# Estimating the Probability of Electrical Short Circuits from Tin Whiskers – Part I

Presented to the
*Tin Whisker Group Telecon*

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Presenter
Dr. Karim Courey, NASA-Johnson Space Center

Co-Authors
Dr. Shihab Asfour, University of Miami
Jon Bayliss, NASA-Kennedy Space Center
Larry Ludwig, NASA-Kennedy Space Center
Clara Wright, NASA-Kennedy Space Center

Presenter Karim Courey



# Outline

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# Notice

- This presentation summarizes the research presented in the article titled:

  *Tin Whisker Electrical Short Circuit Characteristics—Part I,* Courey, K. J.; Asfour, S. S.; Bayliss, J. A.; Ludwig, L. L.; Zapata, M. C.; Electronics Packaging Manufacturing, IEEE Transactions on, Volume 31, Issue 1, Jan. 2008 Page(s): 32 - 40

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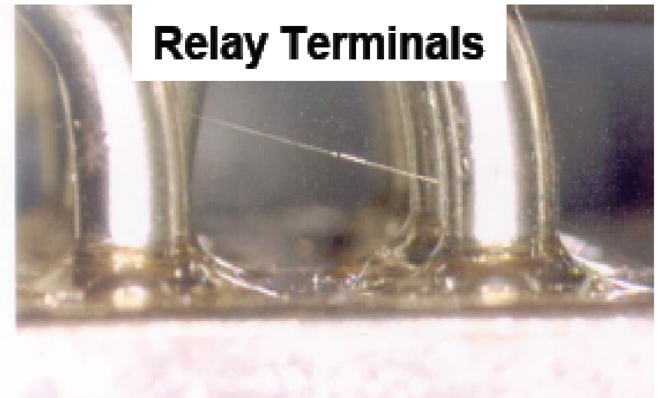
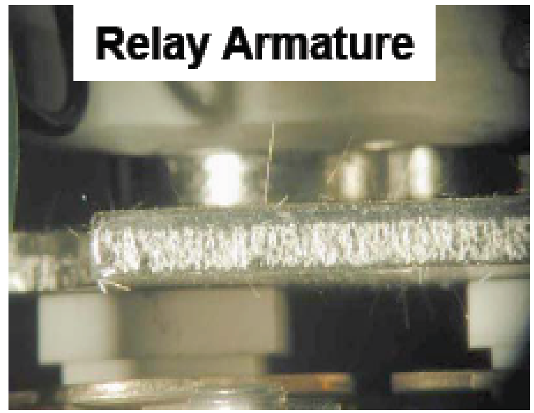
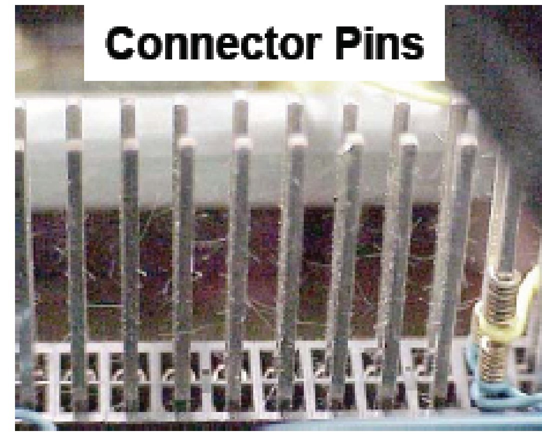
  http://ieeexplore.ieee.org/xpl/freeabs_all.jsp?tp=&arnumber=4427308&isnumber=4427303

# Tin Whiskers on Components (Source: Leidecker & Brusse, 2006)

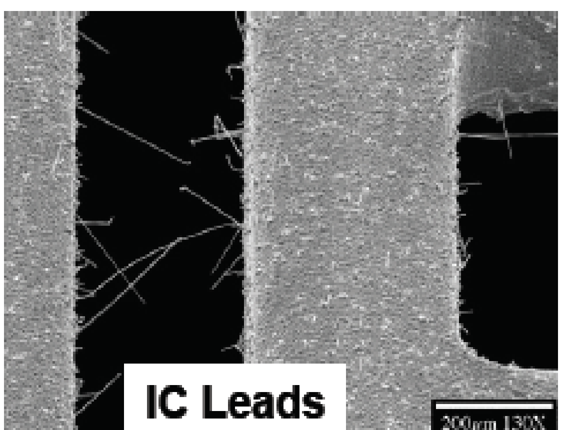
## Optical Microscopy

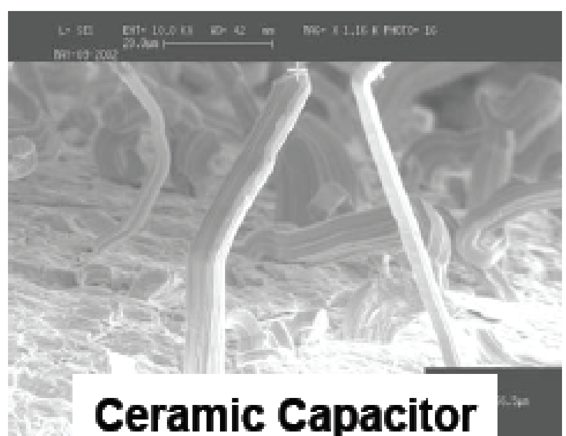


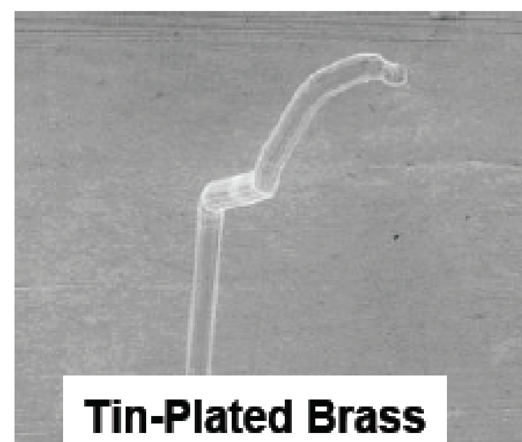




## Scanning Electron Microscopy



# Current Assumption in Risk Models

- In the published simulations it is assumed that physical contact between a whisker and an exposed contact results in an electrical short
- This conservative assumption was made because the probability of an electrical short circuit from free tin whiskers had not yet been determined

# Contact Resistance
## (Source: R. Holm & Holm, 1967)

- Contact resistance is the sum of the constriction resistance and the film resistance
  - ➢ When two surfaces touch, only a small portion of the area actually makes contact due to unevenness in the surfaces
    - Current flow is constricted through the smaller area resulting in a constriction resistance
  - ➢ Film resistance is due to the build up of tarnish films (oxides, etc.) on the contact surfaces that act in a nearly insulating manner

# Objective

- To develop an empirical model to quantify the probability of occurrence of an electrical short circuit from tin whiskers bridging adjacent contacts as a function of voltage

# First Experiment - Methods

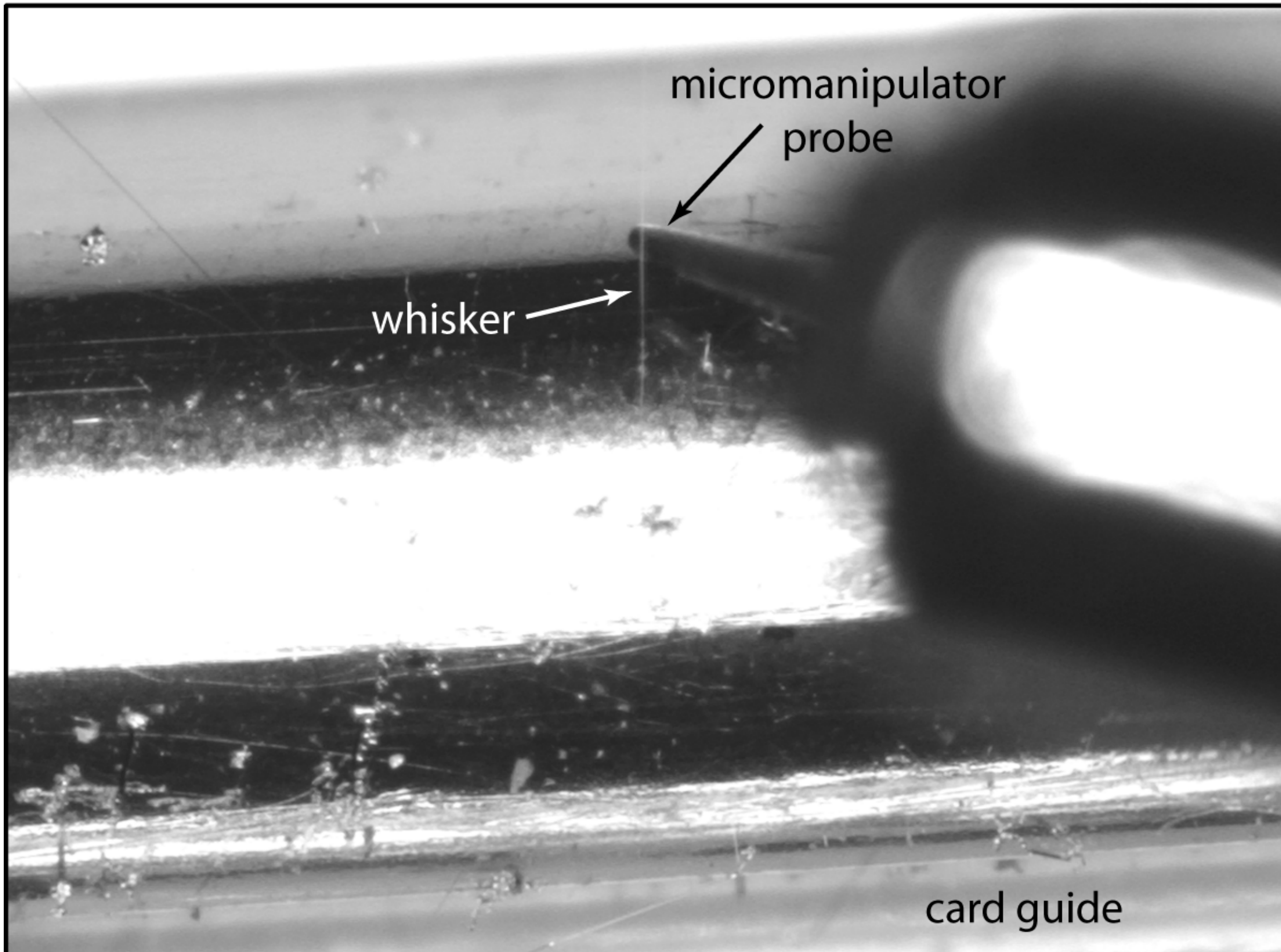


- To determine when a tin whisker's contact resistance breaks down the voltage level at the transition to metallic conduction current must be recorded
- To determine the breakdown voltage of a tin whisker a micromanipulator probe was brought into contact with the side of the tin whisker growing from a tin-plated beryllium copper card guide

# First Experiment - Micromanipulator probe touching tin whisker growing from the card guide.

Presenter Karim Courey





## First Experiment – Methods Cont.

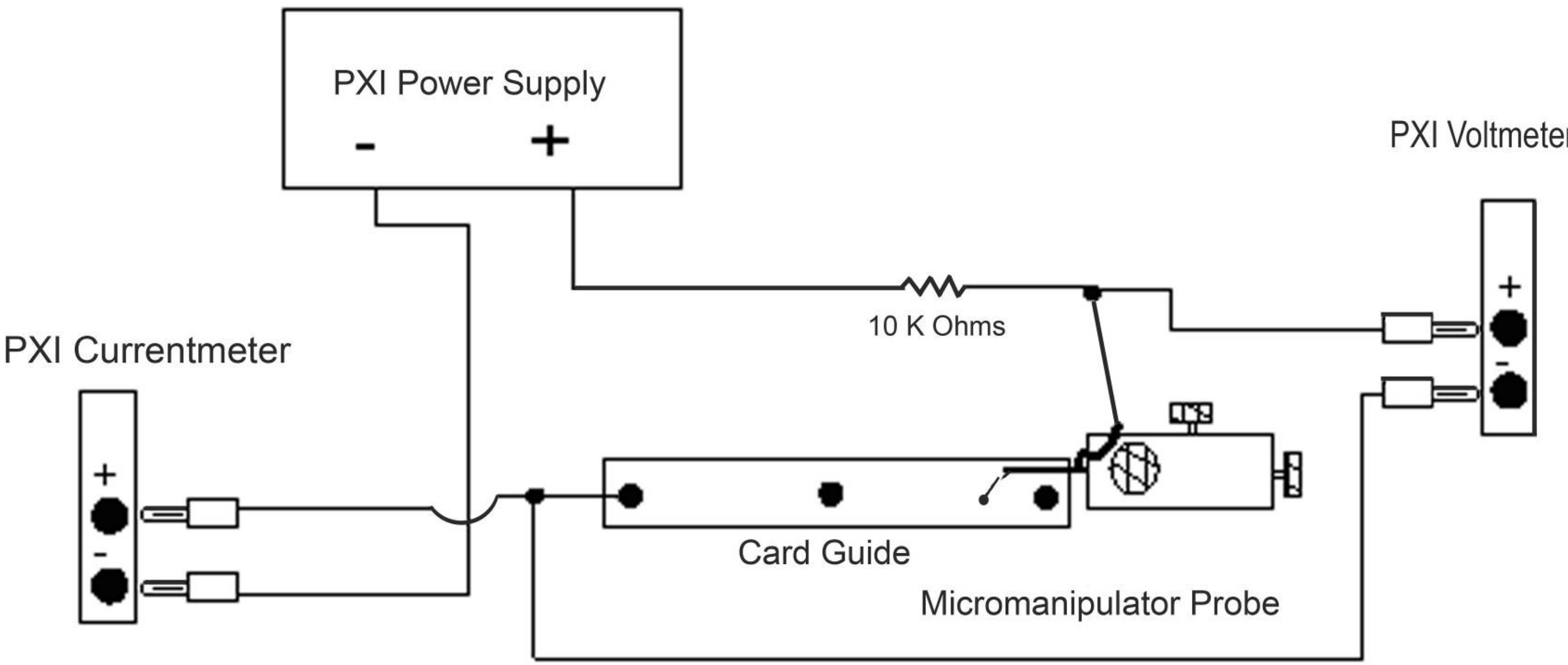
- Data Acquisition (DAQ) software was written using LabVIEW® to automate both the incrementing of power supply voltage changes as well as the gathering and recording of the voltage and current data for each of the tin whiskers
- Once contact was established, as determined with an optical microscope, the power supply voltage was increased from 0 to 45 volts direct current (vdc) in 0.1 vdc increments
- Validation of the automated test station was performed by substituting a calibrated resistor decade box for the micromanipulator, whisker and card guide

## First Experiment - Test Station Schematic



# Automated Tin Whisker Test Fixture

**PXI Instrumentation Running a Labview Program**



# First Experiment - Tin Whisker Test Station

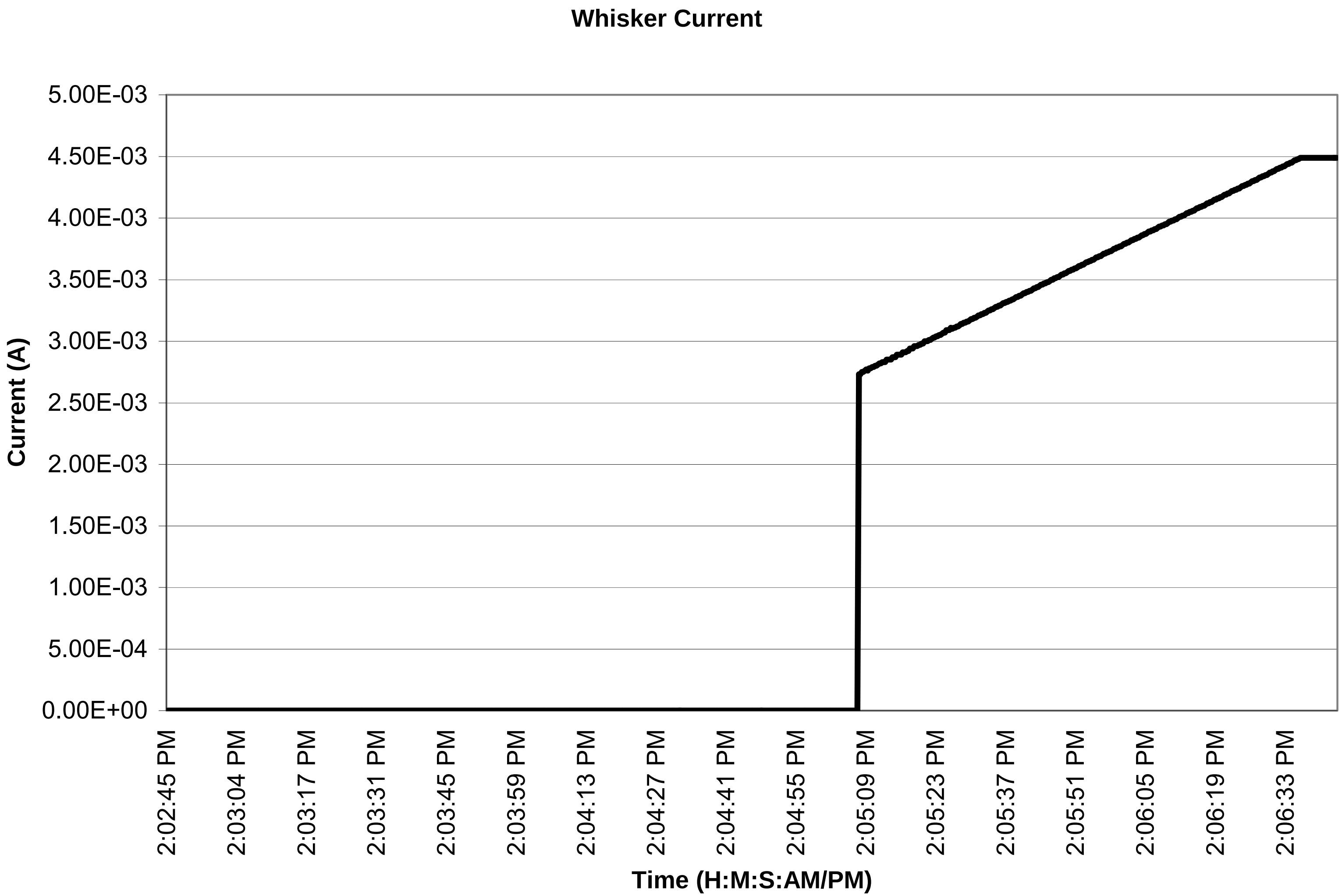


# First Experiment – Results

- The breakdown voltage for each whisker was determined from the graphs of recorded current and voltage data
- There were three different transition categories: Single, Multiple, and Multiple with intermittent contact

# First Experiment – Results (Continued)

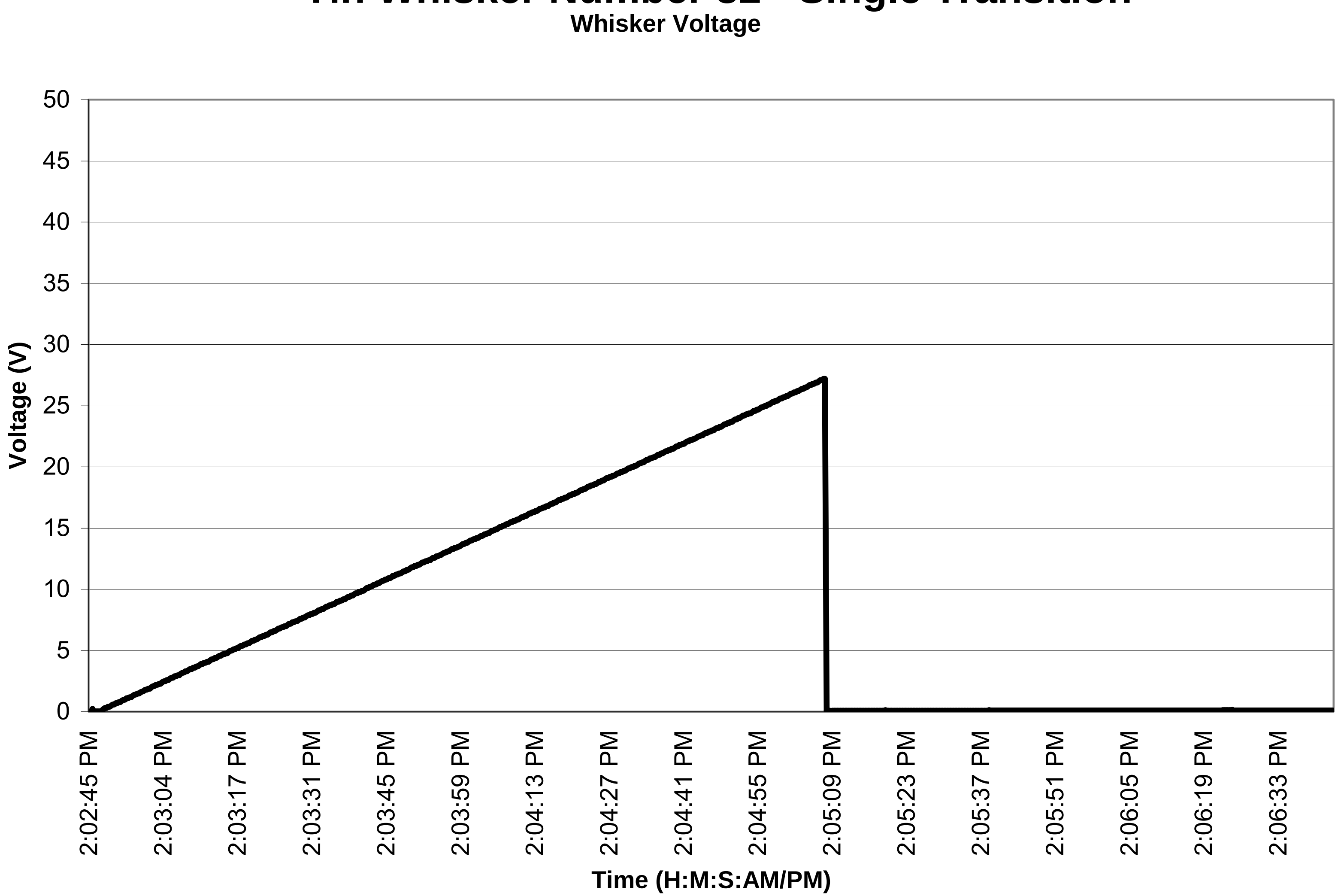
## Tin Whisker Number 32 - Single Transition



## First Experiment – Results (Continued)

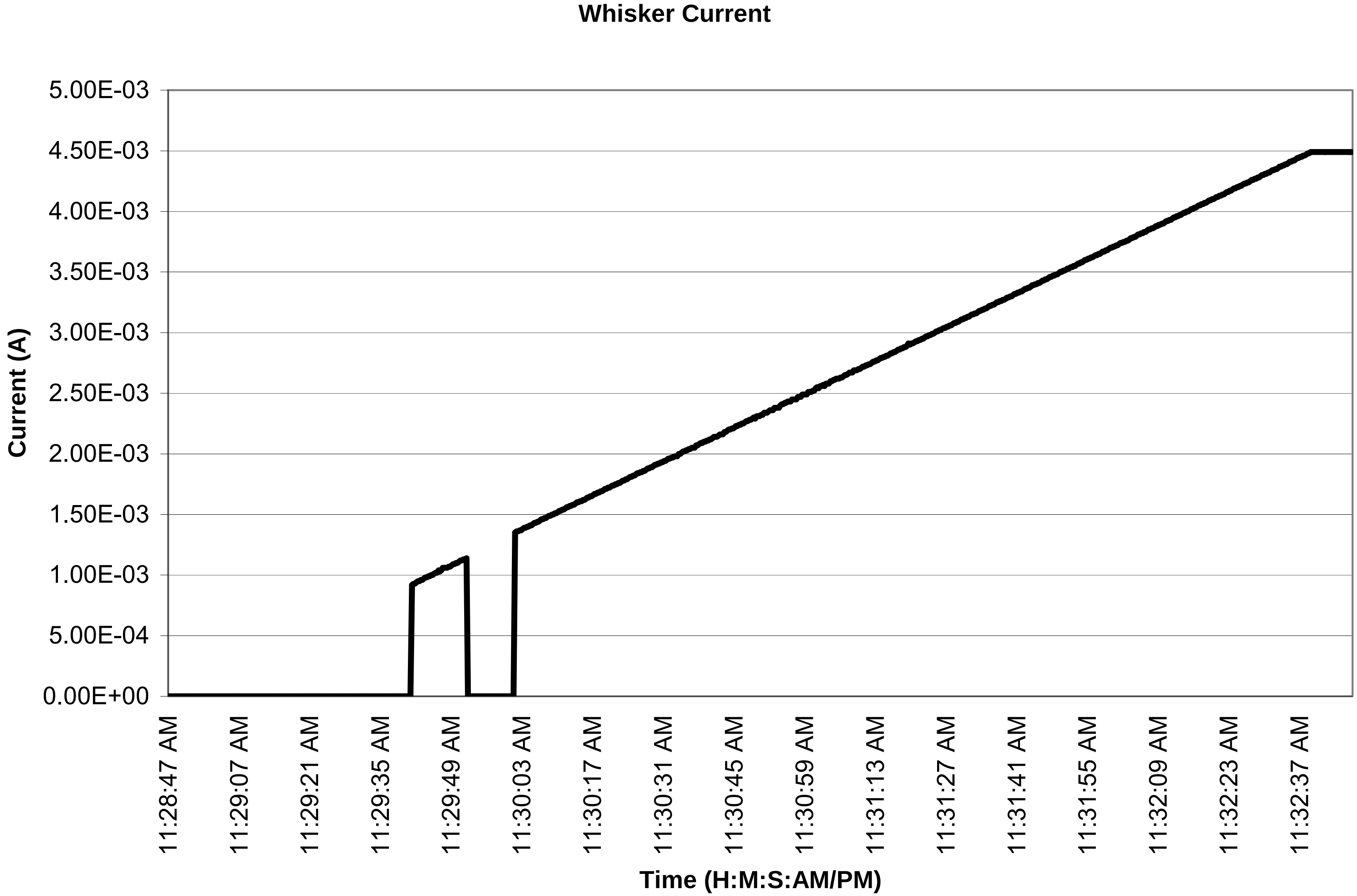


# Tin Whisker Number 32 - Single Transition



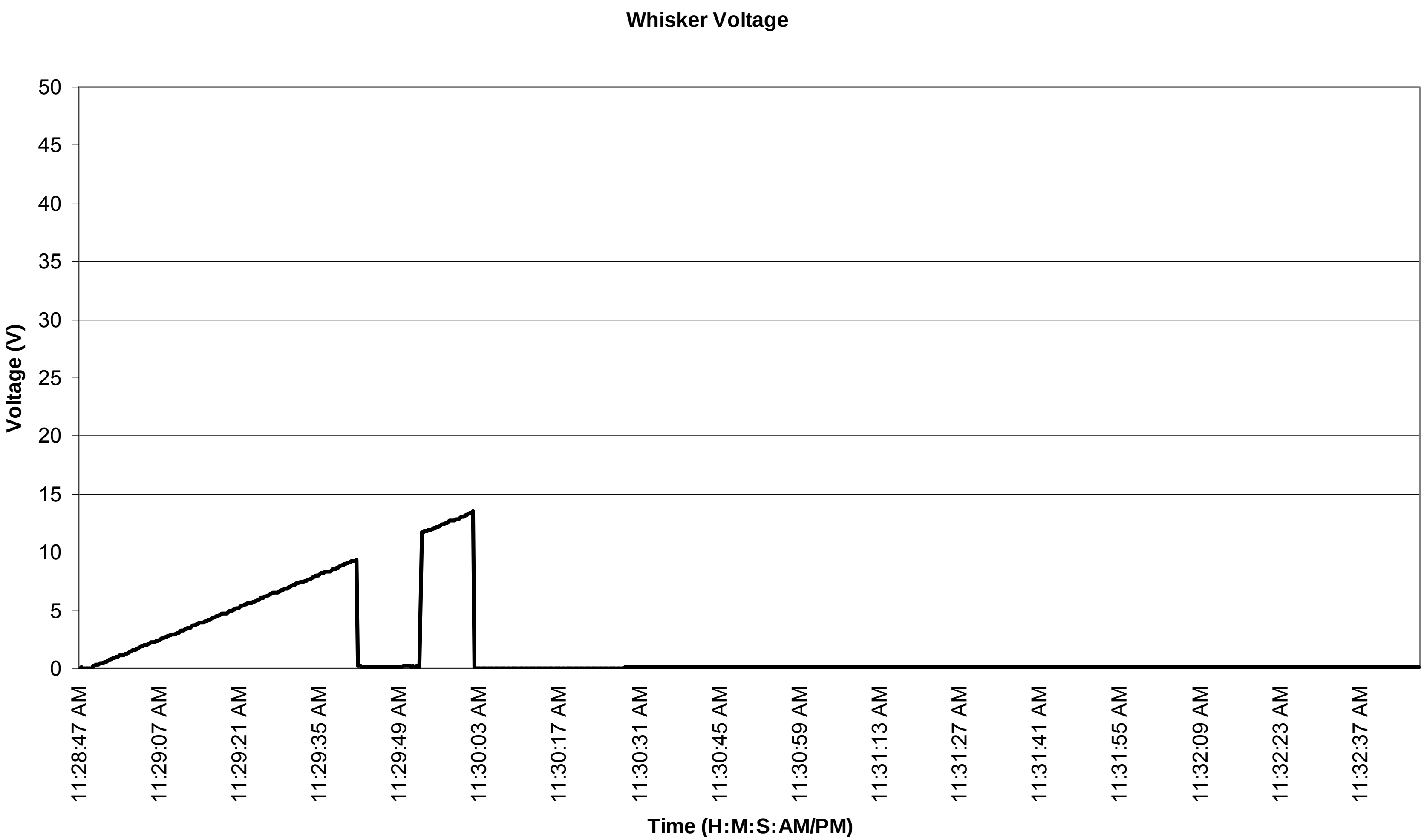
# First Experiment - Results (Continued)

## Tin Whisker Number 4 - Multiple Transition Points



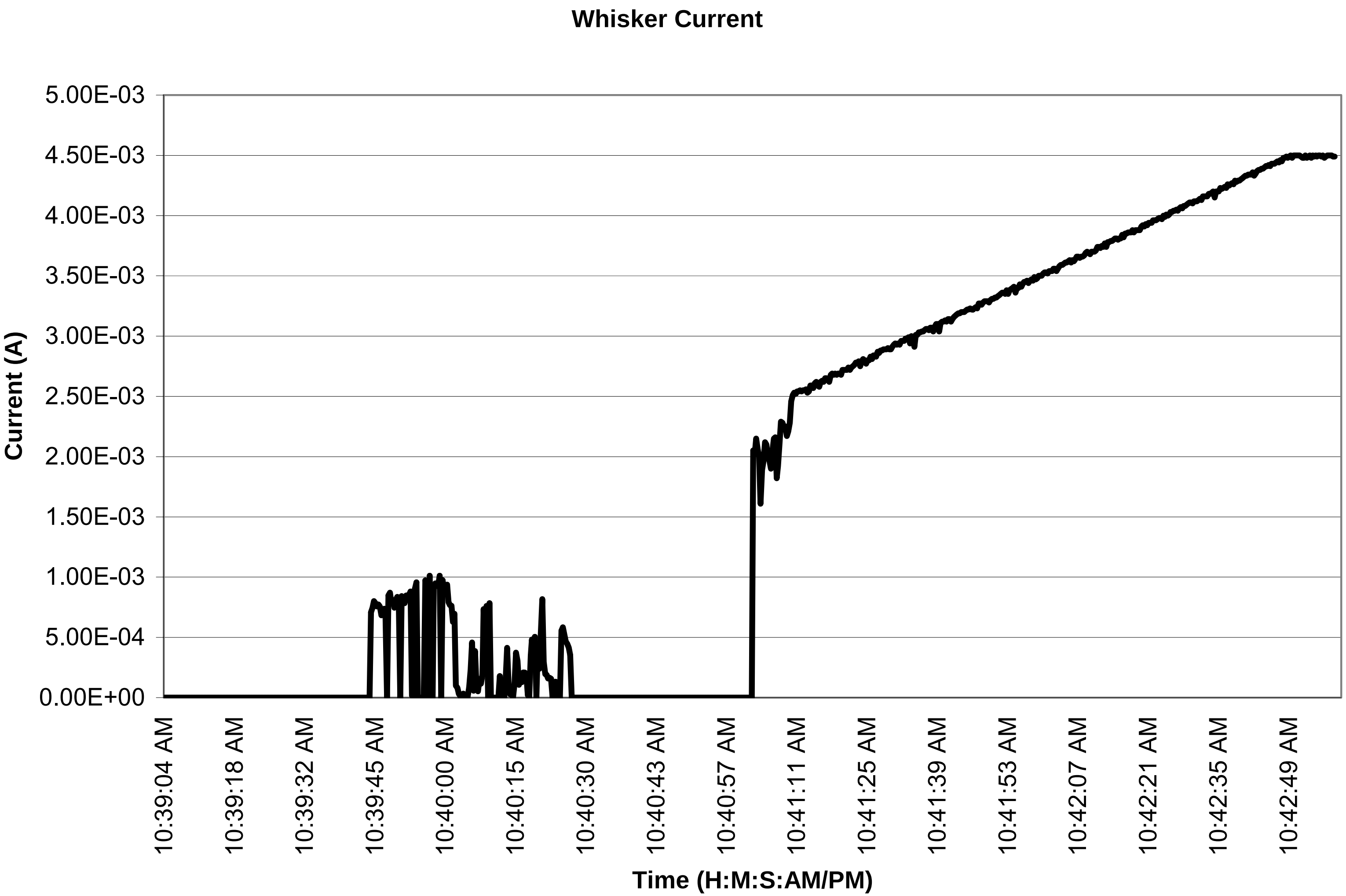
# First Experiment - Results (Continued)

## Tin Whisker Number 4 - Multiple Transition Points



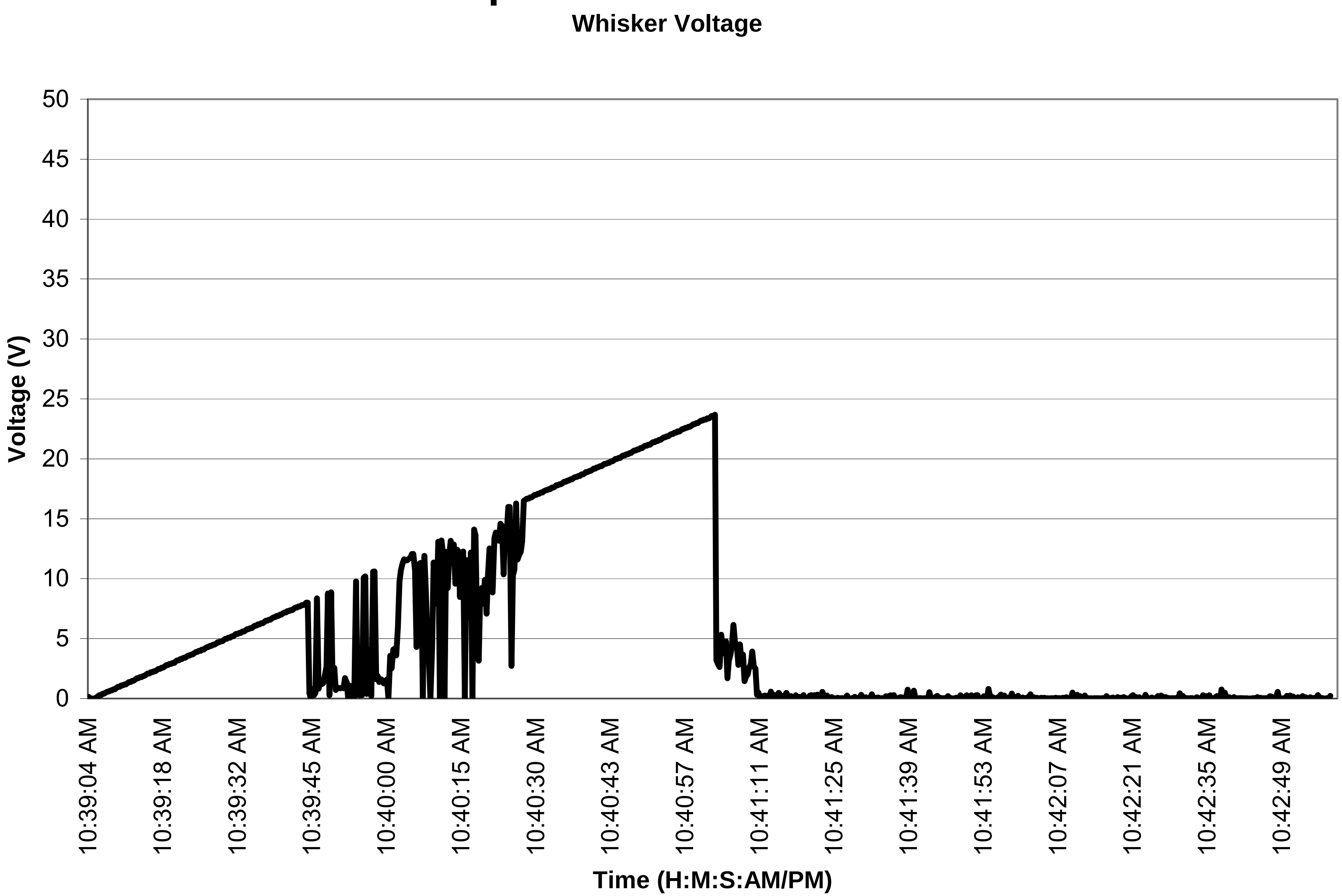
# First Experiment - Results (Continued)

## Tin Whisker Number 2 - Multiple Transition Points with Intermittent Contact



# First Experiment - Results (Continued)

## Tin Whisker Number 2 - Multiple Transition Points with Intermittent Contact



# First Experiment - Results (Continued)



- Although the software had originally been written to stop recording data after the film resistance broke down as determined by the change in whisker current, it was decided to run 35 whiskers to the full range of the test, 0 – 45 vdc, to observe their behavior
- An interesting benefit of running the test from 0 - 45 vdc for all of the whiskers was the opportunity to witness the difference in transitions
  - Single Transitions in 20 of 35 whiskers (~57%)
  - Multiple Transitions in 9 of 35 whiskers (~26%)
  - Multiple Transitions with intermittent contact in 6 of 35 whiskers (~17%)

# First Experiment - Results (Continued)

- Current Carrying Capacity
  - 33 of the 35 tin whiskers (~94%) tested conducted up to 4.5 mA
    - With a 10 KΩ current-limiting resistor in place, the test station was limited to a maximum of 4.5 mA at 45 Vdc
  - 2 of the 35 tin whiskers (~6%) only conducted up to 3.06 mA and 2.00 mA before metallic conduction ceased

# First Experiment - Data Analysis

- Probability-Probability (P-P) plots were used to determine how well a specific model fits the observed data
- The Kolmogorov-Smirnov test was used to further analyze the best fit
- The EasyFit® distribution fitting software tested over 40 different distributions before selecting the 3-Parameter Inverse Gaussian as the best fit

# First Experiment - Three Parameter Inverse Gaussian Distribution

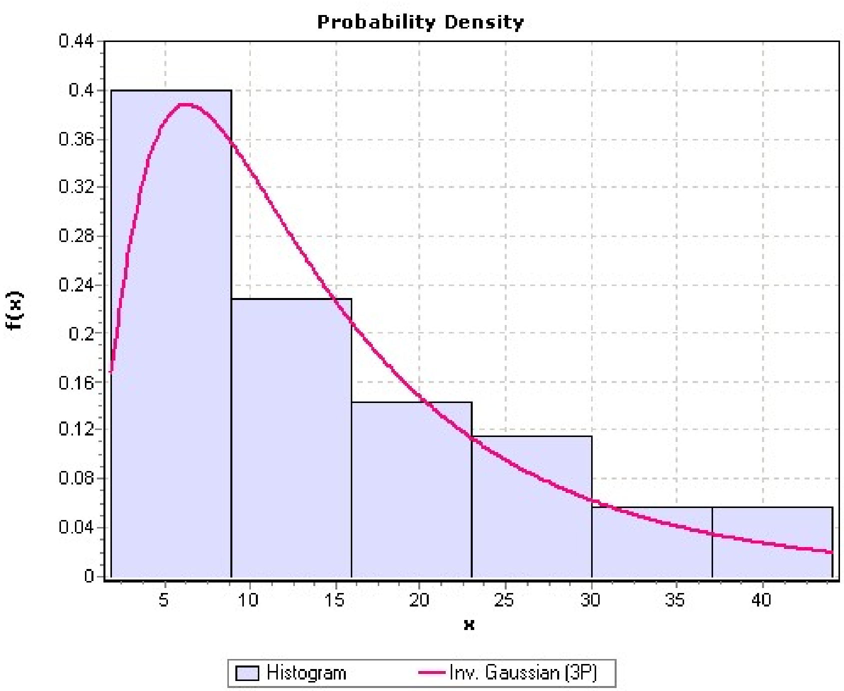
- The values for the Three Parameter Inverse Gaussian Distribution are λ = 31.977, μ = 17.571, γ = -1.9716. The Probability Density Function for the Three Parameter Inverse Gaussian Distribution is shown in the following equation:

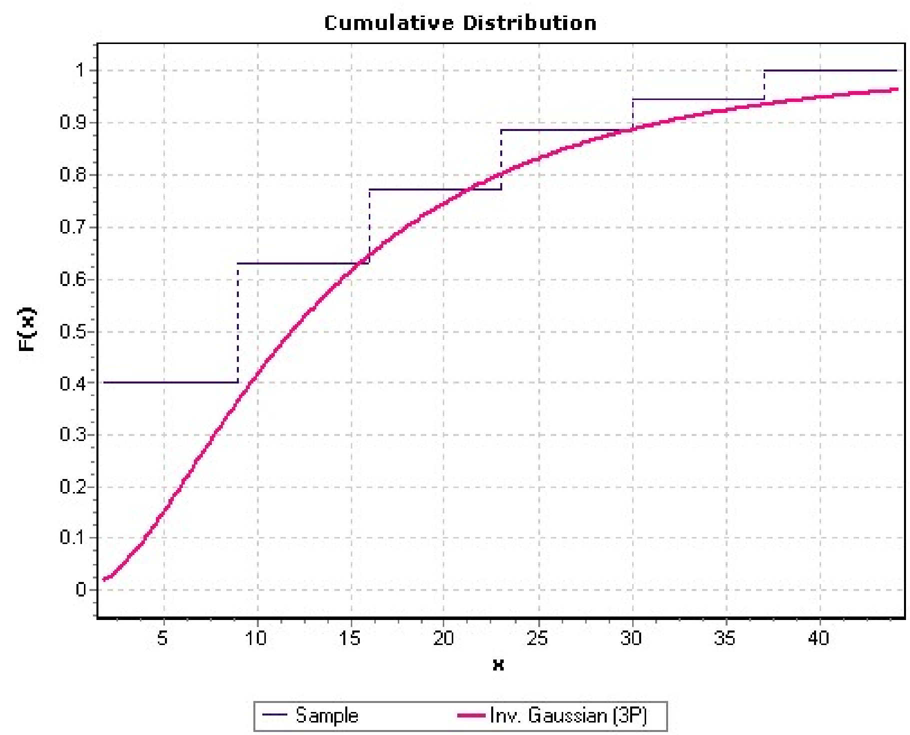
$$f(x) = \sqrt{\frac{\lambda}{2\pi(x-\gamma)^3}} \exp\left(-\frac{\lambda(x-\gamma-\mu)^2}{2\mu^2(x-\gamma)}\right)$$

- The Cumulative Distribution Function for the Three Parameter Inverse Gaussian Distribution is shown in the following equation, where Φ ( ) is the normal cumulative distribution function:

$$F(x) = \Phi\left(\sqrt{\frac{\lambda}{x-\gamma}}\left(\frac{x-\gamma}{\mu}-1\right)\right) + \Phi\left(-\sqrt{\frac{\lambda}{x-\gamma}}\left(\frac{x-\gamma}{\mu}+1\right)\right)\exp(2\lambda/\mu)$$

# Probability Density Function and Cumulative Distribution Function for the Three Parameter Inverse Gaussian Distribution




X = applied voltage

# First Experiment - Film Resistance and the Oxide Layer



- One of the factors that contributes to film resistance is the oxide layer that forms on the tin whisker
- To study the oxide layer, it was necessary to section a few tin whiskers

# First Experiment - Whisker Materials Analysis

- Whisker thickness: 2 to 5 µm
  - ➢ Analysis of whisker structure required high-resolution microscopy
- Conventional techniques for cross sectional microstructural and oxide thickness evaluation not adequate

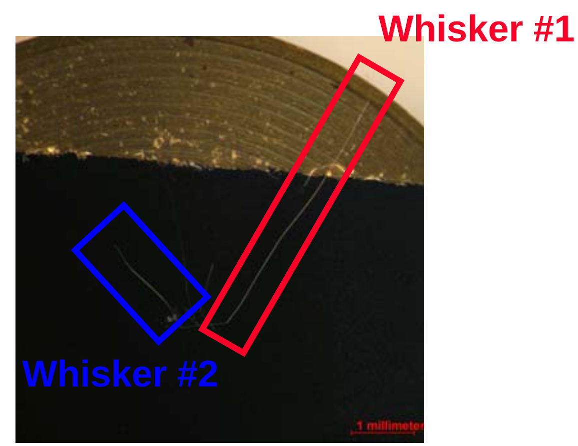


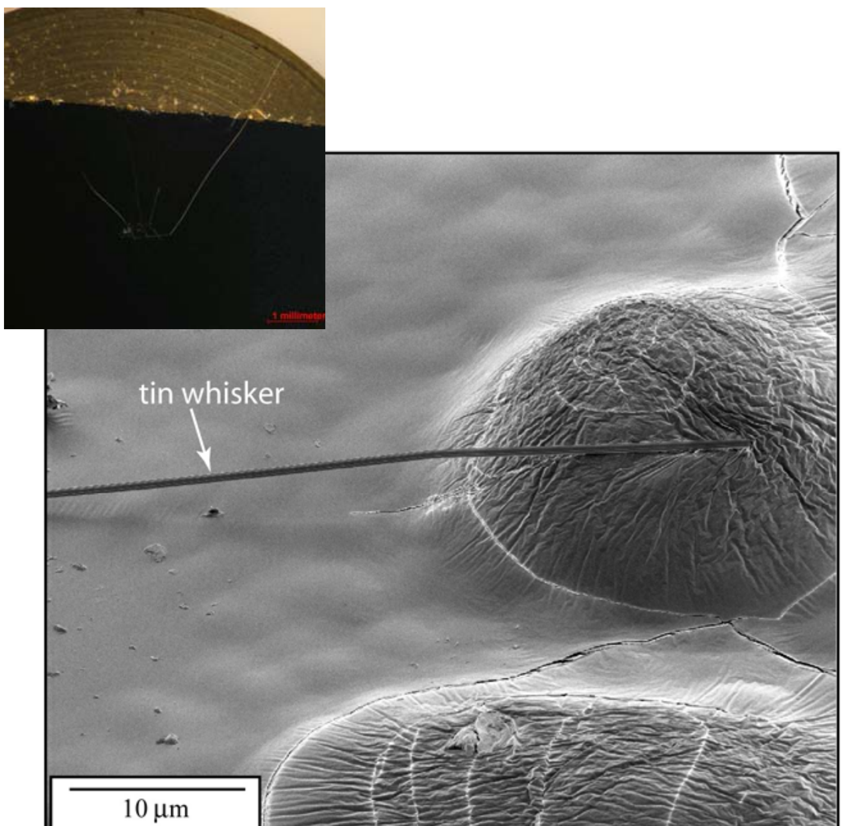


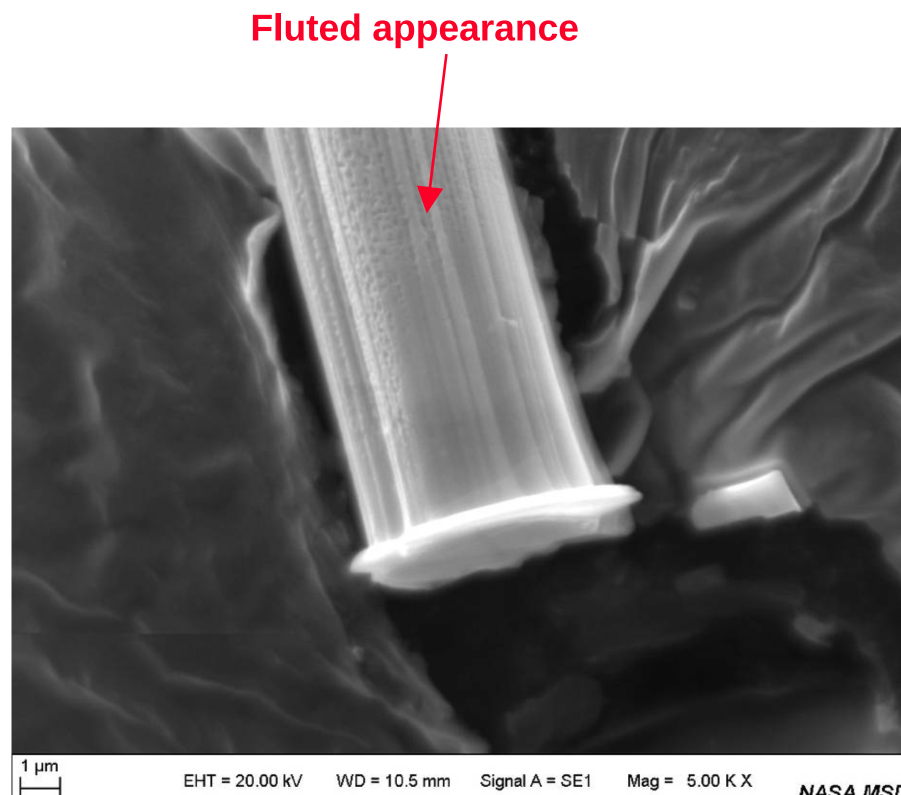

Image of penny at same magnification as whiskers #1 and #2

# First Experiment - Scanning Electron Microscopy



- A scanning electron microscope (SEM) was used for higher-magnification imaging and elemental analysis

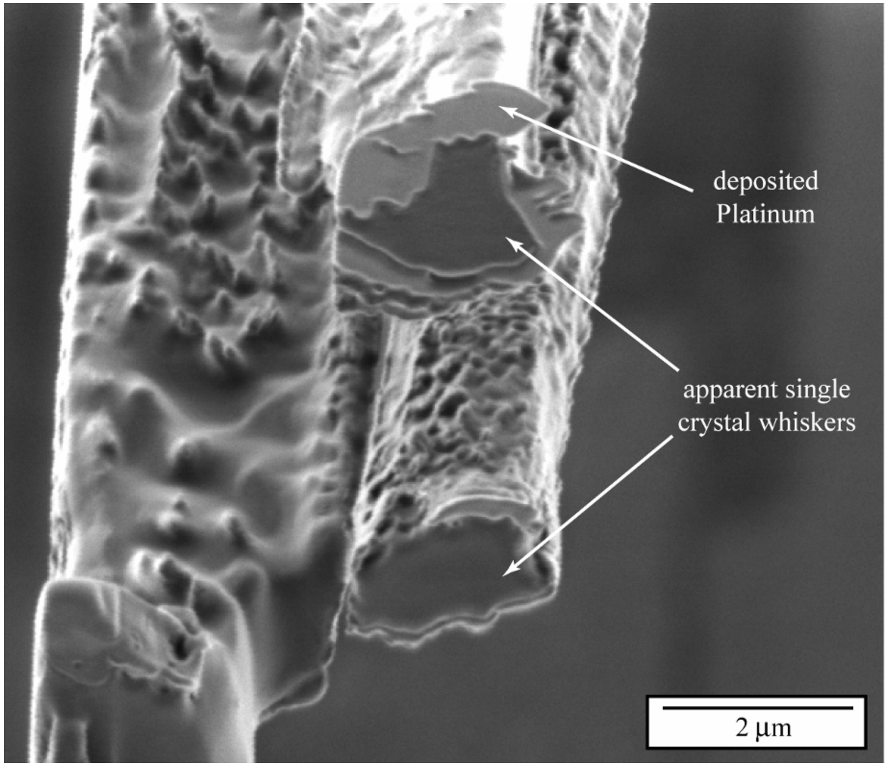


# First Experiment - Focused Ion Beam (FIB) Analysis



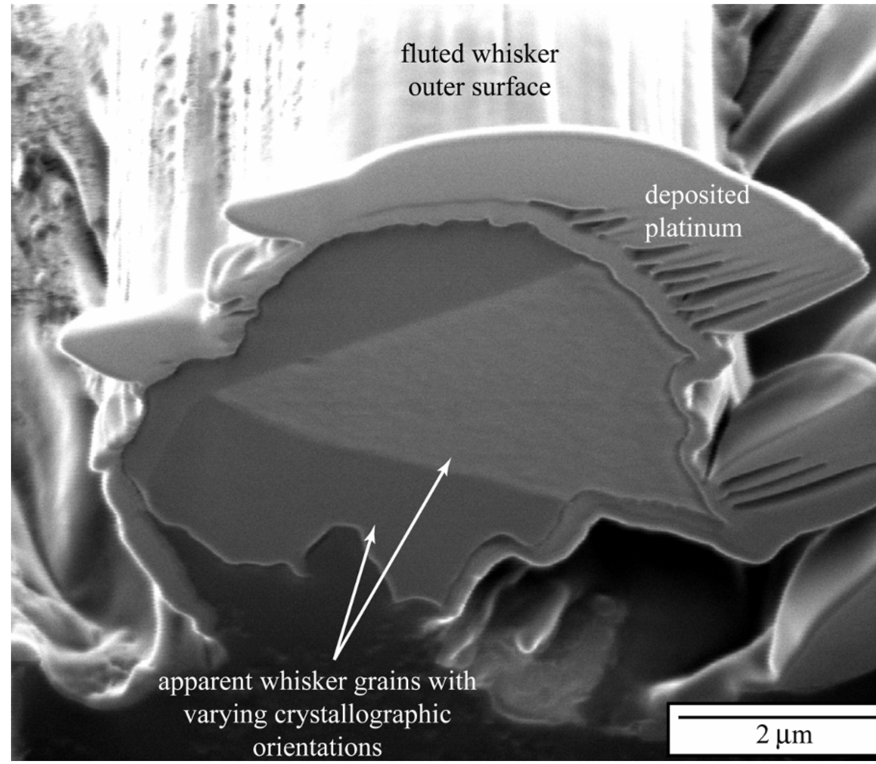
- The gallium ion beam was used to mill away sufficient whisker material to obtain a cross section normal to the whisker's growth direction
- The FIB cross section facilitated the examination of the crystallographic orientations




FIB image of two as-sectioned tin whiskers that exhibited the expected single-crystal cross section. Image was taken 52º from horizontal (NASA/UCF)

# First Experiment- Focused Ion Beam (FIB) Analysis

- One of the three tin whiskers studied here was found with what appeared to be grains with varying crystallographic orientations
  - While polycrystalline tin whiskers have been seen before, in the majority of literature tin whiskers were described as single crystals




FIB image of as-sectioned Tin whisker shows apparent variation in grain orientation within the cross-section. Image was taken at a 52º angle from horizontal (NASA/UCF)

# First Experiment- Focused Ion Beam (FIB) Analysis



- We were not able to identify the oxide layer as originally planned with the techniques and equipment that were used
- However, we were able to find what appeared to be a rare polycrystalline tin whisker

# Second Experiment

- The following improvements were added to the second experiment
  - A larger sample size of 200 whiskers
  - Experimental process improvements
  - Transmission Electron Microscopy (TEM) was used to determine if the tin whisker examined in the first experiment was truly polycrystalline
  - FIB cross-section of the card guides was used to verify whether the tin finish was bright tin or matte tin.
- The second experiment has been completed and the results will be presented in our next KEA presentation

# Limitations

- Limitations of the first experiment included:
  - The number of conducting surfaces
  - The difference and variation between force applied by gravity and the force applied by the micromanipulator probe
  - Sample size (35 Tin Whiskers)

# Conclusion

- In the first experiment, an empirical model to quantify the probability of occurrence of an electrical short circuit from tin whiskers as a function of voltage was developed
- This model can be used to improve existing risk simulation models
- FIB images of a tin whisker show an apparent polycrystalline structure on one of the three whiskers studied

# Future Work

- Effect of the following variables on tin whisker shorting:
  - Applied Pressure
  - Acceleration
  - Whisker Shape
  - Oxidation Layer Thickness
- Free Whisker Test
- Metal Vapor Arcing
- Fusing Current

## Acknowledgments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- Shaun Nerolich of United Space Alliance
- Mike Madden of United Space Alliance

# References

- H. Leidecker and J. Brusse. (2006, April). Tin whiskers: A history of documented electrical system failures - A briefing prepared for the Space Shuttle Program Office

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

- R. Holm and E. Holm, *Electric Contacts Theory and Application.* , 4th ed. New York: Springer-Verlag, 1967