Tin Whiskers – A “New” Problem

February 25, 2004

Summary

Electroplating an object’s surface with a thin layer of corrosion resistant material (e.g., tin, zinc) is a standard method of protecting mechanical parts against corrosion. Platings (e.g., tin-lead solder, tin, gold, palladium) are also used on electrical parts to protect against corrosion and improve their solderability.

It has been known for more than fifty years that a tin layer plated on a surface will spontaneously grow hair-like single-crystal filaments known as “tin whiskers”. These whiskers are electrically conductive and physically strong.

The actual mechanism of tin whisker growth is not fully understood, even after decades of research. There is no test that can accurately determine when whiskers will form, the number of whiskers or their length.

With present circuit geometries so much smaller than they have been in the recent past, adjacent whiskers can easily bridge spaces between leads, and/or whiskers from adjacent areas can touch each other causing short circuits. Loose whiskers can bridge board traces, foul optics, or jam microelectromechanical machines (MEMs).

For decades, the common method of whisker control and lowering the melting point of tin alloys has been the addition of lead (Pb) to the tin. At least 3% lead in tin alloys effectively eliminates the growth of whiskers that could cause harm.

The worldwide movement to eliminate lead from all products has caused the tin whiskers threat to reemerge. There are serious potential consequences to manufacturers and users of high reliability electronic equipment.

Commercial manufacturers are rapidly adopting tin plating to advance their economic interests and to comply with European and Japanese legislation on lead recycling and prevention. By the end of summer 2004, it may be difficult to find anything other than lead-free tin finishes for some parts. It seems impossible that any user of electronic components will be able to totally avoid lead-free tin plating.

There is no lead-free mitigation technique for pure tin or tin alloys that will guarantee whiskerless hardware. None of the commonly available mitigation techniques have been proven to provide the degree of protection required by high reliability applications.

The transition by suppliers responding to the worldwide lead-free movement poses a major reliability risk to manufacturers of high reliability systems. System manufacturers must take immediate steps to understand their current exposure, provide strong direction to their suppliers, and aggressively support development and implementation of effective mitigation techniques.

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Introduction

For decades, electronic component leads have been electroplated and soldered to circuit boards with tin-lead solder. The negative effects of lead (Pb) from some sources (e.g., leaded gasoline, water pipes, paint) on the human body and the environment are well documented. However, there is no evidence linking the lead used in electronics manufacturing and products with any harm to humans or the environment

In 1985, the Swedish government enacted the Chemical Products Act citing the Precautionary Principle: “When an activity raises threats of harm to human health or the environment, precautionary measures should be taken *even if some cause-and-effect relationships are not fully established scientifically.”* Apparently motivated by the Precautionary Principle and economic advantages offered by ‘green’ products, the European Union (EU) and Japan responded to fears of perceived environmental harm by passing legislation on lead recycling and prevention. These will take effect in July 2006.

Lead (among other substances used in electronic products) is subject to this prohibition in spite of the fact that the electronics industry consumption is less than 0.5% of the world’s lead usage

Commercial electronics suppliers around the world have responded to the pressure by supplying lead-free products. Pure tin and high tin lead-free alloys are low cost and have excellent corrosion resistance with relatively low melting points. As a result, they have become the overwhelming choices for replacing alloys containing lead. Many electronics suppliers have already transitioned to lead-free product lines, and most of the rest are in the process of transitioning. Unless something is done to slow or reverse this transition, it soon will be difficult to obtain many parts in anything but lead-free versions.

The United States currently does not have any legislation prohibiting the use of lead in electronics manufacturing or products. This situation could change rapidly with environmental advocates continuing to lobby for legislation.

Military, aerospace, and certain other high reliability applications are exempt from the environmental legislation. However, these markets are a fraction of the total electronics market, and there is little financial motivation to maintain both leaded and lead-free production lines. Suppliers find it more profitable to convert to lead-free products and leave the other applications to fend for themselves.

The transition from established tin-lead solders and finishes to lead-free materials poses a number of reliability risks for high reliability applications. The most immediate and serious risk is that posed by tin whiskers.

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What Are Tin Whiskers

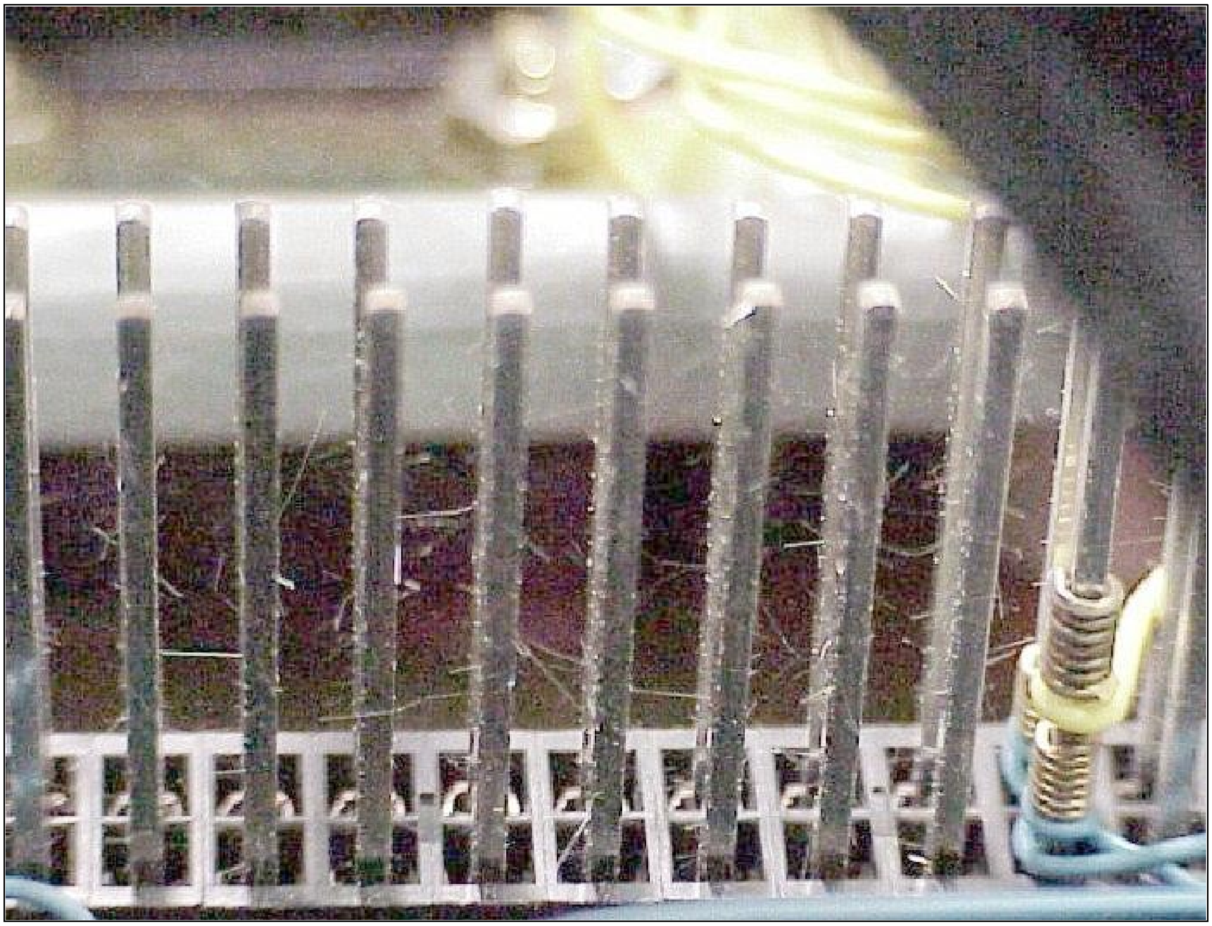


Figure 1 - Tin-Plated Connector Pins after 10 years
Courtesy of NASA GSFC

Tin whiskers are single crystal, hair-like growths that grow spontaneously from surfaces that use tin, especially electroplated tin, as a surface finish. These whiskers are electrically conductive and physically strong.

Whiskers are typically 1-2 mm in length and 1-3 micrometers in diameter. Lengths up to 400 mils (10 mm) and densities of 200 whiskers per square millimeter have been observed. The mechanism of their growth is still not clearly understood, even after decades of observation and experimentation. It has promoted much scientific debate, contradictory experimental results, and conflicting evidence.

Metallic whiskers were first documented in 1946. It has been established that tin, zinc, cadmium, and silver can grow whiskers. This growth can begin any time from within hours to after years of dormancy.

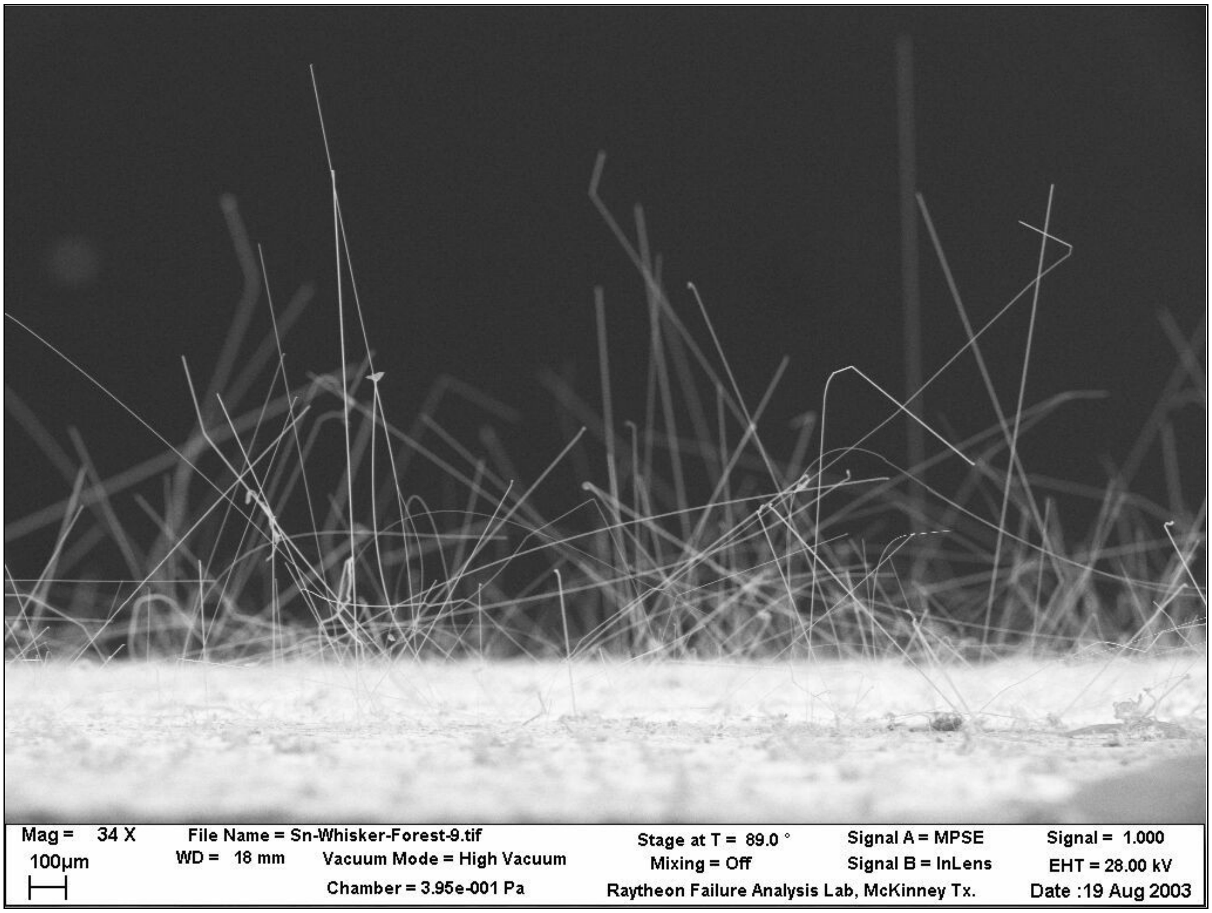


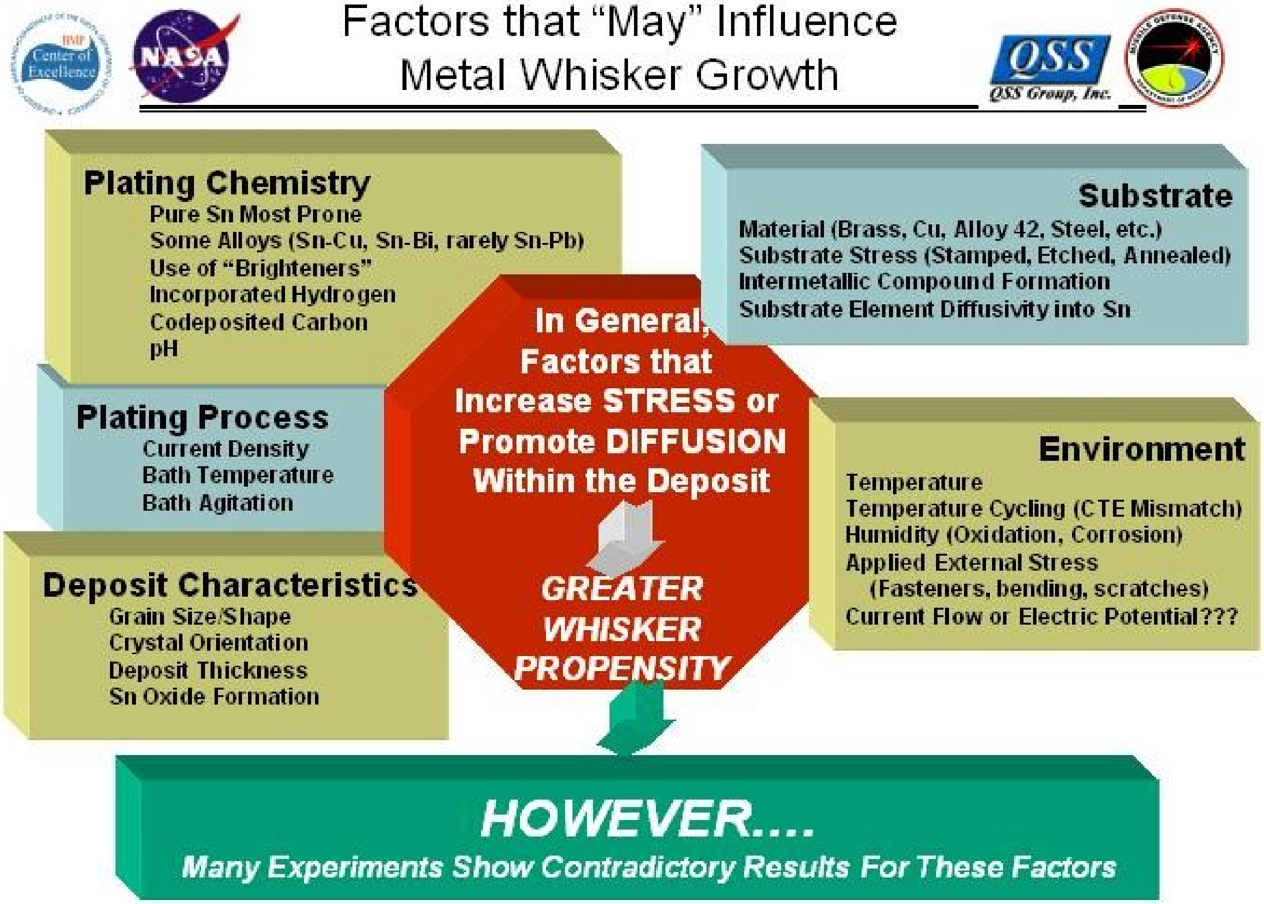
Figure 2 – Tin Whisker “Forest” on test coupon from
CALCE Tin Whisker Group’s collaborative test

Passive and active electronic components with lead-free tin plating are subject to whiskering. Tin-plated mechanical parts (e.g., nuts, bolts, fasteners, panels) may also grow whiskers. Tin whiskers can pierce through thin or soft conformal coatings.

Eutectic tin-lead solder (63% tin, 37% lead) has been a standard material since the beginning of the electronics industry. Solder’s characteristics are well understood. Manufacturing methods and parts have been designed around and optimized for the use of tin-lead solder.

Tin alloys with more than 3% lead have a greatly reduced tendency to whisker, and any whiskers that may form are very small. Pure tin or high tin alloys that do not contain lead are very likely to whisker.

Factors Influencing Whisker Growth



Factors that “May” Influence Metal Whisker Growth

Plating Chemistry
- Pure Sn Most Prone
- Some Alloys (Sn-Cu, Sn-Bi, rarely Sn-Pb)
- Use of “Brighteners”
- Incorporated Hydrogen
- Codeposited Carbon
- pH

Plating Process
- Current Density
- Bath Temperature
- Bath Agitation

Deposit Characteristics
- Grain Size/Shape
- Crystal Orientation
- Deposit Thickness
- Sn Oxide Formation

Substrate
- Material (Brass, Cu, Alloy 42, Steel, etc.)
- Substrate Stress (Stamped, Etched, Annealed)
- Intermetallic Compound Formation
- Substrate Element Diffusivity into Sn

Environment
- Temperature
- Temperature Cycling (CTE Mismatch)
- Humidity (Oxidation, Corrosion)
- Applied External Stress
  - (Fasteners, bending, scratches)
- Current Flow or Electric Potential???

In General, Factors that Increase STRESS or Promote DIFFUSION Within the Deposit

GREATER WHISKER PROPENSITY

HOWEVER….

Many Experiments Show Contradictory Results For These Factors

Courtesy of Jay Brusse, NASA GSFC

Figure 3 – Factors that may Influence Tin Whisker Growth
Courtesy of Jay Brusse QSS Group NASA GSFC

There are many factors that can influence whisker growth as noted in Figure 3. The number and diversity of factors has made the development of accelerated whiskering susceptibility tests very difficult.

There are several efforts to develop an effective test method for assessing the propensity of a tin plating to initiate and grow whiskers. At this time, there is no test that can accurately determine when whiskers will form or the extent of any whisker growth.

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Why Whiskers are a ‘New’ Risk

Manufacturers are rapidly switching to pure tin or lead-free tin-based alloys to comply with “green” initiatives. These initiatives eliminate lead as an alloying option. According to an October 2003 University of Maryland Computer Aided Life Cycle Engineering (CALCE) survey, approximately 70% of 71 major semiconductor suppliers currently or will shortly offer pure tin or lead-free tin-based alloys as final plating. Suppliers are rapidly converting product lines to lead-free materials. By the end of summer 2004, it may be difficult to find anything other than lead-free tin finishes for many parts.

Pure tin and lead-free tin-based alloys allow whiskers to grow. With present circuit geometries so much smaller than they have been in the recent past, adjacent whiskers can easily bridge spaces between leads, and/or whiskers from adjacent areas can touch each other causing short circuits. Loose whiskers can bridge board traces, foul optics, or jam microelectromechanical machines (MEMs).

In previous technologies, circuit voltage and current levels would almost instantaneously vaporize any whiskers, and the circuit would not even notice the event. However, low voltage and current levels in modern circuits do not have the energy needed to melt the whiskers so circuits stay shorted by the whiskers.

There is no test that can accurately determine a plating’s propensity to whisker. Suppliers cannot detect differences in the whiskering susceptibility of different platings. A new plating material will appear to have the same reliability as the one it is replacing. Because there is no detectable change in form, fit, function, quality, or reliability, some suppliers see no need to issue a product change notice.

Many suppliers and distributors are unaware of the tin whisker issue. The stratification of electronics manufacturing gives system integrators little insight into the materials that are actually being incorporated into their products.

Just-in-Time (JIT) manufacturing and use of Commercial-Off-The-Shelf (COTS) parts are common practices. JIT allows parts to be directly incorporated into systems with little or no inspection. COTS typically have very few restrictions on materials. Suppliers may not even be required to provide any prior notice for changes in materials or processes. This means that there is a high likelihood of lead-free tin plating in a part or an assembly.

Tin Whisker Failure Mechanisms

There are four major failure mechanisms associated with tin whiskers.

1. Stable short circuits in low voltage, high impedance circuits where current is insufficient to fuse the whisker open
2. Transient short circuits until the whisker fuses open
3. Plasma arcing in a vacuum where a whisker fuses open, but the vaporized tin initiates plasma that conducts over 200 amps. This phenomenon is reported to have occurred on at least three commercial satellites and rendered the spacecraft non-operational
4. Whiskers or pieces of whiskers that break loose and bridge conductors or interfere with optical surfaces or jam MEMs

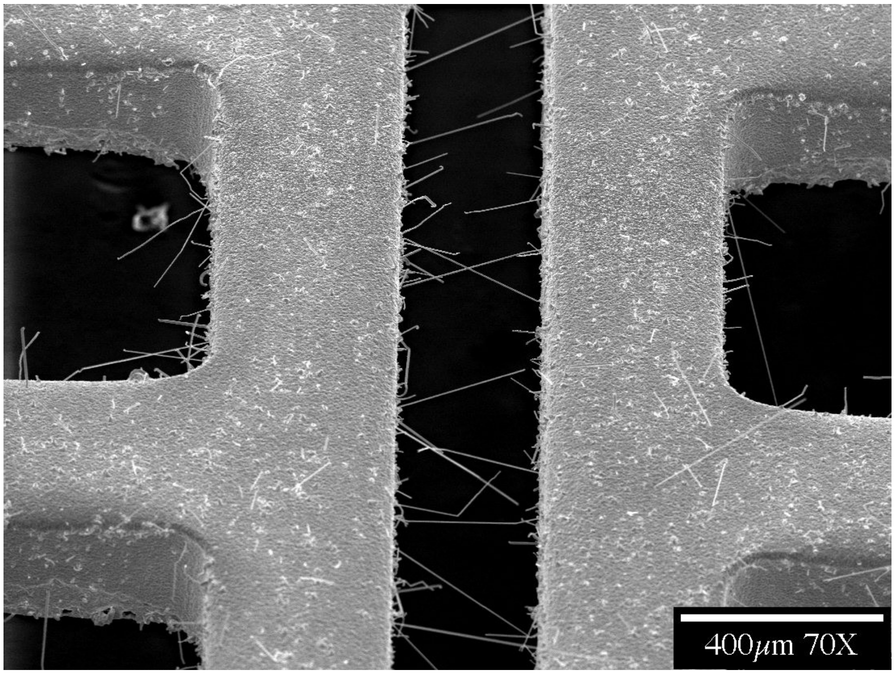

Figure 4 – Tin Whiskers on a Matte Tin SOIC leadframe after three years storage at ambient conditions.
Courtesy of P. Bush, SUNY Buffalo

There have been a number of failures because of tin whiskers in high reliability applications. Systems experiencing tin whisker-caused failures during the past three years have included commercial satellites, power management modules, nuclear and conventional power plants, and military/aerospace system failures.

The vast majority of these items that failed were manufactured before the major shift to tin plating and contained relatively few tin plated items. Reported failure rates ranged from 1% to 10%. Systems with higher numbers of tin plated items will probably experience higher failure rates.

Common Tin Whisker Mitigation Techniques and Limitations

With the exception of the total avoidance of lead-free tin, none of the following commonly available mitigation techniques has been proven to provide the degree of protection required by high reliability equipment.

1. Avoidance of pure tin is the first and best choice. However, suppliers are converting to lead-free tin at a rapid rate, and system integrators are receiving pure tin despite contractual prohibitions.
2. Matte tin (tin with a dull low gloss finish and larger grain size) is more resistant to whiskering than bright tin. It can still grow whiskers, as shown in Figure 4.
3. Annealing tin can reduce the stresses in plating that contribute to whisker growth. However, the benefits are limited and only short term.
4. Robotic solder dipping with tin-lead solder is a solution for some, but not all, components. Components must be handled carefully to avoid damage during the process.
5. Conformal coatings can be applied, but their success is very dependent on the coating material, thickness, and application process. Conformal coating is a promising technique, but long-term success in whisker control has not been established. This complex topic requires further investigation.
6. Stripping the finishes and replating with tin-lead solder is possible but requires extra handling and exposure of finished parts to corrosive materials. This sets the stage for corrosion related issues.

Impact on High Reliability Applications

High reliability systems (e.g., military, aerospace, servers, medical equipment) require long operational lives, high availability, and extraordinary reliability. The longer the application life of the system with lead-free tin plating, the greater the probability that tin whiskers will form. Based on the failure rates of past systems having few tin plated parts, unless aggressive mitigation and control efforts are implemented, it is expected that double-digit percentage failure rates will be experienced in high reliability applications.

Many systems do not have internal diagnostics (e.g., BIT) that are able to detect whisker formation. Short circuits will not be detected until power is applied, and this would be too late in most cases. The shock and vibration associated with missile launch or aircraft takeoff and landings may dislodge whiskers and move them to areas where they can create problems. .

It appears that it will be impossible to totally avoid tin plating. Mitigation techniques are not very robust, and the ability to predict a plating’s propensity to whisker will not be available for the foreseeable future. It is critical to establish mitigation efforts that address both tin avoidance and tin adaptation as soon as possible.

Recommendations

The following actions should be taken to reduce the risk posed by tin whiskers.

Short Term

- Provide formal education to suppliers and users on tin whiskers and related lead-free issues
- Require that contractors audit their manufacturing operations to define their present and future exposure
- Require an audit of existing hardware to understand level of exposure and degree of risk
- Instruct contractors to establish incoming inspection procedures using X-ray fluorescence (XRF) or Energy Dispersive X-ray (EDX) to positively verify composition of incoming materials
- Issue strong policy guidelines regarding tin use and mitigation techniques.
- Support Raytheon-led conformal coating whisker mitigation project

Longer Term

- Establish a Lead-free Council to measure exposure, coordinate avoidance and mitigation efforts, organize education, and provide senior management with progress reports and risk assessments
- Develop and implement an ongoing audit program to monitor and report the status of hardware and contractor tin mitigation efforts
- Provide support to develop effective manufacturing processes for tin whisker mitigation
- Encourage federal legislation to protect critical manufacturing technologies.
- Build tin whiskers surveillance units to monitor critical hardware using tin plating for where normal inspection and/or testing are impossible

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