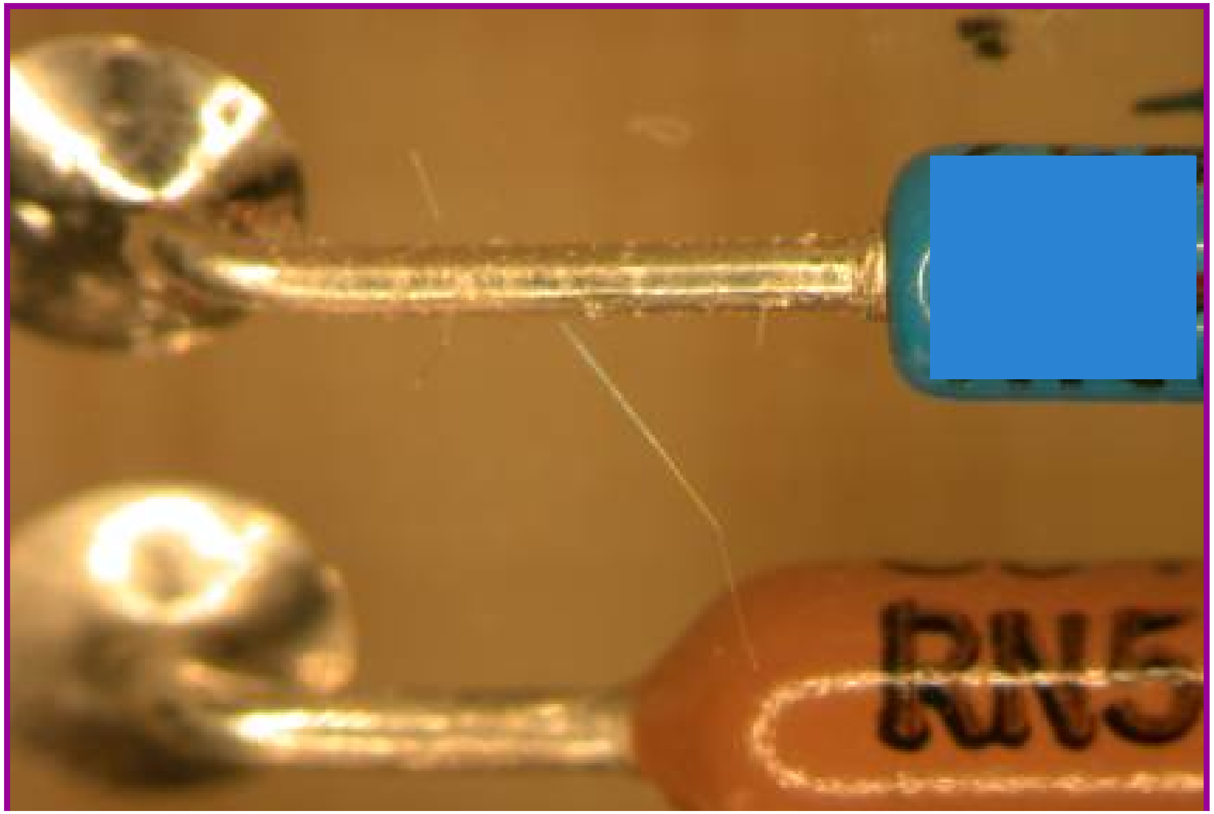
Metal Whiskers

A Discussion of Risks and Mitigation



Jay Brusse / Perot Systems
Dr. Henning Leidecker / NASA Goddard
Lyudmyla Panashchenko / Univ. of MD-CALCE Graduate Student

http://nepp.nasa.gov/whisker

November 12, 2008

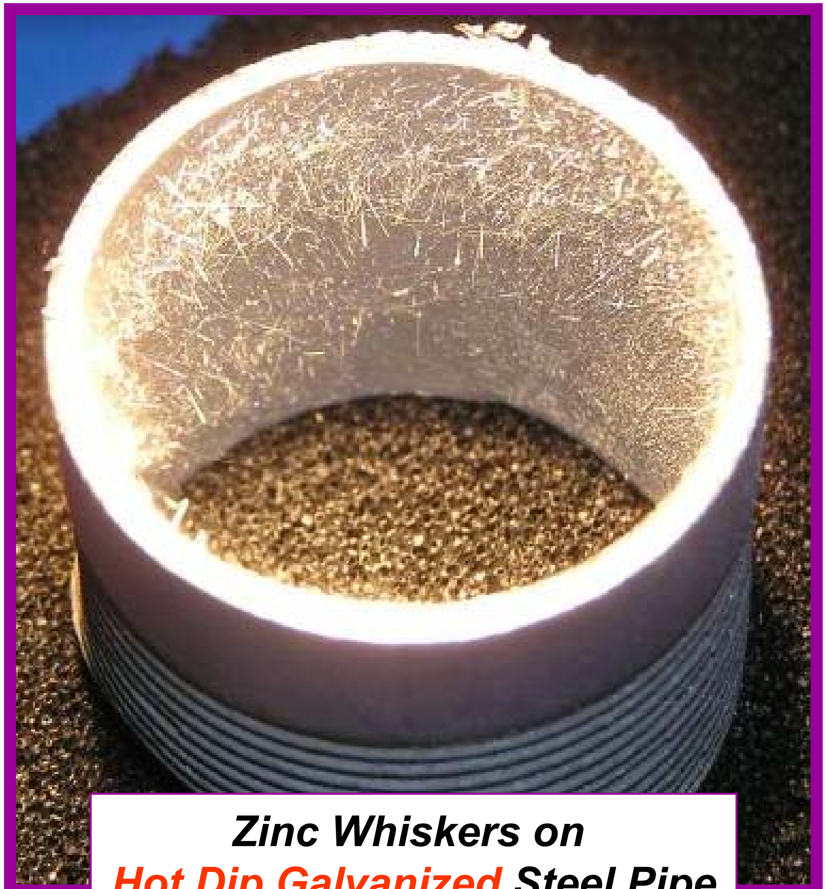
Symposium on Part Reprocessing, Tin Whisker Mitigation and Assembly Rework

Outline

- A Brief History of Metal Whiskers
  No Growth Theory
  To Be Discussed!!!

- Electrical Properties of Metal Whiskers
  Character of Short Circuits

- NASA Whisker Mitigation Study
  Arathane 5750 Conformal Coat



Zinc Whiskers on
Hot Dip Galvanized Steel Pipe

Cover Photo:
Tin whiskers on Tin-Plated Diode Terminals (Courtesy Ted Riccio - STPNOC)

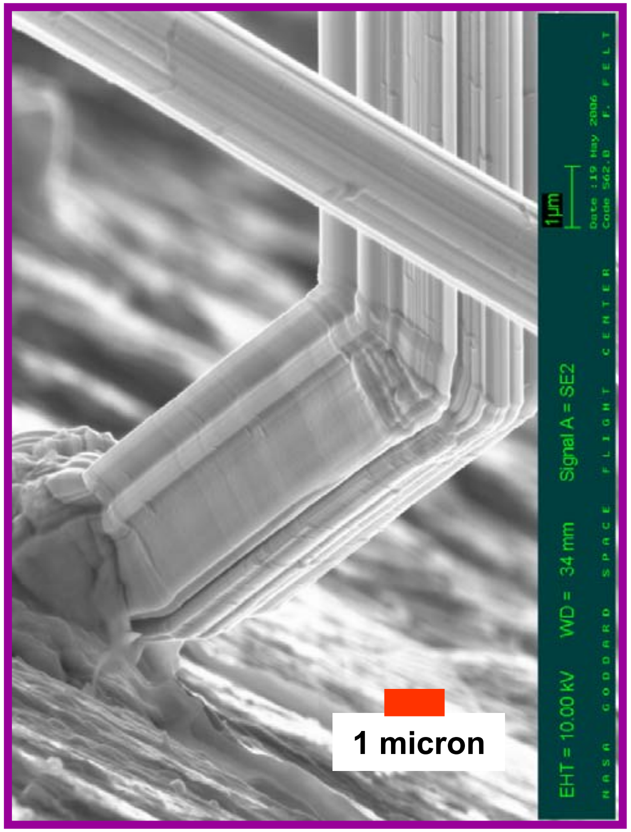
What are Metal Whiskers?

- **DESCRIPTION:**
  - **Hair-like, metallic crystals that UNPREDICTABLY grow out from a metal surface**
    - **Straight or kinked filaments, nodules, odd-shaped eruptions**
    - **Filaments usually have uniform cross section along entire length**
  - **Tin, Zinc and Cadmium coatings are most common sources**
  - **Whiskers are also less frequently seen on metals like Indium, Silver, Lead, Gold and other metals**

- **GROWTH TIMELINE:**
  - ***Incubation:*** **Absence of growth may last hours to years**
  - ***Growth:*** **Accretion of metal ions at base of whisker NOT at tip**
  - ***Growth Rate*****: < 1 mm/yr (typical)**
    Highly variable (up to 9mm/yr reported)

- **LENGTH: Log-normal distribution (CALCE, et al)**
  ~1 mm or less (typical)
  Rarely up to 10 mm or more

- **THICKNESS: A few microns (typical)**
  Range 0.006 to >10 um
  10 to >100 times thinner than a human hair!!!



Tin Whiskers on Tin-Plated Electromagnetic Relay Terminals

The Good News:

Not All Tin, Zinc or Cadmium Surfaces
Will Grow Whiskers
(See Back Up Slide for Discussion)

The Bad News:

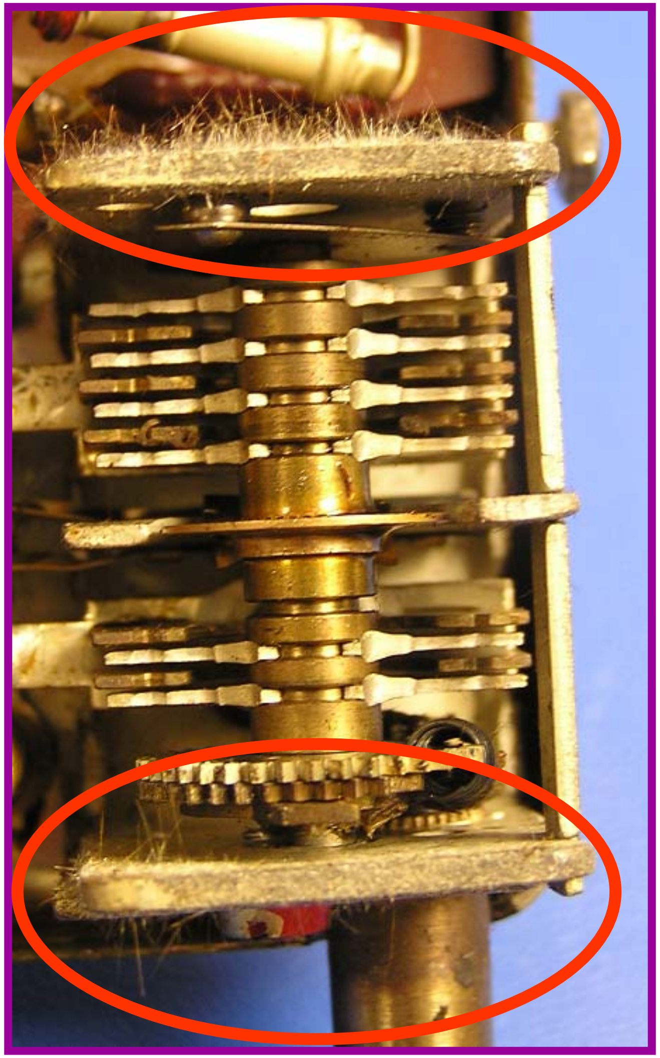
Current theories and test methods **DO NOT**
have predictive power of the time-dependence of
Whisker Density, Length or Thickness Distributions

A useful theory should identify what we must
control to make confident predictions.
Such a theory has remained elusive

Metal Whiskers
“The Early Years”

- **1946: Cadmium Whiskers[1]**
  H. Cobb (Aircraft Radio Corp.) published earliest known account of CADMIUM whiskers on cadmium-coated variable air capacitor plates. Cd whiskers induced electrical shorting in military aircraft radio equipment. These events occurred during WW II (~1942 – 1943)

- **1951: Tin and Zinc Whiskers**
  After learning of electrical failures from Cd whiskers, Bell Labs opted to use Tin and Zinc coatings. But then Compton, Mendizza, and Arnold reported shorting caused by whiskers from these coatings too!



Tin Whiskers on 1960's Era Variable Air Capacitor
Similar to Types Described By Cobb in 1946

[1] H. Cobb, “Cadmium Whiskers”, Monthly Rev. Am. Electroplaters’ Soc., 33, 28, Jan. 1946

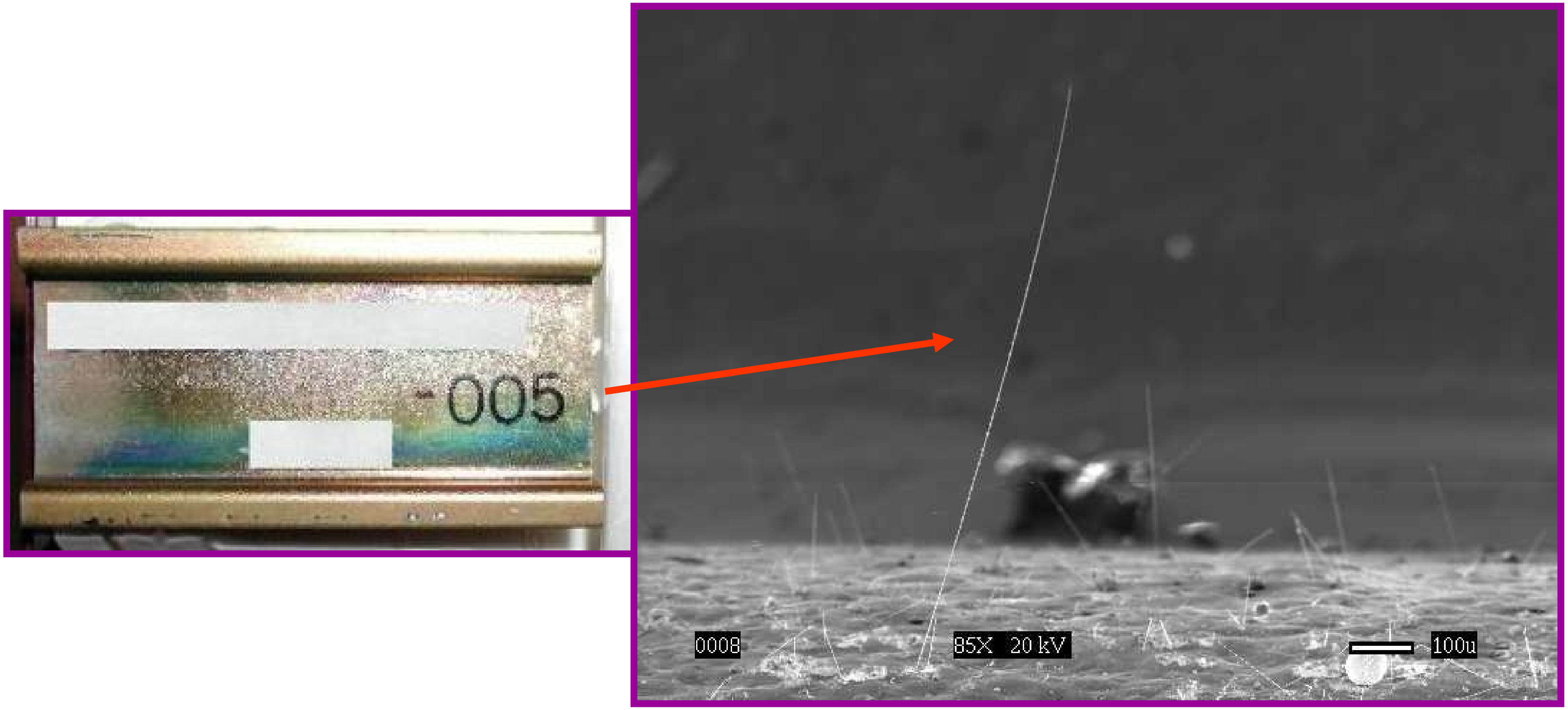
Whisker Resistant Metal Coatings
"The Quest"

- **1950s and 60's [1] [2]:**
  Bell Labs worked through the periodic table to determine whether co-deposition of some element with Tin would "inhibit" whiskering
  - ***Adding 0.5 - 1% by weight or more of Lead (Pb) into tin inhibits whiskering***
  - ***Alloying with metals other than Pb sometimes ENHANCES whiskering***
- **Since 1990s:**
  To inhibit whiskers most US MIL specs require adding Pb to tin coatings used near electronics
  - **For design margin, greater than 2% to 3% Pb by weight is usually specified**
- **What additives quench Zn & Cd whiskers?**
  - **There appear to be no active efforts to investigate**
  - **Chromate conversion finishes DO NOT appear to stop whisker formation**

[1] S. Arnold, "Repressing the Growth of Tin Whiskers," *Plating*, vol. 53, pp. 96-99, 1966
[2] P. Key, "Surface Morphology of Whisker Crystals of Tin, Zinc and Cadmium," *IEEE Electronic Components Conference*, pp. 155-160, May, 1970

Examples of Metal Whiskers

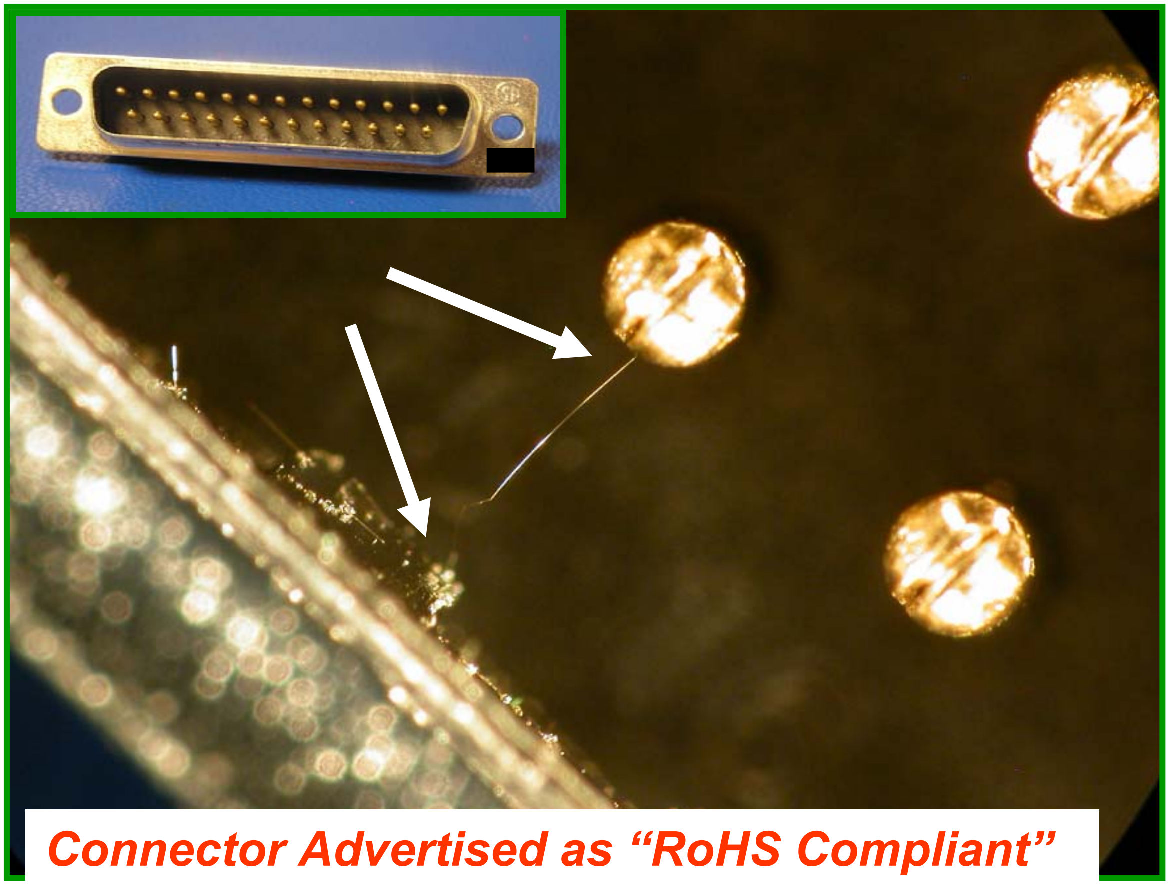
Zinc-Plated Steel Bus Rail with Yellow Chromate Conversion Finish



Zinc whiskers grew up to several mm-long and shorted power to ground producing a metal vapor arc that disrupted the testing of a spacecraft system

Examples of Metal Whiskers

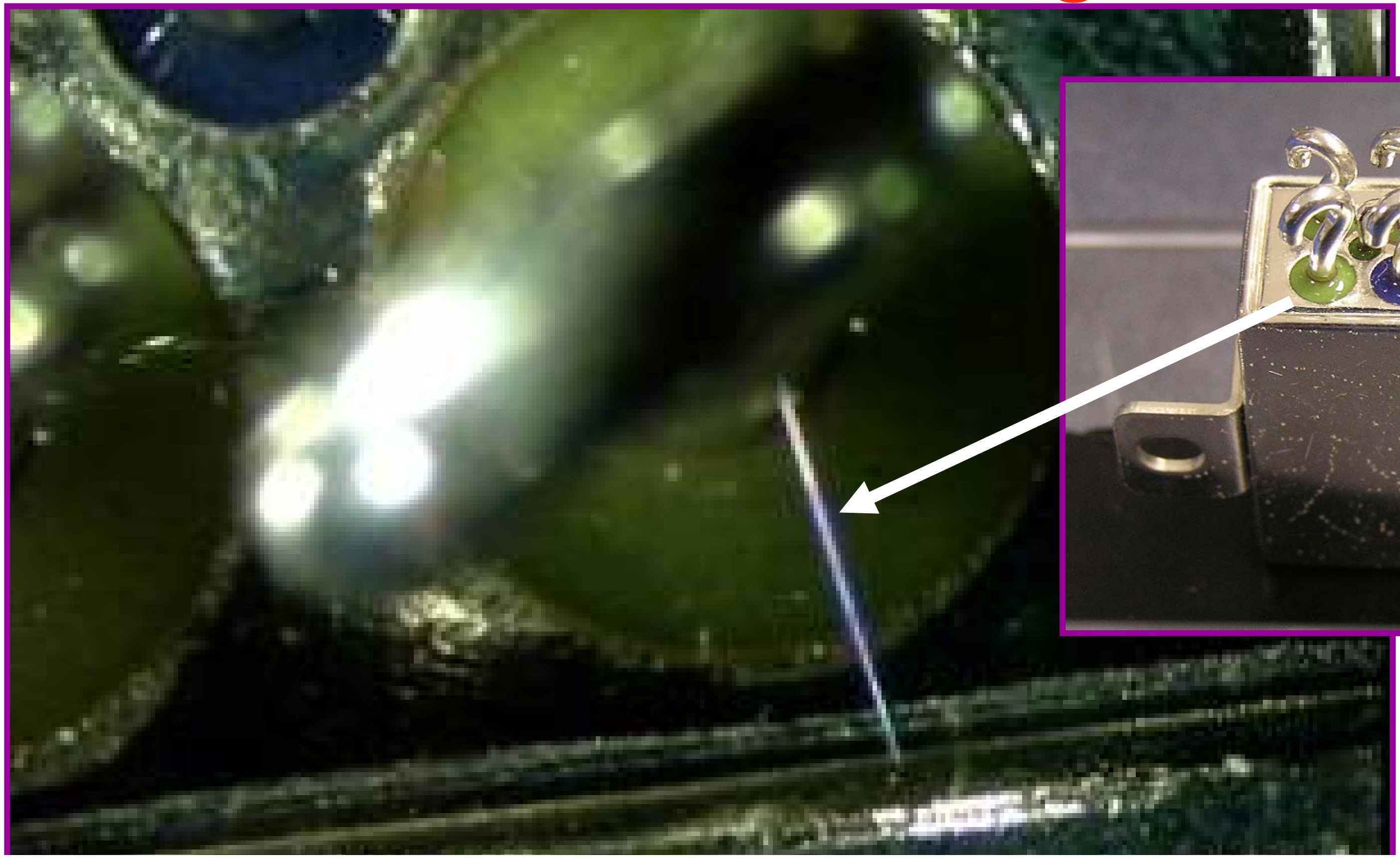
Tin-Plated D-Sub Connector Shell



Connector Advertised as "RoHS Compliant"

Examples of Metal Whiskers

Tin-Plated Electromagnetic Relay

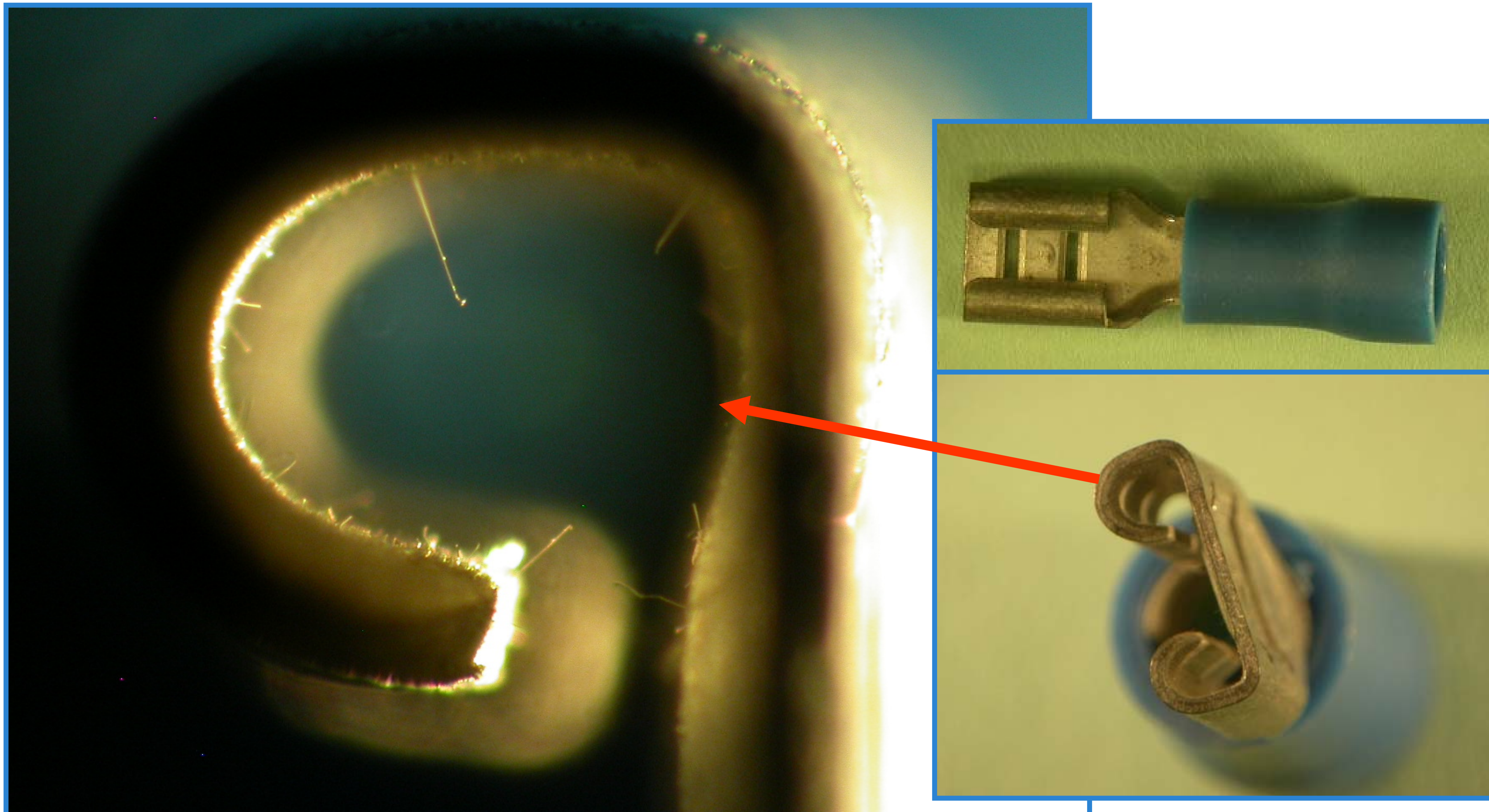


Procurement Specification for this Relay Required >2% Pb in the Tin-Plating, However, Pure Tin-Plated Relays were Supplied

TRUST BUT VERIFY!!!

Examples of Metal Whiskers

Tin-Plated Terminal Lugs

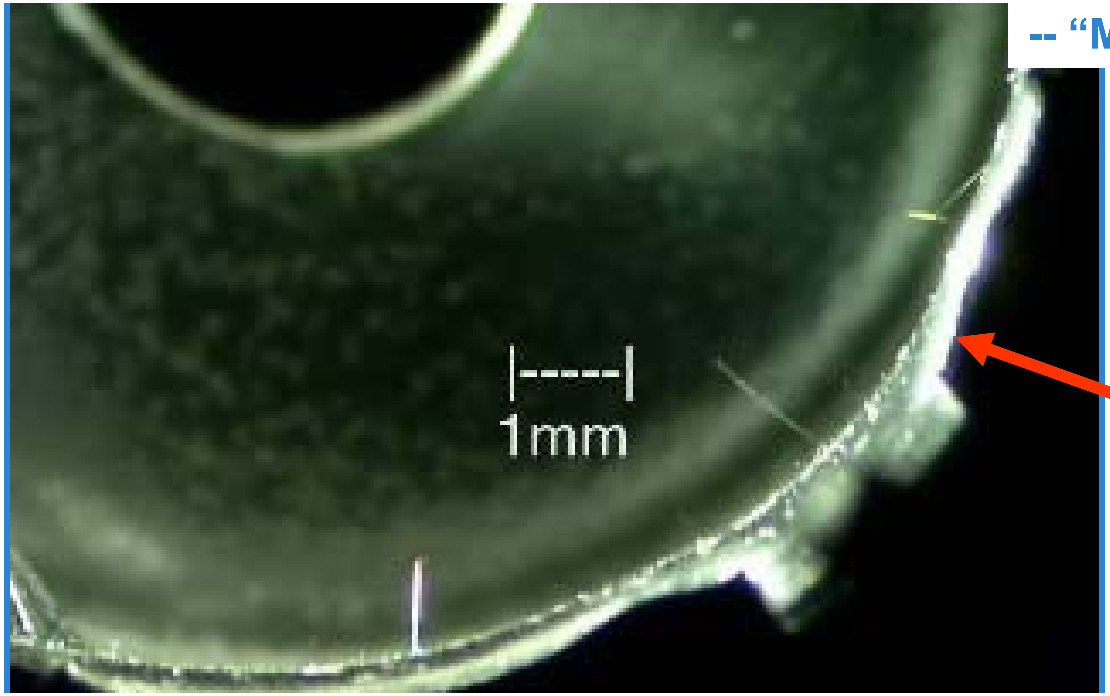


Examples of Metal Whiskers

Tin-Plated Transformer Can

"We appreciate your loyalty for so many years and your email concerning the whisker growth (in our products). The push to be RoHS compliant has caused us to switch our plating process and introduce new materials that are environmentally friendly but they in turn created other problems."

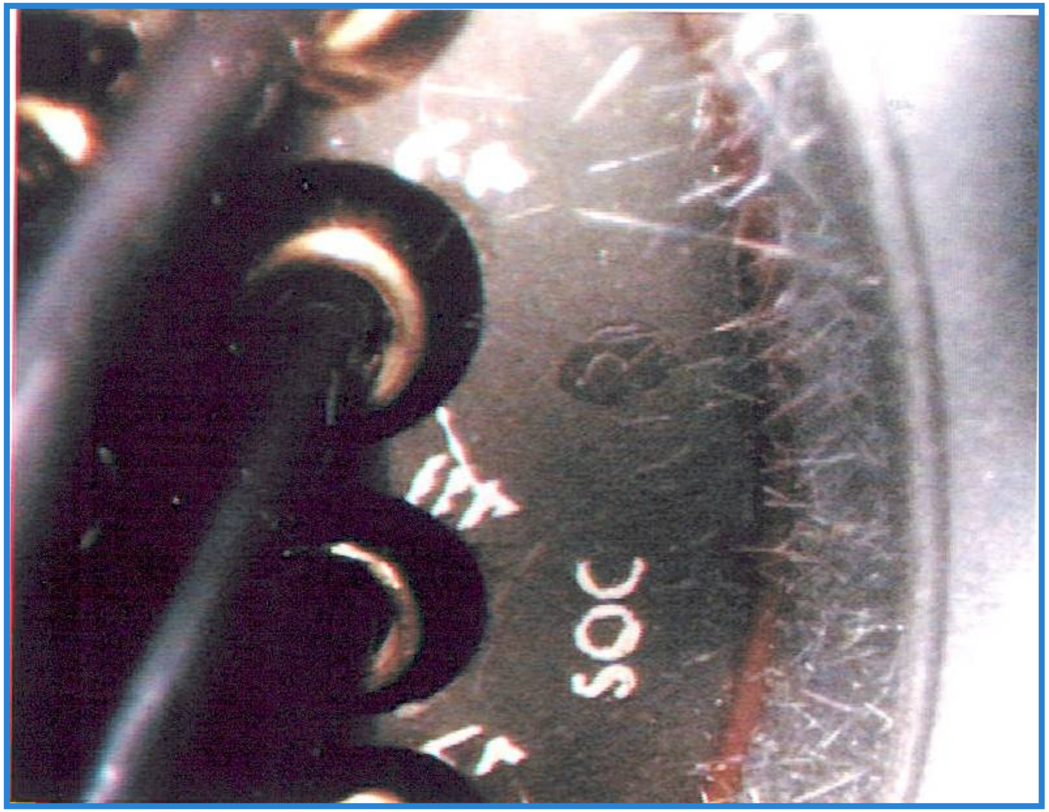
-- "Manager of xxx" (July 2006)



Tin whiskers observed in "as-received" cans
Coincidental with Mfr Switch from Tin-Lead to Pure Tin Finish

Examples of Metal Whiskers

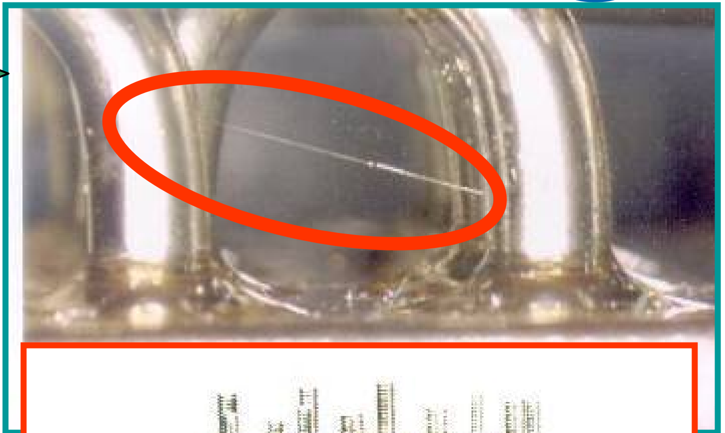
Cadmium-Plated Connector Shell



Cadmium whiskers on a feedthru connector for a thermal-vacuum chamber
Cd whiskers grew to be several mm-long and produced electrical shorts from shell to connector pins that interrupted testing of a spacecraft system

Electrical Properties of Metal Whiskers

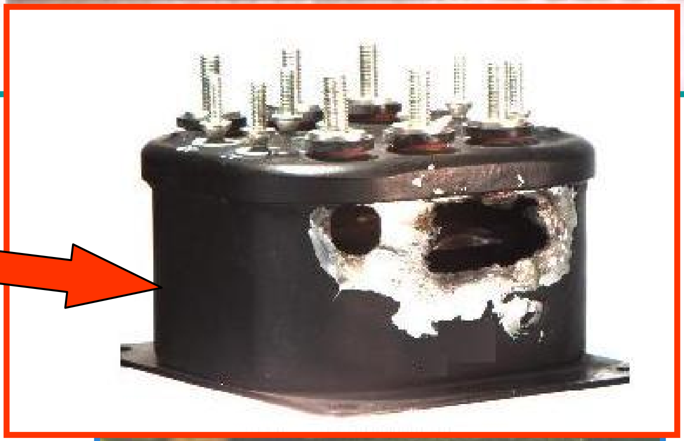
Electrical Short Circuits



$$R = \frac{\rho \cdot L}{A}$$

Where
R = resistance of whisker
ρ = resistivity; L = length;
A = cross sectional area

- **Continuous short if current** $I_{whisker} < I_{melt}$
- **Intermittent short if** $I_{whisker} > I_{melt}$
- ***Metal Vapor Arc!!!*** ***See Discussion***
  Up to HUNDREDS of AMPERES can be Sustained!!!



Debris/Contamination

- **Dislodged whiskers become foreign object debris**
  - **Produce Shorts in Areas REMOTE From Whisker Origins**
    Example: zinc whiskers are often detached from zinc-coated raised floor tiles by physical handling. Once detached they are re-distributed by air currents into nearby electronic assemblies

http://nepp.nasa.gov/whisker/reference/tech_papers/2004-Brusse-Zn-whisker-IT-Pro.pdf

Whisker Melting Current and Voltage (in Vacuum)

$$I_{melt,vac} = \left[\frac{2\sqrt{Lz}T_0}{R_0}\right]\cos^{-1}\left(\frac{T_{amb}}{T_{melt}}\right)$$

$$V_{melt,vac} = 2\sqrt{Lz}\sqrt{T_{melt}^{2} - T_{amb}^{2}}$$

– ***Where*** ***$Lz \sim 2.45 \times 10^{-8}$ $(V/K)^2$ is the Lorenz number, T_{melt} = melting temperature, T_{amb} = ambient temperature, T_0 = ref. temp, R_0 = whisker resistance at ref. temp***

Material	T_{melt}	$I_{melt,\,vac}$ for To = Tamb =293.15K	$V_{melt,\,vac}$ for Tamb =293.15K
Tin	505.1K	87.3 mV / R_0	***129 mV***
Cadmium	594.2K	96.8 mV / R_0	***196 mV***
Zinc	692.7K	104.1 mV / R_0	***162 mV***

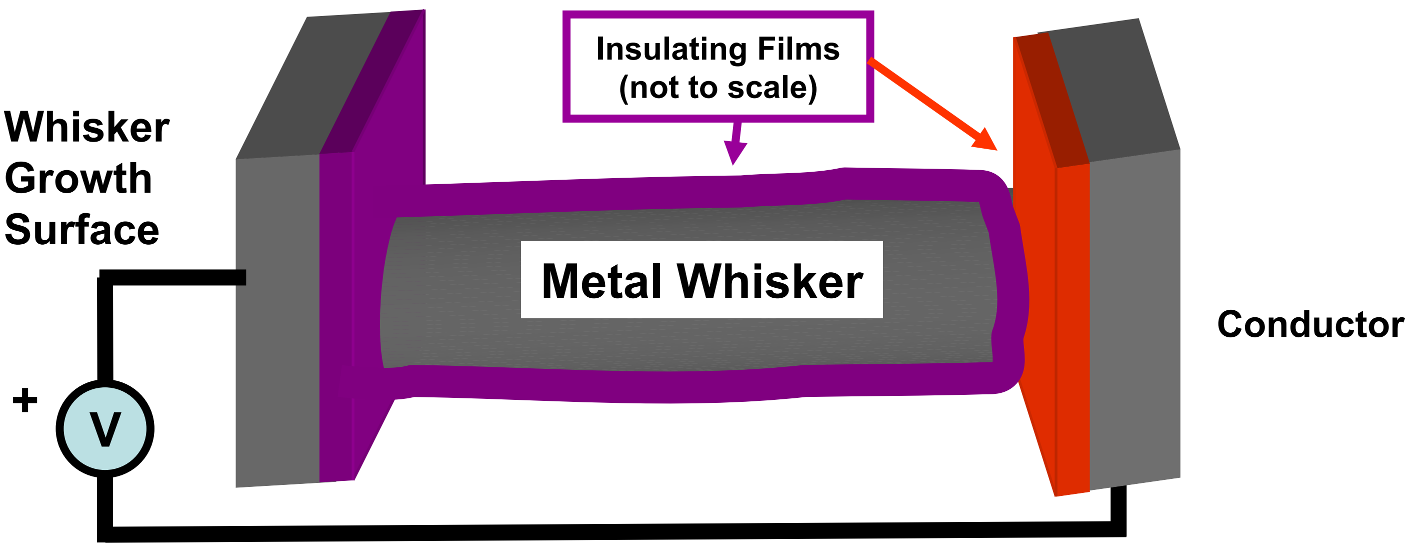
If $V_{whisker} > V_{melt}$

Then the Whisker will Fuse Open

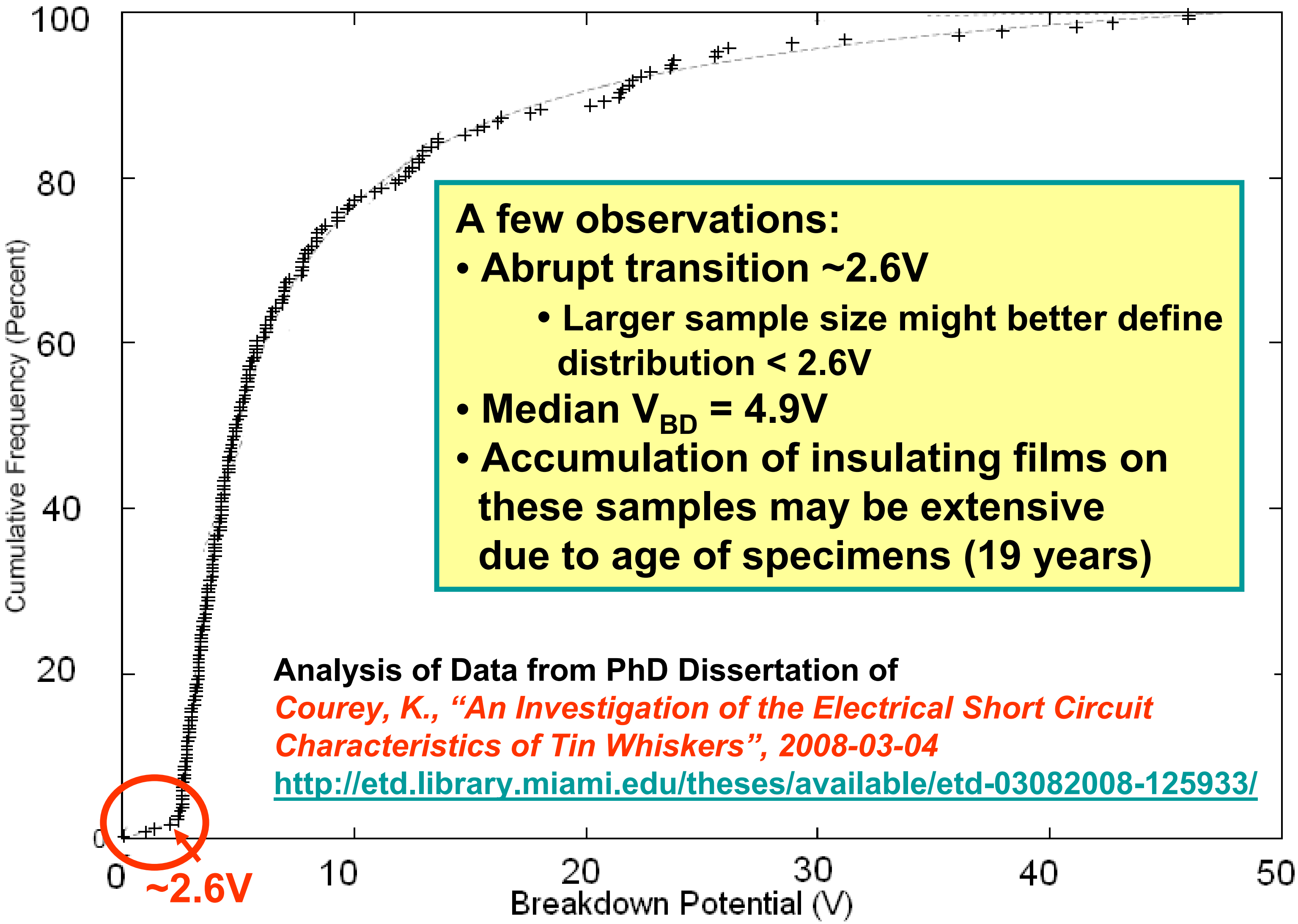
But there is MORE to this story

Metal Whiskers and Adjacent Conductors Accumulate Insulating Films

- Electrically insulating films form on metal whiskers and adjacent conductors
  - Depending on the environment → Oxides, sulphides, sulphates, chlorides, etc.
- These films act as barriers to electrical current flow UNLESS applied voltage exceeds "dielectric breakdown" strength of the combined films
  - Direct **MECHANICAL** contact does NOT guarantee **ELECTRICAL** contact
  - Courey (NASA), et al have measured the breakdown voltage of films on tin whiskers
    - V_{BD} is a probability distribution with a wide range (~60mV to >45Volts)
  - Insulating effects of these films are important to recognize
    - May fool failure analysts when bench testing (e.g., ohmmeter) to detect shorts
    - May explain survival of some electronics in the field despite whisker infestation



Breakdown Potential of Insulating Films on 200 Tin Whiskers from ~19 Year Old Hardware



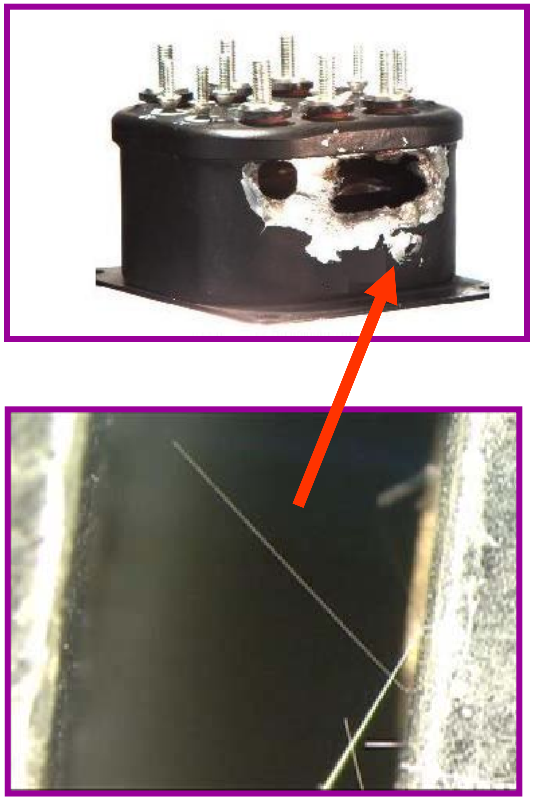
A few observations:

- **Abrupt transition ~2.6V**
  - **Larger sample size might better define distribution < 2.6V**
- **Median V_{BD} = 4.9V**
- **Accumulation of insulating films on these samples may be extensive due to age of specimens (19 years)**

Analysis of Data from PhD Dissertation of
Courey, K., "An Investigation of the Electrical Short Circuit Characteristics of Tin Whiskers", 2008-03-04
http://etd.library.miami.edu/theses/available/etd-03082008-125933/

Sustained Metal Vapor Arcing Initiated by Metal Whisker

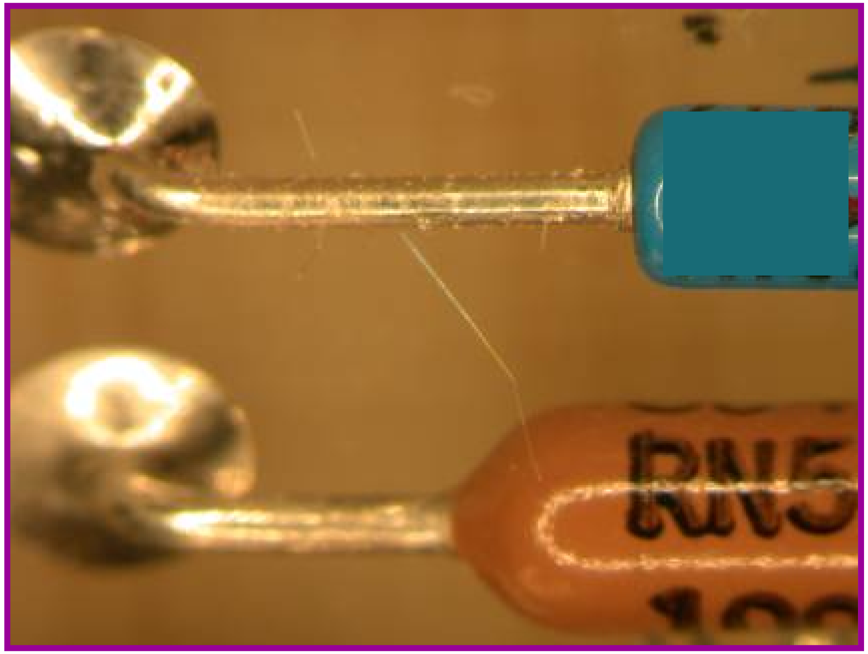
- When a metal whisker shorts two conductors at different potentials, a sustained arc can occur if
  - Current is high enough to vaporize the whisker (i.e., metal gas)
  - Voltage is high enough to ionize the metal gas
- Sustained arcing between metal conductors is possible for voltages as low as ~12 to 14 volts when
  - Arc gap is ***SMALL*** ~ a few tens of microns
  - Available current > ~100 to 300 mA
  - See "Electrical Contacts - Part III" by Paul G. Slade
- However, as arc gap increases, sustaining the arc requires
  - Higher voltage to ionize the metal gas
  - Higher current to boil enough additional metal gas to keep plasma dense enough to sustain it
  - Vacuum (i.e., low pressure) is NOT required, but can reduce the threshold voltage and current required for arcing
- Metal vapor arc testing by NASA of FM08 style fuses made with metal filaments ~5 mm long
  - ~75 volts at more than 30 amperes is needed to generate a sustained arc across this arc gap when P ~1 torr

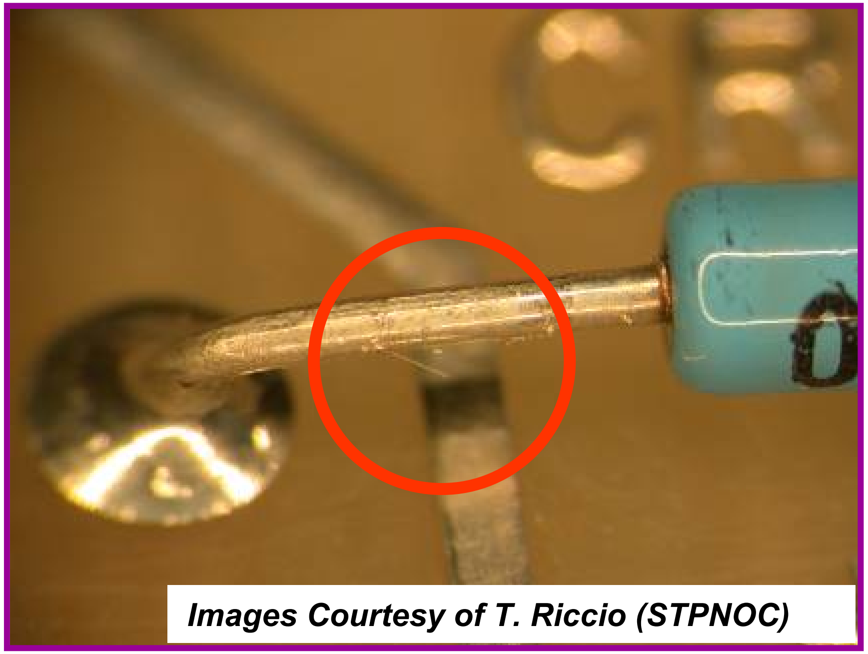


Tin Whiskers Growing on Armature Of Relay Produced Metal Vapor Arc Resulting in Destruction of Device

A Case for Whisker Mitigation Strategies?

Tin Whiskers on Tin-Plated Axial Leaded Diodes





Images Courtesy of T. Riccio (STPNOC)

- Diode Leads were **NOT Hot Solder Dipped** prior to assembly; thus leaving large surface area of pure tin coating prone to whisker growth
- PWB and components were **NOT Conformal Coated**; thus leaving adjacent conductors exposed to bridging by whisker growth

Some Whisker Mitigation Strategies

*Mitigation – to make **less** severe or painful*
Merriam-Webster Dictionary

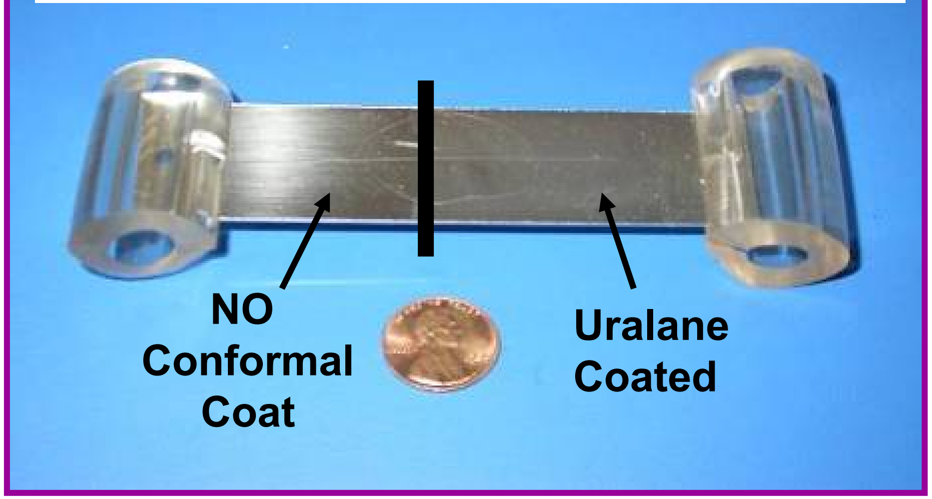
Risk "Mitigation" ≠ Risk "Elimination"

- Avoid Use of Whisker Prone Surface Finishes
  - *"Trust, But VERIFY" Certificates of Conformance!*
  - Perform independent materials composition analysis using X-ray Fluorescence (XRF), Energy Dispersive X-ray Spectroscopy (EDS), etc.
- Use Conformal Coat or Other Electrically Insulating Barriers
  - Benefit #1: When applied on top of a whisker prone surface, conformal coat can sometimes keep whiskers from pushing through
  - Benefit #2: When applied to a distant conductor, can block whiskers from electrically shunting distant conductors
  - Benefit #3: Provides insulating barrier against loose conductive debris
- Remove/Replace Tin Finishes When Practical
  - Hot Solder Dip using lead-tin (Pb-Sn) solders
  - Follow the Principle of "First, Do No Harm"

NASA Goddard Whisker Mitigation Study
Conformal Coat (Uralane 5750* Polyurethane)
~9 Years of Office Ambient Storage

- **Specimens:**
  - 1” x 4”x 1/16” Brass 260
  - Tin-Plated 200 microinches
  - A few intentional scratches created after plating to induce localized whisker growth
- **Conformal Coating:**
  - Uralane 5750 on ½ of sample
  - Nominal Thickness = 2 mils
  - Locally THIN Regions also examined
- **Storage Conditions:**
  - Office Ambient ~ 9 years

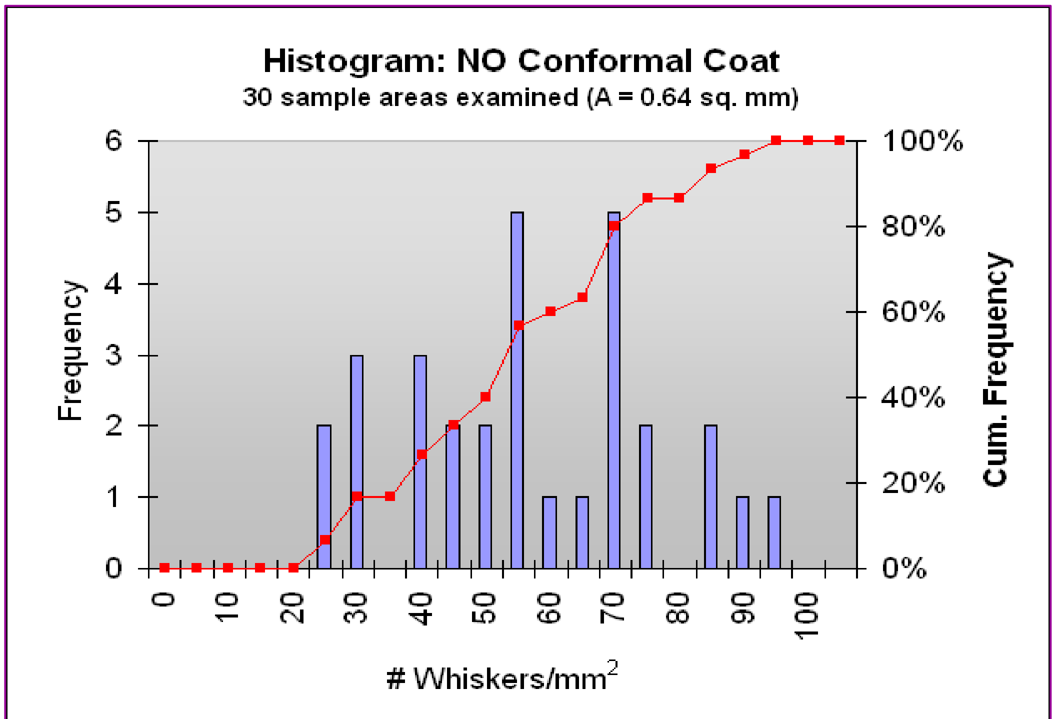
Parameters were Chosen in Hope of Producing Samples that are Prolific Whisker Growers!!!



****Uralane*^{TM}* 5750 now known as Arathane*^{TM}* 5750***

NASA Goddard Whisker Mitigation Study
Control Areas – No Conformal Coat
9-Years of Office Ambient Storage

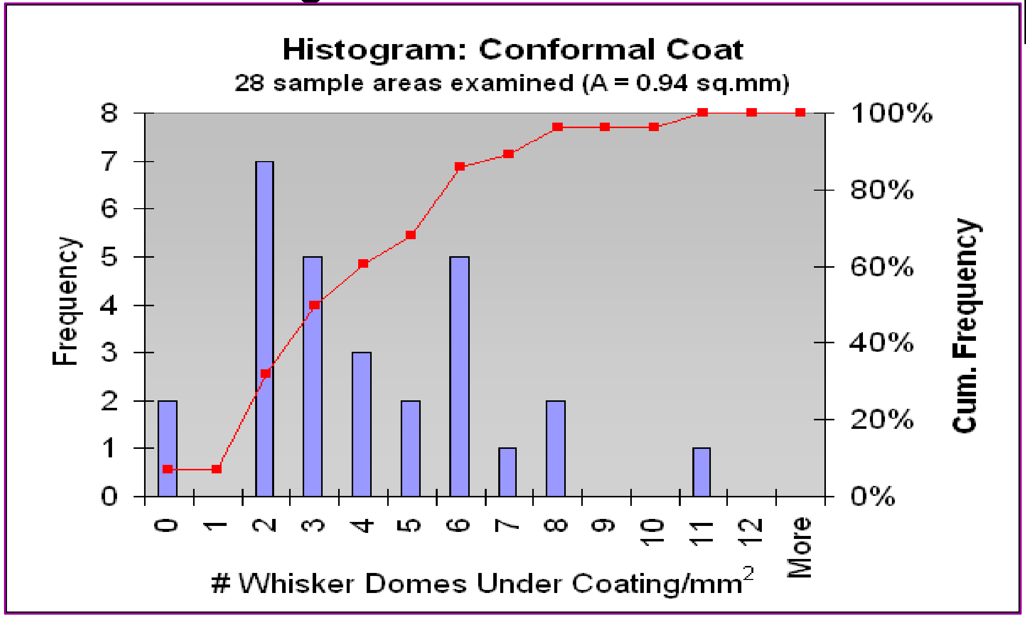
- **Control Areas Grew Whiskers Abundantly within the First Year. After 9 years of storage we found the following:**
  - **30 areas each 0.64 mm^2 were randomly examined for whisker density**
  - **Avg: 55 ± 19.6 whiskers / mm^2**
  - **Range: 23 to 95 whiskers / mm^2**

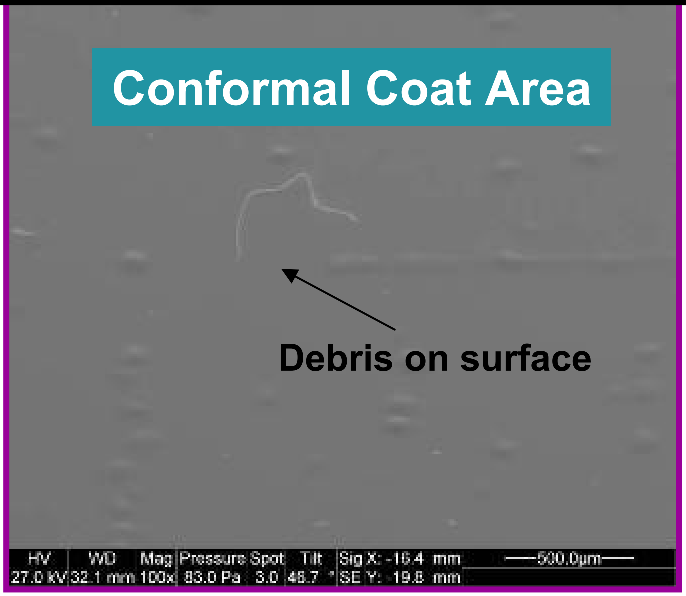


NASA Goddard Whisker Mitigation Study
Uralane 5750 – 2 Mils Thick
9-Years of Office Ambient Storage

- Conformal Coated Areas Grew Whiskers Too within the First Year. After 9 years of storage we find the following:
  - *To date ALL whiskers are contained beneath the coating that is 2 mils thick*
  - *SEM cannot see INTO coating. Thus we see only "domes" caused by whiskers that lift coating slightly*
  - Avg: 3.4 ± 2.6 domes / mm^2
  - Range: 0 to 10.6 domes / mm^2

We suspect we are only counting "thick" whiskers in this statistic because the "thin" ones mechanically buckle before they can lift the coating enough to produce visible "domes"





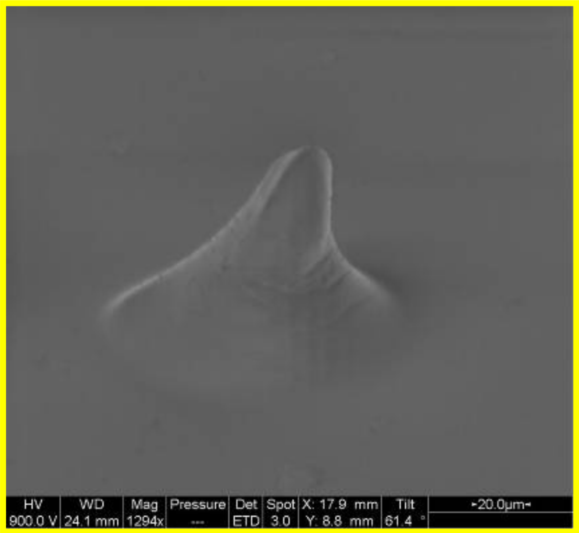
NASA Goddard Whisker Mitigation Study

Uralane 5750 Conformal Coat - 9-Years of Office Ambient Storage

2 Mils Uralane = Very Effective

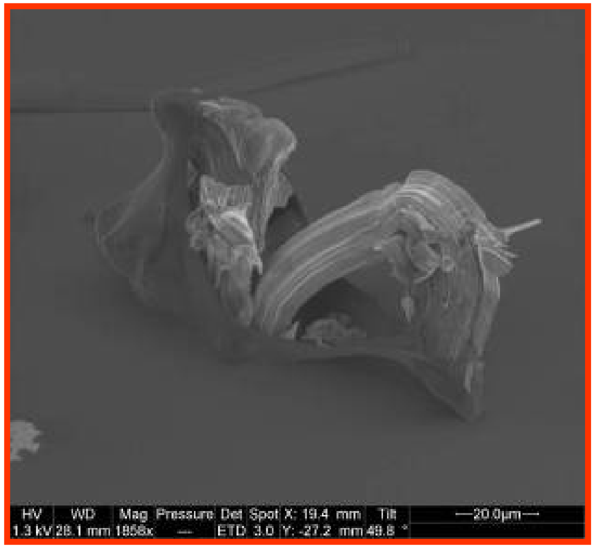
Whiskers Completely Entrapped Under the Coating → Euler Buckling

~0.5 Mils Uralane = Less Effective



Whisker "Lifting" Coating into Shape of Circus Tent, But Not Yet Penetrating

~0.1 Mils Uralane = Not Effective

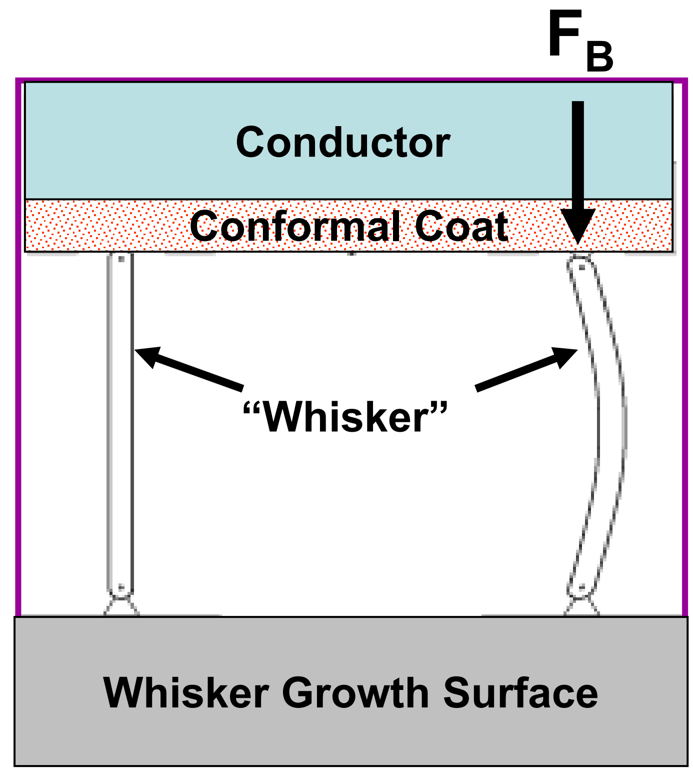


Whiskers Breaking Through "Thin" Coating

Euler Buckling
Axial Force Required to Buckle a Metal Whisker

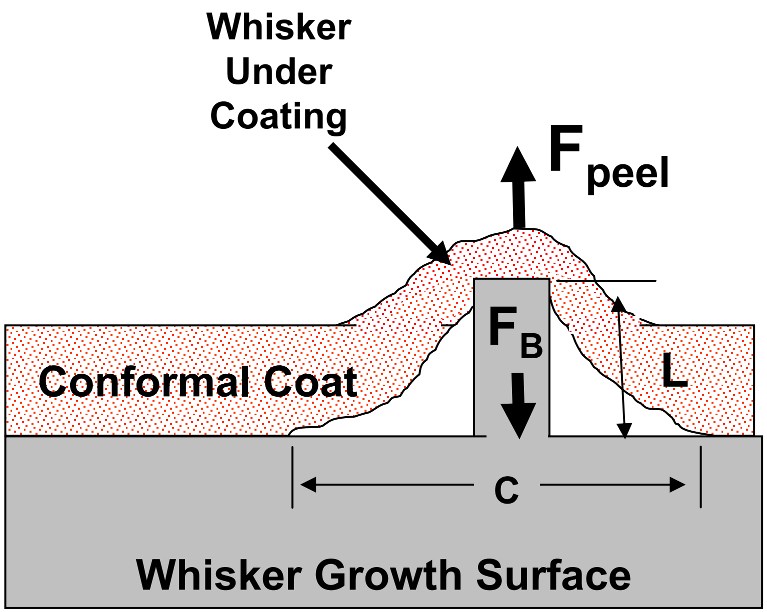
$$F_B = \frac{\pi^2 EI}{(KL)^2} \approx \left(\frac{\pi^3 \cdot E}{32}\right)\left(\frac{d^4}{L^2}\right)$$

E = Young's Modulus of whisker material,
I = Area Moment of Inertia,
(e.g. I = π d^4 / 64 for circular cross section)
L = Length of whisker,
K = Column Effective Length Factor
K = 0.5 for whisker fixed at both ends
K = 0.7 for fixed at one end, pinned at other



Whiskers Lift and Peel Conformal Coat Until Whisker Buckles OR Coating Fails (F_{peel} vs. F_{Buckle})

- As whisker first emerges it is short and stiff thus $F_B > F_{peel}$ and whisker begins to lift the coating forming a "circus tent" with height L = length of whisker;
- "Tent" joins the surface at a circle of circumference $C \sim 2\pi QL$,
  - Q describes the details of tent-like shape
- To peel conformal coating up and away from the surface, one needs to apply a force (F_{peel}) proportional to the circumference:
  - $F_{peel} = \Phi * C = 2 \text{ pi } Q \Phi L$
    Φ = peel strength of material which describes the adhesion of the coating to the tin, and the effect of the separation angle. It also depends on the rate at which the coating is peeled away.

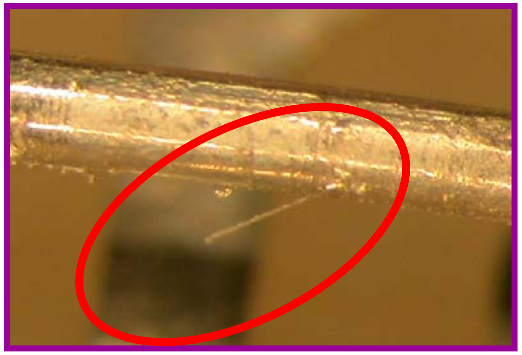


Uralane 5750 has better self-cohesion than adhesion to a tin surface

Will Whiskers Buckle Before Puncturing the Coating on a Distant Surface?

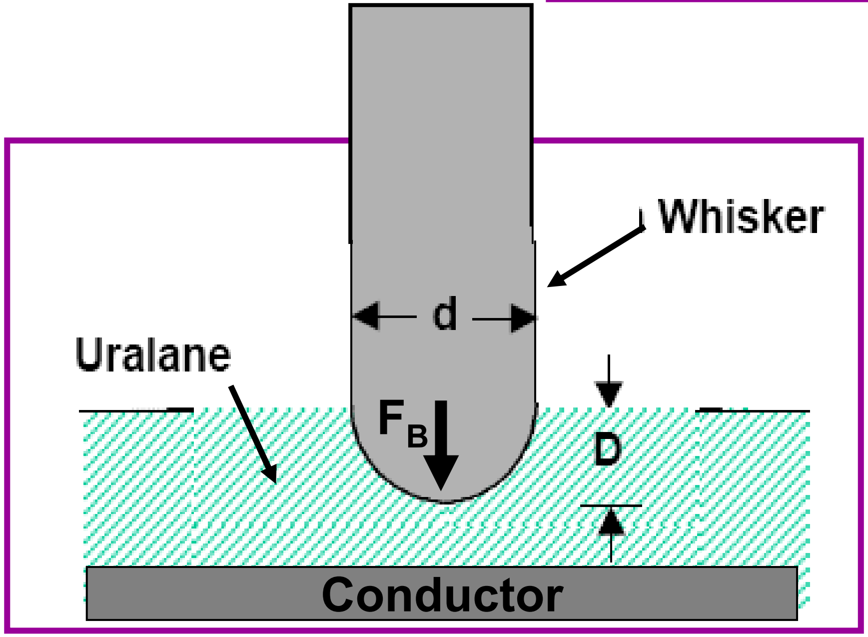
- The displacement of the conformal coat due to a whisker pushing against the coating is:

$$D = \left(\frac{1-\nu^2}{E_{coat}}\right)\left(\frac{F_B}{d}\right) \approx \left(\frac{\pi^3}{32}\right)\left(1-\nu^2\right)\left(\frac{E_W}{E_{coat}}\right)\left(\frac{d^3}{L^2}\right)$$



Where

- D = Displacement of conformal coat
- ν = Poisson's ratio
- E_{coat} = Young's Modulus of coating
- E_W = Young's Modulus of Whisker
- d = "Diameter" of whisker
- L = Length of whisker
- F_B = Euler Buckling Strength of the whisker



Effects of Conformal Coating -- 1

- NASA GSFC has used Uralane 5750, applied to pre-primed tin-plated surfaces to a thickness of 2 mils (50 microns) ± 10%:
  - After ~9 years of office ambient storage, these surfaces have whiskered abundantly
  - ***But the number of whiskers escaping through the 2 mil thick areas has been zero***

- Numerous sorts of coatings have been examined by others:
  - Reports of success vary from "none" to "perfect", sometimes for the same sort of coating.

- Dr. Woodrow (Boeing)[1] has studied Urethane (acrylic) coatings, a silicone coating, and Parylene C coating of varying thicknesses up to ~ 4 mils (= 100 micrometers):
  - Some whiskers have penetrated even the thickest coatings after long term exposure of the coatings to 25°C / 97% R.H.
  - Urgent Need: Characterization of mechanical properties of conformal coatings as well as the degradation of these properties from various environment exposures (moisture, corrosive agents, elevated temperature, etc.)

1. "Evaluation of Conformal Coatings as a Tin Whisker Mitigation Strategy, Part 2", T. Woodrow, SMTAI, Sept. 2006 ***http://nepp.nasa.gov/whisker/reference/tech_papers/2006-Woodrow-Conformal-Coating-PartII.pdf***

Effects of Conformal Coating -- 2

- Conclusion 1: *2 mils Uralane 5750 Provides Substantial Protection*
  - Uralane 5750, applied to at least 2 mils thickness, is a substantial improvement over an uncoated surface.

- Conclusion 2: *Even "Poor" Coatings Can Offer Some Protection*
  - Long whiskers bend easily (Euler Buckling) and are less likely to re-penetrate even thin conformal coat applied on a distant conductor.
  - Conformal coat protects against a conductive bridge from detached whiskers lying across a pair of coated conductors

- Conclusion 3: *Understand YOUR Conformal Coating Processes*
  - Conformal coating processes can leave "weak zones" with less than the nominal thickness of coating.
    - Shadowing effects may prevent complete coverage when applying coating
    - Coating may flow/thin prior to completion of cure
  - Thinner coatings are more prone to whisker puncture

Contact Information

Jay Brusse

Perot Systems at
NASA Goddard Space Flight Center

Jay.A.Brusse@nasa.gov

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Acknowledgment to Dr. Michael Osterman
University of MD – Center for Advanced Life Cycle Engineering (CALCE)

NASA Tin and Other Metal Whisker WWW Site

http://nepp.nasa.gov/whisker

Backup Slides

Circuit to Measure Resistance of a Metal Whisker

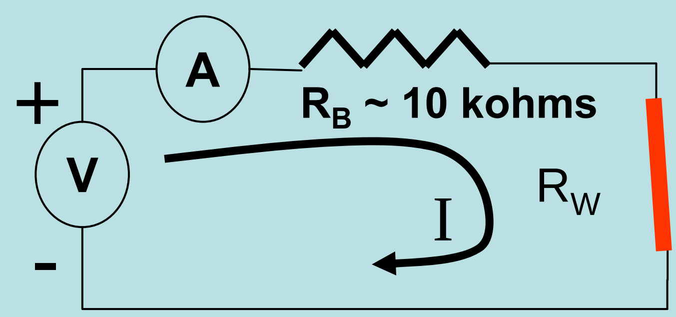
- **Use of a simple "Ohmmeter" to measure the resistance of a metal whisker is NOT preferred**
  - **Ohmmeter may supply $V_{out} < V_{breakdown}$ for the insulating films (oxides, moisture) that form on a metal whisker**
  - **Ohmmeter may supply $V_{out} > V_{melt}$ causing the whisker to melt before resistance can be measured**

- **Instead, a variable power supply and a ballast resistor can be used to overcome the above complications**
  - **Adjust $V_{out} > V_{breakdown}$ of insulating films on whisker**
  - **When $V_{out} > V_{breakdown}$, R_B quickly drops $V_{whisker} < V_{melt}$**

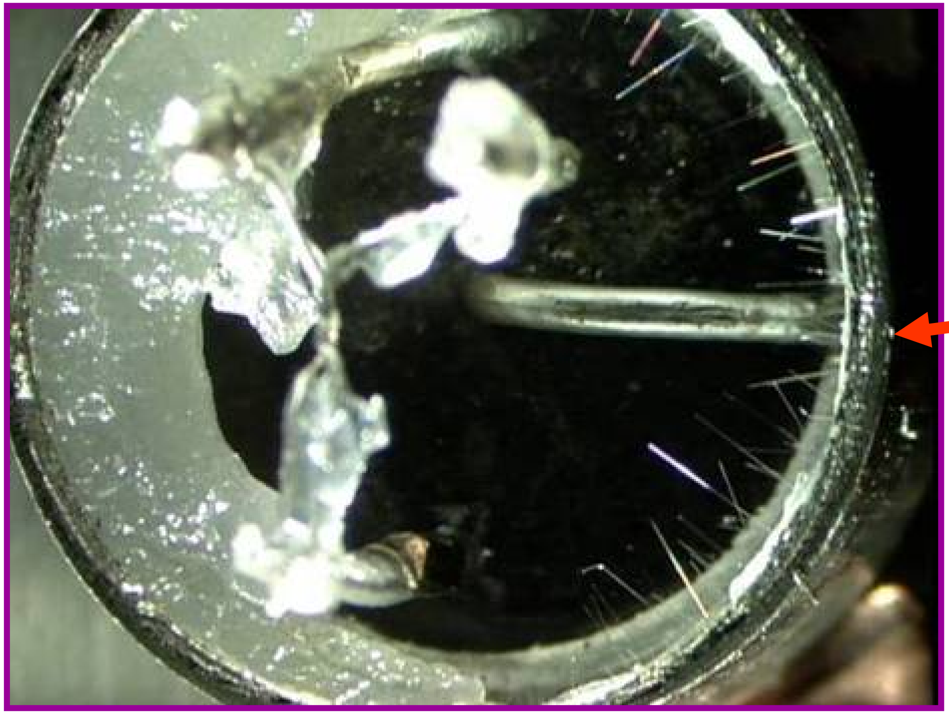
Circuit to measure R_w

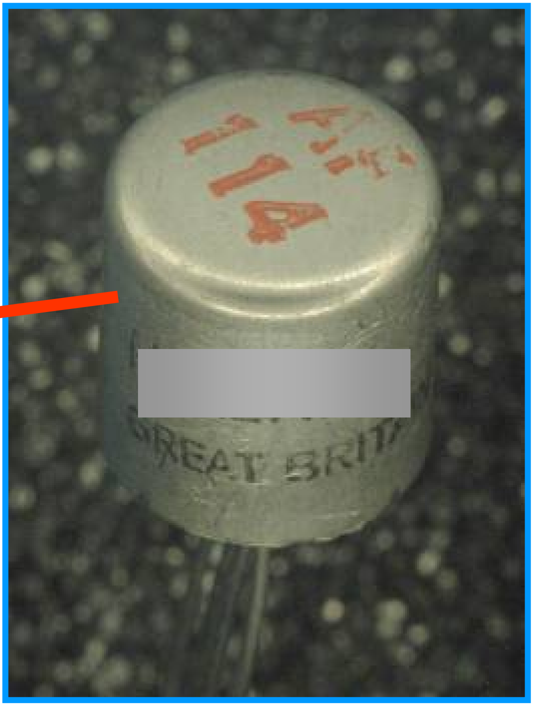
$$R_W = \frac{V - IR_B}{I}$$

Choose R_B such that $V_{whisker}$ < 80% V_{melt}



Guess What's Lurking Inside?





Transistor Package is Tin-Plated Inside.

Many Radio Malfunctions Have Been Attributed to Whiskers Shorting Case to Terminals

1960's Vintage Transistor

http://www.vintage-radio.net/forum/showthread.php?t=5058

2006- NASA Goddard Presented
A Partial History of Documented Metal Whisker Problems

http://nepp.nasa.gov/whisker/reference/tech_papers/2006-Leidecker-Tin-Whisker-Failures.pdf

Year**	Application	Industry	Failure Cause	Whiskers on?
1946	Military	Military	Cadmium Whiskers	Capacitor plates
1948	Telecom Equipme			
1954	Telecom Equipme			
1959	Telecom Equipme			
1959	Telecom Equipme			
1959	Telecom Equipme			
1959	Telecom Equipme			
1986	F15 Radar			
1986	Heart Pacemakers			
1986	Phoenix Missile			
1987	Dresden nuclear Station			
1987	MIL/Aerospace P			
1988	Missile Program "			

Year**	Application	Industry	Failure Cause	Whiskers on?
1990	Apnea Monitors	Medical (RECALL)	Zinc Whiskers	Rotary Switch
1990	Duane Arnold Nuclea Power Station			
1992	Missile Program "C"			
1993	Govt. Electronics			
1995	Telecom Equipment			
1996	Computer Routers			
1996	MIL Aerospace			
1998	Aerospace Electroni			
1998	Computer Hardware			
1998	DBS-1 (Side 1)			
1998	Dresden nuclear Pow Station			
1998	GALAXY IV (Side 2)			
1998	GALAXY VII (Side 1)			
1998	Military Aerospace			
1998	PAS-4 (Side 1)			
1999	Eng Computer Cente			
1999	SOLIDARIDAD I (Side			
1999	South Texas Nuclear			
199X	Telecom Equipment			

Year**	Application	Industry	Failure Cause	Whiskers on?
2000	GALAXY VII (Side 2)	Space (Complete Loss)	Tin Whiskers	Relays
2000	Missile Program "D"	Military	Tin Whiskers	Terminals
2000	Power Mgmt Modules	Industrial	Tin Whiskers	Connectors
2000	SOLIDARIDAD I (Side 2)	Space (Complete Loss)	Tin Whiskers	Relays
2001	GALAXY IIIR (Side 1)	Space	Tin Whiskers	Relays
2001	Hi-Rel	Hi-Rel	Tin Whiskers	Ceramic Chip Caps
2001	Nuclear Power Plant	Power	Tin Whiskers	Relays
2001	Space Ground Test Eqpt	Ground Support	Zinc Whiskers	Bus Rail
2002	DirecTV 3 (Side 1)	Space	Tin Whiskers	Relays
2002	Electric Power Plant	Power	Tin Whiskers	Microcircuit Leads
2002	GPS Receiver	Aeronautical	Tin Whiskers	RF Enclosure
2002	MIL Aerospace	MIL Aerospace	Tin Whiskers	Mounting Hardware (nuts)
2002	Military Aircraft	Military	Tin Whiskers	Relays
2002	Nuclear Power Plant	Power	Tin Whiskers	Potentiometer
2003	Commercial Electronics	Telecom	Tin Whiskers	RF Enclosure
2003	Missile Program "E"	Military	Tin Whiskers	Connectors
2003	Missile Program "F"	Military	Tin Whiskers	Relays
2003	Telecom Equipment	Telecom	Tin Whiskers	Ckt Breaker
2004	Military	Military	Tin Whiskers	Waveguide
2005	Communications	Radio (1960s vintage)	Tin Whiskers	Transitor TO Package
2005	Millstone Nuclear Power Plant	Power	Tin Whiskers	Diode (Axial Leads)

These are ~10% of the Problems We Know About

Why Are Tin, Zinc, Cadmium Still Used?

- Not all Tin (or Zinc or Cadmium) surfaces grow whiskers!
  - Rough estimate: 3% to 30% do whisker.
- Not all metal whiskers cause shorts
  - Application matters: geometry, electrical potentials, circuit sensitivity to shorting
  - Rough estimate: 3% to 30% do short.
- Not all whisker-induced shorts are traced to whiskers
  - They are very hard to see and failure analysis techniques often destroy evidence
  - Rough estimate: 0% to 10% are correctly traced.
- Not all identified whisker adventures are reported
  - Rough estimate: 0% to 3% are reported, once identified
- Hence, we expect between 0.00% and 0.03% of shorting problems caused by these coatings to be reported
  - While some 0.1% to 10% of these coatings are actually causing shorts.
  - With such a few public cases, many say “What, me worry?”
- Whiskering is dramatically inhibited when 0.5% (or more) lead (Pb) is added to Tin coatings: the shorting rate then approaches zero
  - This has been the case for the Hi-Rel community
  - But Pb use is being restricted by international legislation, and so the shorting rate may jump to 10% from zero **==> SWATCH GROUP <==**

"The Five Stages of Metal Whisker Grief"

By Henning Leidecker

Adapted from Elisabeth Kubler-Ross in her book "On Death and Dying", Macmillan Publishing Company, 1969

Denial

"Metal whiskers?!? We ain't got no stinkin' whiskers! I don't even think metal whiskers exist! I KNOW we don't have any!"

Anger

"You say we got whiskers, I rip your $%#@ lungs out! Who put them there --- I'll murderize him! I'll tear him into pieces so small, they'll fit under one of those *^&$#% whiskers!"

Bargaining

"We have metal whiskers? But they are so small. And you have only seen a few of them. How could a few small things possibly be a problem to our power supplies and equipment? These few whiskers should be easy to clean up."

Depression

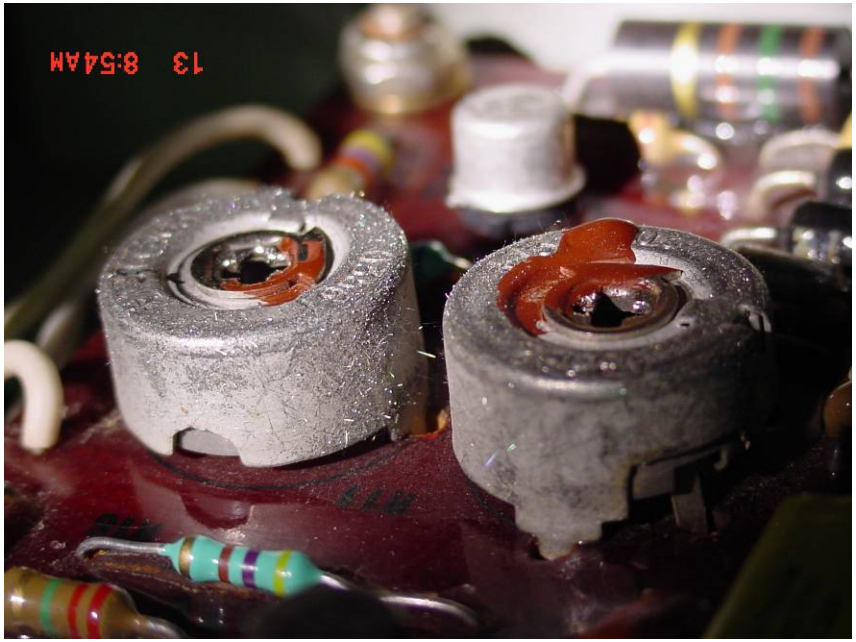
"Dang. Doomed. Close the shop --- we are out of business. Of all the miserable bit joints in all the world, metal whiskers had to come into mine... I'm retiring from here... Going to open a 'Squat & Gobble' on the Keys. "

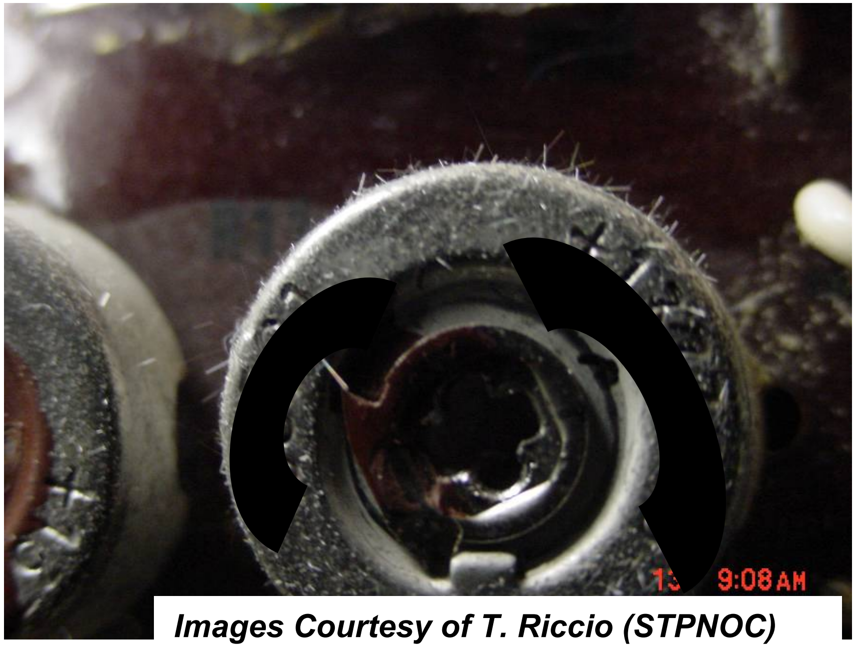
Acceptance

"Metal whiskers. How about that? Who knew? Well, clean what you can. Put in the particle filters, and schedule periodic checks of what the debris collectors find. Ensure that all the warrantees and service plans are up to date. On with life."

Another Case for Whisker Mitigation Strategies?

Metal Whiskers on External Case of Potentiometers



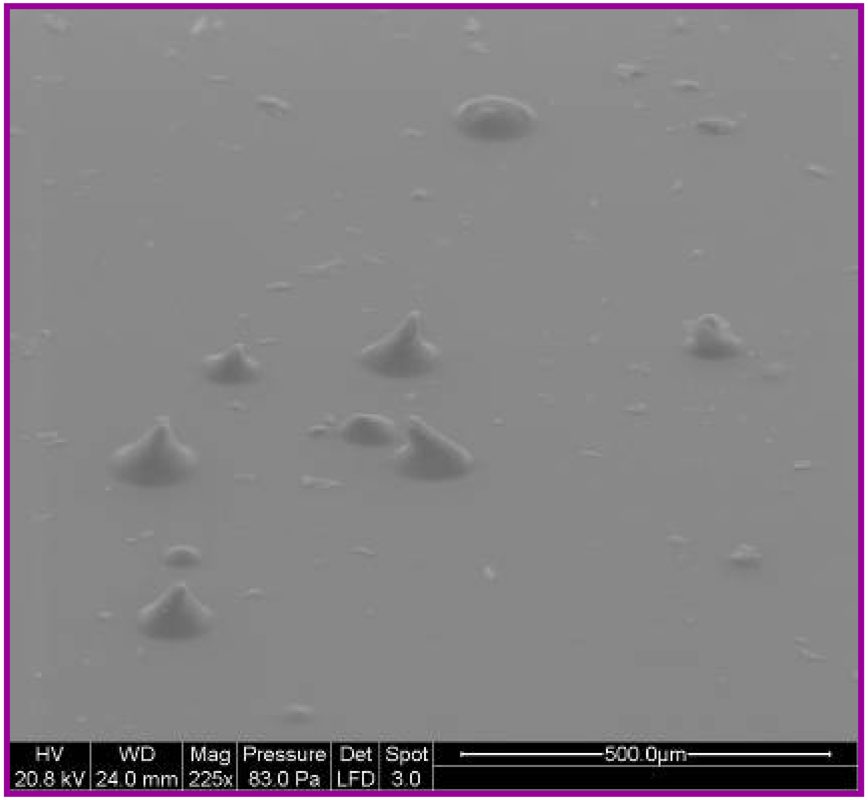


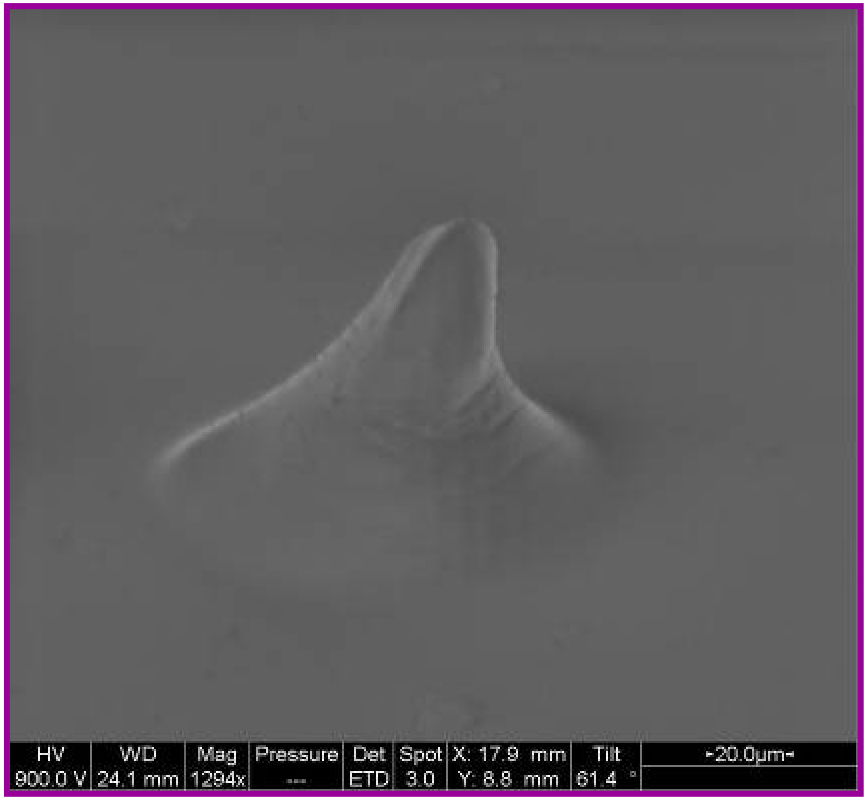
Images Courtesy of T. Riccio (STPNOC)

- No electrically insulating materials were used on the metal cases
- Metal whiskers bridging between the cases or from case to adjacent components can cause circuit malfunction

Tin Whiskers Forming "Circus Tents" in Thin Uralane 5750 Conformal Coat - 9-Years of Office Ambient Storage

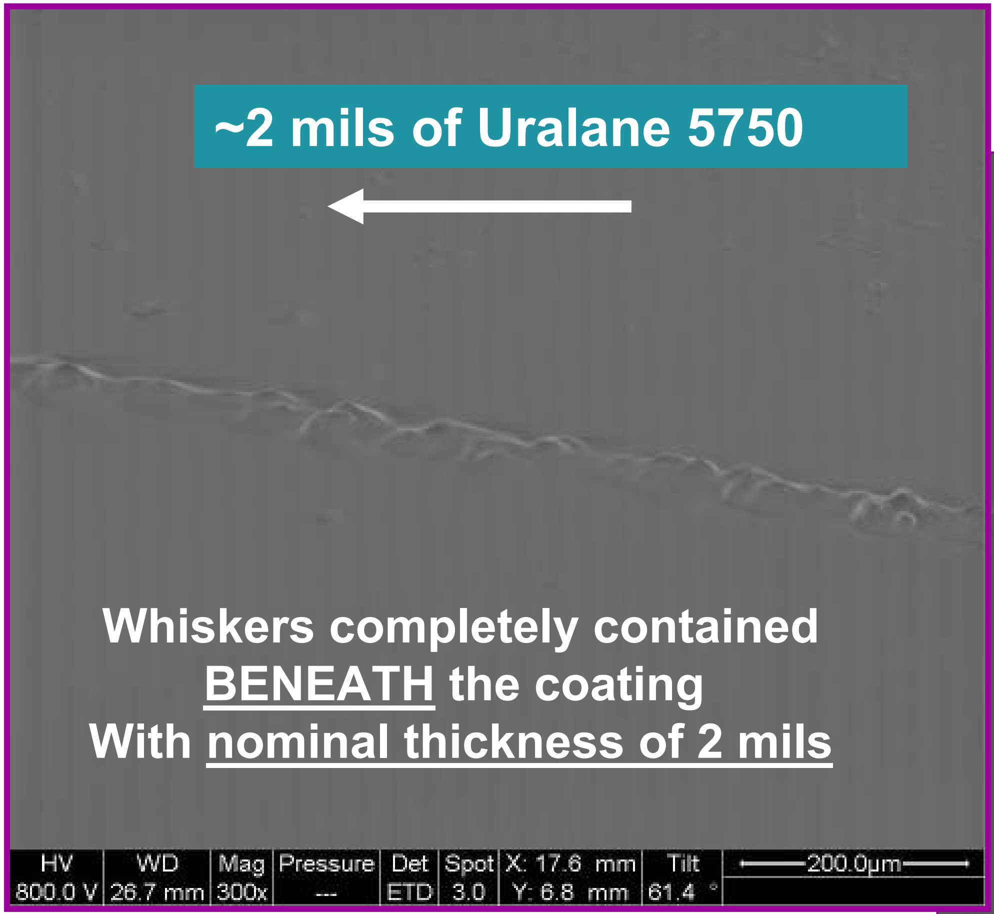
Coating Thickness < 0.5 Mil

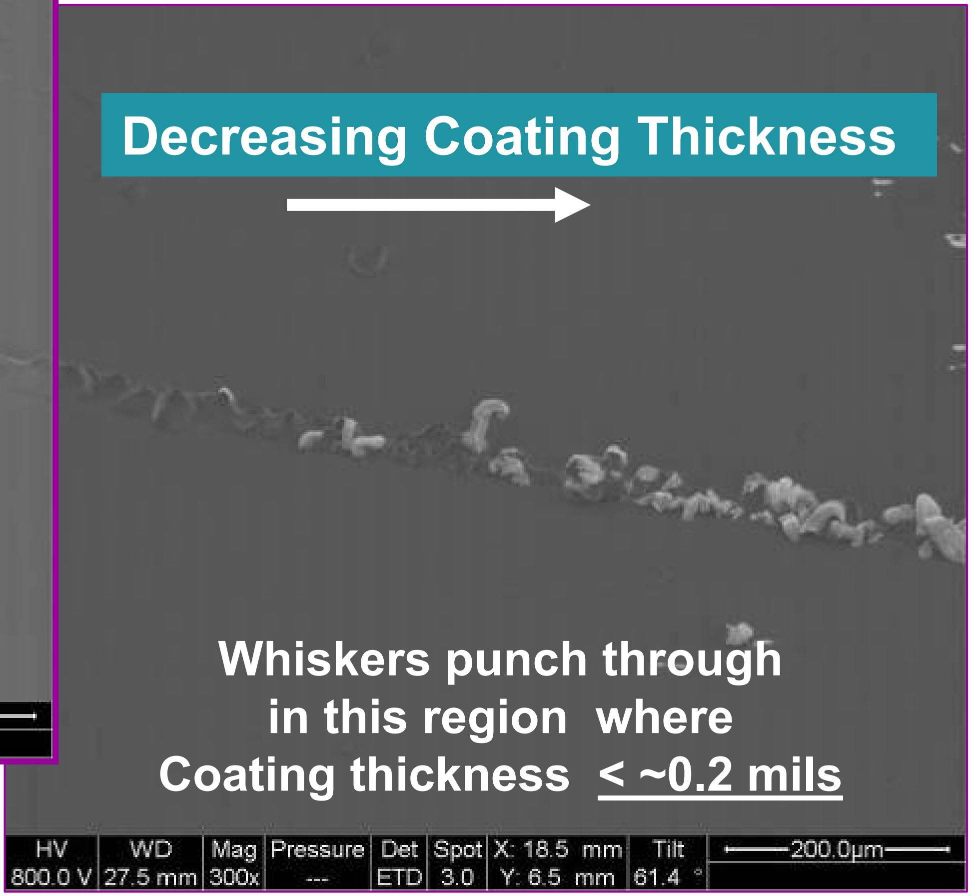




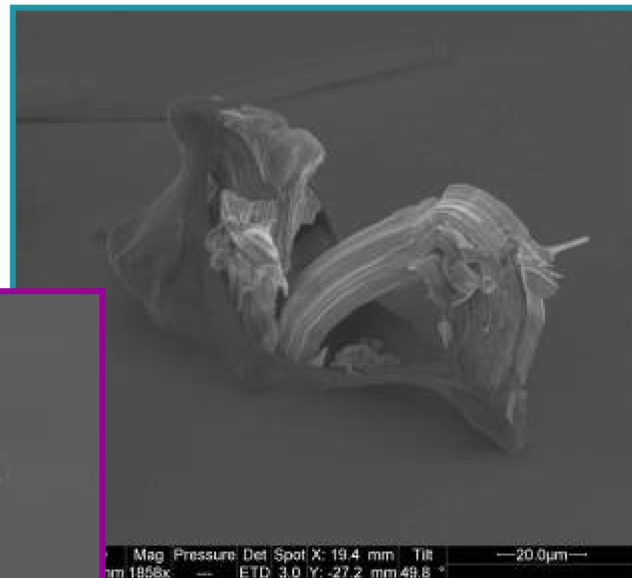
NASA Goddard Whisker Mitigation Study

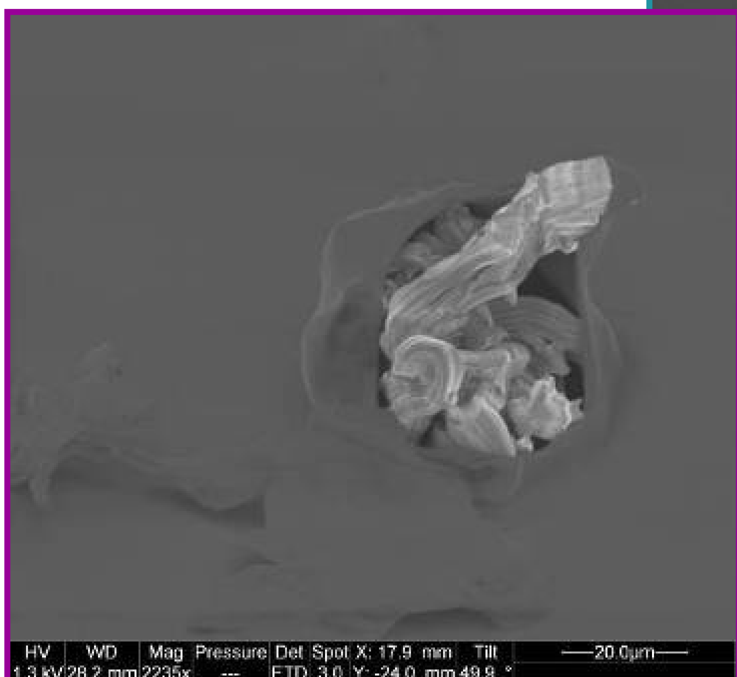
Whisker Puncture vs. Coating Thickness

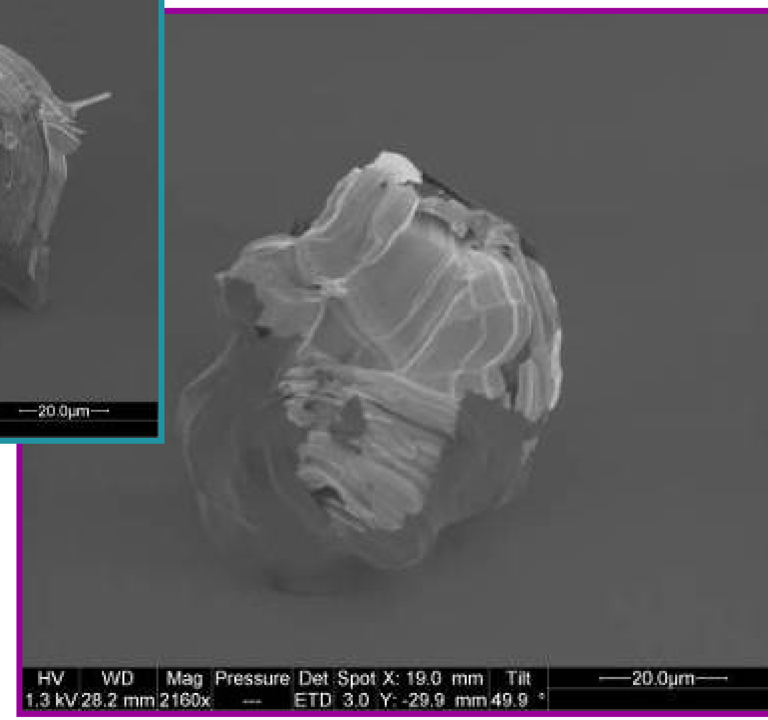




Tin Whiskers Rupturing THIN Coating
~0.1 to 0.2 Mils Uralane 5750 Conformal Coat
9-Years of Office Ambient Storage







Thank Goodness for Euler Buckling and Conformal Coat on this PWB!!!

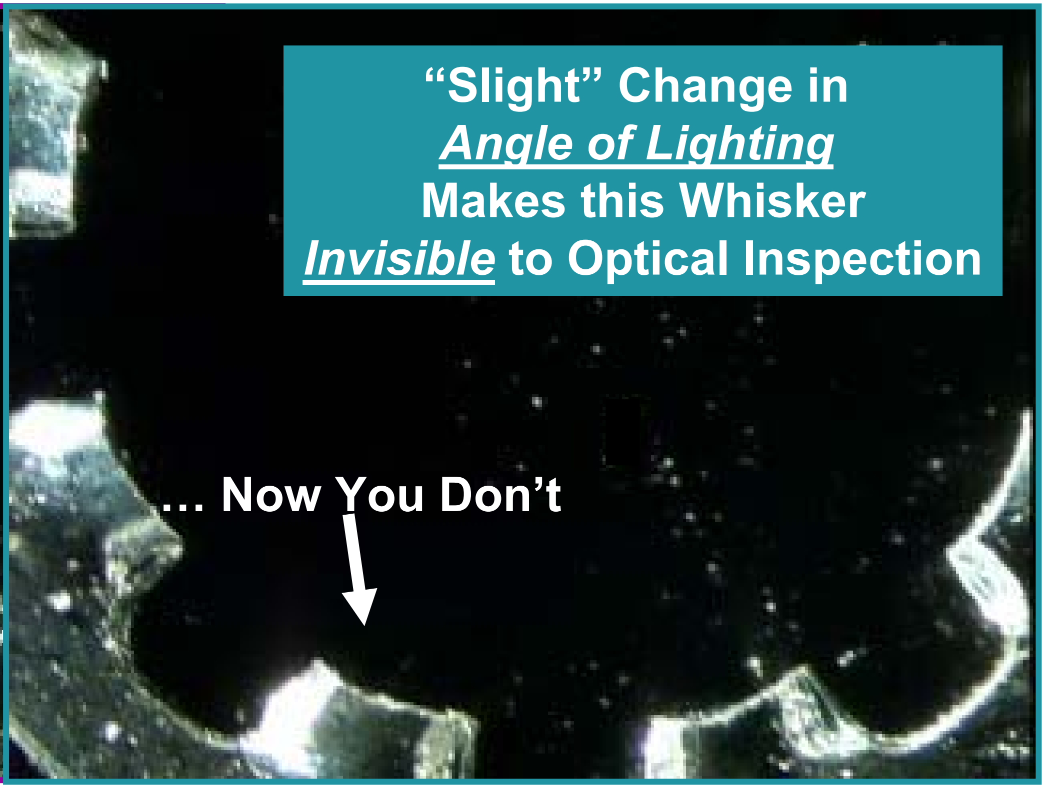
Photo Credit: M&P Failure Analysis Laboratory
The Boeing Company Logistics Depot

Optical Inspection for Metal Whiskers

- Basic Equipment:
  - Binocular Microscope
  - Light Source: Flex Lighting PREFERRED over Ring Lamp
- Freedom to tilt sample and/or lighting to illuminate whisker facets is VERY IMPORTANT

Evidence of "Absence of Whiskers"? (Optical Microscopy)

Tin-Plated Lock Washer



The absence of evidence is NOT evidence of absence

Field Technicians and Failure Analysts Need To Be Acquainted with Metal Whiskers!!!

NASA GSFC has published videos to aid in optical inspection for metal whiskers

http://nepp.nasa.gov/whisker/video

Now You See It
Incident Angle Lighting

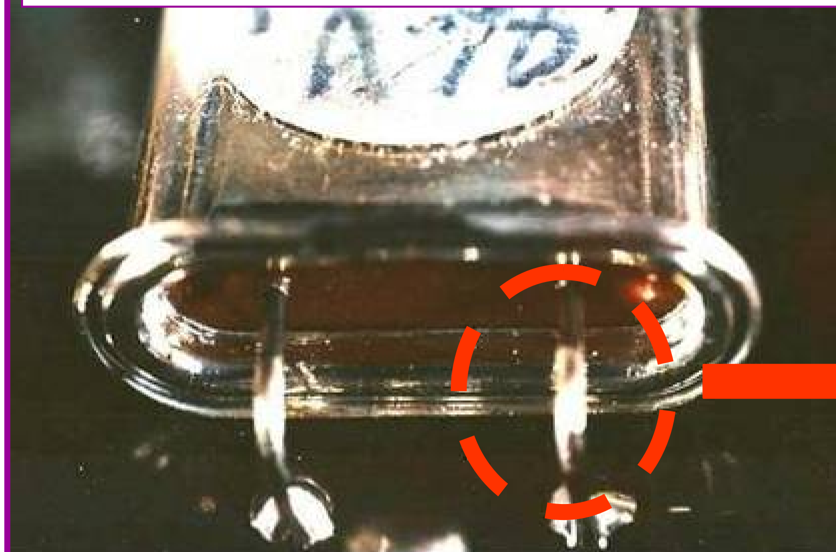
Now You Don’t
“Ring Light”

Small Change in Angle of Lighting Makes Dramatic Difference During Optical Inspection

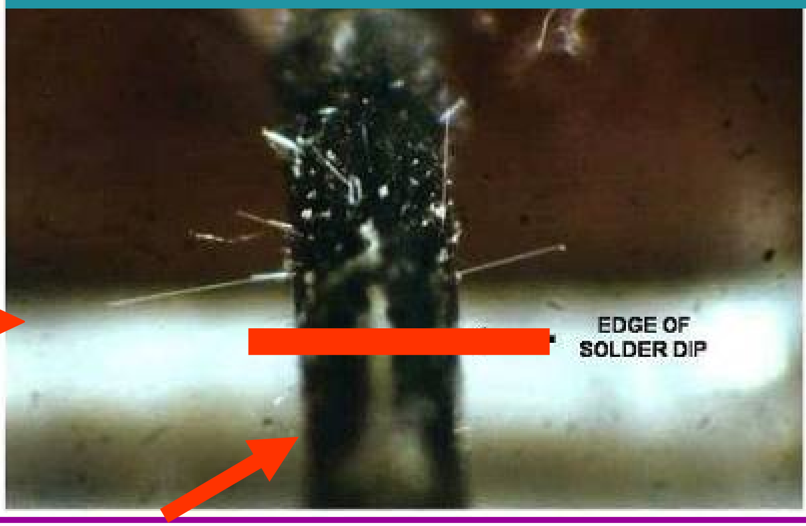
Hot Solder Dip
Benefits & Limitations

Field Failure ONE Year **After Assembly**

Crystal with Tin-Plated Kovar Leads (with Nickel Underplate)



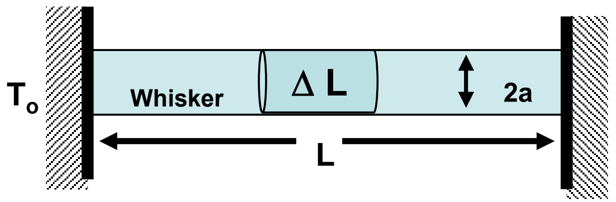
Tin Whiskers (~60 mils) Grew on *NON-Dipped* Region Shorting to Case Causing Crystal to Malfunction



- Leads were *Hot Solder Dipped* (Sn63Pb37) *within 50 mils* of Glass Seal BEFORE Mounting to enhance solderability
- Dip was not 100% of leads due to concerns of inducing harm to glass seal

- No Whiskers on Hot Solder Dipped Surface
- ABUNDANT whiskers on the Non-Dipped Surface

Derivation of Melting Current of a Metal Whisker in Vacuum



Assume both ends of Whisker are thermally grounded to T_o

$$\frac{du}{dt} + \Phi = source$$

du/dt **+** ***Φ*** **=** ***source***

du/dt

$$u = C \cdot T \qquad c = \frac{C}{V}$$

$$u = \left(\frac{C}{V}\right) \cdot V \cdot T = c \cdot V \cdot T$$

$$u = c \cdot \Delta L \cdot A \cdot T$$

$$\boxed{\frac{du}{dt} = c \cdot \Delta L \cdot A \cdot \frac{\partial T}{\partial t}}$$

Φ

Convection loss = 0 for vacuum
Neglect radiation loss

$$\Phi = \left(\frac{\partial J}{\partial x}\right) \cdot \Delta L \cdot A$$

$$J = -k_T \cdot \frac{\partial T}{\partial x} \qquad \frac{\partial J}{\partial x} = -k_T \cdot \frac{\partial^2 T}{\partial x^2}$$

$$\Phi = -k_T \cdot \left(\frac{\partial^2 T}{\partial x^2}\right) \cdot \Delta L \cdot A \qquad k_T = \frac{L_Z \cdot T}{\rho}$$

$$\boxed{\Phi = -\frac{L_Z T}{\rho}\left(\frac{\partial^2 T}{\partial x^2}\right) \cdot \Delta L \cdot A}$$

source

$$source = I^2 \cdot R$$

$$I = J_e \cdot A \qquad R = \frac{\rho \cdot \Delta L}{A}$$

$$source = \left(J_e^2 \cdot A^2\right) \cdot \left(\frac{\rho \cdot \Delta L}{A}\right)$$

$$\boxed{source = \left(J_e^2 \cdot A\right) \cdot \rho \cdot \Delta L}$$

$$\left[c \cdot \Delta L \cdot A \cdot \frac{\partial T}{\partial t}\right] - \left[\frac{L_Z \cdot T}{\rho}\left(\frac{\partial^2 T}{\partial x^2}\right) \cdot \Delta L \cdot A\right] = J^2 \cdot \rho \cdot \Delta L \cdot A$$

$$\left[c \cdot \frac{\partial T}{\partial t}\right] - \left[\frac{Lz \cdot T}{\rho}\left(\frac{\partial^2 T}{\partial x^2}\right)\right] = J^2 \cdot \rho$$

$$\boxed{I_{melt,vac} = \left[\frac{2\sqrt{L_Z T_0}}{R_0}\right] \cos^{-1}\left(\frac{T_{amb}}{T_{melt}}\right)}$$