# Metal Whiskers:

## Failure Modes and Mitigation Strategies

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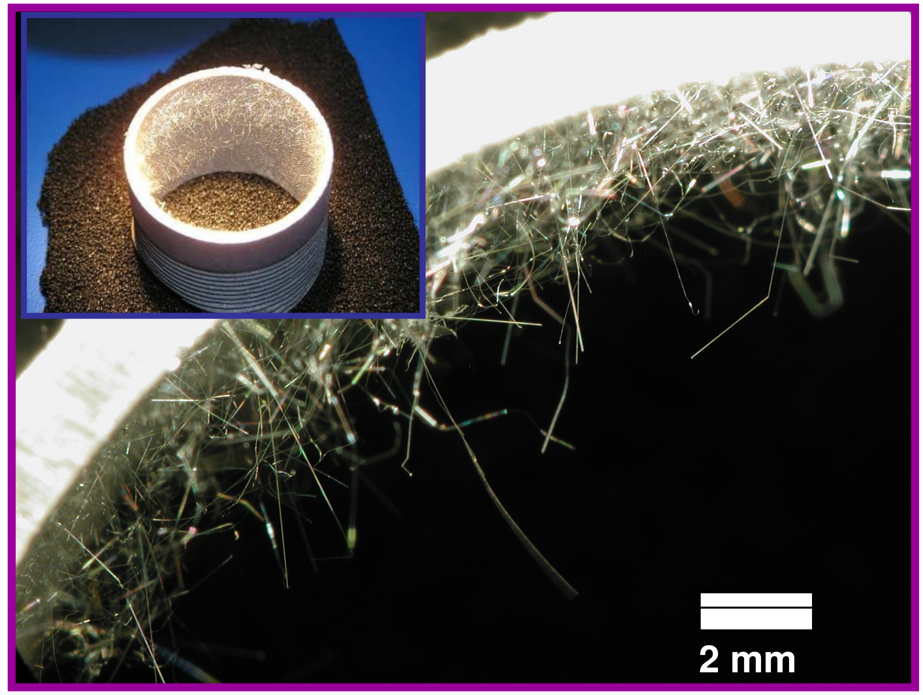
http://nepp.nasa.gov/whisker

# Outline

- A Brief History of Metal Whiskers
- System Failure Modes Caused by Metal Whiskers
- A Few Mitigation Strategies to Reduce Harm From Metal Whiskers
- Inspection Tips



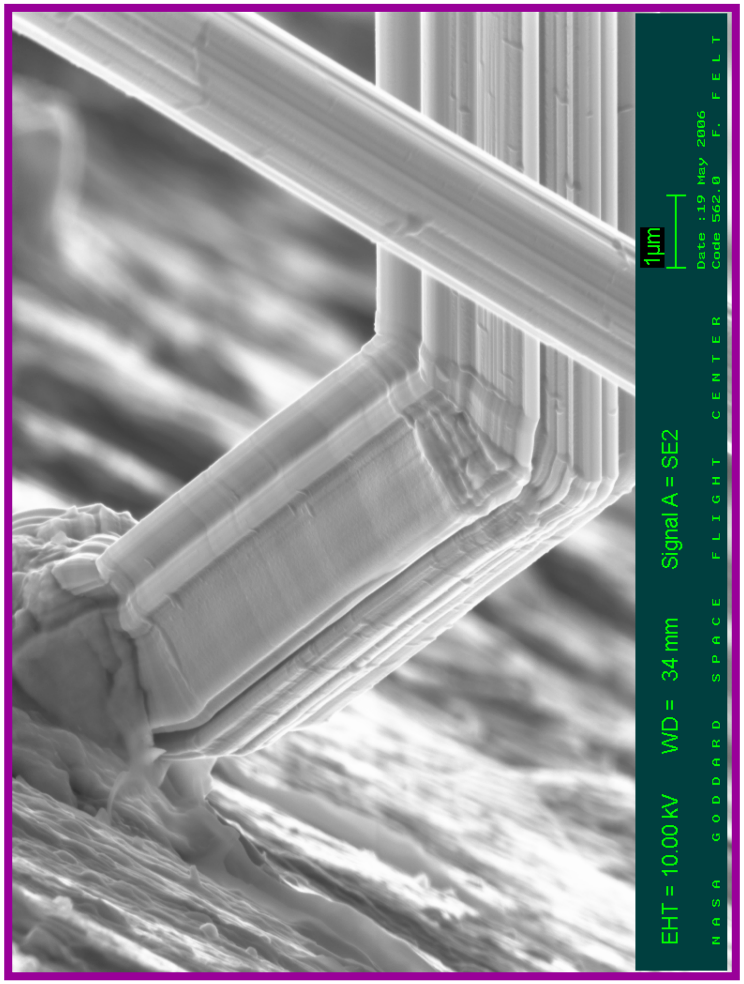

***Zinc Whiskers on***
***Hot Dip Galvanized Steel Pipe***

***Cover Photo:***
***Tin whiskers on Tin-Plated Beryllium Copper PCB Card Rails***

- *NO WHISKER GROWTH THEORY TO BE DISCUSSED!!!*

# What are Tin or Zinc or Cadmium Whiskers?

- **Hair-like structures made of a single grain, or only a few grains, that sometimes erupt from a metal. Coatings of Tin, Zinc and Cadmium are especially able to develop whiskers; but, whiskers have been seen on Gold, Silver, Lead, and other metals too**
- **Growth occurs over time by accretion of metal ions at the base NOT the tip**
- **LENGTH:** **Log-normally distributed**<br>**Rarely up to 10 mm or more**<br>**(Typically ~1mm or less)**
- **THICKNESS:** **Range 0.006 to >10 um**<br>**(Typical ~ 1 um)**
- **Fundamental theories for growth mechanism <u>DO NOT</u> enable prediction of the time-dependence of whisker density, whisker lengths or thicknesses**
  - **To be useful a theory should identify what we must control to make confident predictions**
  - **Such a theory has remained elusive**

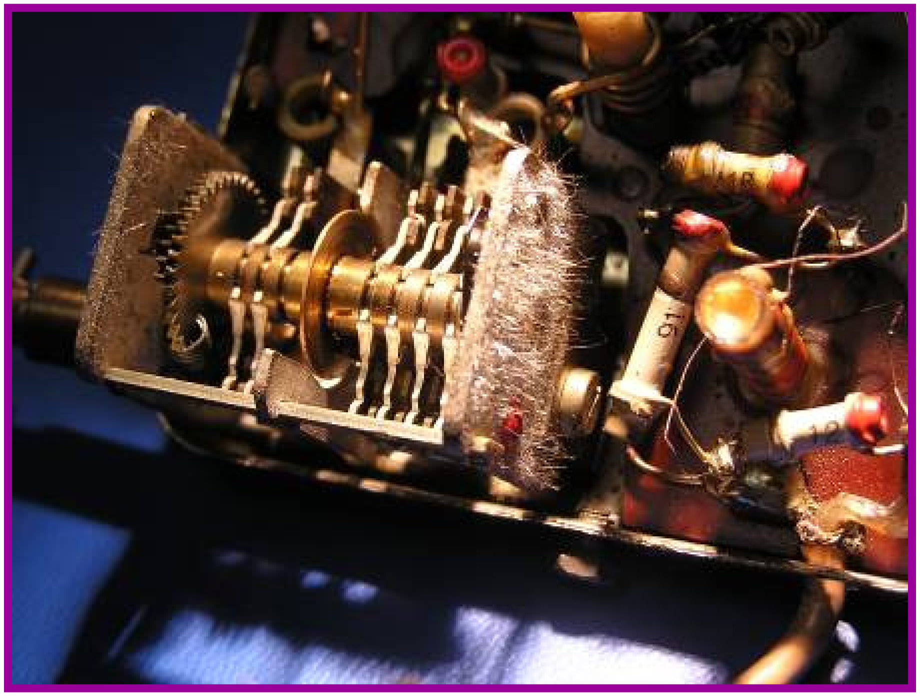



***Tin Whiskers on Tin-Plated Electromagnetic Relay Terminals***

# Metal Whiskers
## "The Early Years"

- **1946:**
  **H. Cobb (Aircraft Radio Corp.) publishes earliest "known" account of CADMIUM whiskers inducing electrical shorting between plates of air capacitors used in military equipment. These events occurred during World War II (~1942 – 1943)**

- **1952:**
  **Since Cadmium coatings resulted in shorting, Tin and Zinc were used instead. But then K.G. Compton, A. Mendizza, and S.M. Arnold (Bell Labs) reported shorting caused by whiskers from these coatings too!**



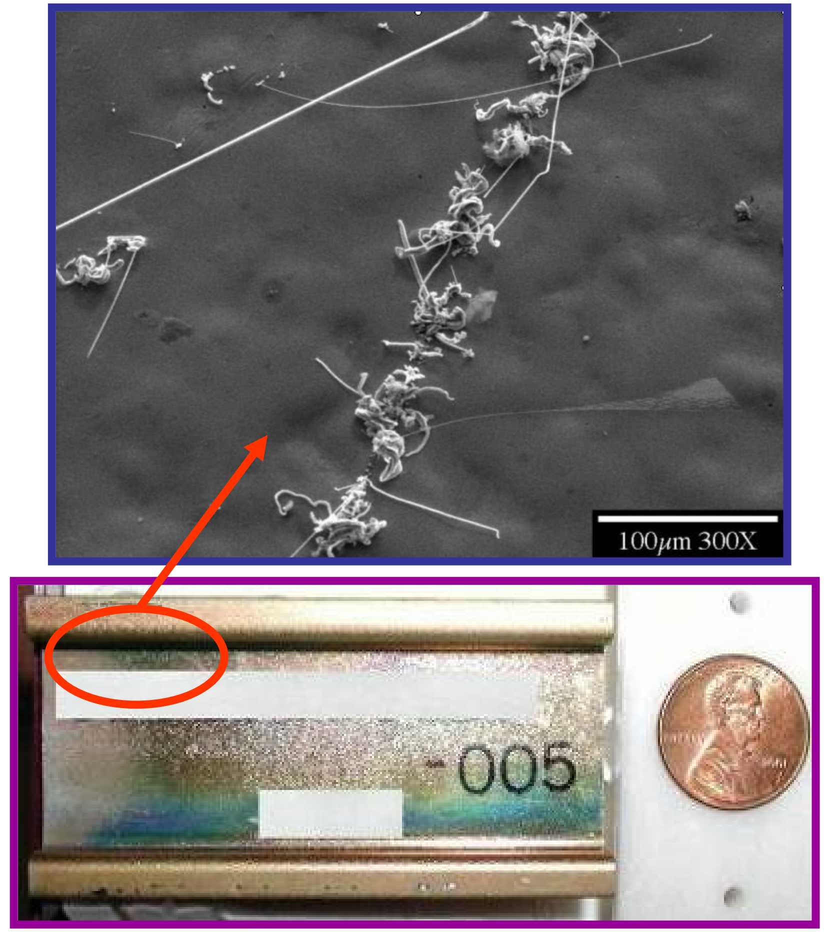
***Tin Whiskers on 1960's Era Variable Air Capacitor***

# Whisker Resistant Metal Coatings
## "The Quest"

- **1950s and 60's [1] [2]:**
  **Bell Labs worked through the periodic table to determine whether addition of some element to a Tin coating would "quench" whiskering**
  - ***Adding 0.5 - 1% (by weight) of lead (Pb) works***
  - ***Some additives seem to enhance whiskering***

- **Since 1990s:**
  **Most US MIL specs require adding Pb to any tin coatings used around electronics.**
  - **Concentration is usually named as 2% to 3% Pb by weight for "margin"**

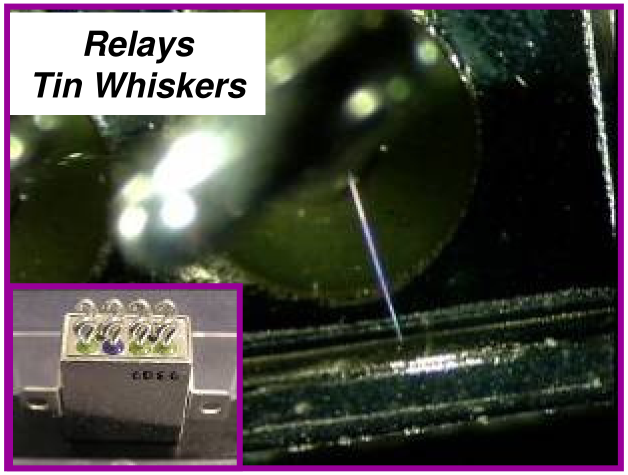
- **What additives quench zinc and cadmium whiskers?**
  - **We don't know, but certainly NOT chromate conversion finishes!**

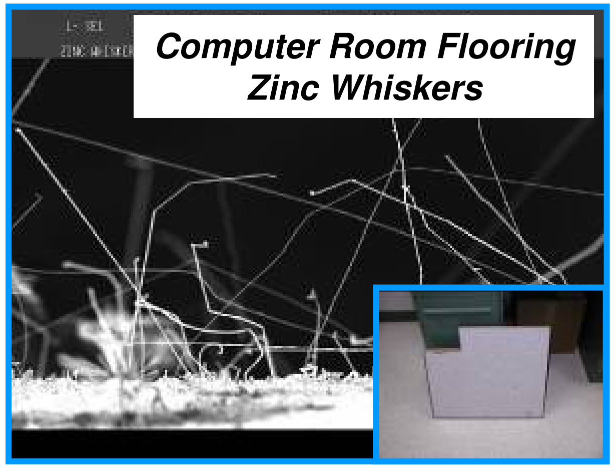


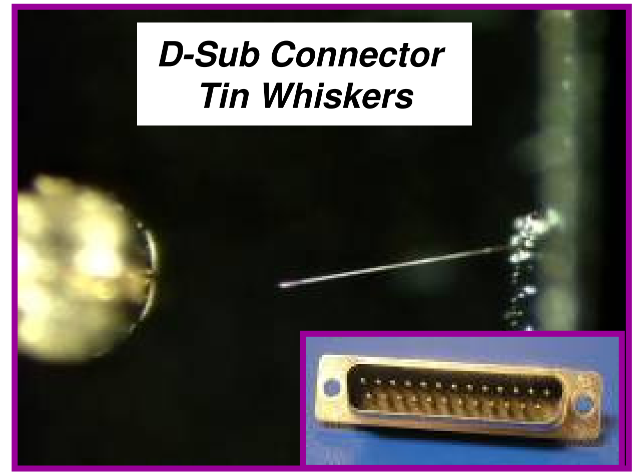

***Zinc Whiskers Growing from Zinc-Plated Yellow Chromate Steel Bus Rail***

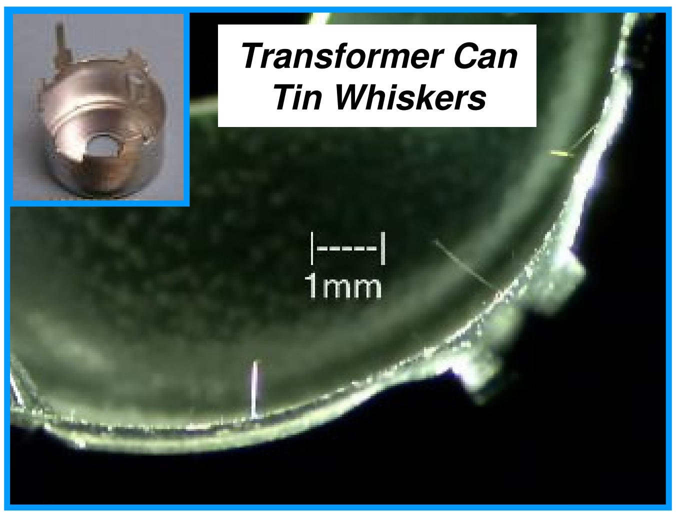
[1] S. Arnold, "Repressing the Growth of Tin Whiskers," *Plating*, vol. 53, pp. 96-99, 1966
[2] P. Key, "Surface Morphology of Whisker Crystals of Tin, Zinc and Cadmium," *IEEE Electronic Components Conference*, pp. 155-160, May, 1970

# Metal Whiskers on Components

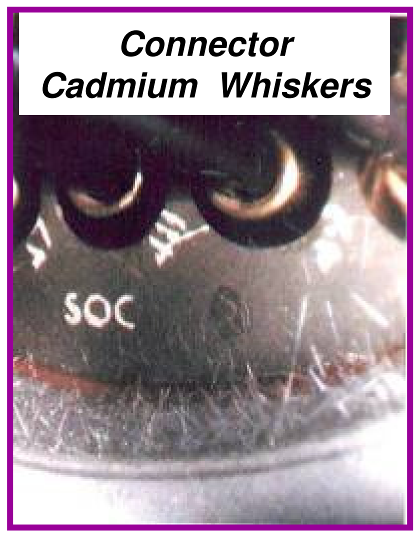

Relays
Tin Whiskers


Computer Room Flooring
Zinc Whiskers

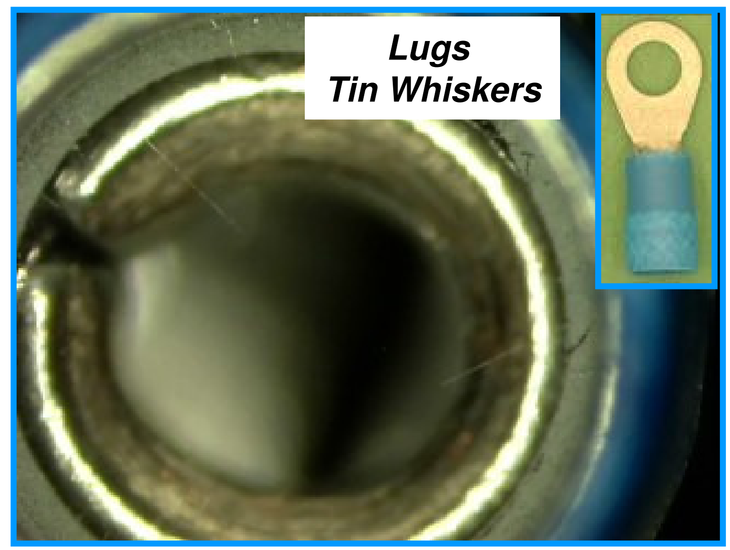

D-Sub Connector
Tin Whiskers



Transformer Can
Tin Whiskers

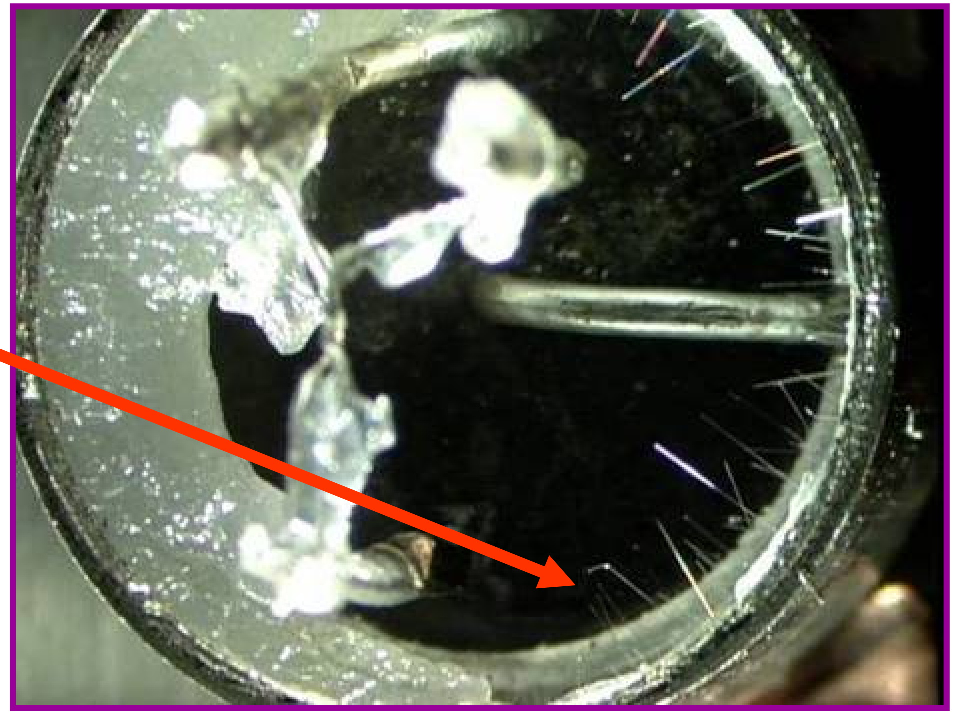


Connector
Cadmium Whiskers


Lugs
Tin Whiskers

# Guess What's Lurking Inside?


***1960's Vintage Transistor***



**Transistor Package is Tin-Plated Inside.**

**Many Vintage Radio Malfunctions Have Been Attributed to Whiskers Shunting Case to Terminals**

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

# 2006- NASA GSFC 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 PV | | | |
| 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 Pov 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***

# A Few Recent Whisker Experiences:
# *It's Not Just Tin Whiskers!!!*

- **Tin Whiskers:**
  - **2005:** Tin Whiskers on ***diode leads*** shut down Connecticut Nuclear Power Plant
  - **2006:** Tin whiskers on ***card rails*** discovered in Space Shuttle Transportation System Some 100 to 300 million whiskers were in OV-105's boxes
  - **2006:** Tin whiskers on ***watch crystals*** reported by SWATCH Group. 30% of new RoHS-compliant Sn-Cu solder sprouting whiskers. 5% catastrophically shorted within months.

- **Zinc Whiskers:**
  - **2005:** Zinc whiskers on ***raised floor tiles*** cripple Colorado State Government data center. Forced to build a new "disaster recovery center"
  - **2005**: Zinc whiskers on ***raised floor tiles*** destroy 75% of the computer equipment in a particular data center. ***Investigation takes ~8 months to properly identify root cause***
  - **2006:** Zinc whiskers identified as root cause of persistent NAVY weapon system failures

- **Cadmium Whiskers:**
  - **2006**: Cadmium whiskers found on ***electrical switch*** proposed for spaceflight program
  - **2007**: Cadmium whiskers on ***connector shells*** cause failure during T-Vac testing

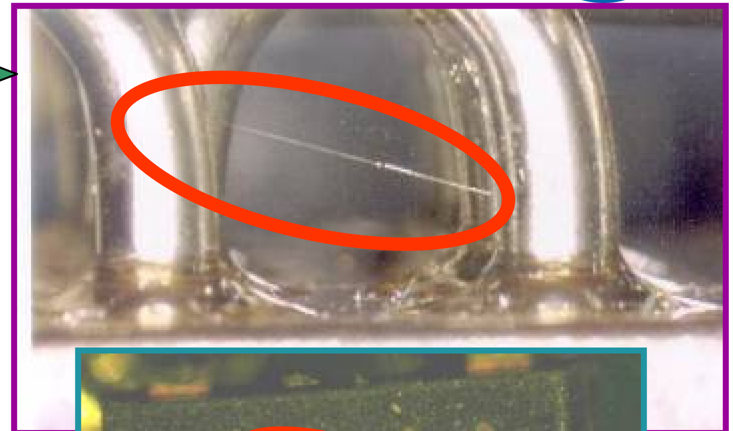
*“There is a name for those who suppose that doing the same thing will produce different results.*

*That name is ‘Idiot’.”*

- Albert Einstein

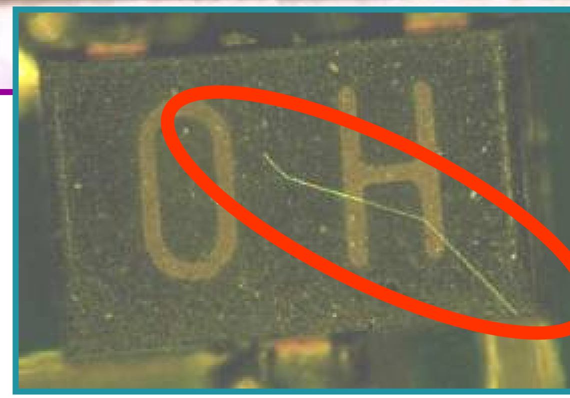
# Basic Whisker Failure Modes

## *Electrical Short Circuits*



- Continuous short if $I_{whisker} < I_{melt}$
- Intermittent short if $I_{whisker} > I_{melt}$

## *Debris/Contamination*




- Interfere with Sensitive Optics or MEMS
- Produce Shorts in Areas REMOTE From Whisker Origins
  *(Zinc Whiskers on raised flooring are a PRIME Example)*

## *METAL VAPOR ARC*

- If $I_{whisker} >> I_{melt}$ Whisker Can Vaporize into a Metal Gas
- If voltage is sufficiently high, then the metal gas can be ionized into a conductive PLASMA of Metal Ions
- Plasma Can Form an Arc Capable of Carrying ***HUNDREDS OF AMPS!***
- Depends on arc gap length, voltage, current, pressure, etc.

# Metal Whisker Melting Current -- Pt. 1

## *(In Vacuum)*

$$I_{melt,vac} = \left[ \frac{2\sqrt{LzT_0}}{R_0} \right] \cos^{-1}\left( \frac{T_0}{T_{melt}} \right)$$

***See Backup Slides for Derivation***

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

| **Material** | $T_{melt}$ | $I_{melt, vac}$ | $V_{melt} = R_0 * I_{melt, vac}$ |
|---|---|---|---|
| Tin | 505.1K | 87.5 mV / $R_0$ | **88 mV** |
| Cadmium | 594.2K | 97.1 mV / $R_0$ | **97 mV** |
| Zinc | 692.7K | 104.4 mV / $R_0$ | **104 mV** |

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

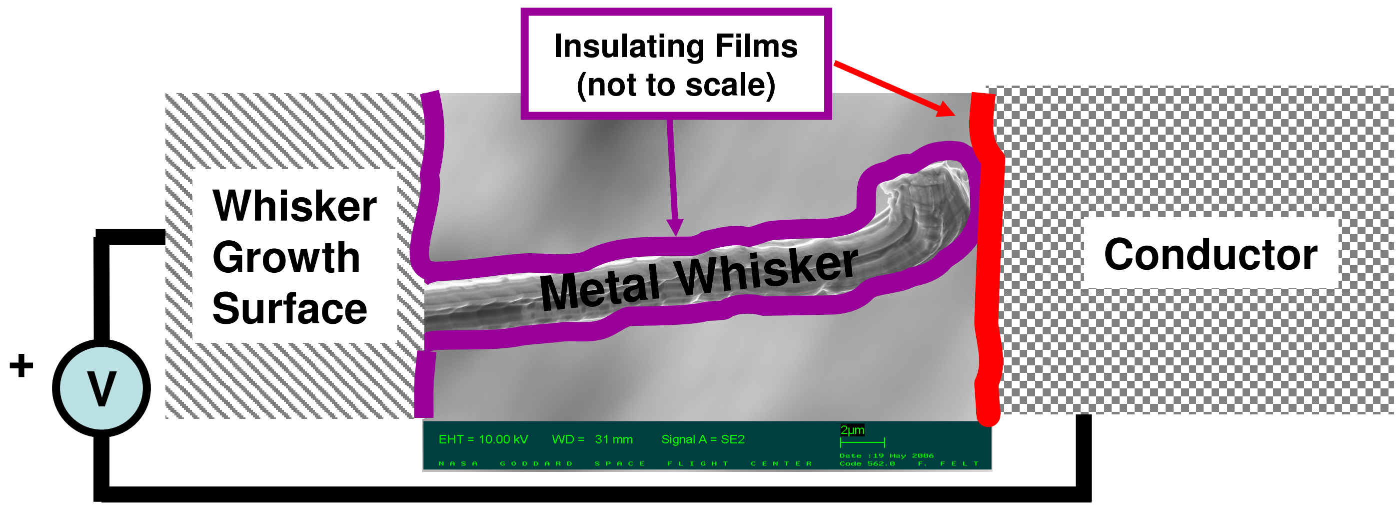
***Then the Whisker will Fuse Open***

***But there is MORE to this story***

# Metal Whisker Melting Current -- Pt. 2

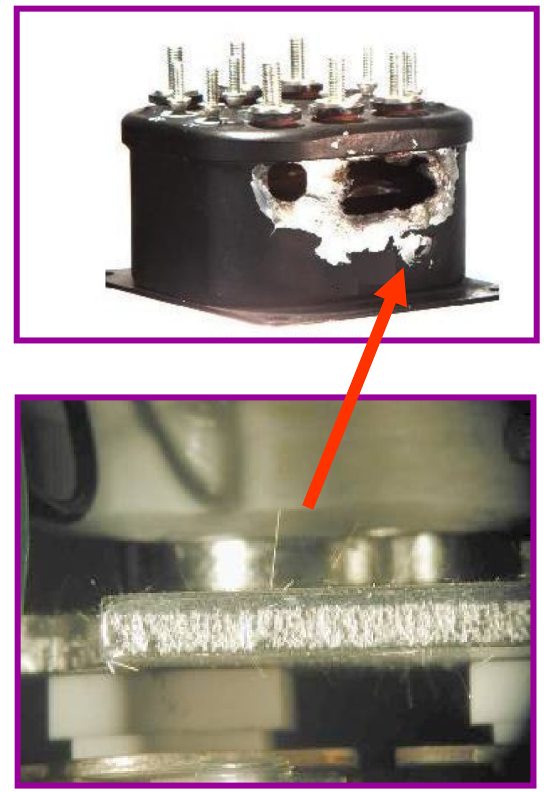
- Electrically insulating films naturally form on metal surfaces INCLUDING surfaces of metal whiskers
  - Examples: oxides, hydroxides, sulfides, moisture films, etc.

- Direct **MECHANICAL** contact by the whisker to another conductor does NOT guarantee **ELECTRICAL** contact
  - For Electrical Contact, the potential difference must exceed "dielectric breakdown" of the insulating films
  - For tin and zinc whiskers, independent groups have confirmed the film breakdown can range from ~ 0.2V to ~ 45V



# 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
- NASA testing of FM08 style fuses with metal filaments ~5 mm long finds ~ 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***

G. Davy, "Relay Failure Caused by Tin Whiskers", Northrop Grumman, Technical Article, October 2002
*http://nepp.nasa.gov/whisker/reference/tech_papers/davy2002-relay-failure-caused-by-tin-whiskers.pdf*

# *How do People with "Whiskers" Cope?*

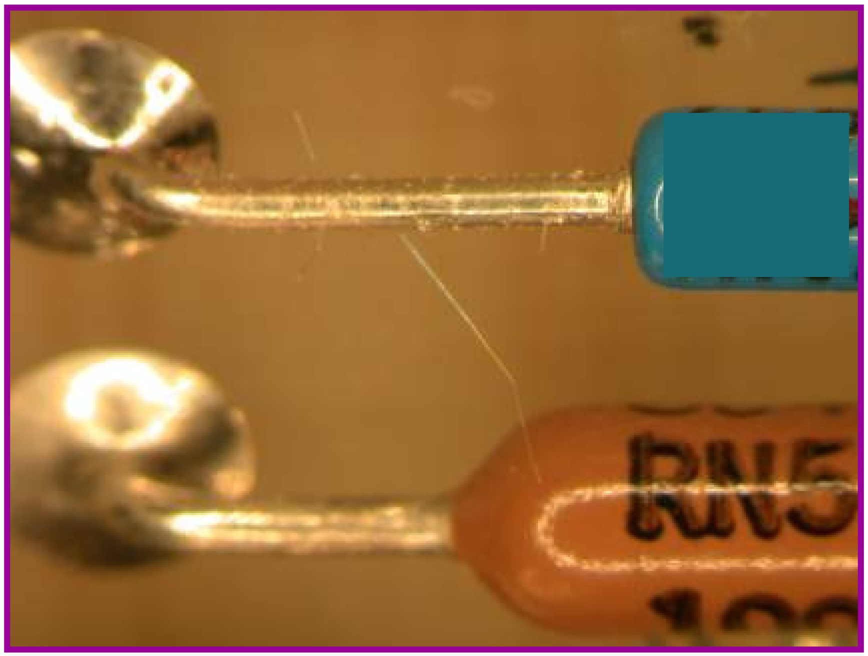
# My Whisker ***“Stress Relaxation Theory”***

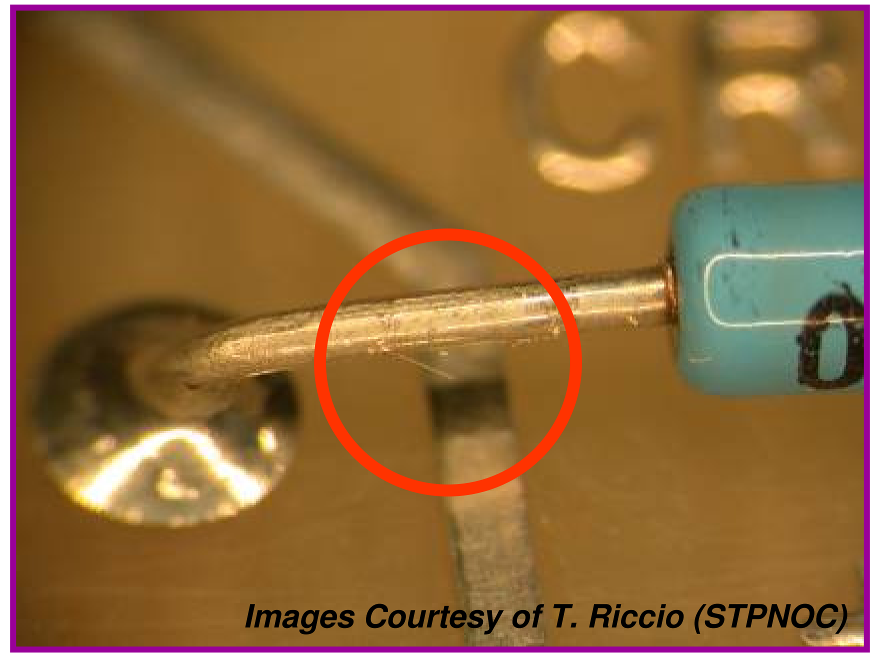
**Man with “Facial Whiskers”**
**Does YOGA!**

**Men with “Metal Whiskers”**
**Find Innovative Ways to Relieve Stress**

# A Case for Whisker Mitigation Strategies?

***Tin Whiskers on Tin-Plated Axial Leaded Diodes***



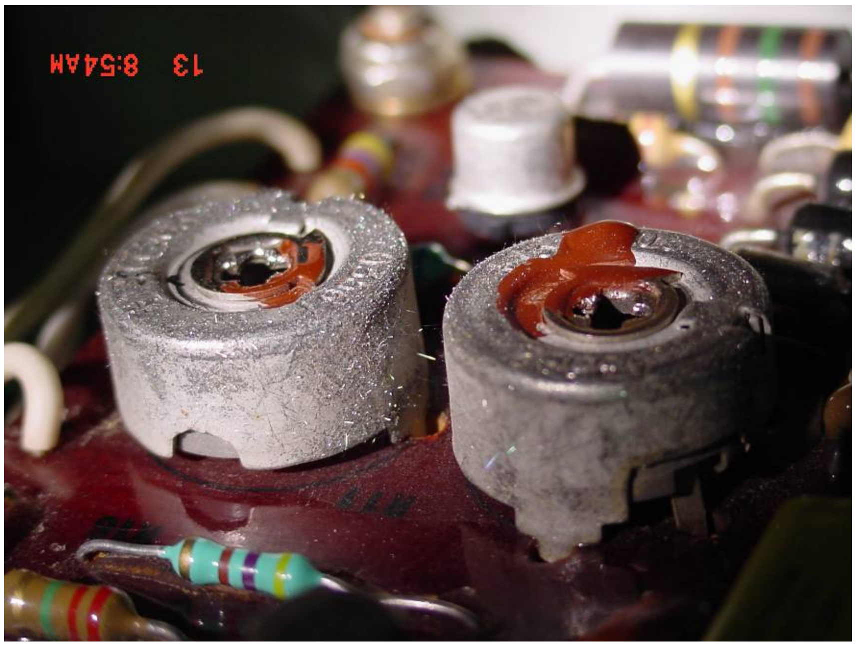



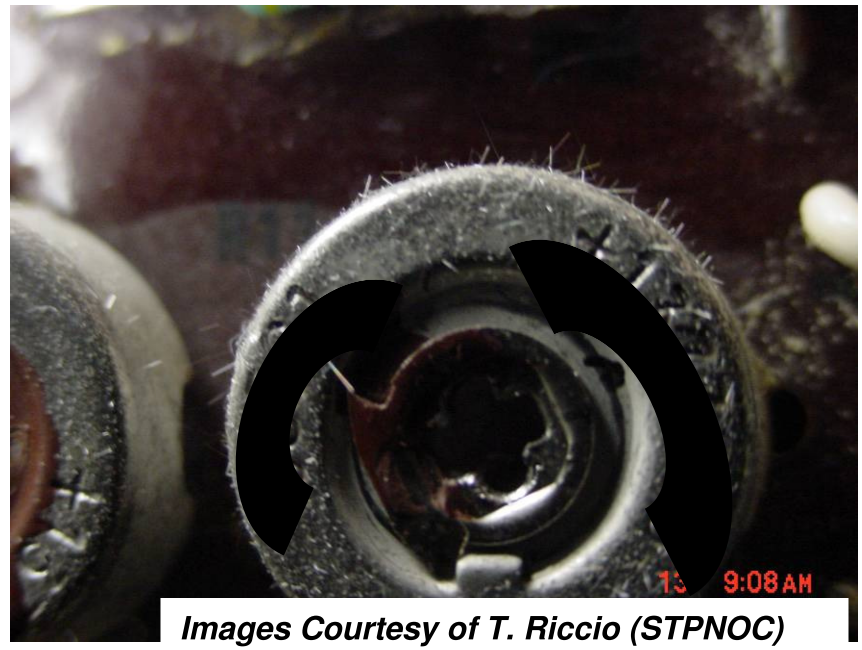
*Images Courtesy of T. Riccio (STPNOC)*

- Diode Leads were **NOT Hot Solder Dipped** prior to assembly
- PWB and components were **NOT Conformal Coated**

# Another Case for Whisker Mitigation Strategies?

***Metal Whiskers on External Case of Potentiometers***






*Images Courtesy of T. Riccio (STPNOC)*

- Potentiometer cans are electrically connected to circuitry
- Metal whiskers bridging between the cases caused circuit malfunction
- No electrically insulating materials were used on these cases to act as a barrier to electrical shorting

# Three Whisker Mitigation Strategies

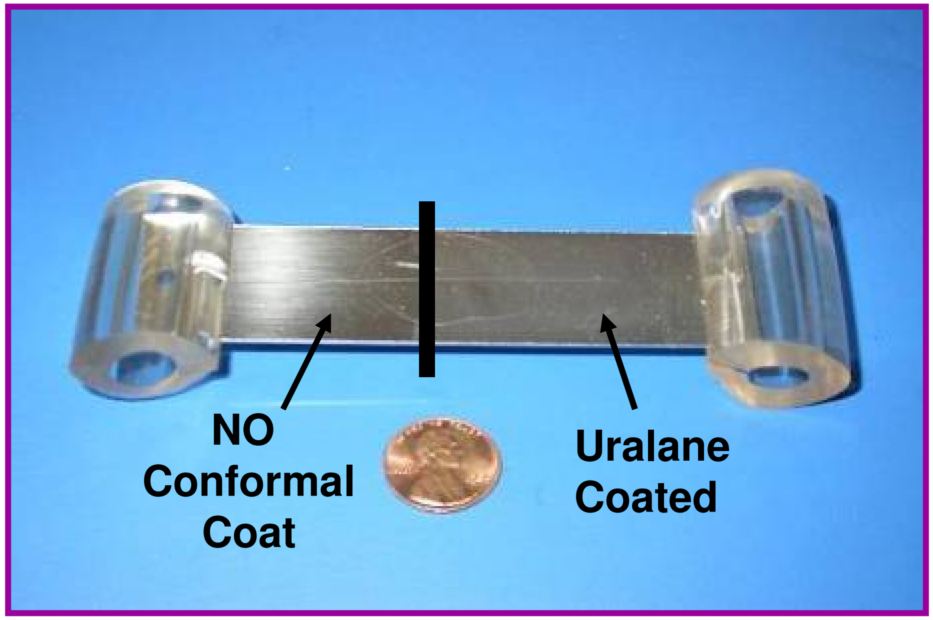
*Mitigation – to make **less** severe or painful*
*Merriam-Webster Dictionary*

***Risk "Mitigation" ≠ Risk "Elimination"***

- Avoid Use of Whisker Prone Surface Finishes
  - Perform independent materials composition analysis
  - *"Trust, But VERIFY!"* using X-ray Fluorescence (XRF), Energy Dispersive X-ray Spectroscopy (EDS), etc.
- Conformal Coat: Electrically Insulating Barrier
  - 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
  - "First, Do No Harm" Principle

# 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



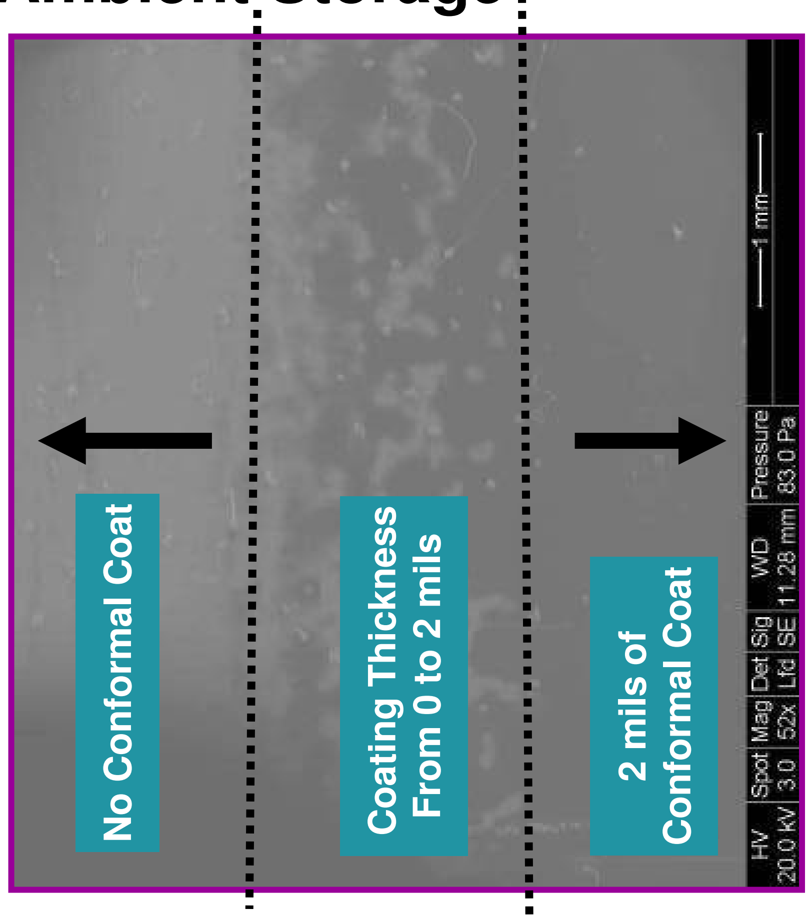

- **Conformal Coating:**
  - Uralane 5750 on ½ of sample
  - Nominal Thickness = 2 mils
- **Storage Conditions:**
  - Office Ambient ~ 9 years

***** Uralane™ 5750 now known as Arathane™ 5750***

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

- **Coating Thickness Can Vary Depending on Process Parameters**

- **Spray and masking techniques used produced a “transition” region ~2 mm wide where the conformal coating thickness was variable between 0 and 2 mils**
  - ***One must understand their own processes to ensure the coating thickness is sufficient everywhere you intend it to be!!***

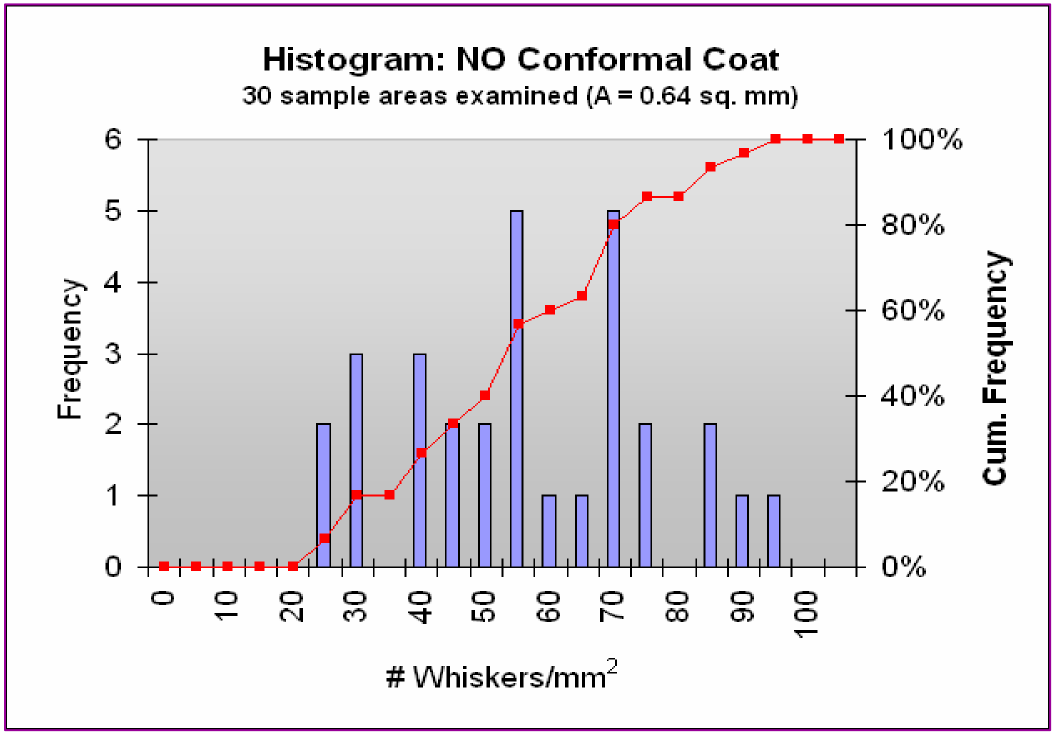


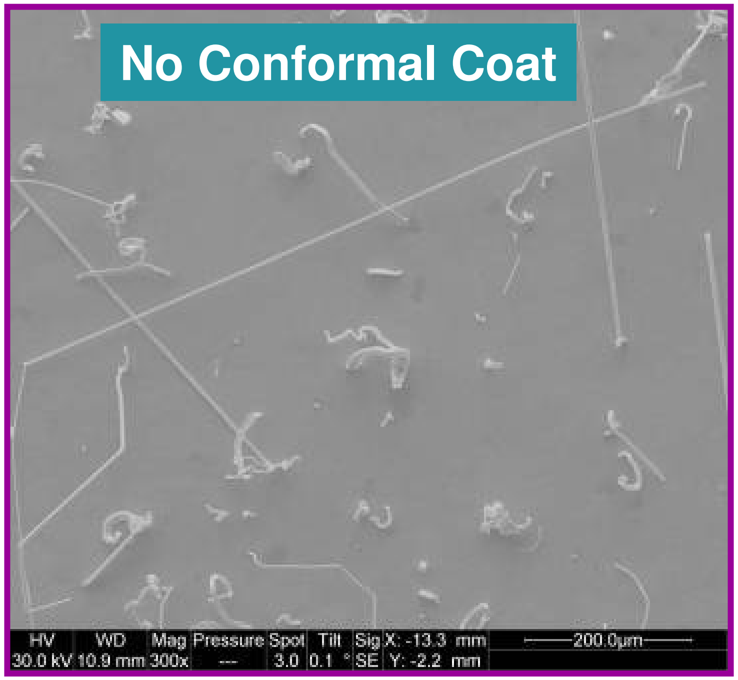

***NASA GSFC Conformal Coat Tin Whisker Test Coupon***

*** Uralane™ 5750 now known as Arathane™ 5750***

# Control Areas – No Conformal Coat
## 9-Years of Office Ambient Storage

- **Control Areas Grew Whiskers Abundantly**
  - **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$^2$**

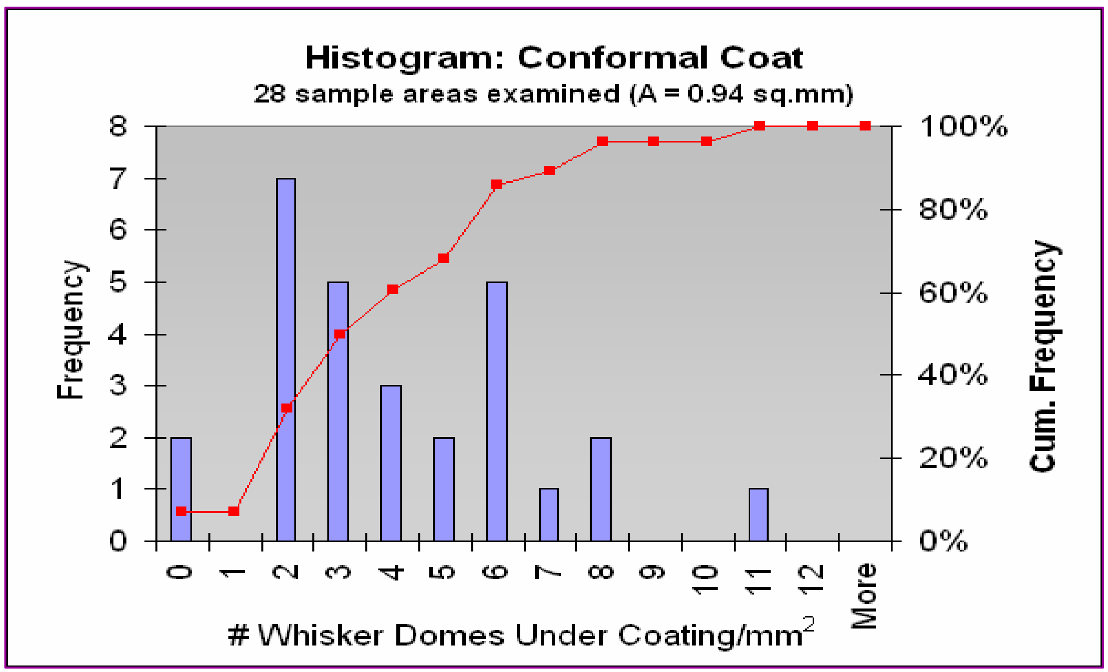


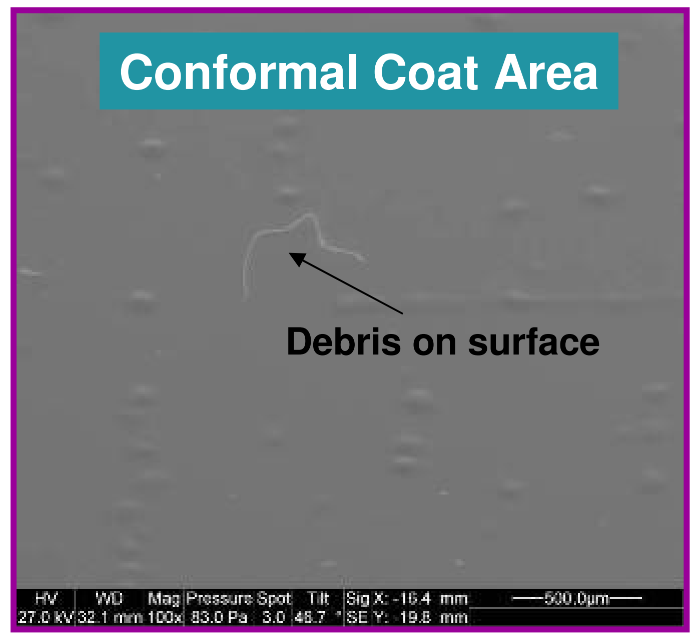



# Uralane 5750 – 2 Mils Thick
# 9-Years of Office Ambient Storage

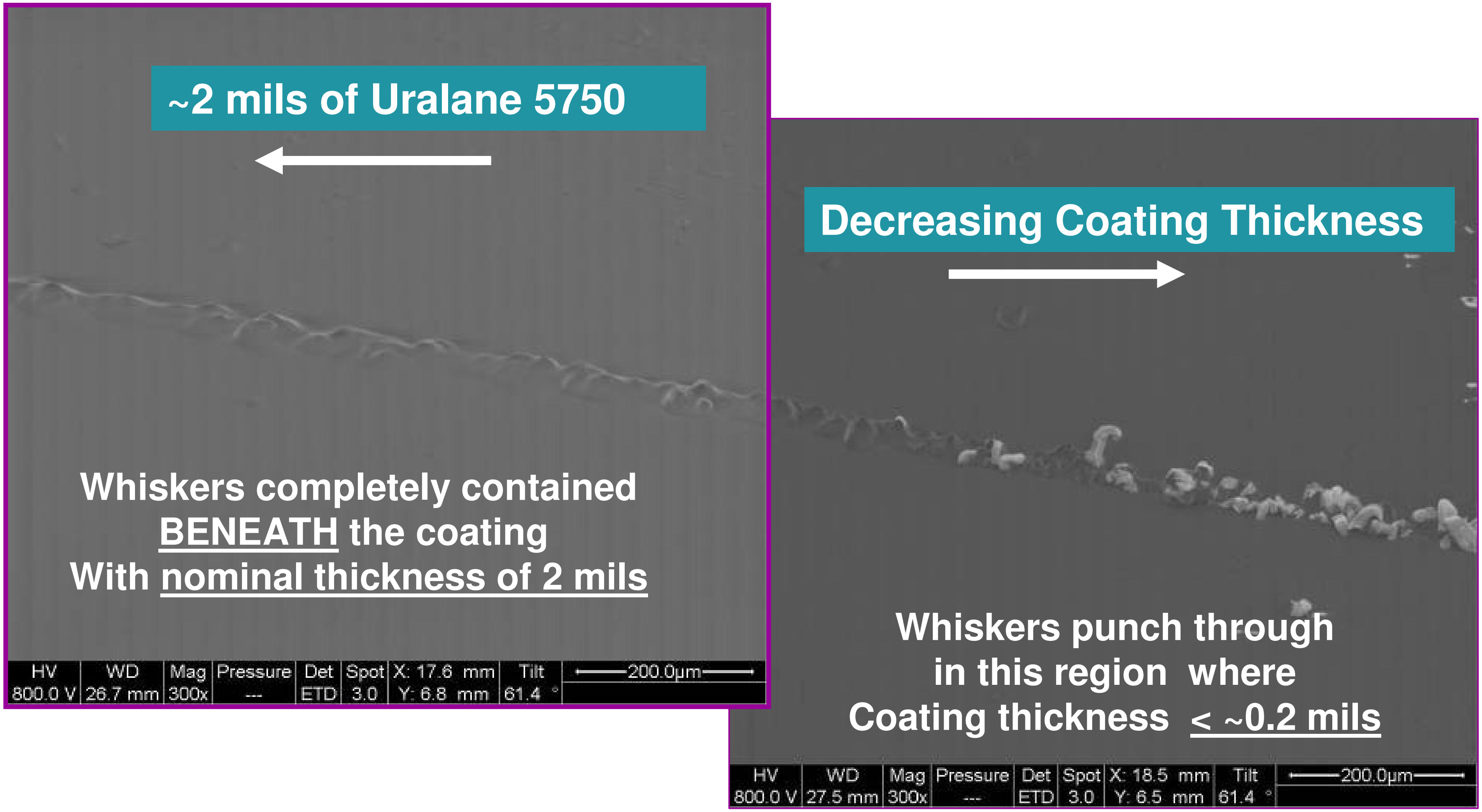
- **Conformal Coated Areas Grew Whiskers Too**
  - *To date ALL whiskers are contained beneath the coating that is 2 mils thick*
  - *With SEM we see "domes" caused by whiskers that lift coating slightly*
  - **Avg: 3.4 ± 2.6 domes / mm$^2$**
  - **Range: 0 to 10.6 domes / mm$^2$**

***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"***



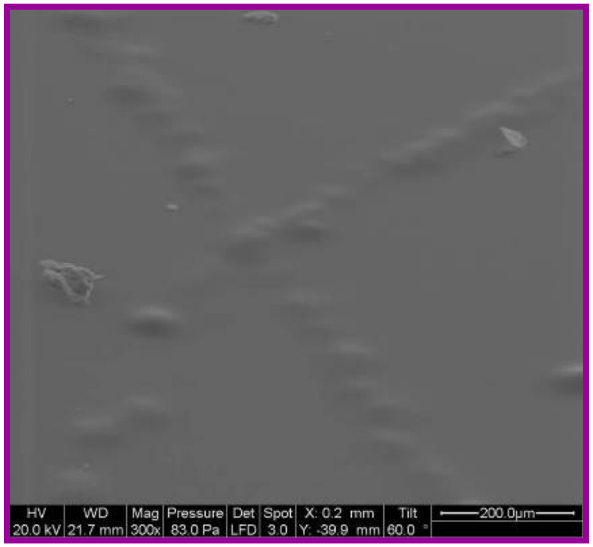



# Whisker Puncture vs. Coating Thickness



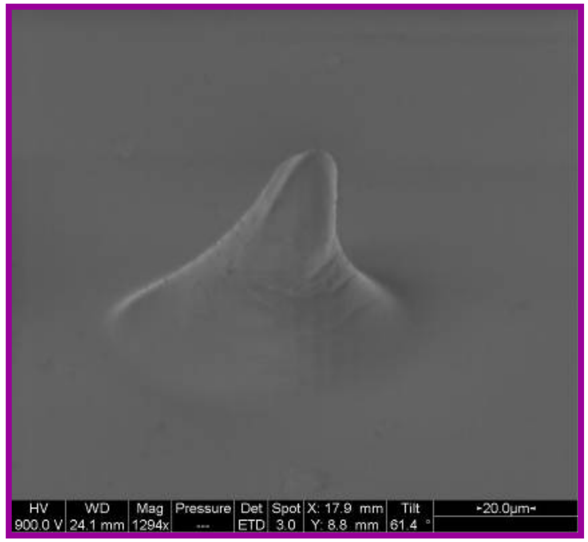
# Uralane 5750 Conformal Coat - 9-Years of Office Ambient Storage

**2 Mils Uralane = Very Effective**



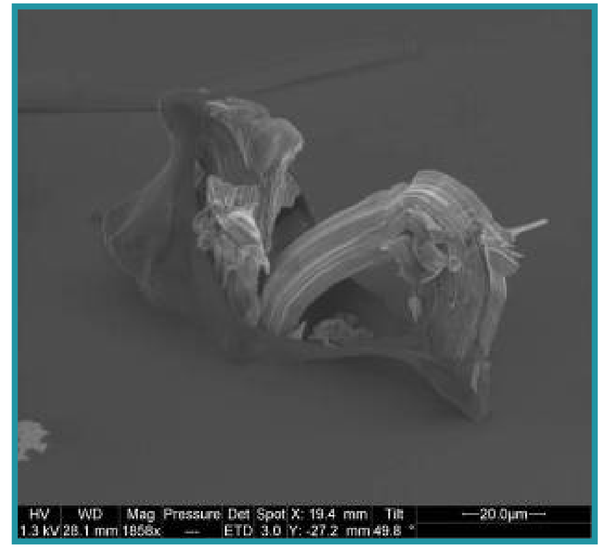

**Whiskers Completely Entrapped Under the Coating → Euler Buckling**

**~0.5 Mils Uralane = Less Effective**




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

**~0.1 Mils Uralane = Not Effective**

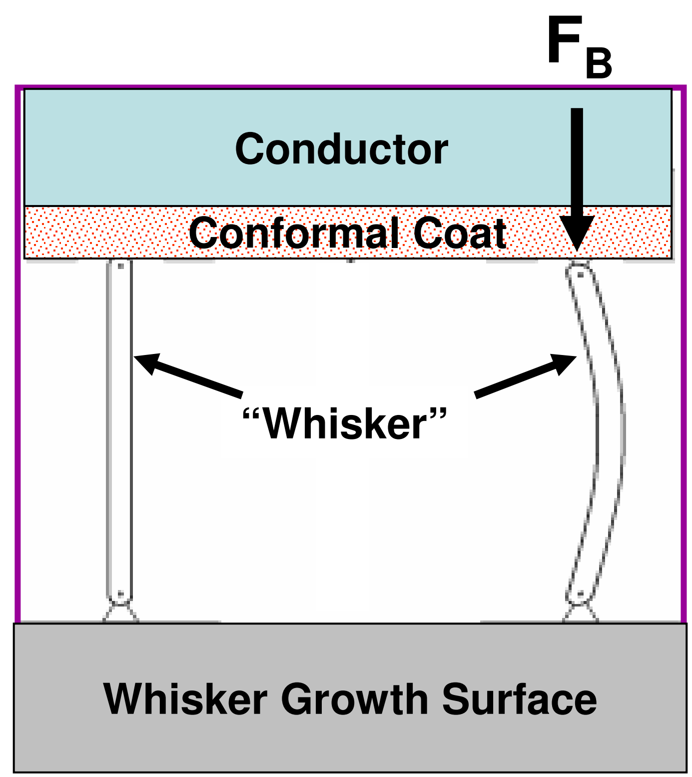



**Whiskers Breaking Through "Thin" Coating**

# 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. $I = \pi d^4 / 64$ 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**

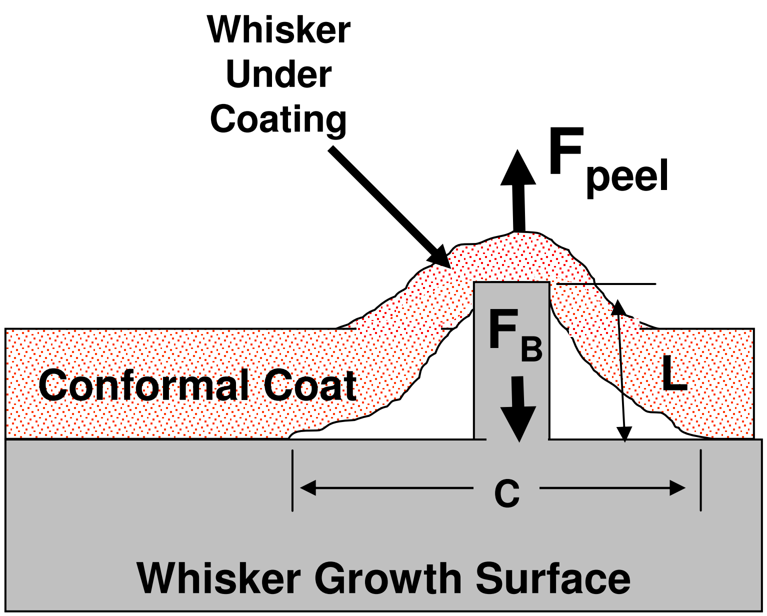


# Whiskers Lift and Peel Conformal Coat Until Whisker Buckles OR Coating Fails ($F_{peel}$ vs. $F_{Buckle}$)

- **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 ~ 2πQL,**
  - **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.**

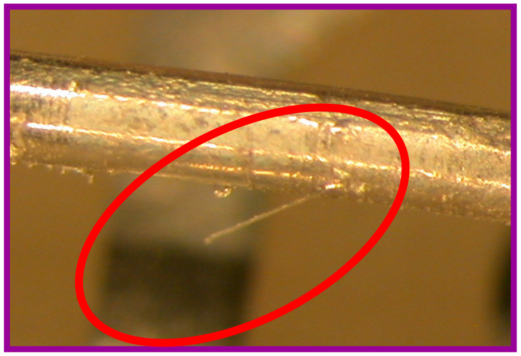



***Uralane 5750 has better self-cohesion than adhesion to a tin surface***

***Additional Analysis Pending***

# 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

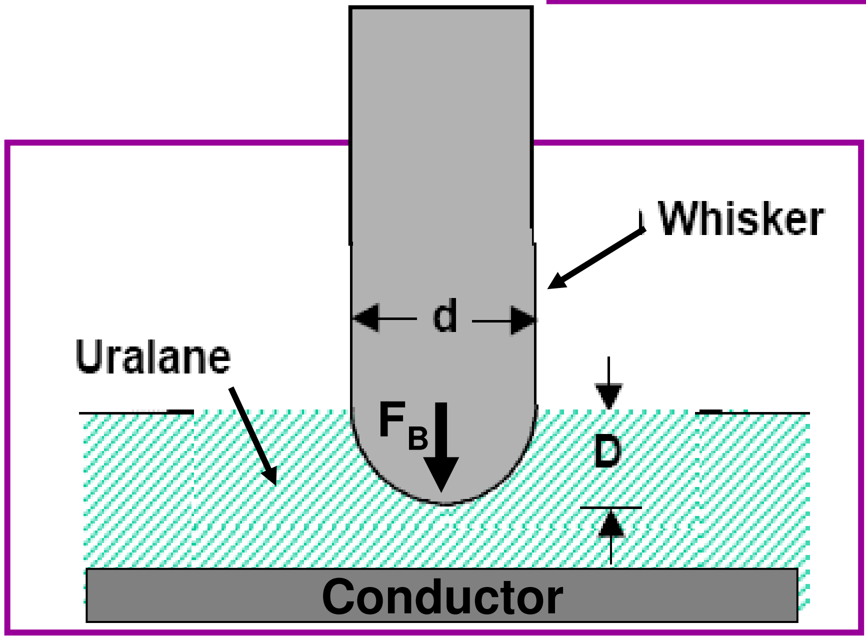
$E_{coat}$ = Young's Modulus of coating

$E_W$ = 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

- Numerous sorts of coatings have been tried:
  - Reports of success vary from “none” to “perfect”, sometimes for the same sort of coating.
- NASA GSFC has used Uralane 5750, applied to pre-primed tin-plated surfaces to a thickness of 2 mils (=50 micrometers) +/- 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
- Dr. Thomas Woodrow (Boeing) 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 when exposed to 25°C / 97% R.H.

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


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

# Effects of Conformal Coating -- 2

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

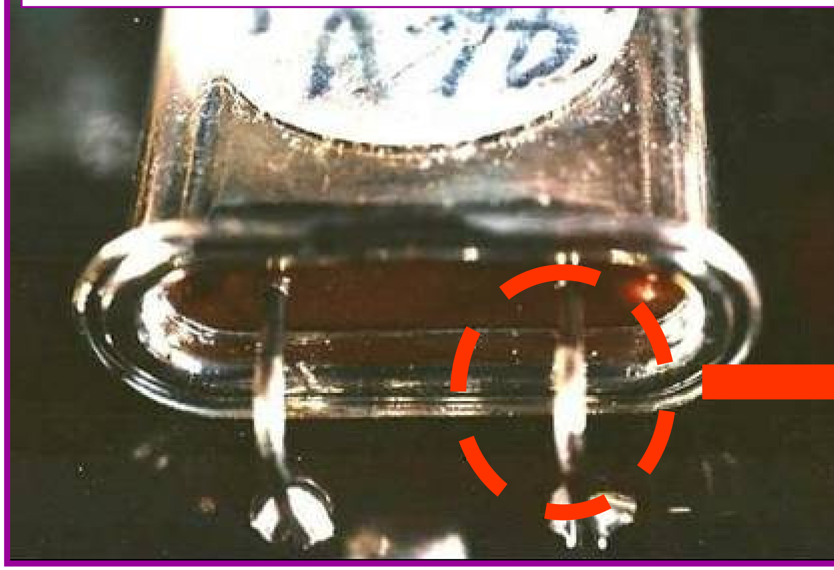
- Conclusion 2:
  - It is possible to suppose the surface is protected when it is not.
  - Coating processes can leave "weak zones" of thin coating allowing vertical escape

- Conclusion 3:
  - Even "poor" coatings can offer some protection against a whisker coming from a distant source and attempting to contact the protected surface --- long whiskers bend easily (Euler Buckling).
  - Conformal coat protects against a conductive bridge from detached whiskers lying across a pair of conductors

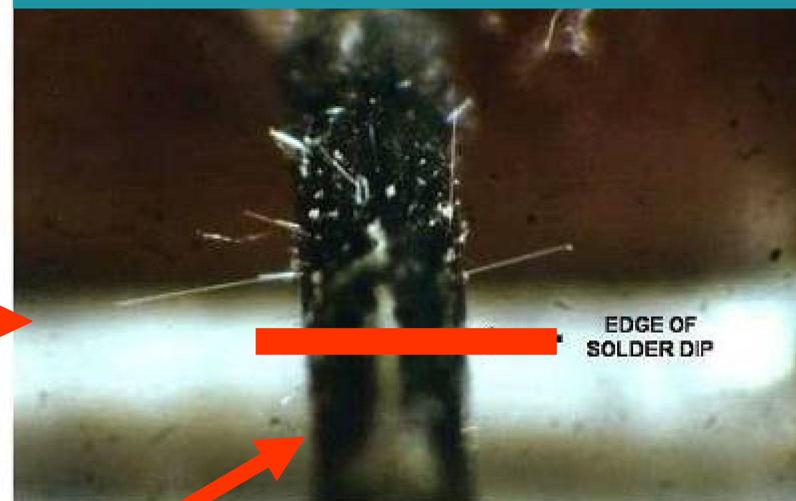
# Hot Solder Dip
## Benefits & Limitations

***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**

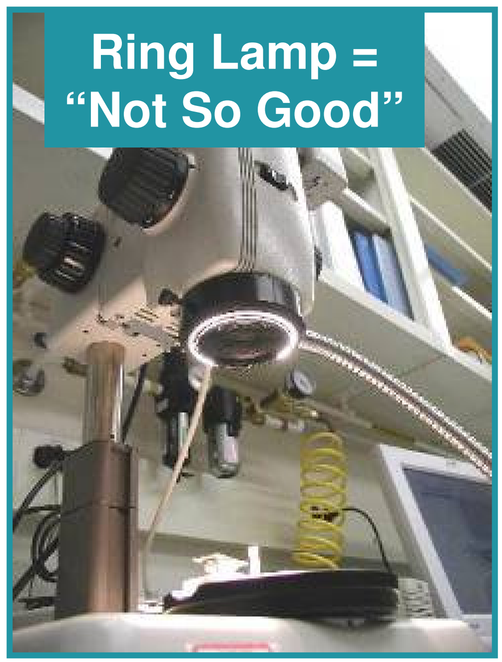



- Leads were *Hot Solder Dipped* (Sn63Pb37) *within 50 mils* of Glass Seal BEFORE Mounting to enhance solderability
- Dip was not 100% of leads due to concerns of inducing harm to glass seal

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

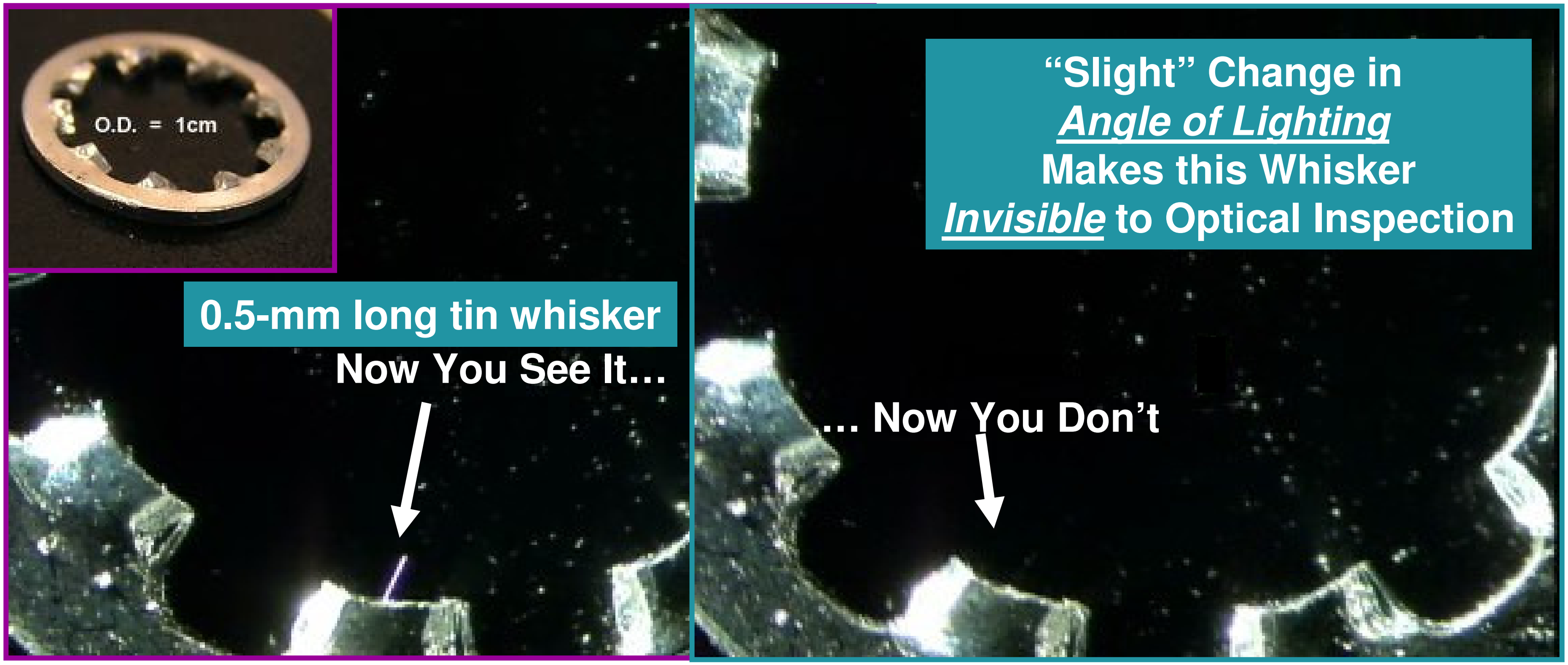
# Optical Inspection for Metal Whiskers

- 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

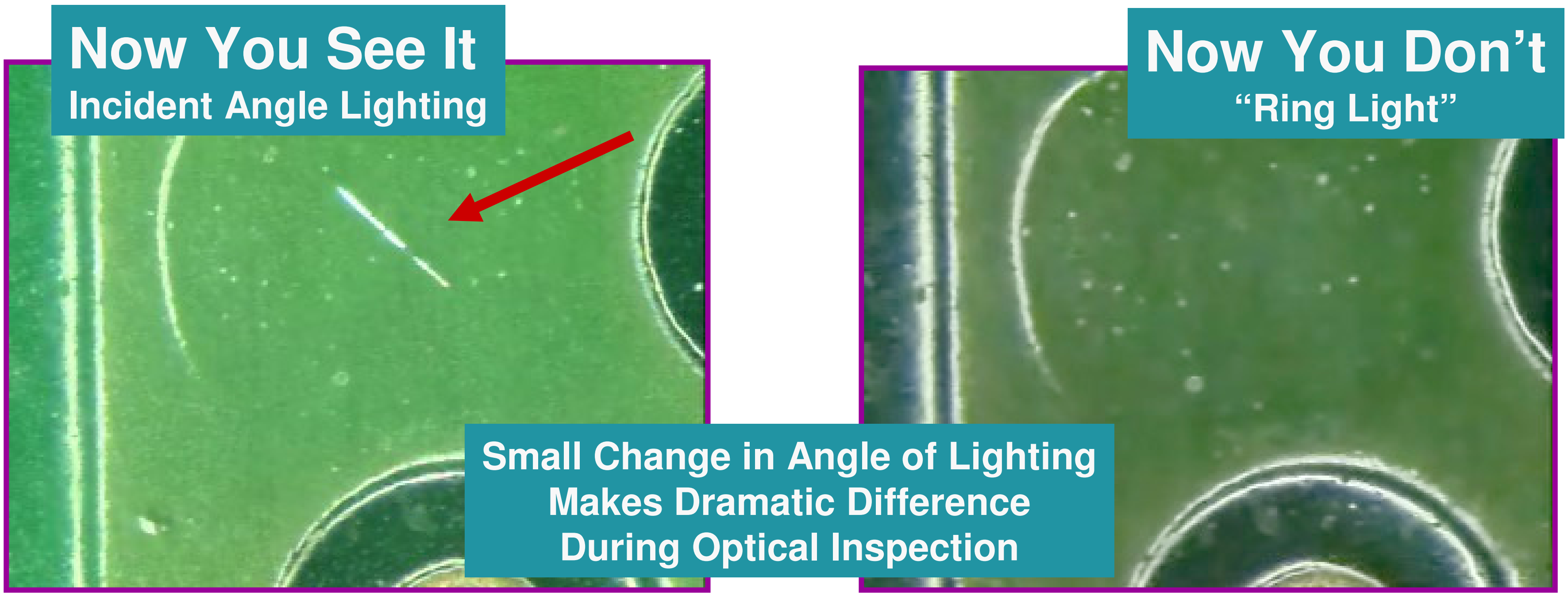



***The absence of evidence is NOT evidence of absence***

# 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**



# Video Demonstration
# Optical Inspection For Metal Whiskers
# (Click Image to Start Video)

# Contact Information

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***NASA Goddard Space Flight Center***

***Jay.A.Brusse@nasa.gov***

## *Work Performed in Support of the NASA Electronic Parts and Packaging (NEPP) Program*

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

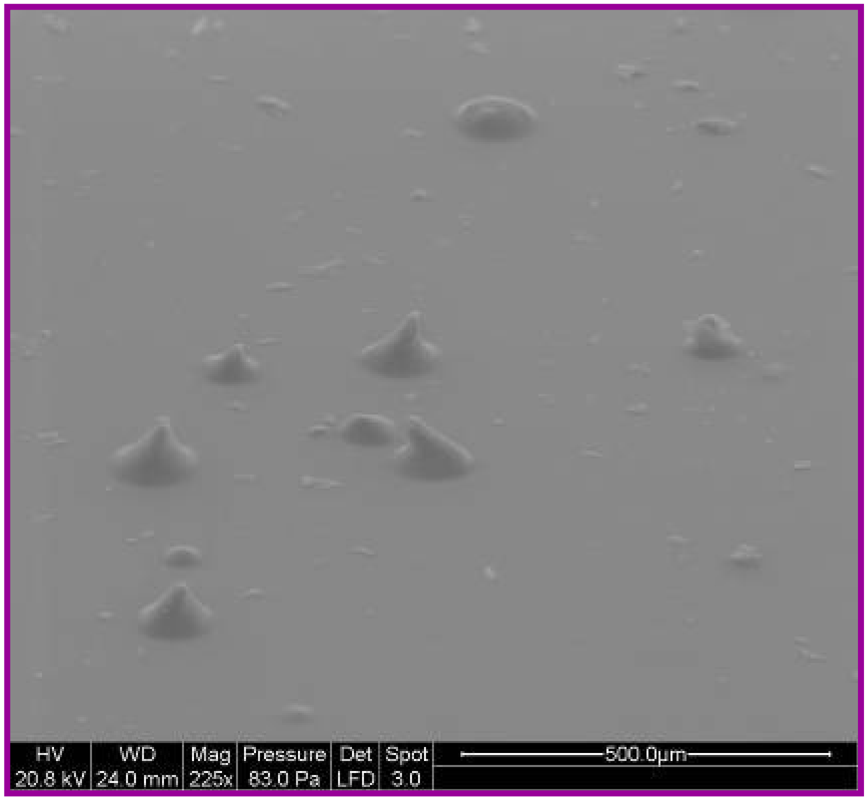
**NASA Tin and Other Metal Whisker WWW Site**

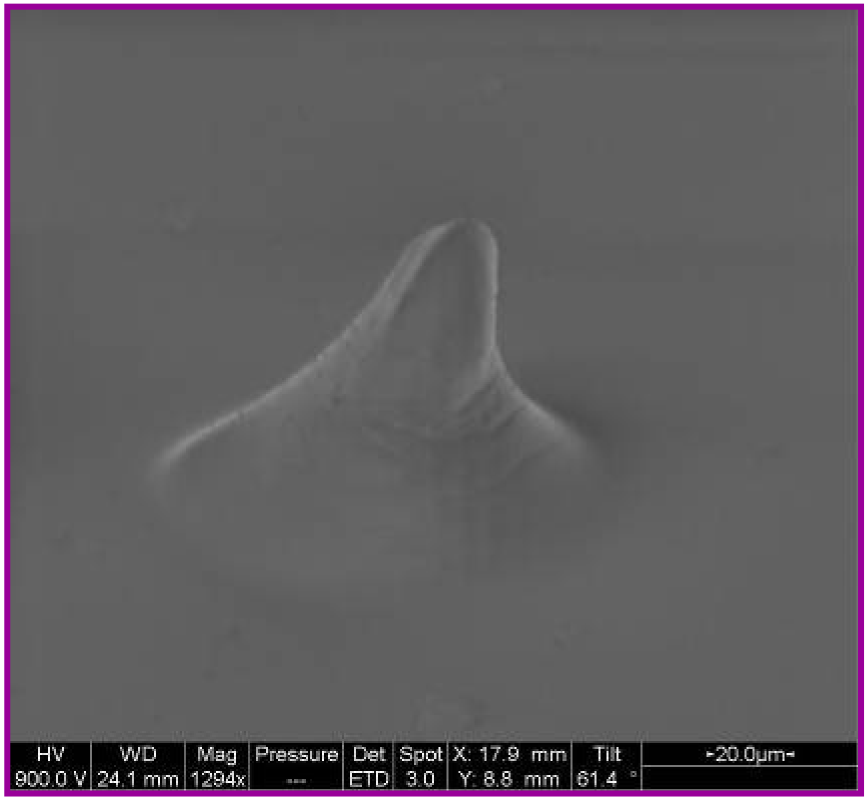
# http://nepp.nasa.gov/whisker

# Backup Slides

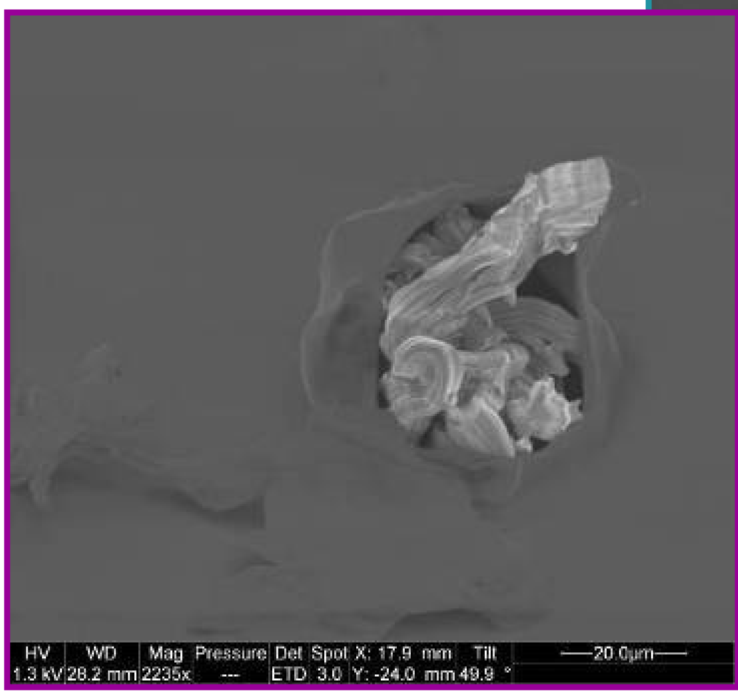
# Tin Whiskers Forming "Circus Tents" in Thin Uralane 5750 Conformal Coat - 9-Years of Office Ambient Storage

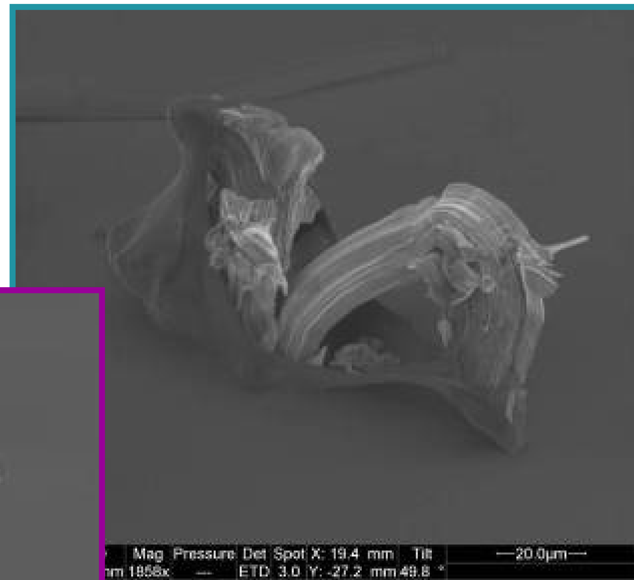
## Coating Thickness < 0.5 Mil

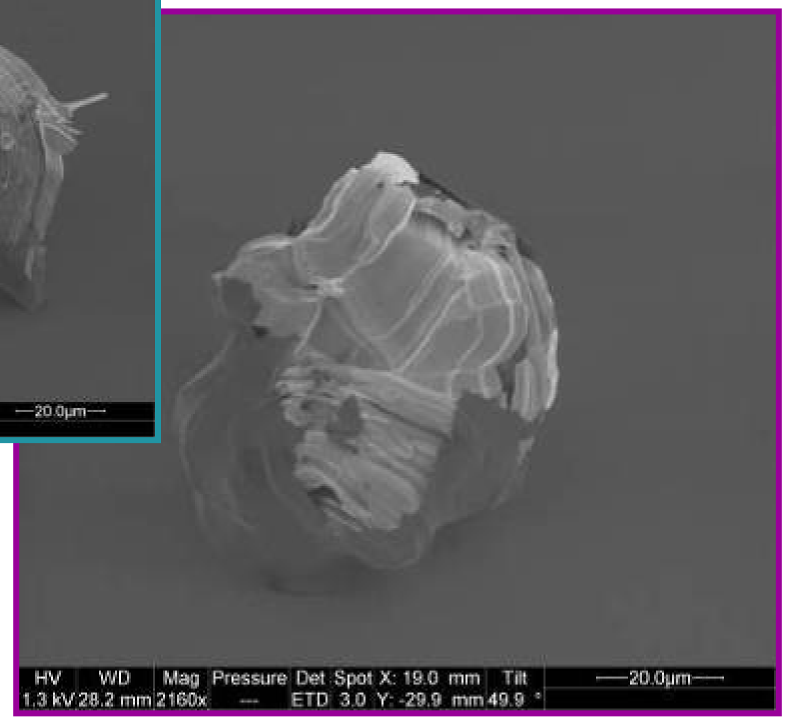


# *Tin Whiskers Rupturing THIN Coating*
## *~0.1 to 0.2 Mils* Uralane 5750 Conformal Coat
## 9-Years of Office Ambient Storage



# Circuit to Measure Resistance of a Metal Whisker

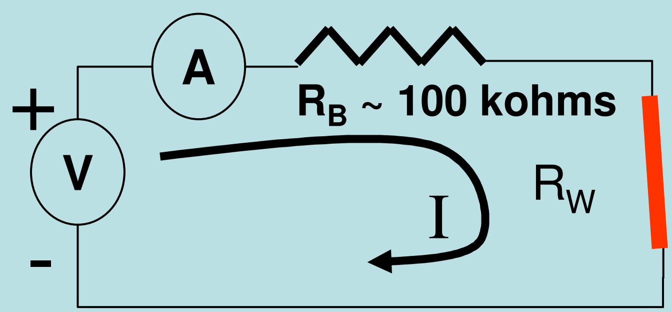
- **Use of a simple "Ohmmeter" to measure the resistance of a metal whisker is NOT preferred**
  - **Ohmmeter may supply $V_{out} < V_{breakdown}$ for the insulating films (oxides, moisture) that form on a metal whisker**
  - **Ohmmeter may supply $V_{out} > V_{melt}$ causing the whisker to melt before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

- **Instead, a variable power supply and a ballast resistor should 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 $V_{whisker} < 80\% \ V_{melt}$*



# Why Are Tin, Zinc, Cadmium Still Used?

- Not all Tin (or Zinc or Cadmium) surfaces whisker!
  - Rough estimate: 3% to 30% do whisker.
- Not all metal whiskers cause shorts
  - Environment (geometry and electrical potentials matter).
  - 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."**

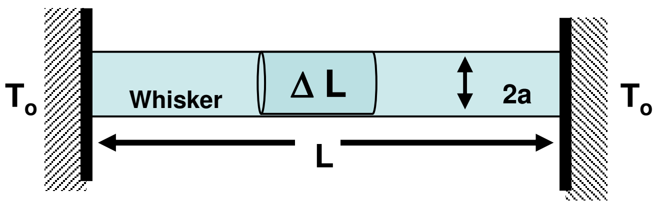
## Depression

**"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."**

# 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**

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

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

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

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

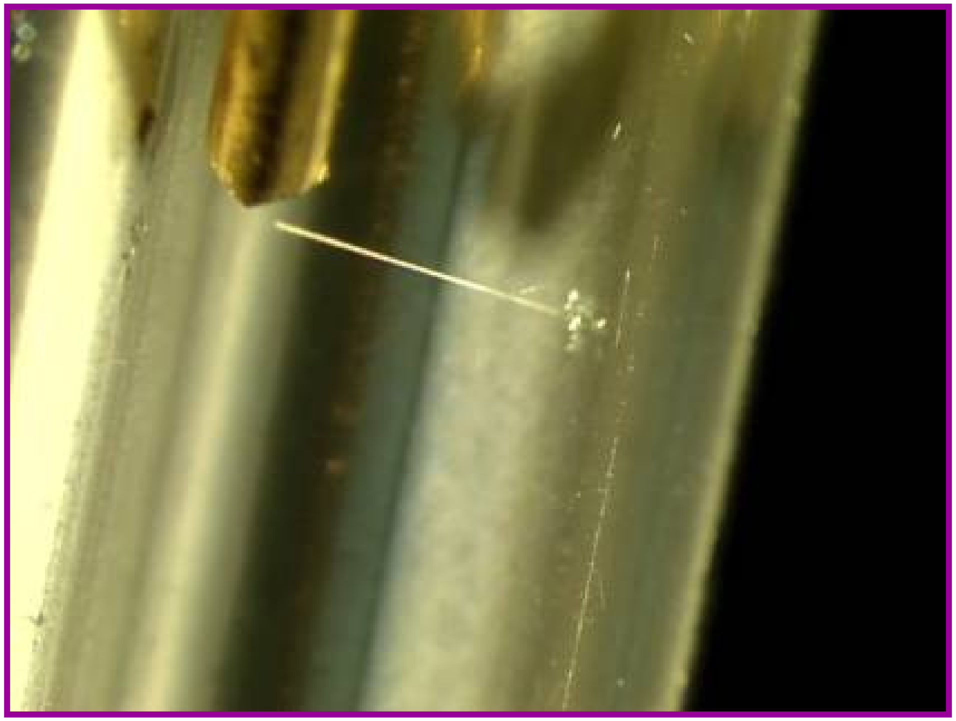
---

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

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

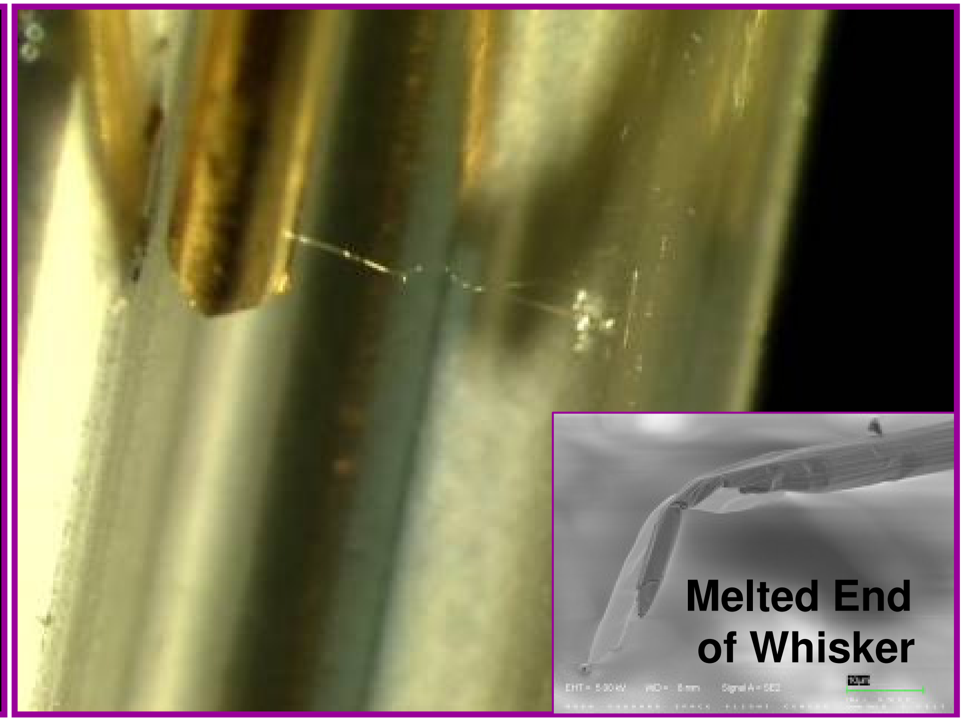
$$\boxed{I_{melt,vac} = \left[\frac{2\sqrt{L_Z T_0}}{R_0}\right] \cos^{-1}\left(\frac{T_0}{T_{melt}}\right)}$$

# An Example of “Melting” a Tin Whisker



## Before Contact

1. Gold-Plated Test Probe has +3 Volts Relative to Tin Whisker




## After Contact

1. Tip of whisker micro-welds to gold test probe
2. Whisker melts mid-length
3. Small section of whisker root remains attached to substrate