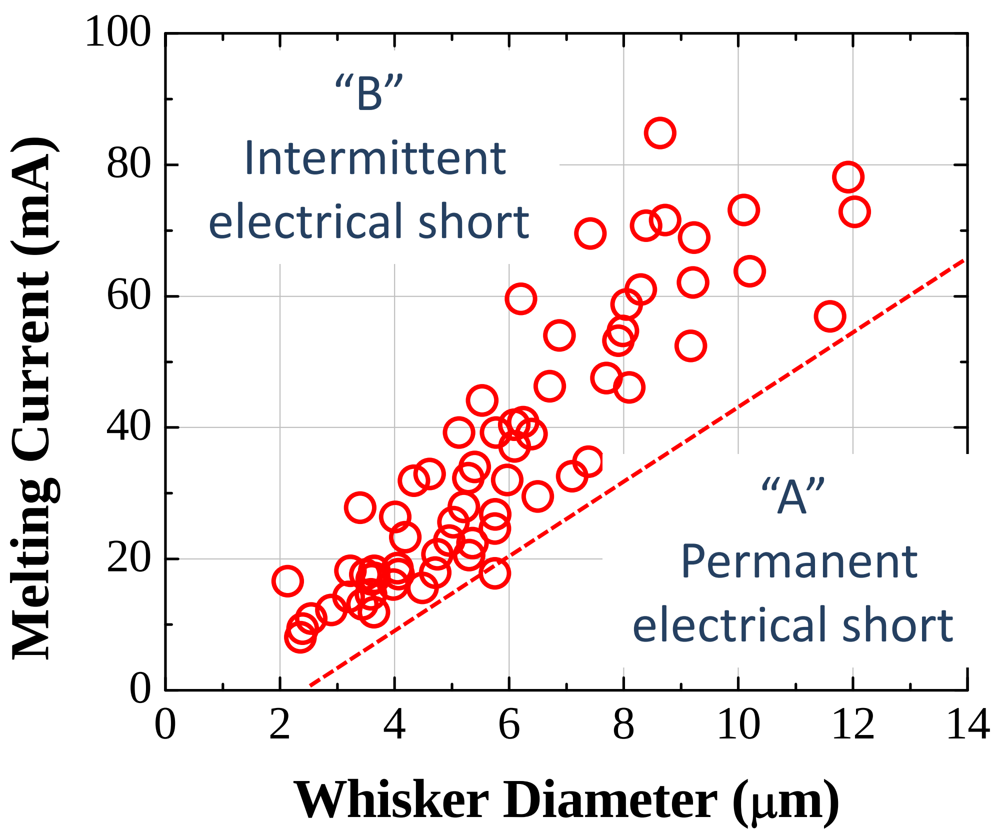


Estimated contact force: 0.048 ~ 0.78 µN

Electrical Shorting Propensity of Tin Whiskers, S. Han, M. Osterman and M. Pecht, *IEEE Transactions on Electronics Packaging Manufacturing*, Vol. 33, No. 3, July 2010.

Electrical short characteristic of tin whiskers

- The electrical short characteristic of tin whiskers can be assessed based on the current level in electronic system.



- Area "A": Whisker can flow current without melting

→ *"Permanent electrical short"*

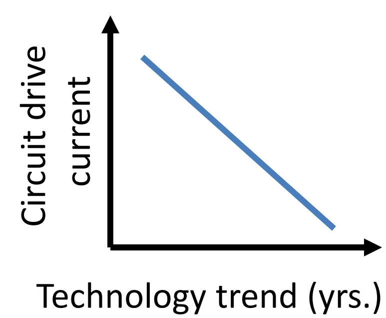
- Area "B": Whisker can be melted within few seconds

→ *"Intermittent electrical short"*

Melting current in vacuum for Sn

$$I_{melt,vac} = \frac{87.5\text{mV}}{R_0} \qquad R_0 = \frac{\rho L}{A}$$

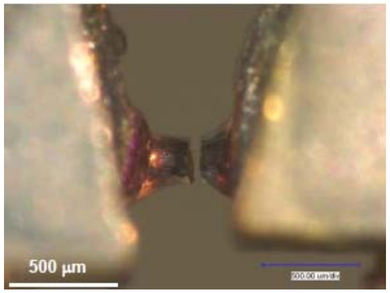
R_0 = Whisker resistance at ambient



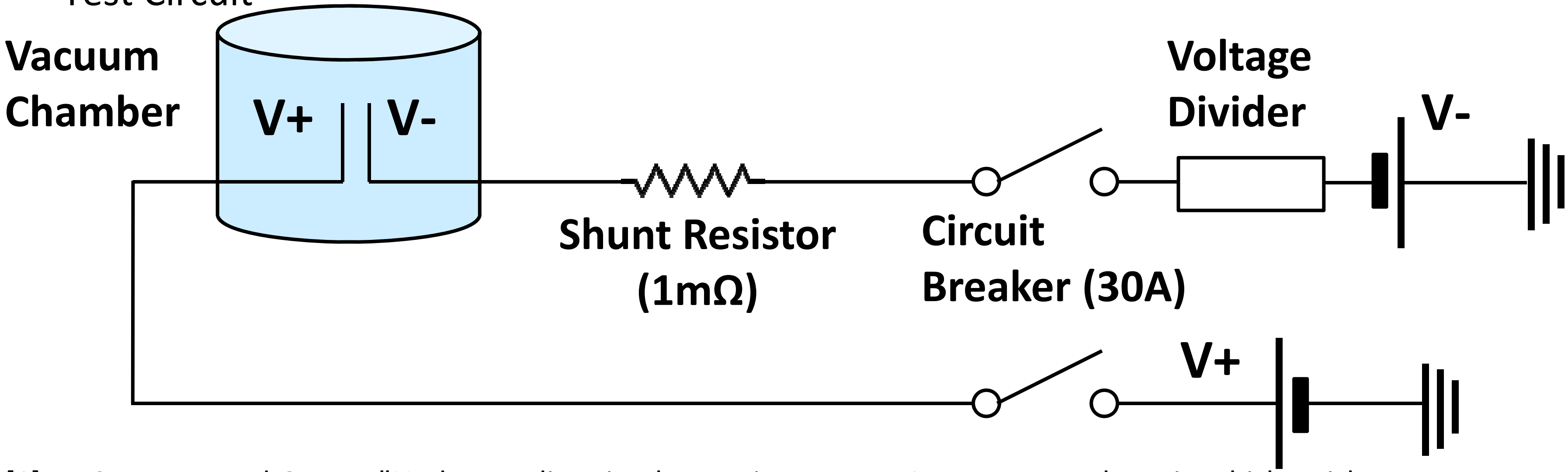
Many circuits have micro amp current levels – no whisker melting

Tin whisker induced vapor arc

- When a sufficient electric current passes through a tin whisker, the high current density can vaporize the tin whisker due to Joule heating and create a highly conductive plasma.
- More likely with low impedance sources
  - Batteries, Capacitor storage, etc.
- More easily created at lower pressures
  - A vapor arc was initiated by a tin wire (diameter of 25 ~ 50 μm) in atmospheric pressure (760 torr) with 28V and 4V in a high vacuum (0.2×10^{-6} to 2×10^{-6} torr) [1].



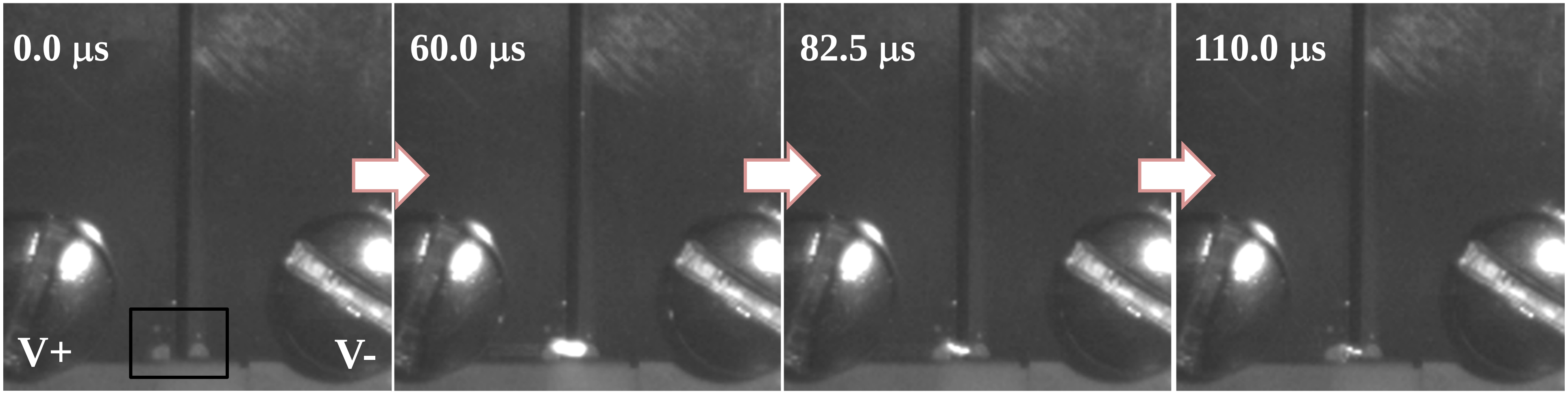
- Test Circuit



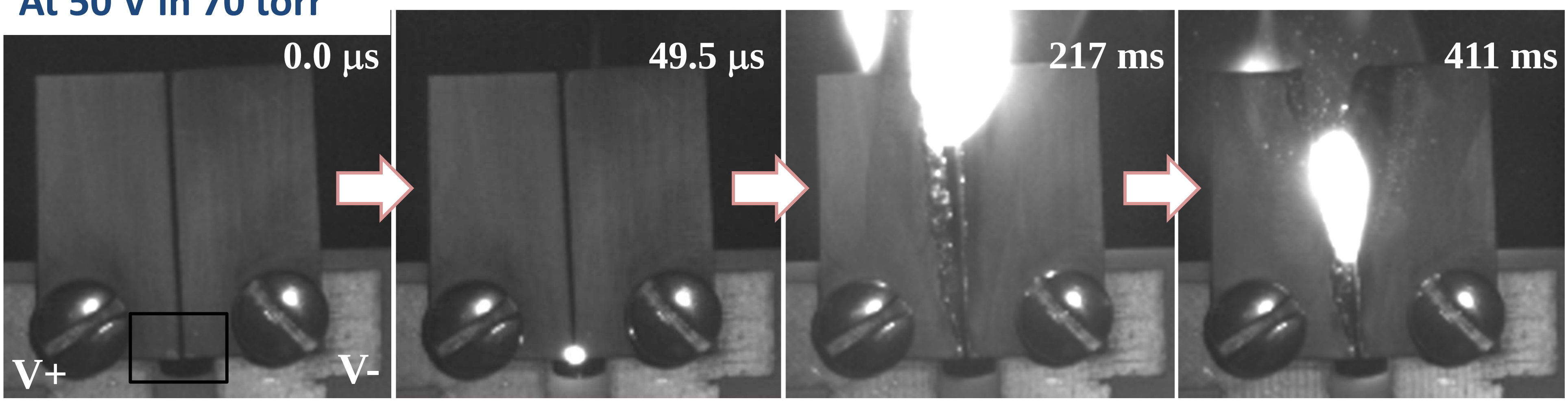
[1] M. S. Mason and G. Eng, "Understanding tin plasmas in vacuum: A new approach to tin whisker risk assessment, " Journal of Vacuum Science and Technology A: Vacuum, Surfaces and Films, vol. 25, pp. 1562-1566, 2007.

Vapor arc behavior depending on pressure

At 50 V in 760 torr



At 50 V in 70 torr



Captured via high speed camera at 180 kHz frame rate

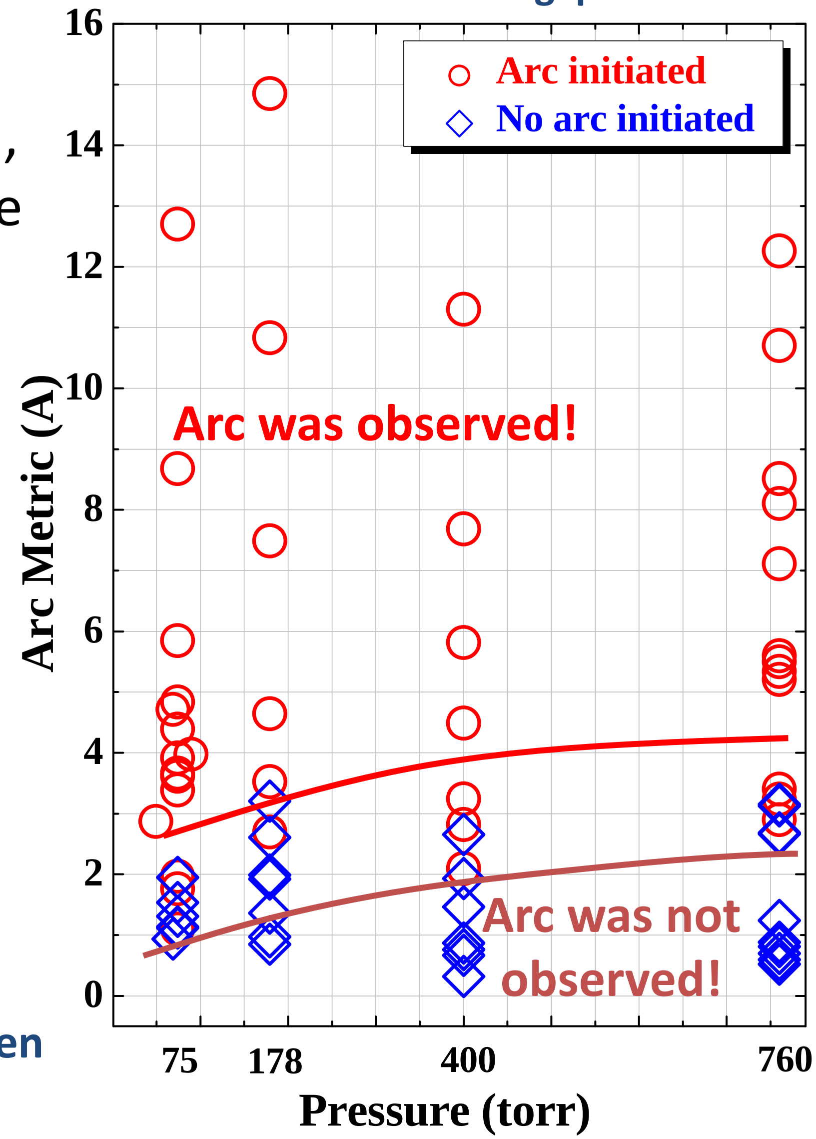
Arc metric

- Among the arc parameters (pressure, voltage, resistance of the test specimen, geometry of the whisker), the resistance of the test specimen is the strongest indicator of whether a vapor arc will occur.
- The arc metric as a function of bias voltage and resistance was proposed to characterize the potential for vapor arc formation by tin whiskers.

$$Arc\_Metric = \frac{V_{Applied}}{R_{Specimen} + R_{Test\_circuit}}$$

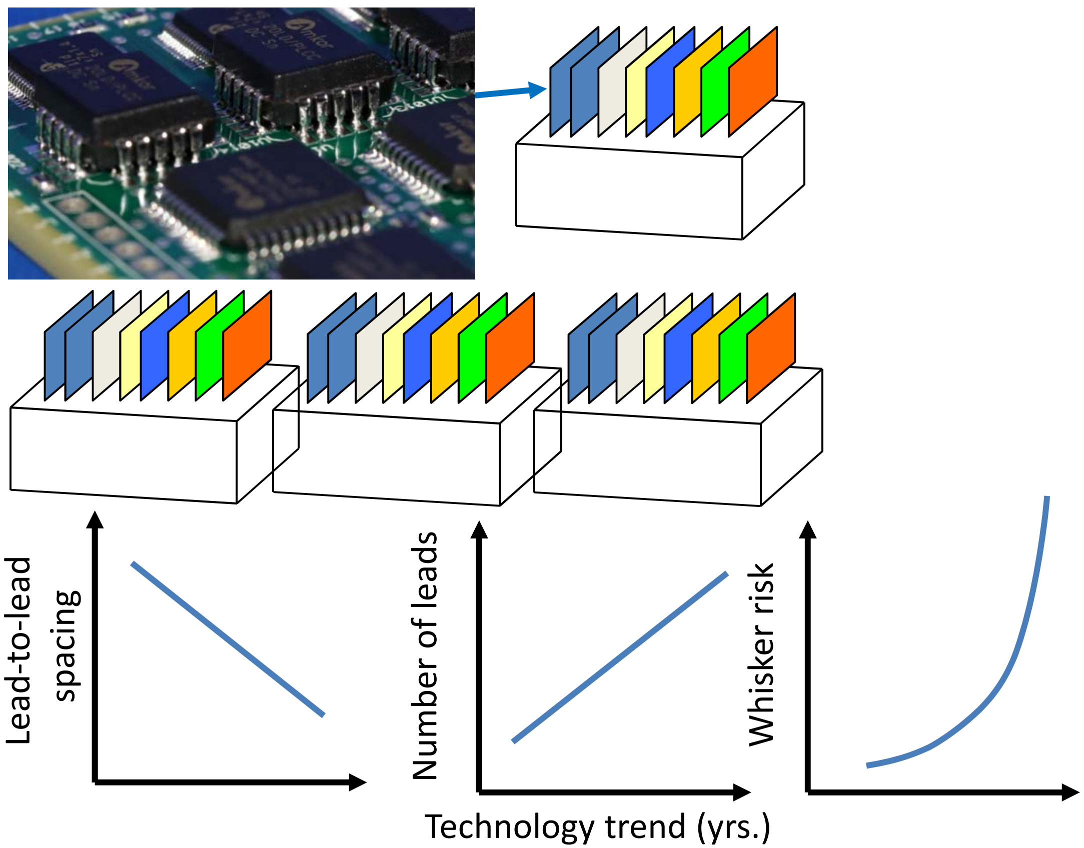
$V_{Applied}$: Bias voltage
$R_{Specimen}$: Measured resistance of test specimen
$R_{Test\text{-}circuit}$: Measured resistance of test circuit

Conductor gap: 600 mm



SYSTEMS ENGINEERING

Tin whisker risk in a typical box (~1996 design)



Description	# of leads
Analog 1	2009
Analog 2	2009
Analog 3	2009
Power Supply	326
Digital 1	2573
Digital 2	2573
CPU 1	3656
CPU 2	3656
Box total:	**18811**
Boxes/year	1000
Years	10
Total Leads	**188,110,000**

188 million leads fielded over 10 years

Whisker mitigation essential; verified coating, solder coverage, etc.

Tin whisker risk impacts:

Systems design consideration

- Mission performance considerations due to a tin whisker failure in a system
  - Safety, availability and reliability
  - Redundancy strategy
  - System fault detection and response to intermittent fault logs
  - Can pyrotechnic or other shock events trigger multiple whisker failures
- Unintended lead-free materials use and tin whisker risk is real
  - Risk is unquantifiable today
  - Single point failure review needed in the context of whisker shorting
  - Possible impact on risk protection offered by redundancies
    - Impacted Hughes HS 601 Satellites in orbit which failed with a common relay in both A and B channels
- Whisker growth leading to shorting
  - Not predictable like fatigue
  - High whisker propensity defect tied to a part lot
  - Unexpected environment combination that triggers whisker nucleation and growth
  - Unintended systemic use of a whisker prone part across multiple functions or across multiple redundant functions
  - Latency effect – increases with greater tin content
    - Period of no growth, period of rapid growth, period of no growth
  - Could manifest itself like "Wear-out"
    - If the whiskers always get longer with time
    - If the whisker density increases with time
- Cannot reliably accelerate whisker growth – no accepted acceleration factor
  - Unclear how to differentiate whisker risk between tin plating populations

Tin whisker mitigation needed
Response somewhat similar to Electrostatic Damage (ESD) risk reduction

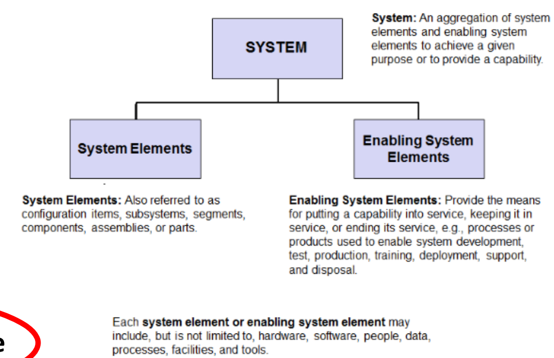
Defense Acquisition Guidebook (DAG) tin risk items during procurement

CH 3–2.7 Systems Engineering Role in Contracting

Within the RFP development team, the Systems Engineer should be responsible for the technical aspects of the RFP and should perform the following actions:

- Referencing current required operational documentation and system performance specifications.
- Identifying SE process requirements (for example, requirements management, **configuration management and risk management**; see CH 3–4. Additional Planning Considerations).
- …
- Identifying any **design considerations including production; reliability and maintainability (R&M);** environment, safety and occupational health (ESOH); human systems integration (HSI); and security.
- Identifying for delivery Government-required technical data rights produced by the developer.
- Listing and describing **technical assessment evidence** and events, including technical reviews, audits, and certifications and associated entrance/exit criteria
- ….
- Coordinating with **Chief Developmental Tester with regard to the test and evaluation requirements**.
- Providing a requirements **verification traceability** database (requirements and test method).
- …..
- Leading or supporting the **technical evaluation during source selection**, to include providing inputs to the development of source selection criteria.
- **Performing schedule risk assessments** as part of the source selection evaluation process.
- ….
- Identifying external or SoS interfaces and **ensuring the technical interface requirement and task scope are unambiguous to** the offerors.
- …..
- Providing a clear description of the **minimum technical requirements used to determine the technical acceptability of a proposal.**

Figure 1: The System



Key discussion points

See also http://sebokwiki.org/wiki/Procurement_and_Acquisition

Just requiring 20 year life is insufficient

Lead-free risk mitigation requirements should be clear in the proposal and contract

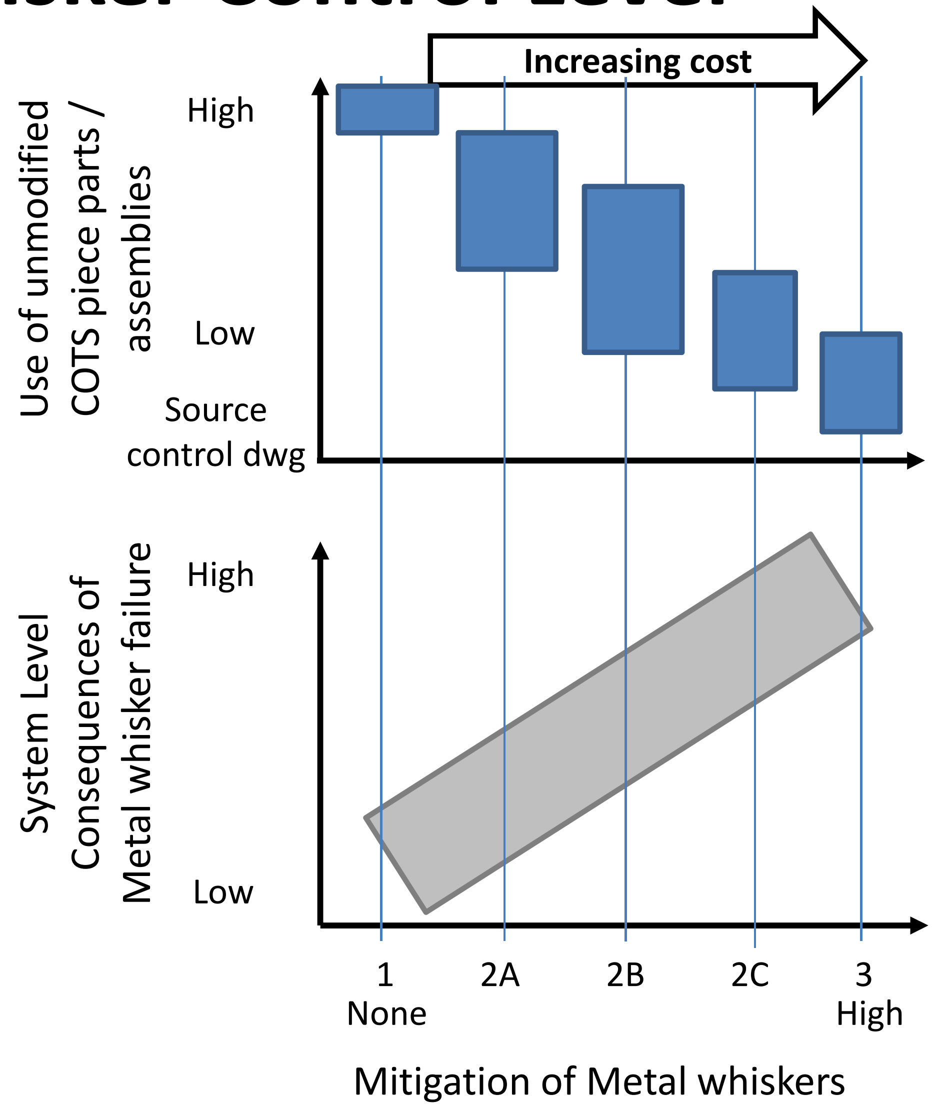
Lead-free systems requirements details

- Where:
  - Systems engineering management plan (SEMP)
  - **Systems safety plan (SSP)**
  - Sub-contracts statements of work
  - Equipment specifications
- Creation of specification
  - Equipment **safety, availability and reliability**
    - Can a reboot clear a whiskers? Can the mission tolerate the reboot time?
  - Lead-free control
    - GEIA-STD-0005-1 Lead-free reliability, configuration management, repair, etc.
    - GEIA-STD-0005-2 **Tin whisker risk management** requirements
    - Sub-tier flow down using Lead-free Control Plan Data Item Description **DI-MGMT- 81772**
    - Can include in Parts Materials and Processes (PMP) section
  - Impacts validation testing and analysis by similarity requirements
  - "Class 2" change definition
    - Class 1: Solder alloy changes?
    - Class 2: Tin finish with mitigation per lead-free control plan?
  - Commercial-off-the-shelf (COTS) electronics use
    - Permit/restrict RoHS compliant lead-free electronics?
- Review/acceptance of specification
  - Requirements versus standard design/build processes
  - Lead-free control plan review with customer
  - What kind of safety, availability and reliability risk is being transferred to you?

RoHS = European Union Reduction in Hazardous Substances Legislation

Selecting a Tin Whisker Control Level

- GEIA-STD-0005-2 Requirements for tin whisker mitigation
- Control levels
  - Level 1: No control
  - Level 2A and 2B: Moderate/high control
    - Many commercial parts with review and modification
  - Level 2C and 3: Very high control
    - Many source control part drawings and custom parts
- Selection factors in GEIA-STD-0005-2 include
  - Consequences of system failure
  - Accessibility for repair
  - Safety, availability and reliability
  - System redundancy
  - Anomaly detection
  - Possible plasma events



See also:
https://www.reliabilityanalysislab.com/tl_dp_0403_TinWhiskerRiskMitigation.html

Mitigating Tin Whiskers

Mitigation ≠ Elimination

To mitigate – to make less severe or painful

Merriam-Webster Dictionary definition

SAE GEIA-STD-0005-2A, originally GEIA-STD-0005-2: "Standard for Mitigating the Effects of Tin Whiskers in Aerospace and High Performance Electronic Systems" (first published 2006, revised 2012, currently under review)

Provides a guideline of how big a risk suppliers and manufacturers should consider whisker and what actions they should be taking as a result

Classifies Control Level based on criticality of the product

Not a qualification or assessment standard – guidelines only

Approaches

- Assembly Level – Potting, Coating, etc.
- Part Level – Sn-Pb solder dipping, reballing, etc.

GEIA-STD-0005-2 Level 2B & 2C Accepted Mitigations

- Hard potting or encapsulation
- Physical barriers
- Circuit design and analysis showing
  - low impact of tin whisker short or FOD
  - that areas sensitive to tin whisker shorts or FOD have at least a 1 cm gap for Level 2B
- SnPb soldering process with validated complete coverage
- Parylene conformal coating with validated coverage and gap size greater than
  - 150 microns for Level 2B (e.g. solder dip part if spacing is below 150 microns)
  - 250 microns for Level 2C
- Other, non-parylene, conformal coating with validated coverage and gap size (prior to coating) greater than
  - 250 microns for Level 2B
  - 500 microns for Level 2C
- Pb-free tin electronic components with gaps greater than 2000 microns (78.7 mils) that have been installed with SnPb and are physically isolated from any Pb-free tin mechanical piece parts for Level 2B
- Mitigation or combination of mitigations approved by the customer

Intermittent/Soft Shorts: Circuit consideration examples

- Digital circuits
  - Address line shorts can result in multiple software errors when instructions are retrieved from the wrong part of the memory map
    - Especially parallel address lines to multiple devices
- Analog circuits
  - Shorts can subtly change input or output signals
    - Effect tolerance and accuracy
    - Can still be within margins and difficult to detect errors
- Power circuits
  - Can effect power regulation if on the control circuits
  - Metal vapor arcing evaluation needed
    - Existing design spacing and derating may be sufficient- but need to be checked
    - Especially low impedance high current sources (e.g. batteries, capacitors, etc.)
    - Flammable environment evaluation
- High frequency circuits
  - Whiskers can be antenna
  - Many are not conformal coated
  - Avoid tin/zinc finished shields
- Optical circuits
  - Debris attenuating optical path

Different circuit types have different system impacts

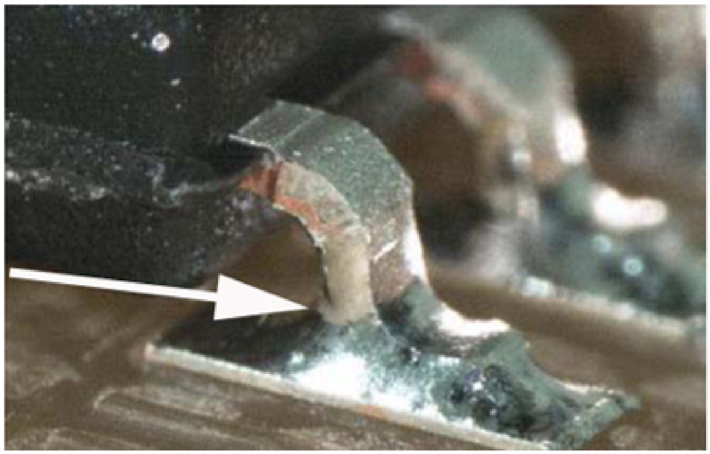
Mitigation by Soldering with SnPb Solder

Mitigation by Soldering with SnPb Solder

Raytheon

- This is a self mitigation or lead poisoning (Pb poisoning) technique
- Uses the tin / lead soldering process to add lead (Pb) to the solder joint and eliminate the risk of tin whiskers
- Still has the risk of insufficient solder flow down component lead surfaces

The arrow at right marks the point at which lead (Pb) containing solder stops



Vertical Termination Height to Horizontal Termination Length found to be a potential criteria to assess self mitigation.

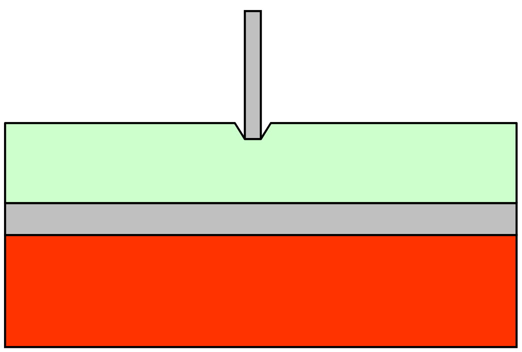
SERDP WP1753 Result:

Thick Sn-3Ag-0.5Cu (SAC305) solder did not grow significant tin whiskers when clean and no active flux residues present

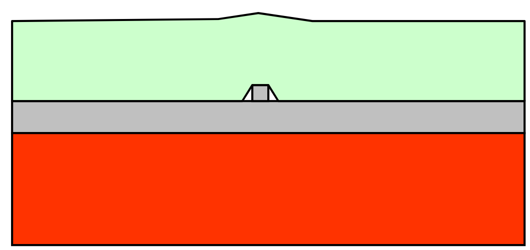
Concept initially presented by Tom Hester Raytheon at
[7th International Symposium on Tin Whisker (2013)]
Held on November 12-13, 2013 in Costa Mesa, CA, USA November 12-13, 2013
Current activity: IPC – PERM Task Group 8-81f

Tin Whisker Failure Risk Mitigation Using Conformal Coating

- The conformal coating has been considered as a mitigation strategy for preventing the electrical shorts by tin whiskers.
- Recent research indicates that under elevated temperature and humidity or in areas of thin covering, whiskers can grow and penetrate conformal coatings.
- For long environmental exposure changes in the effectiveness of conformal coating may be compromised.



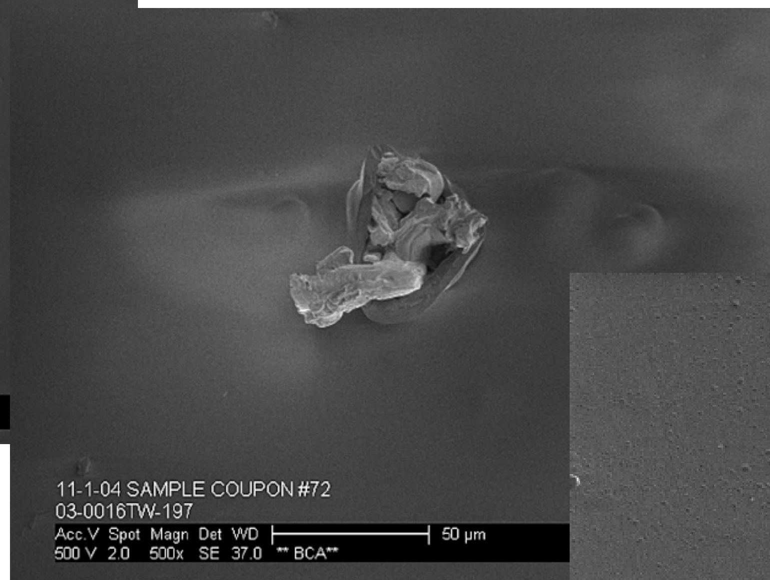
Prevent Contact



Contain Whisker

Tin Whisker Containment Mitigation with Conformal Coat

Urethane Acrylic
~ 33 um



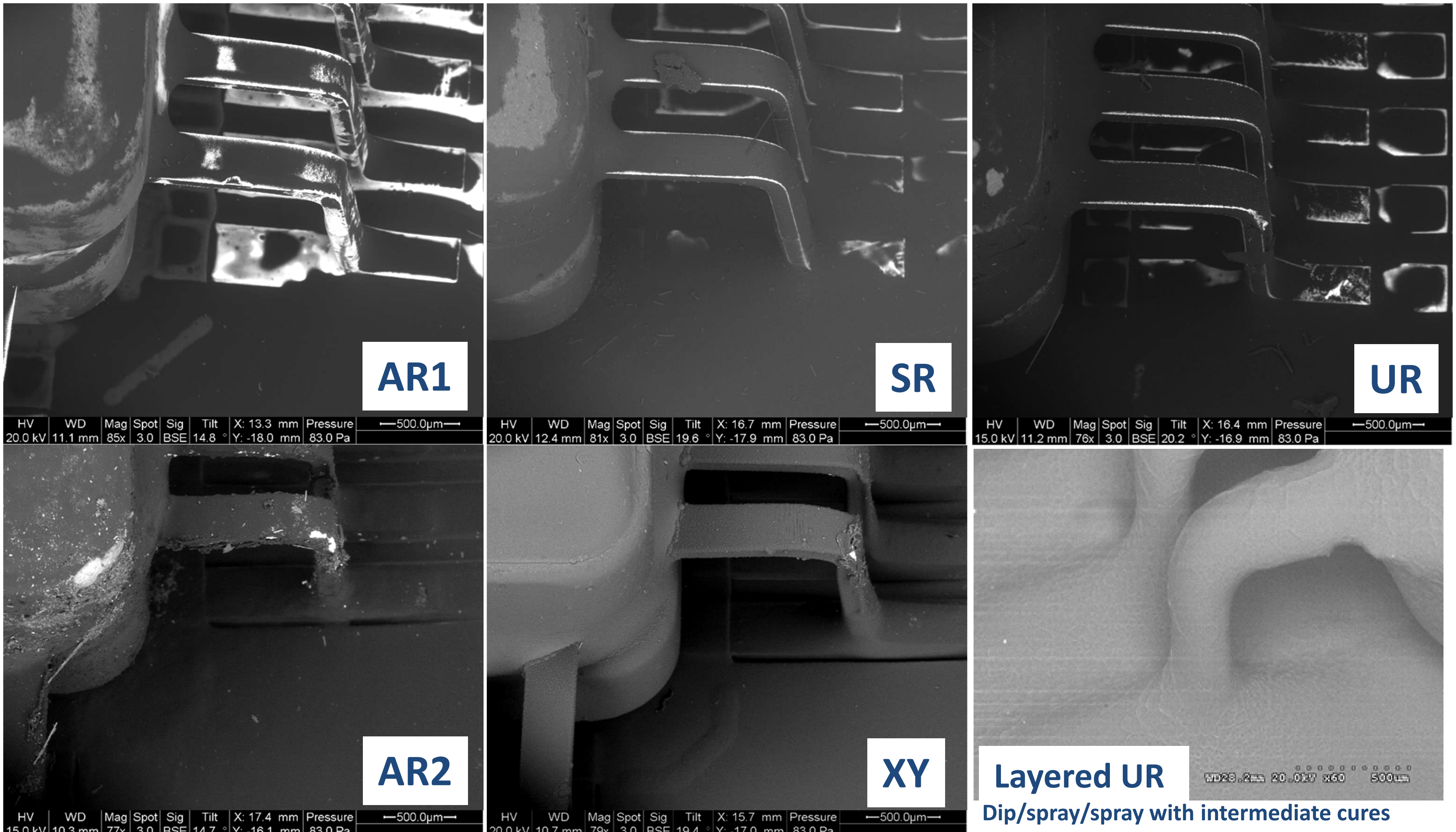
Silicone ~ 33 um

Parylene C ~ 20 um

NASA has test coupons coated with a 50 μm Urethane that has effectively contained whiskers for over 12 years. While conformal coating provided substantial protection against shorts due to tin whiskers, it cannot be assumed to be complete. Above photos show tin whiskers penetrating various coatings.

Photos courtesy of Tom Woodrow, Boeing

Comparison of Coating Coverage

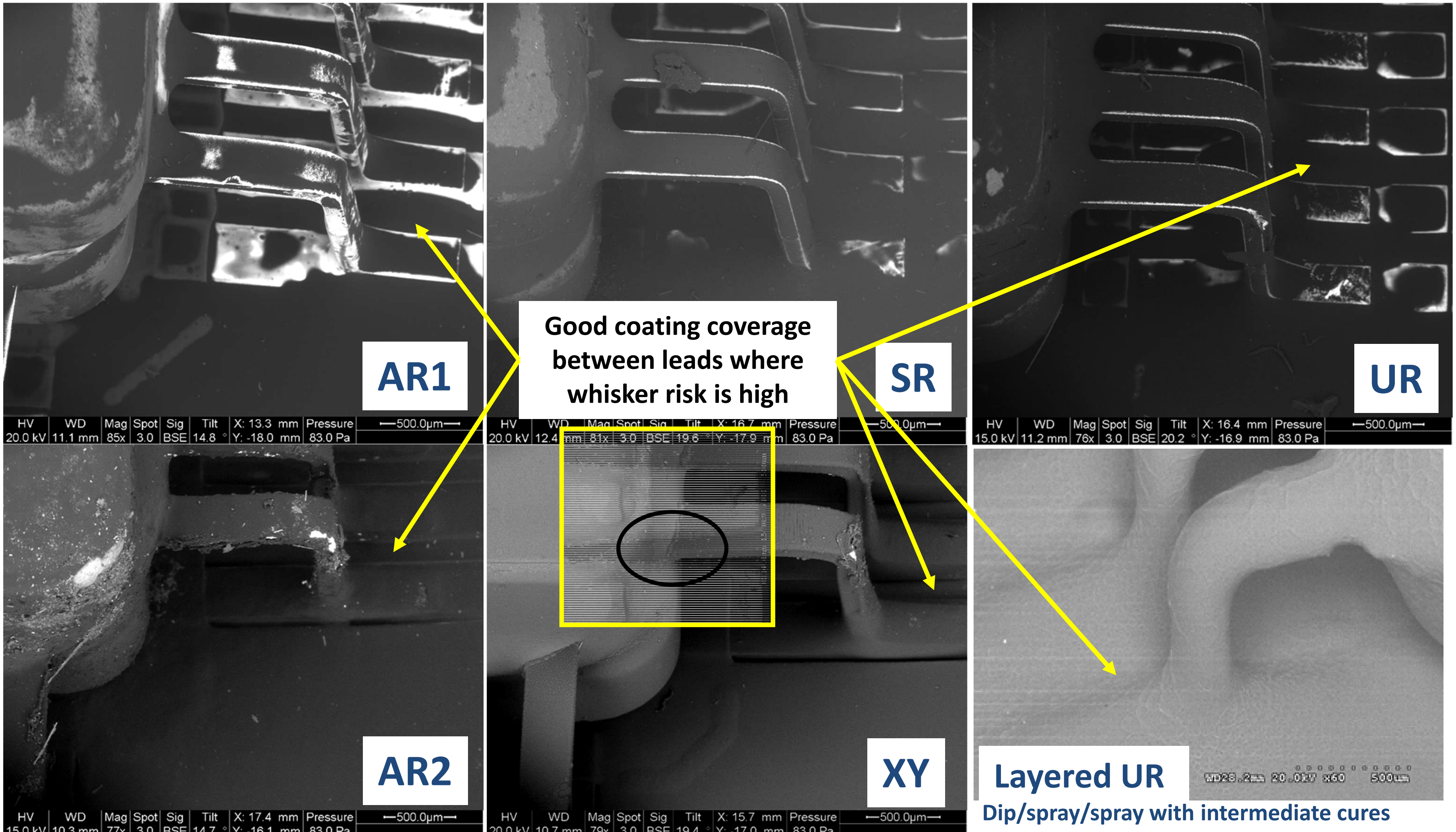


Dip/spray/spray with intermediate cures
SERDP WP2213

IPC Project 5-22ARR Coating coverage state of the industry evaluation in process

Parylene (Type XY) has best coverage, has expenses and can be challenging to rework

Comparison of Coating Coverage



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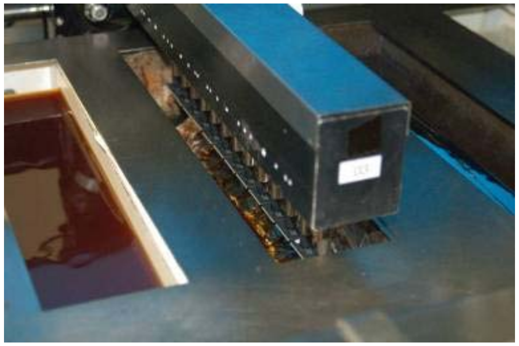
Solder Dip Process

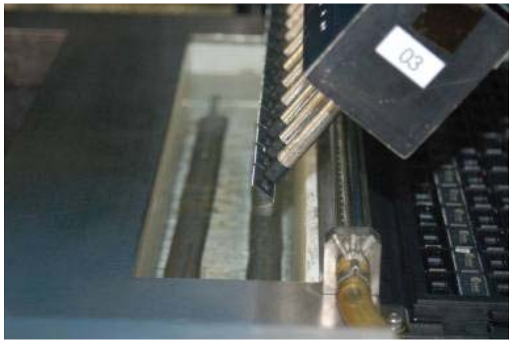
(a) Pick up parts

(b) Flux

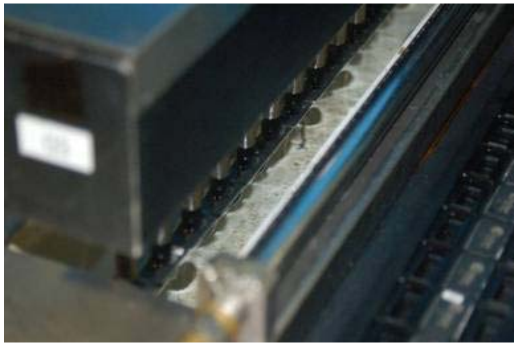


(c) Preheat

(d) Solder dip



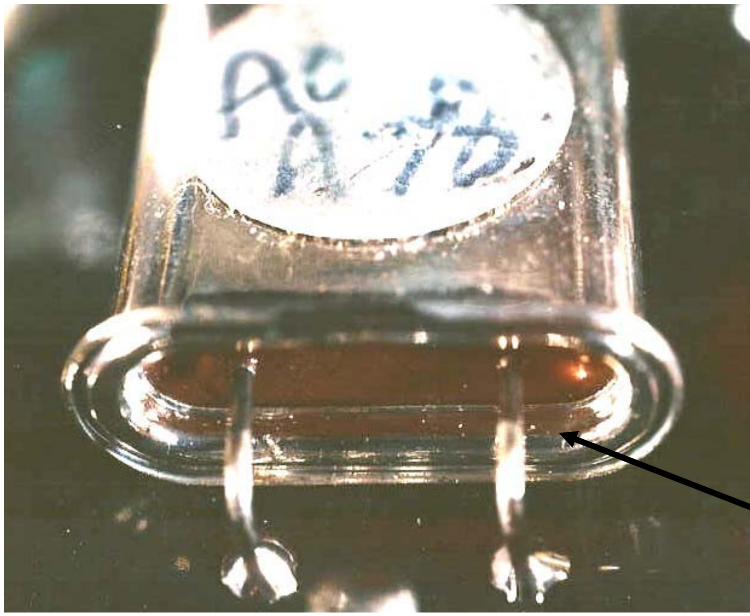
(e) Cool down

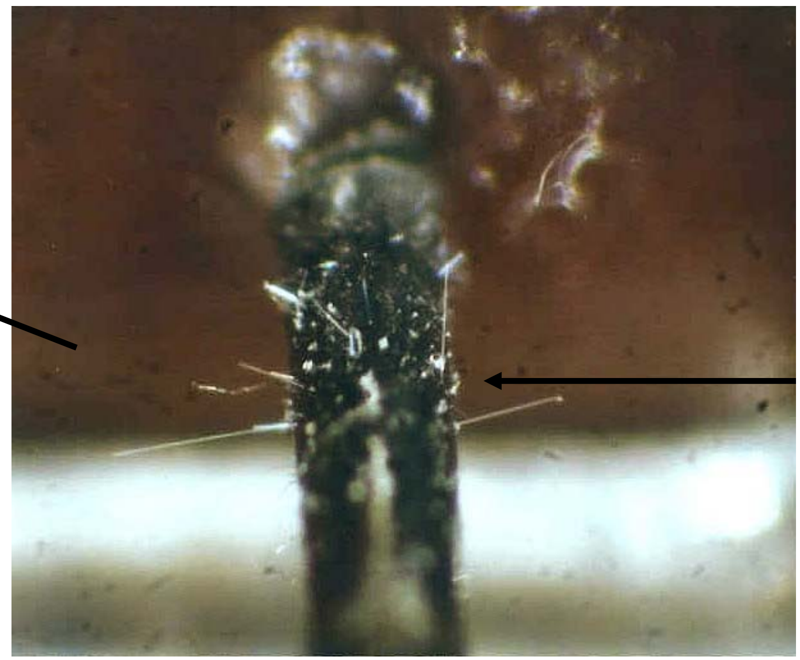


(f) Clean

Solder Dip Mitigation Risk

Tin whisker growth noted from seal to about 20 mils from edge of solder coat.
Electrical failure was traced to a 60 mil whisker that shorted lead to case.



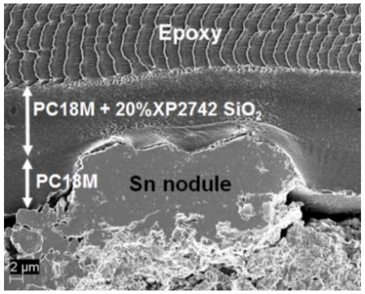


EDGE OF SOLDER DIP

Careful about coverage!

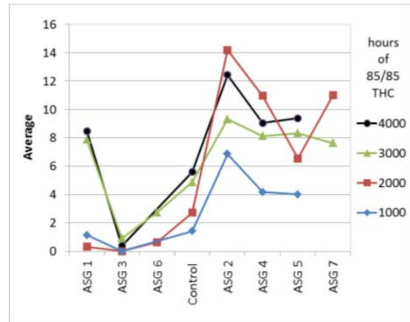
Mitigation research

Nanoparticle strengthened urethane and layered coating for enhanced coverage (SERDP WP2213)



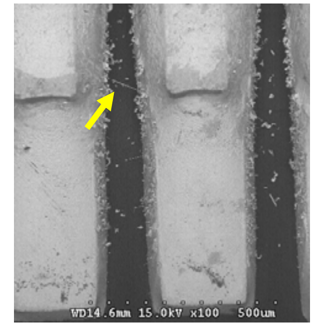
Nanoparticle filled layer over unfilled layer resists nodule penetration

Tin Whiskers Inorganic Coatings Evaluation (SERDP WP2212)



Alkali Silica Glass (ASG3) w/alumina nanoparticles lower whisker density

Tin whisker testing (SERDP WP1753)

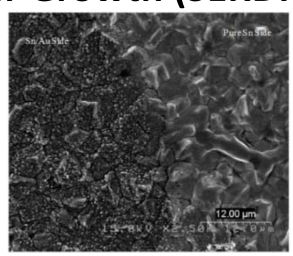


SnAgCu solder can grow whiskers when it becomes thin like tin plating. High cleanliness reduces whisker growth. Interrupting humidity testing stops whisker growth.

Whisker Tough™ coating MDA SBIR Steve Smith

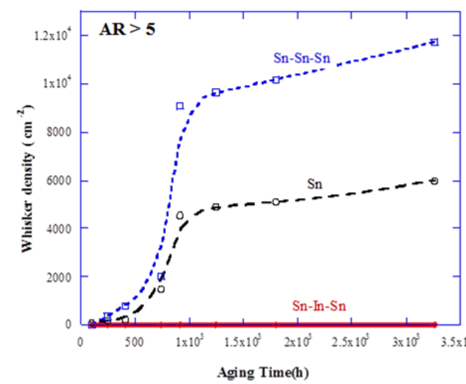
Very high elongation tough coating resists whisker penetration (DMC 2010)

The Role of Trace Elements in Tin Whisker Growth (SERDP-WP1751)



Au, Ge, or Sb additions to Sn substantially reduced whisker growth

Sn-In alloy (I. Dutta WSU)

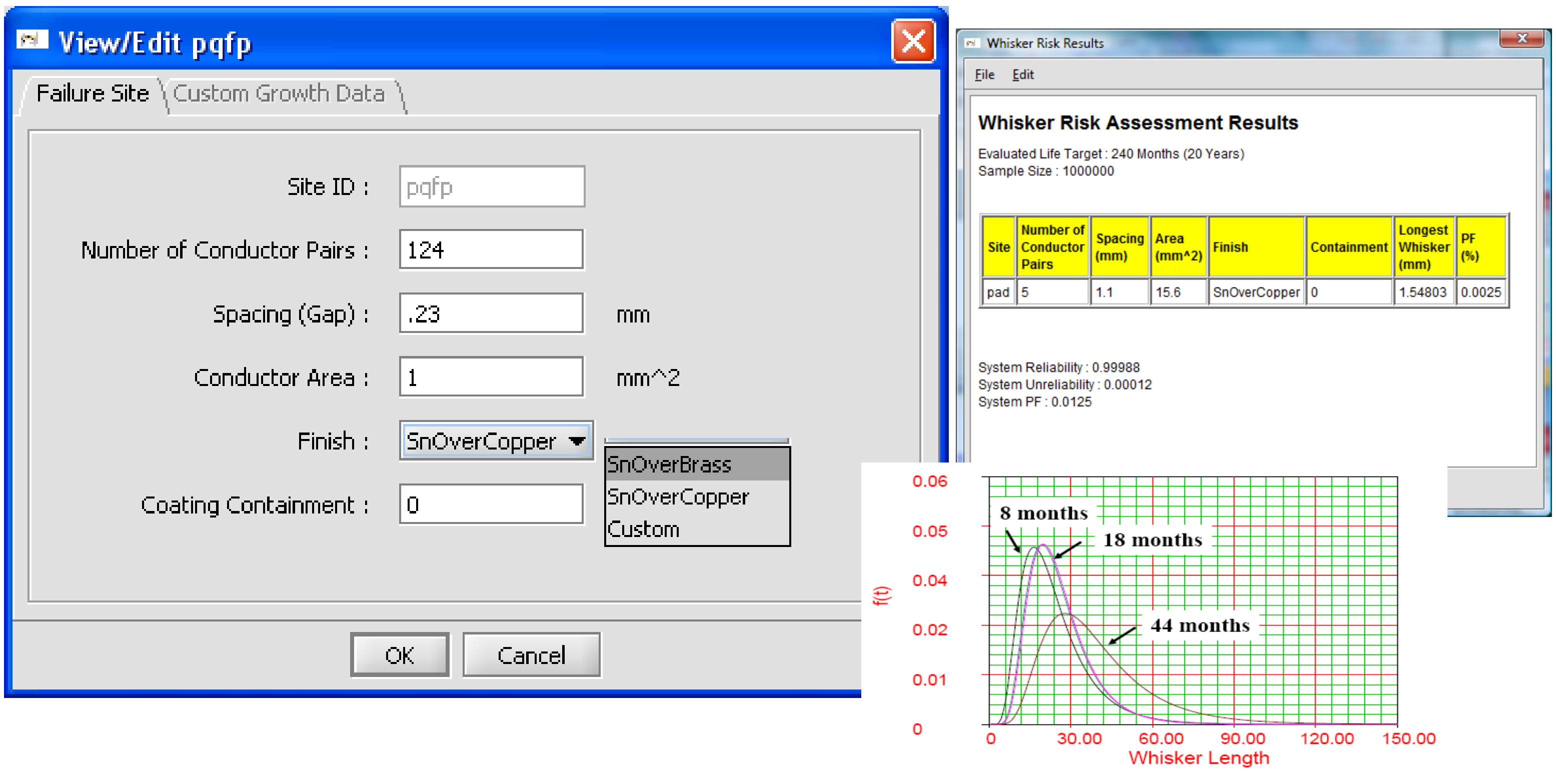


5-10% Indium in Sn significantly retards whisker nucleation during 10 month room temp. test

Others: Photonic Sn sintering (CALCE), Vacuum deposited fluorocarbon coatings NAVY SBIR (http://www.gvdcorp.com/why-gvd/technology), Electroless Ni Metal Cap plating over Sn (Landman), etc...

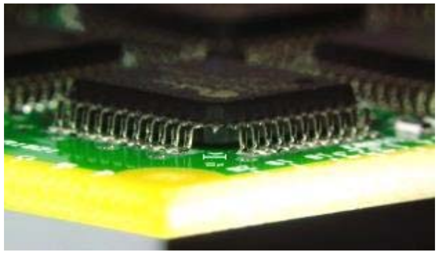
Tin Whisker Risk Assessment

Tin whisker risk is estimated using whisker growth statistics (length and density), and component and assembly conductor materials and dimensions. Distribution of whisker lengths on tin plated surfaces found to follow a lognormal distribution. A Monte Carlo algorithm can be used to evaluate the risk.

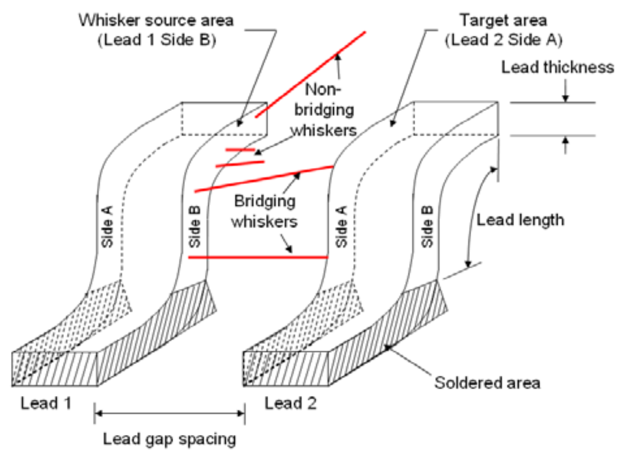


More Information at [**http://www.calce.umd.edu/software/**](http://www.calce.umd.edu/software/)

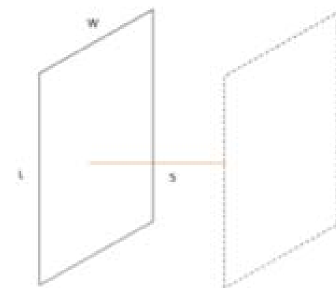
Tin Whisker Risk Assessment Spread-sheet

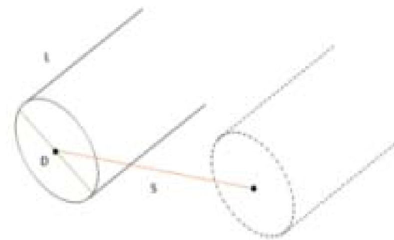


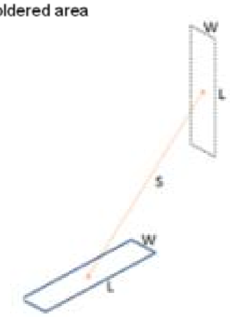
Parts

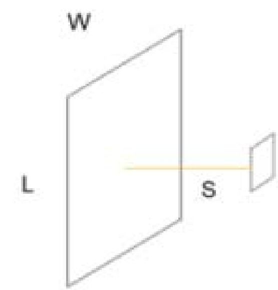


- Part and lead geometry
- Lead, solder, and pad
  - Whisker density
  - Whisker length distribution
- Voltage



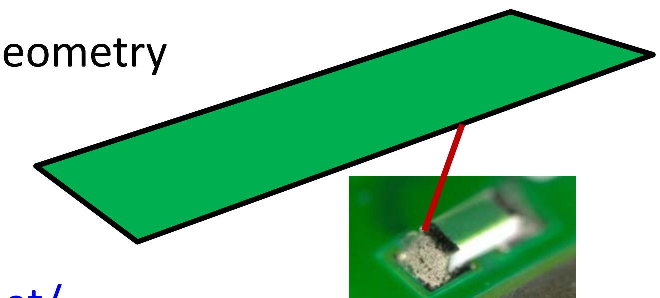






123	WHISKER SHORTING RESULTS:			
124	Coating Effectiveness = 50%			
125	Total lead spaces = 12			
126				
127	Applied Voltage = 5 V			
128	Shorting Probability = 41.4%			
129	Whisker Type:	Lead	Solder	Pad
130	Bridges per lead:	1.773937	1.095674	0.436333
131	Bridges per part:	21.28724	13.14809	5.236
132	Shorts per part:	8.803912	5.437745	2.165489
133	Bridging probability for lead pair:	83.09%	66.62%	35.46%
134	Shorting probability for lead pair:	52.01%	36.45%	16.53%
135	Shorting probability for part:	99.99%	99.57%	88.57%
136	Reliability for not shorting for part:	0.01%	0.43%	11.43%
137				
138	RELIABILITY (this part only) = 0.00%			
139	TOTAL SHORTS (this part only) = 16.41			

Primitive Geometry

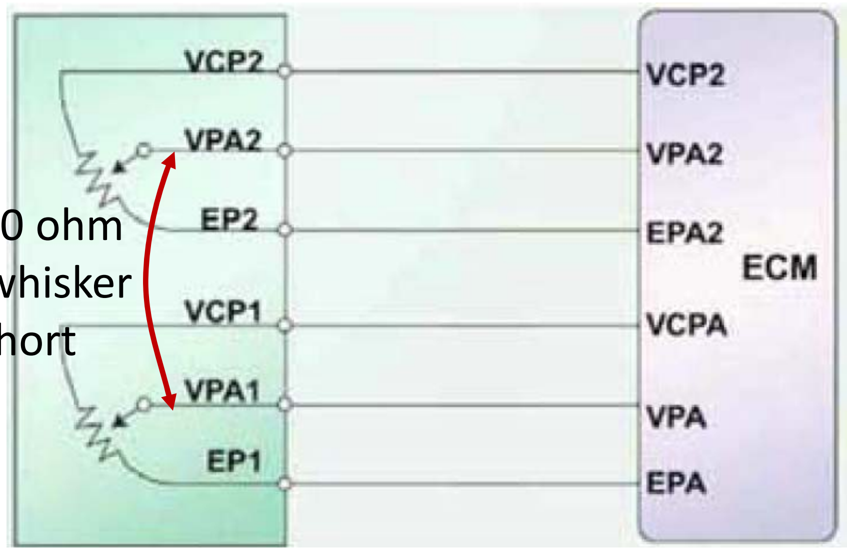


http://www.calce.umd.edu/tin-whiskers/spreadsheet/

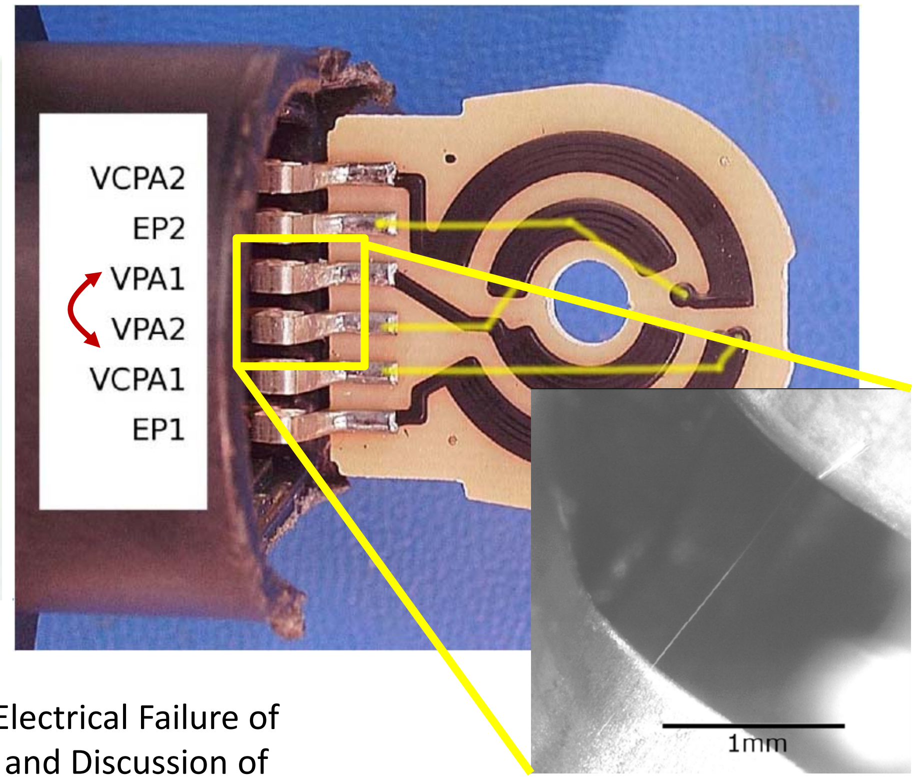
Case study: Tin whiskers in accelerometer pedal position sensor failure

Architecture of Dual Potentiometer Accelerator Pedal Position (APP) Sensor and electronic control module (ECM)

~240 ohm tin whisker short



Actual Dual Potentiometer APP Sensor (partially disassembled)

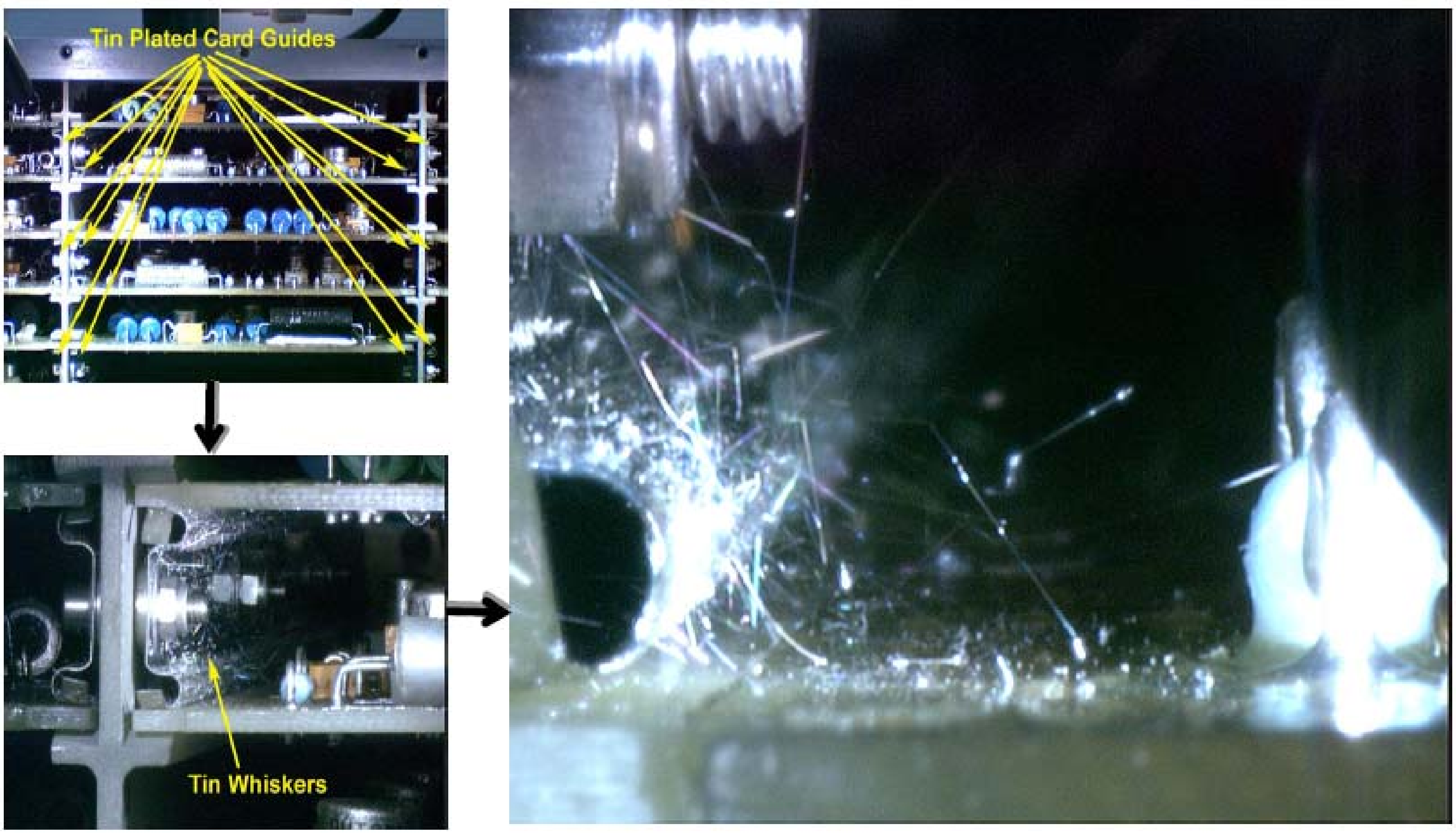


Ref: H. Leidecker, L. Panashchenko, J. Brusse, NASA Goddard, Electrical Failure of an Accelerator Pedal Position Sensor Caused by a Tin Whisker and Discussion of Investigative Techniques used for Whisker Detection, 5th Tin whisker Symposium CALCE University of Maryland 2011

Whisker caused shorting between redundant potentiometer elements

Case study:

Space shuttle tin whisker issue: Whisker growth on card guides



K. Nishimi, Space Shuttle Program Tin Whisker Mitigation, International Symposium on Tin Whiskers, University of Maryland – CALCE, April 24-25, 2007

Case study:

Space shuttle tin whisker issue (continued)

- Multidisciplinary Tiger team formed
  - Design engineering, logistics, test engineering, materials and processes (M&P), ground operations, research
  - Multiple NASA centers, prime contractors, sub-contractors, hardware suppliers
- Remediation plan developed
  - Incoming test, dis-assembly and whisker evaluation (gross order of magnitude)
  - Replace card guides and board/box cleaning
  - Re-assembly and test
- Phased in remediation considering
  - Multiple years/flights, priority to critical boxes
  - Avionics lab staffing level, quantity of test stations
  - Diversion of equipment and personnel for unrelated failures in the same boxes

Multidisciplinary tiger team supported immediate launch and long term equipment dispositions

Summary and Conclusions

- Unintended introduction of lead-free tin-rich materials can significantly increase failure risk including tin whisker short circuit risk
- All pure tin and Pb-free tin alloy finishes appear to be susceptible to whisker formation
- Part supplier mitigation strategies show varying levels of effectiveness
- Solder dip found to be effective
  - But, may not be applicable to all parts and be careful about coverage
- Solder assembly mitigation must confirm solder coverage and thickness
- Conformal coat reduces the probability of whisker short but may not completely contain whiskers
  - Coverage in application remains a critical concern
    - Parylene found to have the best coverage (vacuum deposited, challenging special rework, watch out for connector contacts)
    - Sprayed coatings may have lower coverage (Most commonly used, easiest to apply and rework. Often used in combination with assembly solder mitigation)
- Failure risk due to tin whisker formation is application dependent and should be assessed based on defined geometries and whisker growth characterizations
- Best practice:
  - GEIA-STD-0005-1 & 2 Lead-free control plans
  - OEMs should develop a plan for mitigating risk due to tin whisker formation
  - Include lead-free control plan flow down to sub-tier suppliers

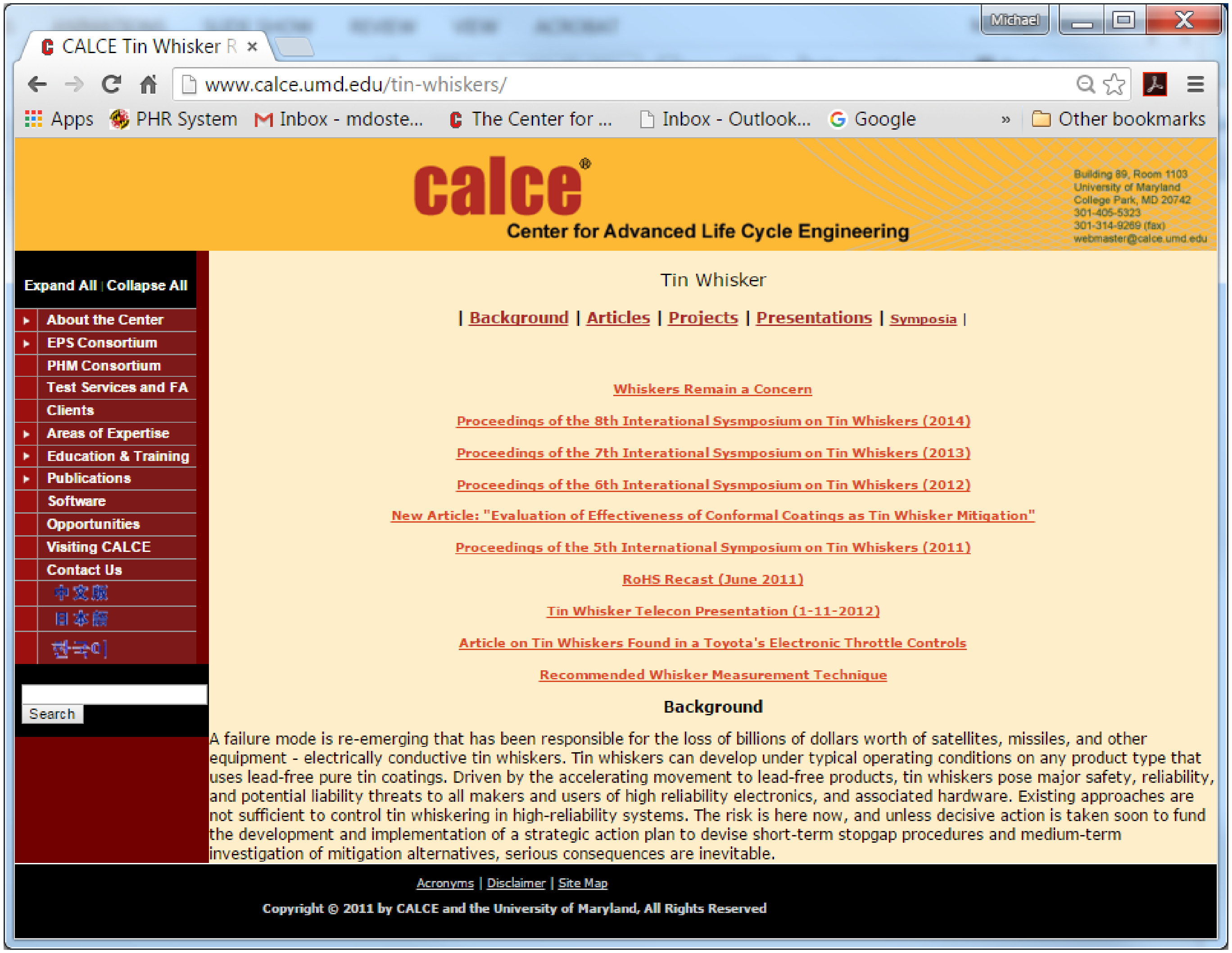
Your Regular Everyday Tasks

- ✓ **Evaluate system requirements in context of lead-free materials risks**
  - **Review contract terms and conditions**
  - How much safety, availability, and reliability is expected by design?
  - Is programmatic safety, availability, and reliability management needed (hot-swap, redundancy, spares, etc.)?
- ✓ **System Lead-Free Control Plan (LFCP) is critical**
  - SAE GEIA-STD-0005-1 Performance requirements (+ see supplemental slides)
  - Include with other PM&P items: e.g. counterfeit, corrosion, etc.
  - **Determine SAE GEIA-STD-0005-2 tin whisker risk mitigation level.**
  - Can lead-free solder be used?
  - **Sub-contract flow down data Item: DI-MGMT- 81772**
- ✓ Consider ways to gain lead-free experience
  - Include some lead-free boards; Path finder vehicles
- ✓ Establish **lead-free team knowledge** for effective control plan review
  - Programs, Systems, Design, Manufacturing, Sourcing, Repair
- ✓ **Leverage resources and invest time, talent, and material**
  - IPC-PERM Council (meets 2 – 3 per year)
  - SERDP lead-free research, industry research

IPC-PERM = IPC Lead(**P**b)-free **E**lectronics **R**isk **M**anagement

If you don't recognize these items, program is at risk…

For More Information on Tin Whiskers



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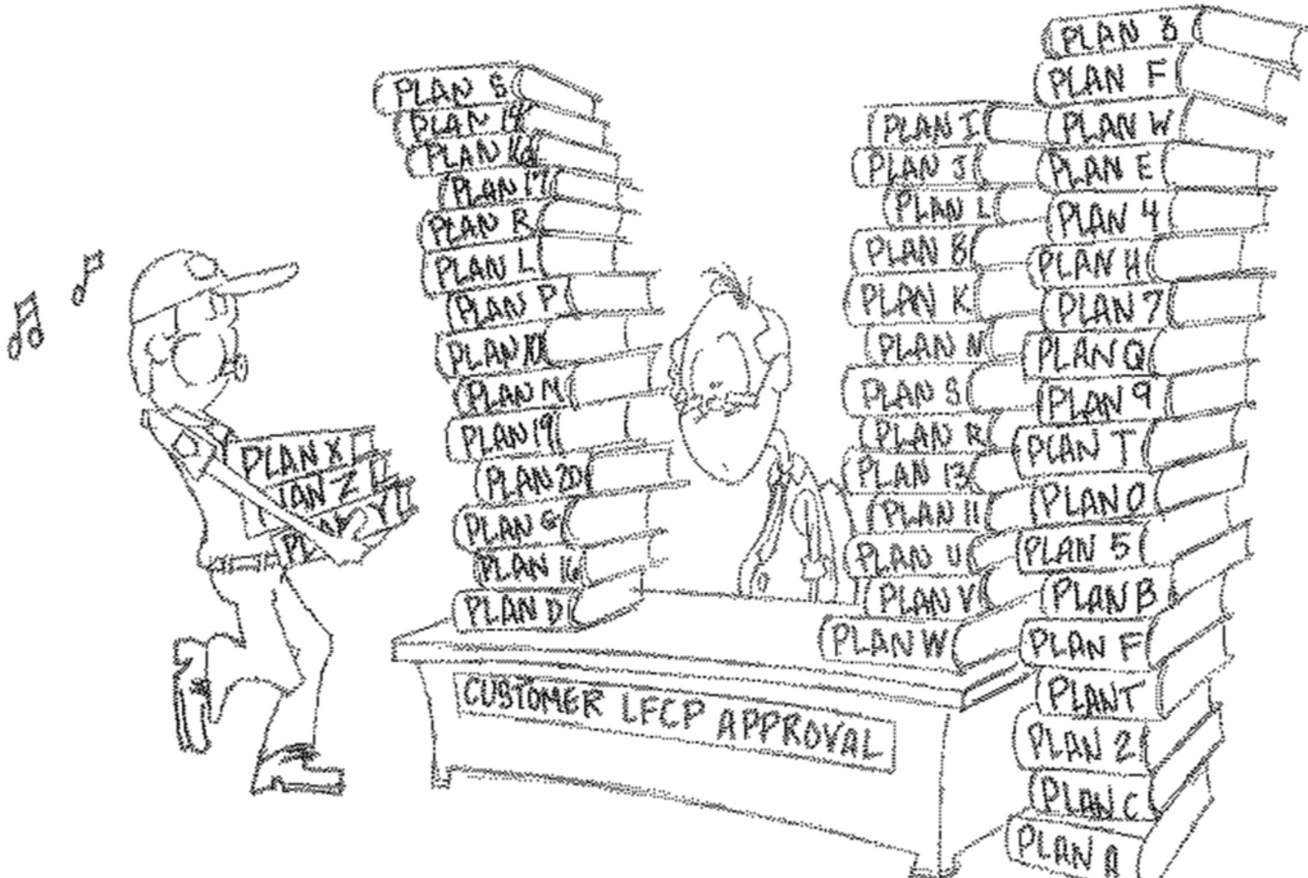

Is your supply base coordinated?
Is your team trained and ready for the review?

QUESTIONS