Appendix B

TIN WHISKER EXPERIENCES

This document is part of a position paper, ***POSITION PAPER ON RISKS TO HIGH-RELIABILITY ELECTRONICS AND ASSOCIATED HARDWARE FROM PURE TIN COATINGS***, that has been issued by individuals working in the electronics industry regarding the potential for failure of electronic products due to tin whiskers. While some failures related to tin whiskers have been reported, the actual number of failures caused by tin whisker is difficult to determine. In some cases, failures determined or suspected to be caused by tin whiskers have not been openly discussed due to the sensitive nature of the failure. A table of failures where tin whiskers have been identified as or suspected of being the cause is presented below. Most of the items found in this table were taken from the NASA Web Site on Tin Whiskers (http://nepp.nasa.gov/whisker). For more details regarding tin whiskers, please refer to ***RISKS OF CONDUCTIVE WHISKERS IN HIGH-RELIABILITY ELECTRONICS AND ASSOCIATED HARDWARE FROM PURE TIN COATINGS.***

Table of Failures Attributed to Tin Whiskers

System	Synopsis	Reference
Heart Pacemaker	Class I Product Recall: Tin whisker short from tin-plated case of a crystal component caused a complete loss of pacemaker output.	FDA March 1986 http://www.fda.gov/ora/inspect_ref/itg/itg42.html
F-15 Radar	Tin whisker short inside hybrid package.	Nordwall, B., "Air Force Links Radar Problems to Growth of Tin Whiskers", Aviation Week and Space Technology, June 20, 1986, pp. 65-70
U.S. Missile Program	Tin whisker from tin plated relays	K Heutel and R. Vetter, "Problem Notification: Tin Whisker growth in electronic assemblies", Feb. 19, 1988, memorandum
U. S. Missile Program	Tin whisker from tin plated TO-3 transistor can shorts collector to case. Short erroneously turned on electrical unit.	J. Richardson, and B. Lasley, "Tin Whisker Initiated Vacuum Metal Arcing in Spacecraft Electronics," Proceedings 1992 Government Microcircuit Applications Conference, Vol. XVIII, pp. 119 - 122, November 10 - 12, 1992.
Phoenix Air to Air Missile	Tin whisker shorts inside hybrid package.	L. Corbid, "Constraints on the Use of Tin Plate in Miniature Electronic Circuits", Proceedings 3rd International SAMPE Electronics Conference, pp. 773-779, June 20-22, 1989.
Patriot Missile II	Tin whisker from tin-plated terminals	Anoplate, Suspected tin whisker related problems, Fall 2000 http://www.anoplate.com/news/pastnews/fall2000/tin.htm
GALAXY IV	Complete loss of satellite operation. Tin whisker short from tin plated relays	http://www.sat-index.com/failures/
GALAXY VII	Complete loss of satellite operation. Tin whisker short from tin plated relays	http://www.sat-index.com/failures/
SOLIDARIDAD I	Complete loss of satellite operation. Tin whisker short from tin plated relays	Space and Tech; http://www.spaceandtech.com/digest/sd2000-25/sd2000-25-002.shtml
Additional Satellites	Three additional satellites of same general design have lost one of two redundant control processors due to tin whiskers	http://www.sat-index.com/failures/
Nuclear Utilities	Tin plated contact support arms on relays grew tin whiskers causing a resistive shunt path.	Nuclear Regulatory Agency (NRC), 1999; http://www.nrc.gov/reading-rm/doc-collections/event-status/part21/1999/1999352.html
Rocket Motor Initiator	During assembly-level testing, the rocket motor initiators were showing an ohmic short from the charge wires to the case.	See Report ROCKET MOTOR INITIATOR Failure Analysis

In addition to the table of tin whisker failures, stories of failure have been provided on the condition that the individuals and companies involved are not revealed. Below are anecdotes of suspected or known tin whisker failures.

Experience #1 - A major producer of commercial satellites discovered that many tin-plated parts were built into flight hardware. This discovery was made early this year after one customer requested that all hardware used on their program be checked to assure that it contained no pure tin anywhere in its construction.

The satellite manufacturer has long been aware of the tin whisker concern and tin has been prohibited on electronic parts for several years. However, this was the first time that the manufacturer implemented a thorough search of all entries on the Bills of Materials. Unfortunately, pure tin was found on several items, such as washers, ring terminals, lug terminals and assorted mechanical connections. Worse yet was the fact that this hardware was common to two other ongoing satellite programs.

Additional concern was raised because of recent findings that have determined that whiskers can penetrate through conformal coatings.

Although no evidence of whiskers or short circuits has been detected, a very costly effort had to be undertaken to trace forward each tin-plated item used in the satellite designs and to replace the item or otherwise mitigate the risk of failure. In addition, all hardware containing tin had to be purged from stock.

Experience #2 - Metal vapor arcs in the 100's of amperes range (not just 10's) can be caused by whiskers in vacuum environments seen in space applications.

This phenomenon occurred on FM08 style fuses which have a filament type element which could be likened to a tin whisker but of different material and geometry. In those experiments we sought to characterize the behavior of such a fuse that may have lost its internal atmosphere (they are NOT hermetic devices). As you are aware a fuse is a current limiting device that melts with a characteristic time/current characteristic. Once the fuse is blown, it still needs to function as a protective device and minimize the risk of arcing across the open circuit voltage across the fuse. Well in our experiments we intentionally evacuated the atmosphere from the fuse and then subjected it to a "clearing event" with various bus voltages available at the fuse to simulate various application conditions. The power source was "unlimited" in current (batteries capable of 100's of Amperes) . At reduced pressure, we documented horrific metal vapor arcs being initiated as the fuse element vaporized at the instant of clearing and then ionized into a plasma capable of sustaining hundreds of amperes. For the fuses, this event occurred for bus voltages in excess of roughly 50V (tin whiskers may need around 18 V). Some of the events were so dastardly that they sustained the arc for periods nearly as long as 30 seconds all the while the arc was being sustained by metal supplied by the end caps of the fuse and the bus wire used in the test circuit (i.e., the arc ate its way through the fuse element and into the hook up wire of the test circuit). It's a SCARY THING indeed. It is precisely such metal vapor arcs that make the space community (and I should think the ballistic missile community) so highly concerned about tin whiskers in a reduced pressure environment.

Experience #3 - An air launch missile was found to have tin whiskers bridging across a fusing switch with tin coated contacts. Many missiles had to be reworked to correct this problem.

Experience #4 - A missile had tin whiskers growing from a tin plated spring in a vendor supplied accelerometer assembly. The whiskers grew over to adjacent electrical contacts, providing a short to system ground. A major recall program resulted, costing about $5M.

Experience #5 - A missile flight failure was solved by failure analysis of surviving debris. A tin whisker had grown from a tin plated pin in a potted seal through a void in the epoxy potting to make contact with the case of an accelerometer. The failure analysis lab was elated to identify the root cause of the flight failure. That was perhaps the only elation associated with the flight failure.

Experience #6 - A power resistor selected for a missile was found to have tin coatings on the leads and heat sink. A part from a different vendor (not having tin coatings) was eventually used instead, but not until after a substantial effort was expended to evaluate tin whisker risk mitigation on the original part.

Experience #7 – A recent failure analysis of two GPS receivers revealed the presence of tin whiskers. The assemblies were to be used in high altitude applications and were expected to demonstrate successful use of commercial off the shelf (COTS) technologies. During failure analysis of the parts, the analyst noted an accumulation of metal debris (including solder melt balls) on the bottom of the GPS enclosure (hurray for "best commercial practices!"). Further inspection revealed a bunch of 'twinkles.'

The unit consisted of four satellite receiver modules mounted to a PC board, two on one side and two on the other. Each was (roughly) 8 cm by 4 cm by 1cm, and was mounted within a metal box, presumably for rf shielding reasons. The rf shields were implemented by a press-on lid. The metal boxes were tin plated, and each lid was covered with tin whiskers! It is possible that the side walls also contained whiskers, but the inspection focused only on the lids, which were easier to inspect. One lid was apparently more densely covered than the others.

The investigators reported that it is easy to miss these whiskers, which show up only as a sort of 'twinkle' in the right kind of lighting. Another analyst was called over to review the assembly and was told that there were tin-whiskers on the tops of these tin-plated lids --- and he could not find them at first (no discredit to him in any way!). Only when he reoriented the unit, to get just the right lighting, could he see the 'twinkles.' Even then, one could not "see" these as whiskers, until one put one's eye to within several inches, and got the lighting right, and knew what one was looking at.

It would have been easy to brush the whiskers away without ever seeing them, as one was working on the units. Even removing the lid could result in the loss of many, or all, of the whiskers, depending on how the lid was handled as it was removed.

Inspection of one lid using a binocular microscope indicated 5 whiskers (lengths ranging between 1 and 3 mm) in a 6 mm by 4 mm area. This gives a density of (5 whiskers)/(0.24 cm**2) = 20 whiskers per square cm, and allows an estimate of the total number of such whiskers per lid: (8 cm)*(4 cm)*(20 whiskers/cm**2) = 640 whiskers per shield top.

There were many places within the receiver where connectors (apparently consisting of uncovered metal) were spaced by 0.5 mm and less. The whiskers could have easily bridged across those connectors.

During the inspection, the "press-on" tops of the rf shields were not removed, so it was not possible to confirm whether there were whiskers on the inside surfaces of the lids, next to the receiver electronics.

The investigators were reasonably certain that the whiskers they observed were not producing the original high-altitude failures that initiated the failure analysis. However, the whiskers certainly constituted a threat to un-interrupted, glitch-free operation of those units!

Experience #8 - A field failure, experienced in an electronic system used in the "electric power utility" industry, was found to be caused by tin whiskers. The failure occurred on a dual inline package (DIP) with a matte pure tin finish. Failure was found to occur in 2002 (~20 years after part manufacture and assembly of the electronic system). The part was hand soldered to a printed wiring board using a tin-lead solder and a large portion of the leads were not covered by the tin-lead solder. Unfortunately, the information provided about this event is not sufficient to know if
a) the whisker growth remained dormant for a very long time, or
b) the growth process was continuous and slow for the entire period.
This type of failure is of particular importance to applications that require very long term reliability and for which field servicing may be impractical or impossible (space missions included). The lack of accepted "accelerated" test methods for judging whisker propensity is a further complication. The NASA web-page (http://nepp.nasa.gov/whisker/ancedote/20year/index.html#facts) on tin whisker failures presents additional details of this failure experienced by the power utility industry.