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 TOPICAL REVIEW

# How the Risk of Tin Whiskers Affects Design Decisions: Is the Aerospace and Defense Approach to Tin Whiskers the Right Approach

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**ABSTRACT** Most of the electronics industry, including piece part (electronic component) suppliers, have been involved with developing and implementing lead (Pb)-free risk reduction methods since the introduction and enforcement of RoHS in 2006. The most widely used standard to assess the risk of tin whiskers has been JESD201 “Environmental Acceptance Requirements for Tin Whisker Susceptibility of Tin and Tin Alloy Surface Finishes”. The JESD201 standard requires that aged samples be put through thermal cycling, humidity, high temperature, and ambient testing. Another companion standard, JESD22-A121 “Test Method for Measuring Whisker Growth on Tin and Tin Alloy Surface Finishes” can be used to assess the results of the JESD201 tests. If assemblies and piece parts meet the requirements of JESD201, it is generally expected that their use of Pb-free solders, finishes and plating should not result in tin whiskers that can cause failures. This approach is currently used in the commercial industry with products having lifetimes of up to 7 years, as well as in the automotive and gas industry with much longer expected lifetimes. This paper investigates the benefits of using this approach by industries, including the medical devices, aerospace and defense industries, that are still producing lead-based electronics.

**INDEX TERMS** Tin whiskers, lead-free solder, component reliability, environmental testing, reliability testing, failure analysis, aerospace and defense, medical devices.

## I. INTRODUCTION

The shift to Pb-free solders in electronics manufacturing occurred due to the significant health and environmental concerns associated with Pb, prompting regulations that mandate the use of alternative, less toxic solder alloys that do not contain Pb, prioritizing worker safety and minimizing environmental contamination from electronic waste. In 2003 the European Union enacted the Restriction of Hazardous Substances (RoHS) regulation which was enforced by the European Union in 2006. The US followed

suit by giving tax breaks to any company that reduced the use of lead-based solder. In addition to RoHS, other governments, such as China and Korea, produced regulations similar to RoHS resulting in a global transition to Pb-free electronics, particularly in the commercial electronics sector.

Today, most piece parts and board suppliers have transitioned away from tin-lead (SnPb) finishes to pure tin or other Pb-free finishes, and Pb-free soldering is now mainstream, with Pb-free solder alternatives, such as pure tin (Sn), tin-silver-copper (SnAgCu) and tin-copper (SnCu), being commonly used. While it's difficult to provide an exact percentage, it's estimated that less than 2% of electronic components are being plated with Pb-based solders

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today. Furthermore, there are few high-quality high-volume contract manufacturers willing to provide Pb-based soldering processes, and if conducted, usually require significant surcharges. The result is that the electronics industry is continuing to focus more on the profitable and high-volume Pb-free alternatives while simultaneously complying with regulations to reduce health and environmental risks.

The aerospace and defense electronics sectors, on the other hand, have been more cautious in the adoption of Pb-free technologies for several reasons: stringent reliability requirements (e.g., safety critical or security critical applications), long service life, complex harsh environments, and sustainment (i.e., existing SnPb products may require repair/rework). Similarly, active implantable medical devices (AIMD) and their accessories are exempt from RoHS and can still use SnPb solder paste to attach components to a circuit board. However, given the commercial electronics transition to Pb-free, there are major incentives for products and systems to transition to Pb-free materials. These incentives include the use of significantly less expensive commercial-off-the-shelf (COTS) components and assemblies, the availability of new electronic package styles that are Pb-free, and the risks associated with the need to modify Pb-free electronics to meet current standards that prohibit their use.

## II. TIN WHISKERS

Tin whiskers are tiny, hair-like single-crystal pure tin filaments that can grow from surfaces plated with tin or tin-based alloys. Whiskers have been reported to grow to more than 10 mm (250 mils) in length (though they are more typically 1 mm or less) and from 0.3 to 10  $\mu\text{m}$  in diameter (typically 1 to 3  $\mu\text{m}$ ). Whiskers grow spontaneously without an applied electric field or moisture (unlike dendrites) and are independent of atmospheric pressure (they grow in vacuum). Whiskers may be straight, kinked, hooked or forked and some are reported to be hollow. Their outer surfaces are usually striated. Whisker growth may begin soon after plating. However, initiation of growth may also take years. The unpredictable nature of whisker incubation and subsequent growth is of particular concern to systems requiring long term, reliable operation. The addition of as little as 1% by weight Pb into tin plating has been demonstrated to reduce tin whisker risk with the addition of 3% or more by weight Pb considered to eliminate the tin whisker risk.

Tin whiskers can cause electrical short circuits, signal interference, and other reliability issues in electronic devices, resulting in intermittent or permanent failures, depending on the electrical conditions. In low voltage, high impedance circuits may draw insufficient current to fuse the whisker open and a stable short circuit can result. Depending on the diameter and length of the whisker, it can take more than 50 milliamps (mA) to fuse open a tin whisker. If the available current exceeds the fusing current of the whisker, the circuit may only experience a transient glitch as the whisker fuses open. The view from the SAE GEIA working group is that the “vast majority of reported tin whisker-induced failures have

resulted from the growth of the tin whisker from a conductor that bridged the gap to an adjacent conductor at a different electrical potential, resulting in an intermittent short.

Being tin and brittle, tin whiskers may break loose and bridge isolated conductors remote from the original site of whisker growth. In addition, whisker debris may interfere with optical surfaces or the smooth operation of unprotected microelectromechanical structures (MEMS).

Tin metal vapor arcs have been observed to form at 1 atm under a 28 V supplied voltage, while only requiring a 4 V supply under vacuum conditions [1]. Tin metal vapor arcs form when the tin whisker is fused open, the tin is vaporized, and tin metal ions and electrons are exchanged between formerly bridged surfaces. An adequate supply of tin and other metals from the surrounding plated surface can help to sustain the arc until the available metal is consumed or the supply current is interrupted by a protective fuse element. However, this has mostly been a concern in vacuum.

Finally, experimenters, including those with NASA and IPC, have reported whisker growth from tin-lead (SnPb) alloys. In the case of whiskers on SnPb alloys, the observed whiskers have been reported to be smaller than those from pure tin plated surfaces and may be sufficiently small so as not to pose a significant risk [2]. [See NASA NEPP. (2007). *Mitigating and Preventing the Growth of Tin and Other Metal Whiskers on Critical Hardware*. Retrieved from NASA NEPP; IPC. (2013). *Effects of Tin Mitigation Processes on Whisker Growth and Solder Joint Reliability*. Retrieved from IPC; and NASA Goddard Space Flight Center. (2018). *Tin Whisker Growth on Sn77.2-In20-Ag2.8 Solder*. Retrieved from NASA NEPP].

## III. THE CURRENT STATE OF PRACTICE

Most of the electronics industry, including piece part (electronic component) suppliers, have been involved with developing and implementing Pb-free risk reduction methods since the introduction of RoHS in 2006. Two of the major standards are JESD22-A121 “Test Method for Measuring Whisker Growth on Tin and Tin Alloy Surface Finishes” and JESD201 “Environmental Acceptance Requirements for Tin Whisker Susceptibility of Tin and Tin Alloy Surface Finishes”, which require that aged samples be put through thermal cycling, high temperature/humidity, and ambient tests. The view is that if assemblies and piece parts meet these standards, their use of Pb-free solders, finishes and plating do not produce risks of tin whiskers. These tests are not only implemented by the commercial community, which have expected lifetimes from 3 to 7 years, but also for the automotive and natural gas industry with expected lifetimes of 10+ years.

As an example, Murata makes Sn3.0Ag0.5Cu plated MLCCs that they claim are substantially risk free of tin whiskers [MMC200A-0639 dated 2023/7/1]. Their foundation for this is “passing” certain Japan Electronics and Information Technology Industries Association (JEITA) and

JEDEC JESD201<sup>1</sup> standard tests, as well as stating that “More than 2000 billion products have been shipped, and the failure caused by tin whisker has not occurred in our products, not only with lead free solder (SnAgCu), but also with SnPb eutectic solder in customer’s process and field.” It must be noted that the test conditions were limited to 3 samples each conducted at 30°C/60RH for 4000 hours, 55°C/85RH for 4000 hours and 1500 – 55°C to 85°C thermal shock cycles, with the passing criteria that whiskers that do grow are less than 10  $\mu\text{m}$ . Since there are no acceleration factors available, it is not possible to determine what this actually means for a different set of environmental conditions, for longer times or for more thermal cycles. However, the electronics industry has historically seen the widespread use of the Sn96.5Ag3.5 eutectic tin/silver alloy for electronics in harsh use environments such as sour gas well, automotive, and high temperature applications, with lifetimes of 10+ years with negligible issues of tin whiskers being reported. Generally, SnAg with at least 3.5Ag is considered a low risk for whiskers [3], [4], and this is likely the case with SnAgCu solders as well.

The SAE GEIA-STD-0005-2A notes that there is very limited data on the correlation of the test results in the standards with field performance. This standard claims that there have been reported cases of parts with tin whisker field failures that previously passed JESD201, although most have been unofficial reports with little detail. They further admit that “...there does not appear to be harm in selecting parts with the testing and there is the possibility of the results helping to reduce the risk of early failures”. For products with longer lifetime requirements or without thorough inspections in less than 7 years, if qualification or other test data is included, the SAE GEIA-STD-0005-2A states that the “analysis should include a discussion of why the test was representative and how the results were generalized to the application environment and product life length”, and notes that, “...until the fundamental mechanisms of tin whisker growth are understood and acceleration factors established, customers with environmental exposures longer than the test length should be cautious about extrapolating the test results too extensively.” It is notable that the automotive industry is using Pb-free components under the assumption that the JESD201 test methods are appropriate for vehicles that require 10+ years life in harsh environments.

Given this information, a possible solution for high reliability applications (such as medical) is to consider the use of parts tested to the standards, especially those finished / plated with Ag as an alloy – and the addition of other tin whisker risk mitigation methods, including conformal coatings can be used to further reduce the risks. This could result in a more reliable product than that obtained by re-finishing piece parts with SnPb, due to the numerous

opportunities to introduce defects resulting from handling and processing the parts.

In general, the commercial and consumer electronics industries have not considered tin whiskers to be a significant failure risk, and as a result, Pb-free solders, finishes and plating are used without the purposeful application of tin whisker mitigation methods. This perspective is in part due to the lack of evidence that tin whiskers cause failures in their products (and thus an extremely low probability is being assigned to the risk), and in part due to the products not being long life (typically 3 – 7 years) or safety critical. Similarly, the natural gas and oil industry which requires 20-year lifetimes, and the automotive industry which requires 10+ years life and compliance to strict safety standards, are using COTS devices with pure tin finishes under the requirement that they pass JESD201 tests. These groups also do not appear to view Pb-free finishes and tin whiskers as a major concern. On the other hand, there are factions in the aerospace and defense industry who have and continue to advocate against any use of the current Pb-free solders, finishes and plating, as can be seen in the development of the SAE GEIA-STD-0005-2.

The automotive industry follows the AEC – Q005 – REV – Pb-Free Test Requirements Specification, last updated in June 2010. The purpose of this specification is to “...determine that a component is capable of passing the specified stress tests and thus can be expected to give a certain level of quality/reliability in the application”. It is stated that a verified whisker mitigation practice is required when Sn-based finishes are used, unless otherwise agreed between user and supplier on a case-by-case basis. The qualification process is documented in JESD201. The specification notes that “The test conditions defined in JESD201 have been shown to generate whiskers. If whisker growth is not detected on test samples during the required test duration for the temperature cycling or high temperature / humidity storage (55°C  $\pm$  3°C and 85%  $\pm$  3% RH) test conditions, data demonstrating capability to generate whisker growth (e.g., additional samples, coupons, etc.) must be provided to validate the test conditions that were used. However, the lower temperature / humidity storage test condition (30°C  $\pm$  2°C and 60%  $\pm$  3% RH) per JESD201 is exempt from this requirement. A component will be defined as passing Sn whisker acceptance testing if all test samples meet the criteria established by the Class level 2 requirements as defined in JESD201 or as negotiated between the user and supplier.

The SAE G-24 and IPC PERM groups were formed primarily by aerospace and defense personnel to develop standards, handbooks, and guidelines to manage the risks of transitioning to Pb-free technology. The GEIA-STD/HBK-0005 suite of documents, as well as documents released by IPC such as IPC/PERM-2901, are the approaches developed and recommended by these committees. The GEIA documents have been under active review and revision, with the initial release in 2006 and updates in 2012 and the latest updates starting in 2017. It should however be noted that there is internal conflict in the aerospace and defense

<sup>1</sup>Successful passage of JESD201 is needed to satisfy SAE GEIA-STD-0005-2A Control Level 2 requirements.

communities, because cost is also an issue for these systems and since the Perry Memo in 1994 [Perry, W. Specifications and Standards - A New Way of Doing Business, Government Printing Office, Washington DC, June (1994)], there has been an increasing push to use COTS components, which are, with few exceptions, Pb-free. As a result, although these standards exist, it does not mean that they are followed in all system programs (e.g., there are many waivers).

#### IV. EXAMPLES OF PASSIVE COMPONENT MANUFACTURERS

Many passive electronics manufacturers produce lead-free components while taking steps to mitigate tin whisker formation. These companies often use alternative materials, coatings, or finishes to reduce the risk of tin whiskers. Below are some notable companies and their approaches:

- **Murata Manufacturing**  
Approach: Murata uses matte tin finishes and conformal coatings to reduce the risk of tin whiskers in their capacitors, inductors, and filters.  
Products: Ceramic capacitors, inductors, filters, and RF components.  
Compliance: RoHS-compliant and suitable for high-reliability applications.
- **TDK Corporation**  
Approach: TDK employs tin alloys with additives (e.g., nickel or copper) and matte tin finishes to mitigate tin whisker growth in their passive components.  
Products: Multilayer ceramic capacitors (MLCCs), inductors, and ferrite beads.  
Compliance: RoHS-compliant and widely used in consumer and industrial electronics.
- **Vishay Intertechnology**  
Approach: Vishay uses matte tin finishes and conformal coatings for their resistors, capacitors, and inductors. They also offer nickel-barrier layers to prevent tin whiskers.  
Products: Resistors, capacitors, inductors, and diodes.  
Compliance: RoHS-compliant with options for high-reliability applications.
- **KEMET (now part of Yageo Corporation)**  
Approach: Kemet claims [5] that they have dramatically reduced the potential for tin whisker growth by:
  - using a matte tin finish for the plating of the termination. The matte finish does not contain any brighteners known to cause tin whisker growth.
  - applying a nickel underlayer to tin finished MLCCs. This acts as a stress relief for the tin, and thus reduces the ability of tin whiskers to grow.
  - using a plating process that uses a smaller grain size and slower deposition rate, which reduces the stress on the termination and thus helps mitigate tin whisker growth.
  - during the plating process, each MLCC goes through a 150°C drying process for 60 minutes,

which anneals the termination. This “annealing” process reduces the stress on the termination, thus reducing the risk of tin whisker growth.

- and in some products, KEMET uses tin-silver-copper (Sn-Ag-Cu) alloys

Products: Ceramic capacitors, tantalum capacitors, and film capacitors.

Compliance: RoHS-compliant and suitable for automotive and industrial applications.

- **AVX Corporation**  
Approach: AVX employs matte tin finishes and nickel-barrier layers to mitigate tin whiskers in their capacitors and connectors.  
Products: Ceramic capacitors, tantalum capacitors, and connectors.  
Compliance: RoHS-compliant with a focus on high-reliability applications.
- **Panasonic**  
Approach: Panasonic uses matte tin finishes and tin alloys with additives to reduce tin whisker formation in their passive components.  
Products: Film capacitors, ceramic capacitors, and resistors.  
Compliance: RoHS-compliant and widely used in consumer and automotive electronics.
- **Taiyo Yuden**  
Approach: Taiyo Yuden uses matte tin finishes and conformal coatings to mitigate tin whiskers in their capacitors and inductors.  
Products: Ceramic capacitors, inductors, and RF components.  
Compliance: RoHS-compliant and suitable for high-frequency applications.
- **Würth Elektronik**  
Approach: Würth Elektronik uses matte tin finishes and tin alloys with additives to reduce the risk of tin whiskers in their passive components.  
Products: Inductors, capacitors, and transformers.  
Compliance: RoHS-compliant and widely used in industrial and automotive applications.
- **Samsung Electro-Mechanics (SEMCO)**  
Approach: SEMCO uses matte tin finishes and conformal coatings to mitigate tin whiskers in their MLCCs and other passive components.  
Products: Multilayer ceramic capacitors (MLCCs), inductors, and RF components.  
Compliance: RoHS-compliant and suitable for consumer and automotive electronics.
- **KYOCERA AVX**  
Approach: KYOCERA AVX uses matte tin finishes and nickel-barrier layers to reduce tin whisker formation in their capacitors and connectors.  
Products: Ceramic capacitors, tantalum capacitors, and connectors.

Compliance: RoHS-compliant with a focus on high-reliability applications.

By choosing components from these manufacturers and verifying their mitigation strategies, you can reduce the risk of tin whisker-related issues in your designs. The verification process involves checking the manufacturer's datasheets for information on finishes and coatings; looking for compliance with industry standards like JEDEC JESD201 (standard for tin whisker testing); and contacting the manufacturer's technical support for specific details on their tin whisker mitigation strategies.

## V. IS THE AEROSPACE AND DEFENSE APPROACH TO TIN WHISKERS THE RIGHT APPROACH

The aerospace and defense industry has been generally conservative when considering the adoption of Pb-free materials and components. The approach is based on creating a Pb-free control plan, as called for in the SAE GEIA-STD-0005-1 Performance Standard for Aerospace and High-Performance Electronic Systems Containing Lead-free Solder. The Pb-free control plan documents the processes the plan owner uses to produce, supply, rework, repair, or maintain equipment containing Pb-free solder, piece parts and printed boards. These processes must satisfy the requirements for performance, reliability, safety, and certifiability of the equipment through the specified life of the equipment. The identified areas include configuration control and product identification, COTS, deleterious effects of tin whiskers, repair, rework, maintenance, and support.

Regarding the deleterious effects of tin whiskers, compliance with SAE GEIA-STD-0005-2, requires the supplier's assignment of a control level and the customer's specification of their required control level. The standard provides five control levels, ranging from control level 1, which has no control over Pb-free materials, to control level 3, which prohibits the use of Pb-free finishes. Control level 2 has three options, A through C, which place increasing restrictions on the use of Pb-free finishes. For control level 2A, the tin whisker risk is accepted and mitigated to a lesser extent. For control level 2B, the tin whisker risk is managed through the application mitigation strategies, including design rules. For control level 2C, tin whisker risk is mitigated through prohibiting Pb-free finishes while using mitigation approaches when Pb-free finish is unavoidable.

Through applying the Pb-free control plan and introducing tin whisker control levels, aerospace and defense equipment manufacturers and end users use a cost-risk function for equipment under consideration. Through discussions with individuals within aerospace and defense, it appears that tin whisker control level 2B is identified as the most frequently used across the wide range of applications. At the same time, space and missile equipment most frequently use control levels 3 or 2C.

For control level 3, part terminal reprocessing such as reballing and solder dip must be applied to replace Pb-free

terminal finishes with a SnPb finish. The application of reballing requires at least two additional elevated temperature steps where the part surfaces encounter temperatures above the melting point of the Pb-free finish. The application of solder dipping requires a single exposure above the melting point of the finish. While most parts can handle these temperature steps, the risk of damage due to mishandling is present. Costs for reballing and solder dipping can be considerable and production schedules can also be impacted.

When considering that the cost of a commercial airline or satellite failure can run in the hundreds of millions to over a billion dollars, the cost justification applying tin whisker control levels 3 and 2C may be justified. For the automotive industry, the cost-risk function is expected to be lower. As a result, the automotive industry, which is very cost driven, is more likely to accept the risk of tin whiskers.

Failure Mode and Effects Analysis (FMEA) is used to systematically identify and prioritize potential failures in products. In FMEA, potential failures are identified and the severity, likelihood, detectability of each failure are used to rank the failure risks. For tin whisker failures, the likelihood of whisker induced failures is difficult to determine. However, considering the consumer market has fielded equipment with Pb-free finished terminal assembled using Pb-free solder for more than 20 years, it is apparent that the whisker risk is at very low level. The authors assessed the risk of a tin whisker failure in a representative personal computer mother board to be less than 0.03% [6]. At this estimated low probability failure, it is more likely solder fatigue, connector wear, or other mechanisms will cause failure prior to a tin whisker.

## VI. CONCLUSION

Each company must make their own determination related to tin whisker risk and the extent to which the tin whisker risk is mitigated. The SAE GEIA-STD-0005-2A standard provides an approach to make this determination and mitigate tin whisker risks, but it is ultra-conservative and not cost effective, especially in its requirements for defense, aerospace and medical systems. For most electronics, SAE GEIA-STD-0005-2A control class 1 and class 2A are acceptable. For the remainder, control class 2B or control class 2C are adequate and are being applied by the automotive and natural gas industries. Furthermore, control class 3 is becoming unrealistic to achieve and fraught with quality issues associated with obtaining Pb-free components, re-finishing them, and using contract manufacturers to use old soldering technologies.

If companies want to implement affordable leading-edge parts into their products, they need to embrace COTS components. For high reliability applications, such as medical, aerospace and defense, parts should be tested to the JESD201 standard and tin whiskers monitored according to JESD22-A121; e.g., use SAE GEIA-STD-0005-2A control class 2A. If the risk is judged to be higher, applying SAE GEIA-STD-0005-2A control class 2B may be appropriate. Specifically, the addition of other tin whisker risk mitigation

methods, including conformal coatings, can be used to further reduce the risks. This should result in:

- significantly lower costs (as much as 10x savings due to not having to re-finish parts that are only available as Pb-free),
- the ability to use new electronic parts that are only available as Pb-free, and
- a more reliable product than that obtained by re-finishing piece parts with SnPb, due to the numerous opportunities to introduce defects resulting from handling and processing the parts.

## REFERENCES

- [1] M. Mason and G. Eng, "Understanding tin plasmas: A new approach to tin whisker risk assessment," in *Proc. 45th Annu. IEEE Int. Rel. Phys. Symp.*, New York, NY, USA, Apr. 2007, pp. 150–155.
- [2] S. Mathew, W. Wang, M. Osterman, and M. Pecht, "Assessment of solder-dipping as a tin whisker mitigation strategy," *IEEE Trans. Compon., Packag., Manuf. Technol.*, vol. 1, no. 6, pp. 957–963, Jun. 2011.
- [3] I. Yanada, "Electroplating of lead-free solder alloys composed of Sn-Bi and Sn-Ag," in *Proc. IPC Printed Circuits Expo*, 1998, pp. 457–467.
- [4] K. Suganuma, "Tin whisker mitigation project of JEITA," in *Proc. CALCE 4th Int. Symp. Tin Whiskers*, College Park, MD, USA, 2010.
- [5] KEMET Corporation. *Ceramic Capacitor FAQ and Application Guide*. KEMET Corp. Accessed: Apr. 23, 2023. [Online]. Available: <https://www.kemet.com/en/us/capacitors/ceramic/ceramics-faq.html>
- [6] G. P. Pandian, D. Das, M. Osterman, and M. Pecht, "Risk assessment of transition to lead-free electronics assembly," in *Proc. Soc. Machinery Failure Prevention Technol. Conf.*, Virginia Beach, VA, USA, 2017.



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