White Paper

Risk Assessment of Sn Plated Solder Lug

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Abstract:

This paper presents a thorough analysis of the risks and considerations for tin whiskers. A particular product was presented to DfR Solutions with concerns about the risk of whisker related failures. The major failure modes, static contact and debris are discussed. In the present case, the product under concern is 150 microinches matte tin over copper. Some parts are conformally coated and some are not.

An analysis of the potential risks was performed. The result was that in the present case, tin whiskers did not pose a significant risk. This conclusion was based on historical data on lead spacing and comparison to the present product.

Risk Assessment of Sn Plated Solder Lug

1. Introduction

DfR Solutions assessed the risk of tin whisker induced failures due to the presence of tin-plated solder terminals on a customer supplied product.

2. Background

Risk assessment is the practice of determining if the actual reliability will meet or exceed the desired reliability and the consequences if these performance goals are not met. The actual reliability of a product is driven by the failure modes that can initiate and the materials, design, and environment that interact to drive failure processes.

To perform a sufficient risk assessment requires a review of the failure modes that can initiate due to tin whiskering, the materials and design existent within the product, and the expected operating environments.

2.1 Failure Modes

There are two major failure modes that can initiate due to the presence of tin whiskers. Static contact is when a tin whisker grows and makes a physical connection with an adjacent conductor. Debris is when the whisker becomes dislodged and has the potential to provide a conductive bridge and other locations within the product. Both of these failure modes create a leakage path, inducing an electrical short.

2.2 Materials

The solder terminals in question are part numbers 341-093, 390-169, and 11-120 from Zierick Engineered Interconnection Solutions (see Figure 1). The solder terminals are solid copper. Zierick has indicated that the finish code is "0", which indicates a matte tin plating of 150 microinches (3.75 microns) in thickness (see **Error! Reference source not found.**)[1]. Information on minimum or maximum plating thickness specifications or statistical variation in plating thickness was not provided. Standard range in commercial plating thickness for matte tin is 150 to 350 micro-inches.[2]

2.3 Design

The design of the solder terminals is provided in Figure 1. It was also indicated that in some applications, the adjacent conductors are conformally coated. The conformal coating is Urelane 5750 with a nominal thickness of 5 mil.

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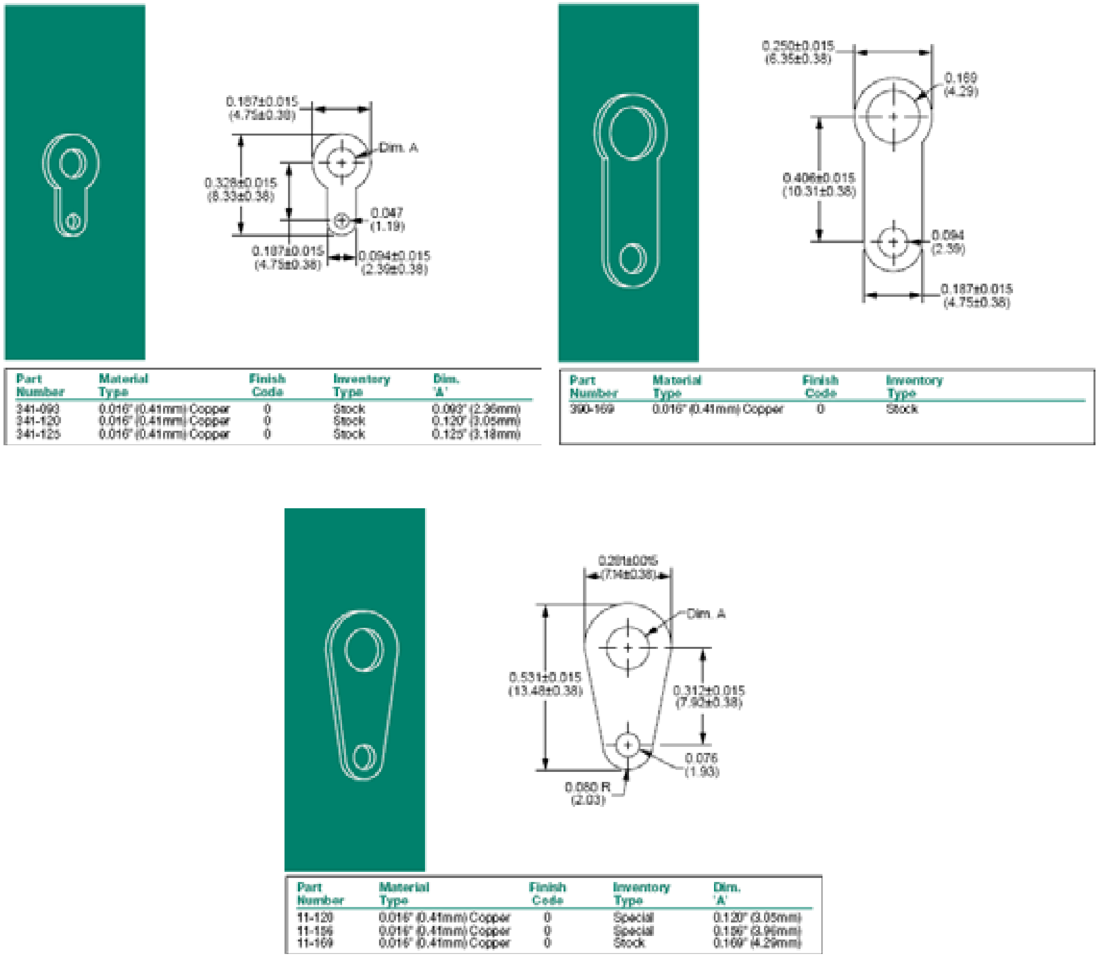
[1] This would seem to be in violation of MIL-Spec 14550A, which requires an underlayer of 1 7 μm Ni.

2.4 Environment

The operational environment for this study is the military, aerospace, and satellite applications. All three uses demand paramount reliability performance over an extended-period of time (20+ years). Potential environments would be expected to consist of a broad range of temperature cycling, temperature and temperature/humidity exposure. The solder terminal will also experience compressive stresses at the inner ring due to attachment of a nut or bolt.



Part Number	Material Type	Finish Code	Inventory Type	Dim. 'A'
341-093	0.016" (0.41mm) Copper	0	Stock	0.093" (2.36mm)
341-120	0.016" (0.41mm) Copper	0	Stock	0.120" (3.05mm)
341-125	0.016" (0.41mm) Copper	0	Stock	0.125" (3.18mm)

Part Number	Material Type	Finish Code	Inventory Type
390-169	0.016" (0.41mm) Copper	0	Stock

Part Number	Material Type	Finish Code	Inventory Type	Dim. 'A'
11-120	0.016" (0.41mm) Copper	0	Special	0.120" (3.05mm)
11-156	0.016" (0.41mm) Copper	0	Special	0.156" (3.96mm)
11-169	0.016" (0.41mm) Copper	0	Stock	0.169" (4.29mm)

Figure 1: Design specifications for solder terminals from Zierick Engineered Interconnection Solutions

3. Matte Tin Vs Bright Tin

A critical aspect of this risk assessment is the differentiation between matte tin and bright tin plating. This terminology was initially used by plating chemists, who focused on differences in plating chemistry and visual appearance. Bright tin is usually plated in sulfate baths and matte tin in stannate baths.

More recently, attempts were made to provide a more quantitative and physical justification for the terms matte and bright tin. As this effort was still primarily based on visual appearances, the results provided more a general range than an exact value. These ranges consisted of organic content and grain size. The brightening agents in the sulfate baths generate in a higher co-deposited organic content in bright tin. As an example, one plating company (SAMTEC)[2] quantifies the organic content for their bright Sn plating to approximately 0.15% and for their matte Sn plating to approximately 0.015%. Tyco specs <0.3% for bright Sn plating and <0.05% carbon content for matte Sn. Both of these values are roughly inline with the range put forward by iNEMI.[3] The organic content also influences grain size, with matte tin having a grain size approximately an order of magnitude higher than bright tin (see Table 1 and Table 2).

Table 1: Tin plating specifications from iNEMI

Parameter	Matte Sn	Bright Sn
Carbon Content	.005%-0.050%	0.2%-1.0%
Grain Size	1µm-5µm	0.5µm-0.8µm

Table 2: Tin plating specifications from Tyco

Property	Value for matte tin	Values for bright tin
Electrolyte	Tin MSA	Tin MSA
Process Type	High speed reel to reel plating	High speed reel to reel plating
Current Density	50-400 ASF	50-250 ASF
Sample size	30 contacts per sample	30 contacts per sample
Agitation range	Moderate to strong	Moderate to strong
Carbon content	<0.05%	<0.3%
Grain size	Nominally 3 um	< 1 um
Plating thickness	2.7 um	5.5 um

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[2] http://www.samtec.com/standard_products/environmental_compliance/matte_tin_faq.pdf
SAMTEC USA, P.O. Box 1147, New Albany, IN 47151-1147, Phone: 800-SAMTEC-9 (800-726-8329)

[3] iNEMI Recommendations on Lead-Free Finishes for High-Reliability Products (v3, May 2005)

4. Risk Assessment (Static Contact)

The risk of a static contact failure mode is driven by several probabilities, including whisker growth of sufficient length, whisker growing in the correct orientation, whisker penetrating the conformal coating, and carrying a high enough amount of current for a sufficient period of time to trigger an upset during operation.

4.1 Maximum Whisker Length

Numerous publications over the past 50 years have assessed the mechanism of tin whisker formation. The strongest statements regarding whisker length was provided by Gaylon and Gedney[4]. As seen in Figure 2, the authors state that a matte tin whisker has never exceeded 1000 microns in length. More specifically, based upon a review of 131 published articles, Gedney states that the maximum recorded length of matte tin over copper is 800 microns and refers to an article by Brusse et. al.[5] A review of this article finds no statement to this effect. Brusse, in other presentations, does refer to a field failure where spacings between conductors were approximately 800 microns (see Figure 7).

4.1.1 Literature Review

A review by DfR of articles present within our database finds that statements regarding whisker length are based upon either the results of controlled testing or observations of field failures. Test results often more clearly state if the plating was matte or bright tin. Under these situations, the longest matte tin whisker over copper identified in the references was approximately 450 microns. A listing of these references is provided in Table 3. Dunn[6] did identify matte tin whiskers longer than 1mm when plated over a steel substrate.

Because of the time limitation of testing programs, it was speculated that growth rates could be obtained from the data and theoretical maximum whisker lengths could be calculated based upon the operational lifetime. However, review of the data suggests parabolic behavior, with an upper limit on whisker length. Cases where this upper limit was not observed tended to be under very high humidity (>93%RH) conditions where the investigators believed unintended condensation occurred.

Field failures provide much longer time periods and this has resulted in the identification of longer whiskers, upwards of 10 mm in length[7]. However, failures attributed to matte tin over copper have initiated over lengths less than 1 mm (see Figure 7 and Figure 8). Longer whiskers, upwards of 10 mm, have not been attributed to matte tin plating over copper substrate (see Figure 9 and Figure 10 for examples).

4.1.2 Caveats

It is important to directly compare findings from the literature and to the materials, design, and environment of the solder terminal to ensure that comparisons are relevant. The material set, matte tin over copper, has been replicated in a number of studies. The design is sufficiently similar to other test coupons, which consists of leadframes, connectors, and simple metal squares. The ambient environment could potentially experience some of the same loads, such as temperature cycling and temperature/humidity, as applied during testing.

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[4] Avoiding Tin Whisker Reliability Problems ,G.T. Galyon and Ron Gedney, Circuits Assembly, AUGUST 2004

[5] J. Brusse, G.J. Ewell, and J.P. Siplon, .Tin Whiskers: Attributes and Mitigation, *Proc. Of the 22nd Capacitor and Resistor Technology Symposium (CARTS)*, pp. 67-80, March 2002.

[6] B.D. Dunn, "A Laboratory Study of Tin Whisker Growth", European Space Agency (ESA) STR-223, pp. 1 - 50, September 1987.

[7] V. Glaxunova and N Nudryavstev, “An Investigation of the Conditions of Spontaneous Growth of Crystals on Electrolytic Coatings,” J. Appl. Chem. USSR, 1963, 36, pp. 519-525.
P. Key, “Surface Morphology of Whisker Crystals of Tin, Zinc, and Cadmium,” Proc. 20th Electric Componenents Conf., 1970, pp. 155-160
Y. Hada, O. Morikawa, and H. Togami, .Study of Tin Whiskers on Electromagnetic Relay Parts., Proc. of the 26th Annual Relay Conference at Oklahoma State University, Stillwater, Oklahoma, pp. 9-1 to 9-15, April 1978.

The solder terminal will also experience an additional environmental stress consisting of a mechanical load due to torquing. This application of stress could create a compressive stress gradient which could drive material movement and increase the propensity for whiskering. This phenomenon has already been observed in a number of applications, specifically press fit connections.

While the application of a compressive stress increases the propensity for whiskering, it is not clear if it increases the maximum length. Studies by Sakuyama[8] and Elmgren[9] definitively displayed an increase in growth rates, but the reported maximum lengths are in line with other publications. Additional evidence is provided by the inspection of an electronic product with similar tin-plated solder terminals subjected to storage environments for 20 years. The maximum whisker length, 18 mils (450 microns), is within the inner ring, at the location of maximum compressive stress. This length is inline with the values presented in Table 3. This length is also only slightly higher than the 12 mil (300 microns) observed on the bottom of the solder terminal. These observations may suggest compressive stresses drive an acceleration of growth rates, as opposed to a definitive increase in maximum length. The results are displayed in Figure 13.

4.2 Whisker Orientation

Several publications have pointed to the requirement that the whisker must grow in the correct orientation to make contact with an adjacent conductor. The required angle of growth for the solder terminal could be highly variable due the round surface of the outer ring. As a result, while acknowledging that even whiskers that grew the length of the separation distance may not come into physical contact with the adjacent conductors, a quantification of this risk reduction is not theoretically possible within the boundaries of this report.

4.3 Penetration of Conformal Coating

In some cases the adjacent electronics are conformally coated. The type of coating and thickness were provided in section 0. Conformal coating over the solder terminal was not controlled and therefore, for the purposes of this risk assessment, it will be assumed that there is no physical barrier over the solder terminal.

The use of conformal coating as a barrier to tin whiskering has been assessed by several organizations, with the most quantitative information provided by NASA[10]. There are two primary effects in the use of conformal coating. The application of conformal coating over the tin whisker producing surface can reduce exposure to humidity, a potential whisker accelerant, and has been shown to constrain whisker growth if the coating is of sufficient thickness.

However, since there is some uncertainty about the application of conformal coating over the solder terminal, the more applicable approach is conformal coating of the surface where the whisker will make physical contact. Leidecker and Kadesch have calculated the potential for buckling in this situation, due to the very high aspect ratio of the whisker and the resistance to deformation of the conformal coating. The results are shown in Figure 14. It can be seen that a 1 micron diameter whisker that grew across the 3 mm gap between the solder terminal and the adjacent conductors would be expected to penetrate only 0.001 microns before buckling. Even though this modeling does not consider tearing, which is an alternative failure mode, the very small penetration strongly suggests buckling as a likely occurrence.

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[8] Substitute Materials for Complete Elimination of Hazardous Substances - Study of Whisker Growth on Lead-Free Plating, Seiki Sakuyama and Michinori Kutami, FUJITSU Sci. Tech. J., 41,2,p.217-224(July 2005)

[9] Tin Whisker Formation on Lead-Free Coatings, Pete Elmgren, October 2002, www.psma.com/ul_files/forums/leadfree/pbfree_connector_overview2.pdf

[10] H. Leidecker, and J.S. Kadesch, "Effects of Uralane Conformal Coating on Tin Whisker Growth", Proceedings of IMAPS Nordic, The 37th IMAPS Nordic Annual Conference, pp. 108-116, September, 10-13, 2000.

4.4 Current Carrying Capability

The current carrying capacity of tin whiskers ranges from 10 to 50 mA, depending upon the diameter. This current level is more than sufficient to induce signal upset. As the resistance of a 3 mm long whisker is approximately 50 ohms, this can result in blowout at voltage levels as low as 0.5 to 2.5 VDC.

This suggests the likelihood of single event upsets, unless the product is in a vacuum environment. If a sufficient amount of current surges through the whisker, it will experience a rapid increase in temperature and melt and or vaporize, depending upon the particulars of the situation (whisker geometry, environment, electrical load, etc.). This will effectively eliminate the shorting event, unless the product is in a low-pressure environment. In this situation, the tin metal is more likely to proceed directly to vaporization due to a vapor pressure above the existent ambient conditions. In addition, the absence of any reactive gases increases the likelihood that the elevated temperatures will be sufficient to strip electrons from the tin atoms, creating an ionic cloud (plasma) that has the capability of carrying higher levels of current due to its higher conductivity. For example, previous experiments[11] have demonstrated that at atmospheric pressures of about 150 torr, a tin whisker could initiate a sustained metal vapor arc where the supply voltage was approximately 13 Volts (or greater) and supply current was 15 Amps (or greater).

This process also becomes self-fulfilling as higher currents induce higher temperatures, which are more effective in maintaining the plasma arc. Tin (or other materials) from the adjacent surfaces can help to sustain the arc until the available material is consumed or the supply current is interrupted. While current carrying capability of the tin-based plasma is up to 200A, power supplies incorporated within the present product are limited to approximately 1A.

4.5 Probability

Hilty et. al. recently published an article detailing an attempt to provide a probability of failure due to static contact of tin whiskers. The Monte Carlo-based model using extreme value statistics was based upon one set of experiments of two plating systems. The first sample set, described as unmitigated tin, consisted of a 3 micron layer to matte tin over brass. The second sample set, described as mitigated tin, consisted of matte tin over nickel. Tin plating thickness was not provided.

Neither plating system, tin over brass or tin over nickel over copper is directly relevant to the tin over copper products that are currently under consideration. As shown in Figure 15, the maximum whisker length for mitigated tin is approximately 0.3 microns (too small) and for unmitigated tin is approximately 10 microns (too long). This is even more clearly demonstrated in Figure 16.

However, the basic approach of the Hilty model, which assesses the extreme value behavior of maximum whisker lengths, takes into consider whisker orientation, and computes these effects through Monte-Carlo simulation. Therefore, a possible modified approach to determine a probability for the present analysis be to take the probabilities for the mitigated tin plating and shift accordingly so that zero probability occurs at 1 mm (which is currently the longest matte tin whisker over copper that has been recorded). In this situation, the values provided in Figure 17 can be shifted by approximately 1000/380 = 2.63. However, the point of 0 ppm failure rate will always be the maximum whisker length, which for the purposes of this report is assumed to be 1 mm.

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[11] J.H. Richardson, and B.R. Lasley, "Tin Whisker Initiated Vacuum Metal Arcing in Spacecraft Electronics," 1992 Government Microcircuit Applications Conference, Vol. XVIII, pp. 119 - 122, November 10 - 12, 1992.

5. Risk Assessment (Debris)

The second potential failure mode is breakage of the tin whiskers followed by creation of a low resistance path between exposed contacts as debris. While there have been numerous observations of broken whiskers (see Figure 18), there have been relatively few investigations that have performed controlled experiments on the susceptibility of tin whiskers to vibration and mechanical shock loads.

The most relevant results are from Dunn[12] and Hashemzadeh, as both publications tested samples with relatively long whiskers (0.8 to 1.0 mm) and both attempted to subject these whiskers to their natural frequencies (see Figure 19). Dunn's samples also contained whiskers growing perpendicular and parallel to the loading axis. Ando[13] performed vibration and shock testing, but their maximum whisker length was limited to only 75 microns. McDowell[14] claims whiskers are so strong they cannot be broken by mechanical shock or vibration, but provides no evidence. There are also claims that Z. Mei of Cisco Systems has subjected whiskers to vibration, shock, and wind tunnel testing, but these results have not been published to date.

The testing approach of each investigation is detailed in Table 4. In each case, the investigators could not identify any whisker breakage due to mechanical loading. This would seem to suggest that whisker breakage only occurs when the whisker is physically contacted during handling.

A theoretical approach can also demonstrate the probability of whisker breakage. Dunn determined an ultimate tensile strength of 0.8 Kg/mm^2, which is the equivalent to approximately 8 MPa. The appropriate structure to model loads during vibration would be expected to be a uniform load on a simply supported beam. In this case, the maximum stress within the beam (or whisker) is given by the formula

$$_{\text{max}} \qquad L^2 p / 2(d^3/6)$$

where p is the load, L is the length and d is the diameter. The load during vibration would be expected to be equal to the acceleration times the mass of the whisker.

Using a whisker 1 mm long x 2 microns in diameter results in a total mass of

0.007 g/mm3 x 1 mm x 0.002 mm x 0.002 mm = 2.8 x 10^{-8} grams

Maximum acceleration detailed in Table 4 was 3000 G, which is equivalent to 30,000 m/sec^2. Combined with the mass of the whisker gives us a force of 8.4 x 10^{-7} Newtons. Inputting this force into the stress equation above results in 315000 Pa, or 0.3 MPa. This stress is more than an order of magnitude below the ultimate tensile strength measured by Dunn.

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[12] B.D. Dunn, "Mechanical and Electrical Characteristics of Tin Whiskers with Special Reference to Spacecraft Systems," European Space Agency (ESA) Journal, 12, pp. 1-17, January 14, 1988.

[13] Ando, Toshihiro, Shibata, Masamitsu, Okada, Seiichi, and Namasuya, Yoshikazu, "Stress Analysis and Accelerated Evaluation of Tin Whisker under Thermal Shock Stress," Murata

[14] Tin whiskers: a case study, McDowell, M.E., Aerospace Applications Conference, 1993. Page(s): 207-215

6. Mitigation

There currently is no effective method for the elimination of whiskers from tin-based alloys. Even SnPb solder has been observed to whisker to some degree. However, the most effective mitigation technique has been found to include the addition of varying amounts of Pb. The minimum concentration necessary for this mitigation is often cited as 3%[15]. These requirements are often called out within MIL specifications for EEE parts. However, other non-military sources often call out lower amounts of Pb. R. Diehl[16] of the Burndy Corporation suggests as little as 2% Pb suppresses whisker growth. Reynolds et. al.[17] of British Telecom cited a lower limit of 1% Pb to inhibit the growth of tin whiskers. An understanding of the physics by which Pb interacts with Sn and a review of the original experiments provides some guidance on these contradictions.

The two primary articles that quantitatively demonstrated the effectiveness of Pb in suppressing whisker growth were Arnold[18] and Key[19]. Arnold stated that “lead (Pb) of the order of one per cent in a tin coating either completely prevents the formation of tin whiskers or reduces growth to a degree that would eliminate any hazard of short circuits caused by whiskers even where components are closely spaced.” This statement was based upon years of observation. Key found that the addition of 0.5 percent Pb significantly reduced the whisker forming tendency of the tin finish, with only a few short whiskers (about 10 um long max.) observed.

Reviewing the Sn-Pb phase diagram shows that only 0.1% Pb is soluble in Sn at room temperatures. The relatively small amounts of Pb (>0.5%) necessary to suppress tin whiskering may suggest that the Pb alloy’s primarily role is at the grain boundaries. Therefore, it is possible that a Pb concentration greater than 0.1% that is well dispersed within the tin plating may be also be sufficient to provide some degree of mitigation. Once the percentages of Pb within the plating surpass 2%, the tin whisker behavior does not change substantially[20].

The rationales behind a 3% minimum is probably a combination of limited confidence in material detection techniques (is 1% really 1%?) and the ability of plating houses to maintain tight control over Pb content.

There is also some belief that a Pb gradient may exist outwards from a SnPb solder joint through a non-alloyed Sn plating. However, this has not yet been substantiated through experimental testing.

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[15] MIL-PRF-23269, MIL-PRF-39003, MIL-S-19500, etc.
http://www.empf.org/empfasis/july05/whiskers705.htm

[16] Significant characteristics of tin and tin-lead contact electrodeposits for electronic connectors, Diehl, R P, Met. Finish. Vol. 91, no. 4, pp. 37-42. Apr. 1993

[17] PROCEEDINGS OF THE IEEE, VOL. 62, NO. 2, FEBRUARY 1974 223, Specikations for Integrated Circuits in Telecommunications Equipment, FREDERICK H. REYNOLDS, ROBERT W. LAWSON, AND PETER J. T. MELLOR

[18] Arnold, S.M. "Repressing the Growth of Tin Whiskers", Plating Magazine, Jan. 1966

[19] P.L. Key, "Surface Morphology of Whisker Crystals of Tin, Zinc and Cadmium," IEEE Electronic Components Conference, pp. 155-157, May, 1970

[20] H. Leidecker, NASA, communication

Lead-Frame Spacing (microns)	Comments
50-100	• Ultra fine spacings not commonly used. • Non-tin finishes strongly recommended. • Mitigation practices strongly recommended for tin finishes.
100-500	• Common fine-pitch spacings. • Non-tin finishes strongly recommended for critical applications: military, medical, automotive, mission critical hardware, aerospace, etc. • Mitigation practices strongly recommended for tin finishes.
500-1000	• A fairly long gap for a tin whisker on matte tin finishes. • Long-term reliability (> 5 yrs.) requires mitigation. • Short-term (< 3 yrs.) may use pure tin without mitigation. • Special care is recommended to not use pure tin on iron substrates without either an underlay or an anneal.
1000-2500	• A very long Sn whisker, longer than any matte tin whisker to date. • Common spacings for pin-through-hole (PTH) devices. • Pure matte tin over alloy 42 or Cu a minimal risk. • Mitigation is recommended for critical applications.
2500-5000	• Whiskers this long have been reported, but they are extremely rare, and all known to these authors have been on bright tin deposited onto an iron substrate. • Common spacings for pin-through-hole (PTH) devices. • Mitigation recommended for critical applications where there is either mechanical shock or temperature cycling.
>5000	• There are no matte tin whiskers of this length in the known technical literature. • There is at least one recorded bright tin whisker >10.0 mm in length known to these authors.[5] • Mitigation is recommended for critical applications where there is either mechanical shock or temperature cycling.

Figure 2: Risk analysis based on conductor spacing

Table 3: Listing of maximum recorded lengths for matte tin over copper (controlled experiments)

Reference	Environment	Time Period	Maximum Length
Peng (Freescale)[21]	60C/93%RH	3000 hours	70 microns
Hashemzadeh (Linköping)[22]	-60C/60C	500 cycles	130 microns
Okada (Murata)[23]	-40C/85C	2200 cycles	85 microns
Gedney (iNEMI)[24]	60C/95%RH	3000 hours	60 microns
	-55C/85C	3000 cycles	35 microns
Brusse (NASA)[25]	-40C/90C	500 cycles	250 microns
Hilty (Tyco)[26]	60C/93%RH	5000 hours	450 microns
	Room Conditions	8500 hours	100 microns
	-55/85C	3000 cycles	40 microns
Romm (TI)[27]	51C/85%RH	3634 hours	34 microns
Dittes (E4)[28]	30C/60%RH	450 days	275 microns
	-55C/85C	3000 cycles	35 microns

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[21] Peng Su, Min Ding, and Sheila Chopin, "Effects of Reflow on the Microstructure and Whisker Growth Propensity of Sn Finish", Proceedings of the 55th ECTC

[22] Study of Tin Whisker Growth and their Mechanical and Electrical Properties, Moheb Nayeri Hashemzadeh, Undergraduate Thesis, Linköping University, 2005

[23] S. Okada, et al, "Field Reliability Estimation of Tin Whiskers Generated by Thermal Cycling Stress", Capacitor and Resistor Technology Symposium (CARTS) Europe, October 2003

[24] R. Gedney, J. Smetana, N. Vo, G. Galyon, "NEMI Tin Whisker Projects", Second International Conference on Lead Free Electronics, June 21-23, 2004 (Amsterdam)

[25] J. Brusse, "Tin Whisker Observations on Pure Tin-Plated Ceramic Chip Capacitors", Proceedings of the American Electroplaters and Surface Finishers (AESF) SUR/FIN Conference, June 24-28, 2002, pp. 45-61

[26] Tin Whiskers in Electronic Components, Bob Hilty, www.tycoelectronics.com/environment/ leadfree

[27] D. Romm, D. Abbott, S. Grenney, M. Khan, "Whisker Evaluation of Tin-Plated Logic Component Leads", Texas Instruments Application Report SZZA037A, February 2003

[28] Standard for Whisker Acceptance Level in Pb-free Lead Finish. A Step towards Green Packaging for Consumer Products to Drive Future European Strength, Final Report. Contract No: IST-2001-37826. 01.06.2002 - 30.11.2004, Marc Dittes, Infineon Technologies

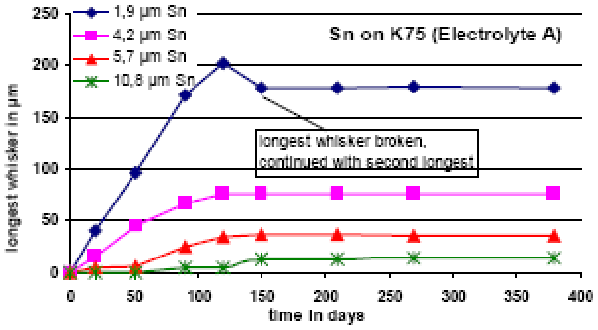


Fig. 20 Influence of thickness on whisker formation, electrolyte A on K 75, ambient storage

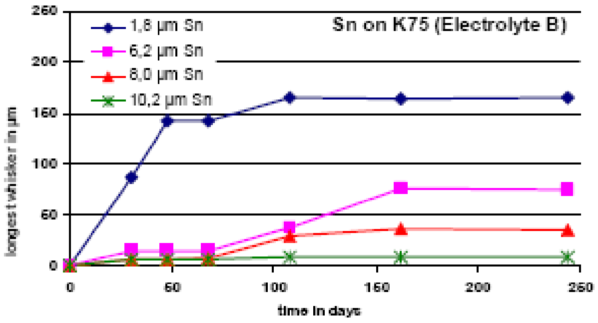


Fig. 21 Influence of thickness on whisker formation, electrolyte B on K 75, ambient storage

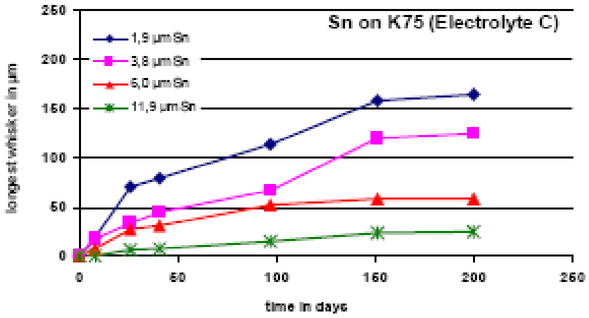


Fig. 22 Influence of thickness on whisker formation, electrolyte C on K 75, ambient storage

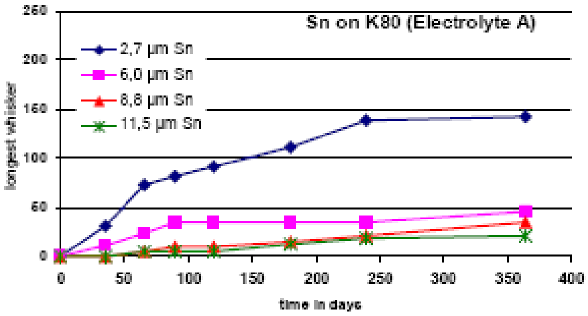
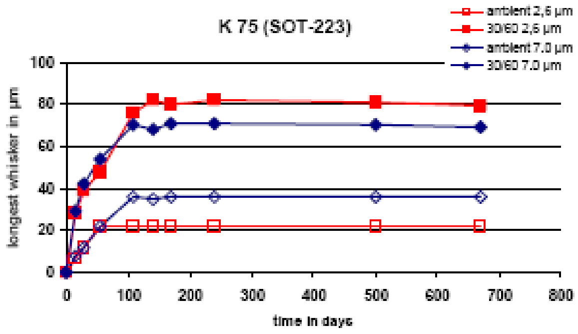


Fig. 23 Influence of thickness on whisker formation, electrolyte A on K 80, ambient storage

Figure 3: Examples of tin whisker growth behavior from experiments performed by the E4 group (Dittes)



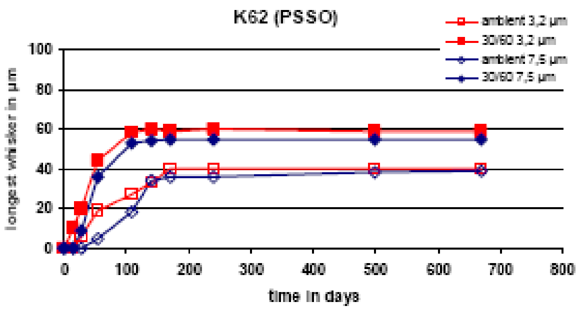
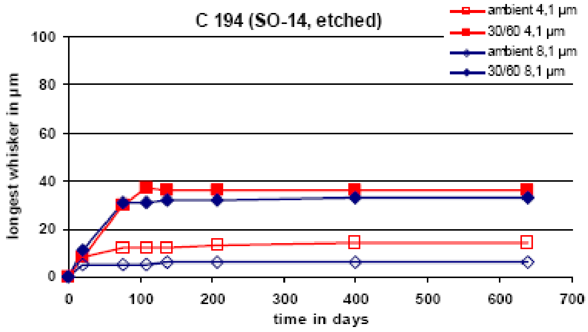


Fig. 29: Whisker growth for various plating thickness and various atmospheres on tin plated K 75

Fig. 30: Whisker growth for various plating thickness and various atmospheres on tin plated K62



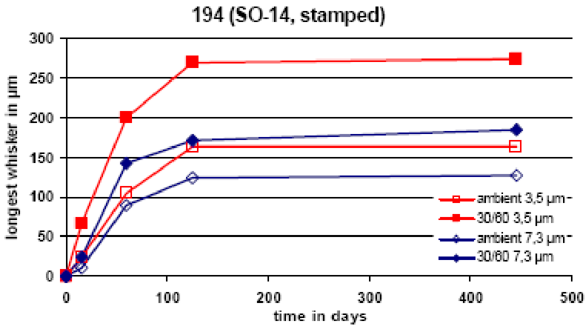


Fig. 31 Whisker growth for various plating thickness and various atmospheres on tin plated C 194 (etched frame)

Fig. 32 Whisker growth for various plating thickness and various atmospheres on tin plated C 194 (stamped frame)

Figure 4: Examples of tin whisker growth behavior from experiments performed by the E4 group (Dittes)

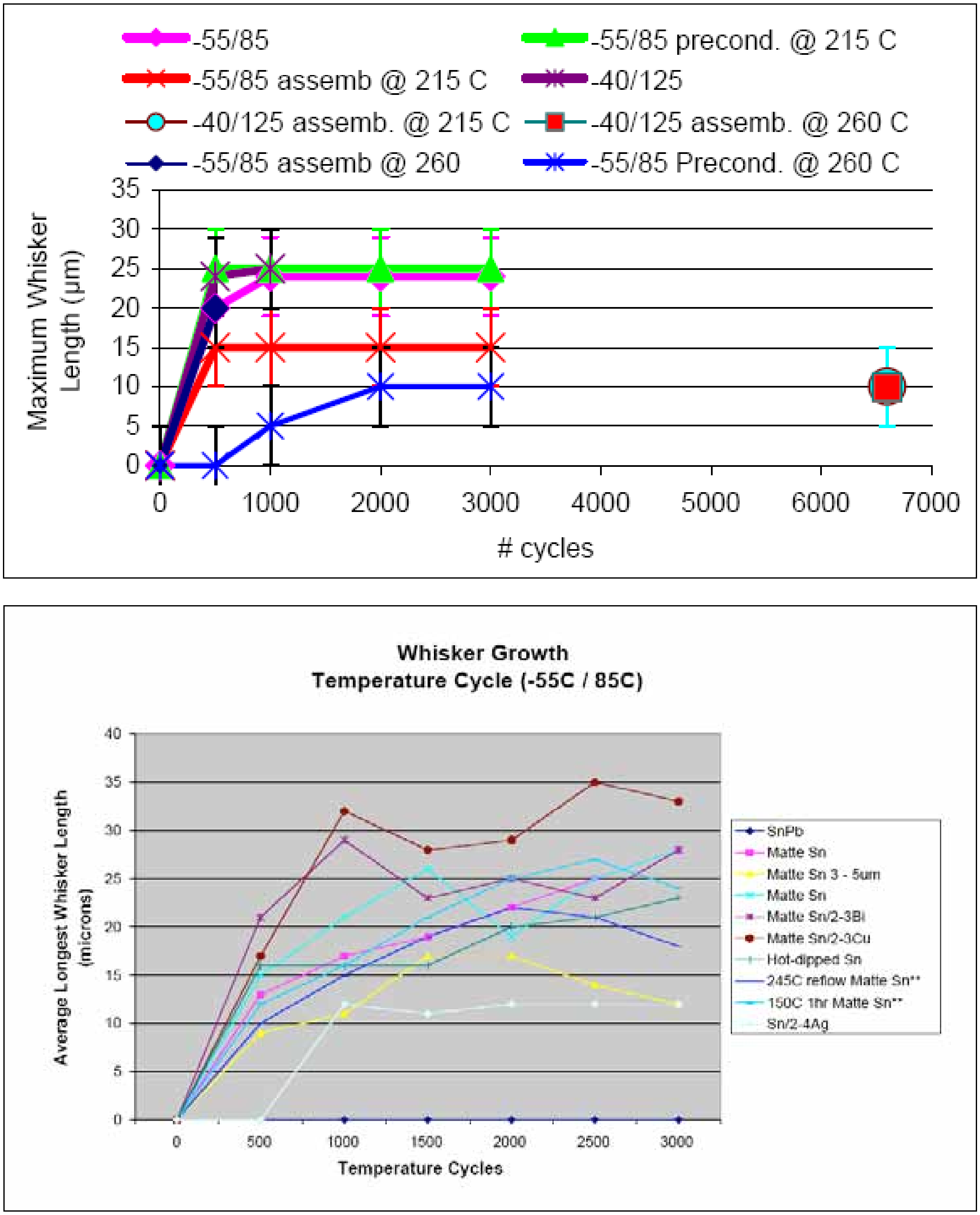


Figure 5: Growth of whiskers from matte tin over copper from studies performed by the E4 (left) and iNEMI (right)

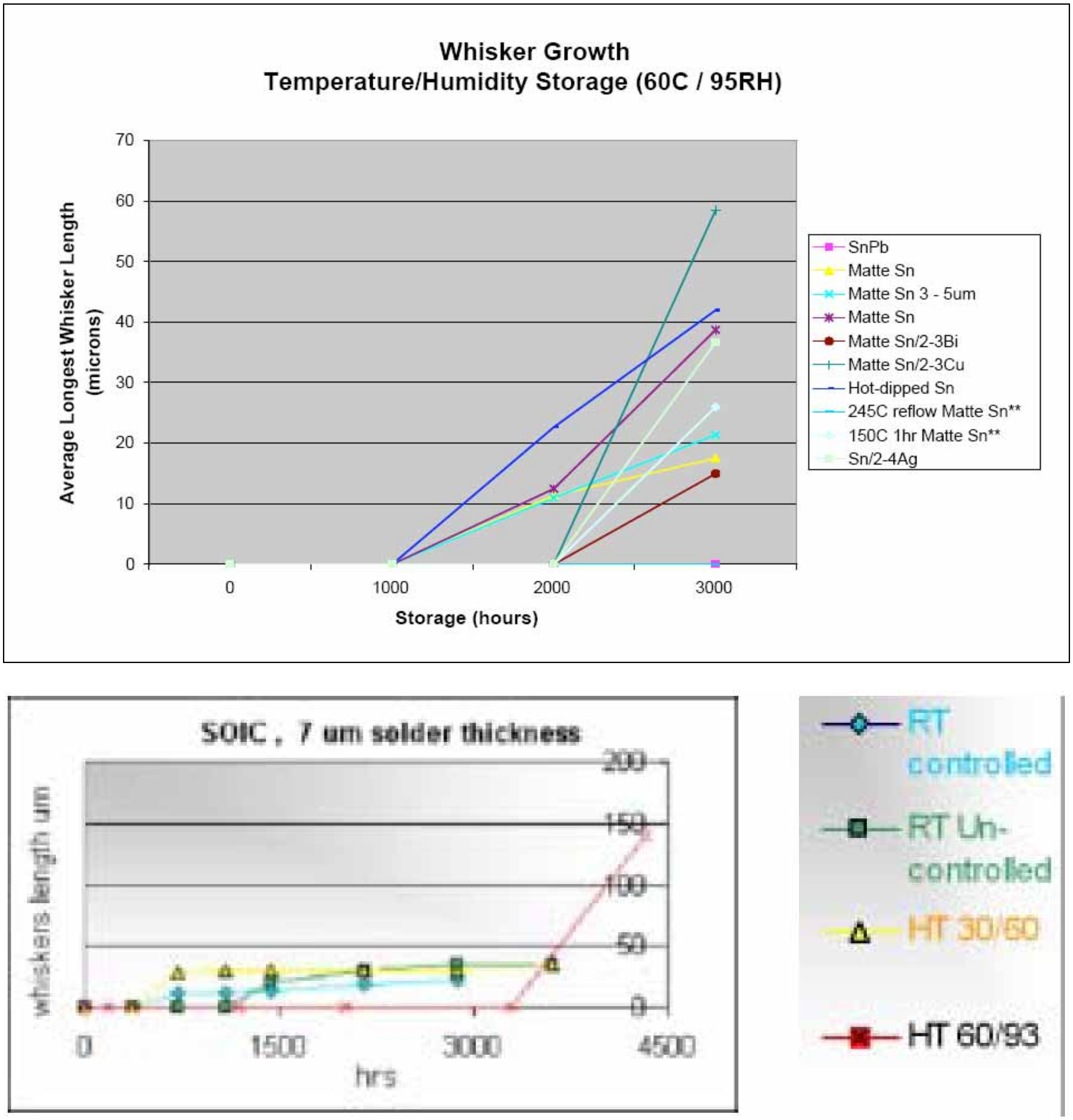


Figure 6: Tin whisker growth behavior under potential condensation conditions (top: iNEMI; bottom: ST Micro)

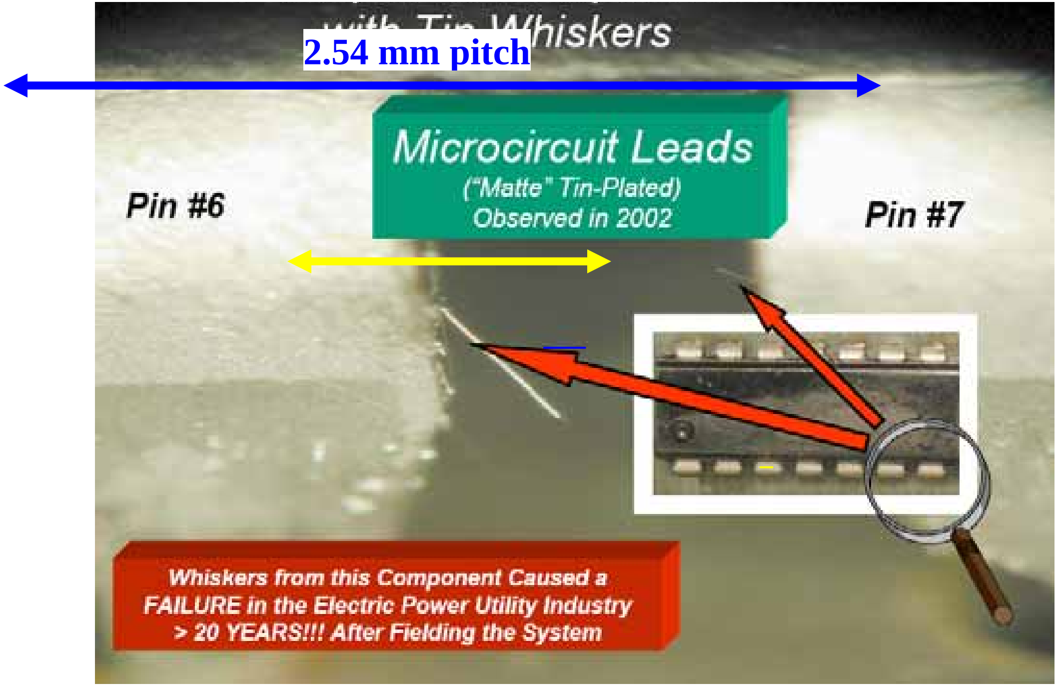


Figure 7: Image of whisker emanating from matte tin over copper leadframe[29]. Lead spacing is approximately 750 to 800 microns.

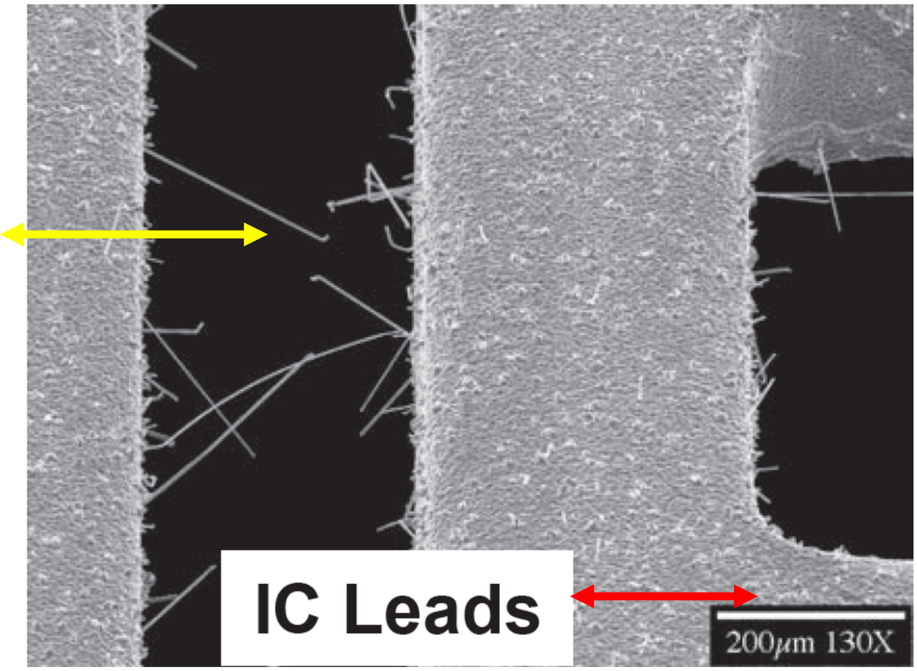


Figure 8: Tin Whiskers on a Matte Tin SOIC leadframe after three years storage at ambient conditions. Courtesy of P. Bush, SUNY Buffalo. Lead spacing is 300 microns.

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[29] Tin Whiskers: The Unexplained Phenomenon, November 5, 2003, Jay Brusse Presenter, IPC Webcast

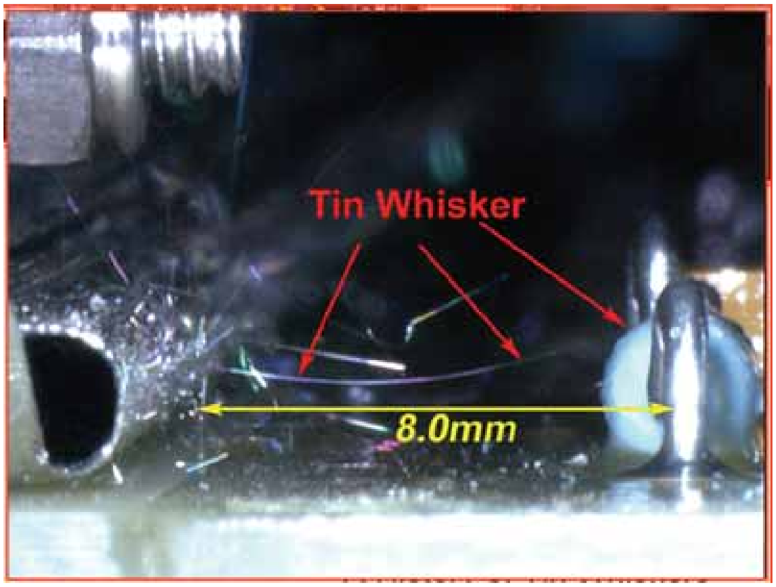

Figure 9: Image of whisker emanating from card guide on Space Shuttle electronics module[30]. The type of tin plating was not identified. While metal card guides can be fabricated from beryllium copper or stainless steel, stainless steel is typically used for extra strength in shock and vibration environments. Stainless steel substrates are known to greatly increase whisker lengths (Dunn).

Figure 10: Image of whiskers emanating from a variable air capacitor (manufactured 1959; inspected 2006). The type of tin plating was not identified. Steel plates were typically used in variable air capacitors. Steel substrates are known to greatly increase whisker lengths (Dunn).

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[30] "Tin Whiskers Found on ATVC S/N 0034", Don McCorvey, March 8, 2006

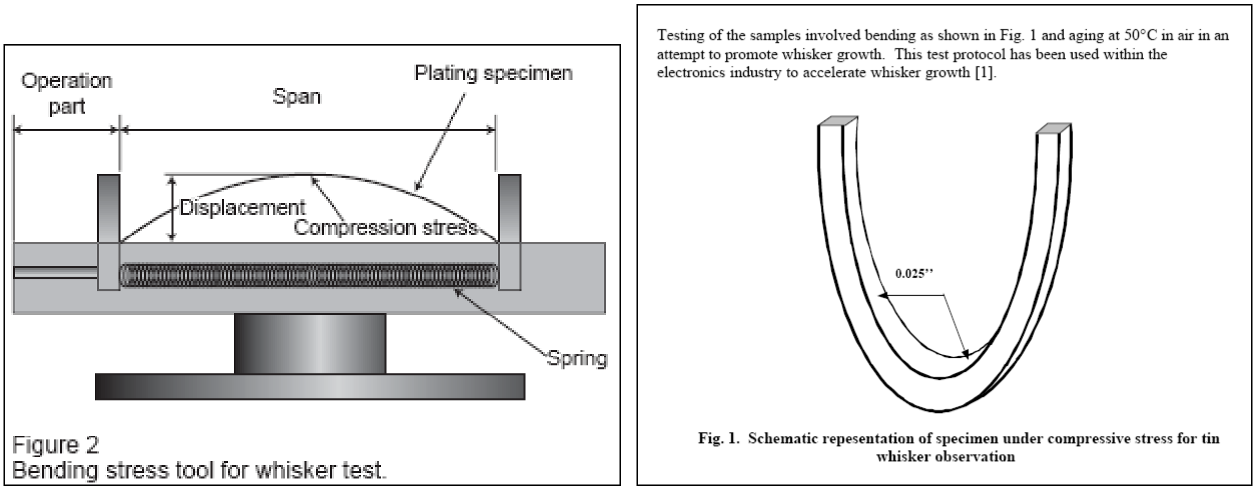


Figure 2
Bending stress tool for whisker test.

Testing of the samples involved bending as shown in Fig. 1 and aging at 50°C in air in an attempt to promote whisker growth. This test protocol has been used within the electronics industry to accelerate whisker growth [1].

Fig. 1. Schematic repesentation of specimen under compressive stress for tin whisker observation

Figure 11: Test configuration for Sakuyama (left) and Elmgren (right)

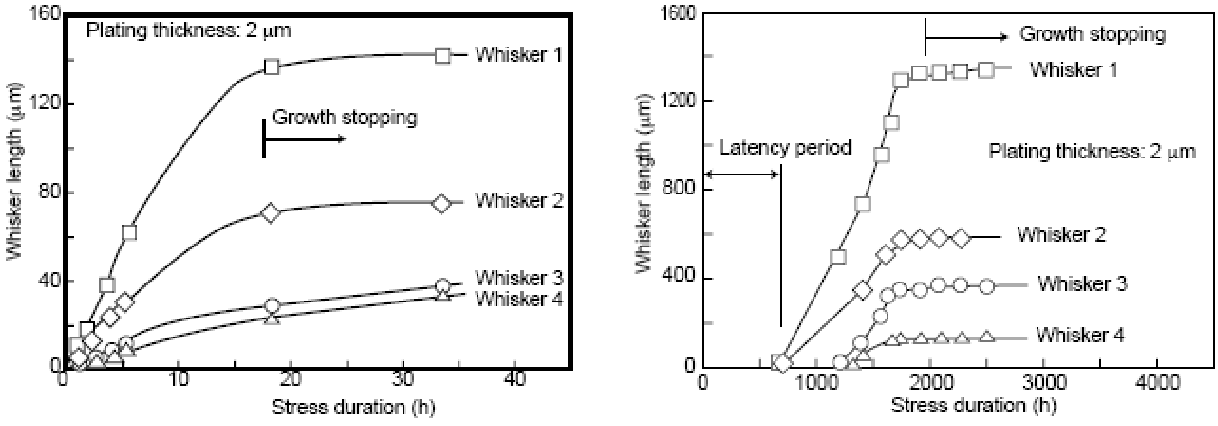
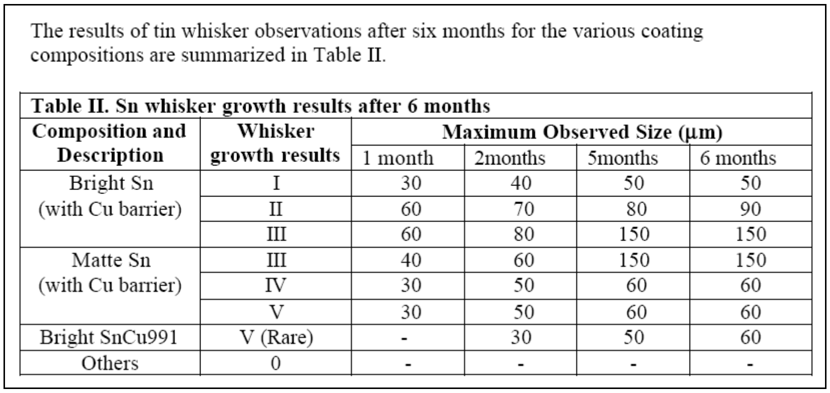


Figure 3
Whisker growth on stressed Sn-Cu plating at 25°C.

Figure 4
Whisker growth on stressed Sn plating at 25°C.



The results of tin whisker observations after six months for the various coating compositions are summarized in Table II.

Table II. Sn whisker growth results after 6 months

Composition and Description	**Whisker growth results**	**Maximum Observed Size (µm)**			
		1 month	2months	5months	6 months
Bright Sn (with Cu barrier)	I	30	40	50	50
	II	60	70	80	90
	III	60	80	150	150
Matte Sn (with Cu barrier)	III	40	60	150	150
	IV	30	50	60	60
	V	30	50	60	60
Bright SnCu991	V (Rare)	-	30	50	60
Others	0	-	-	-	-

Figure 12: Whisker growth results from Sakuyama (top) and Elmgren (bottom)

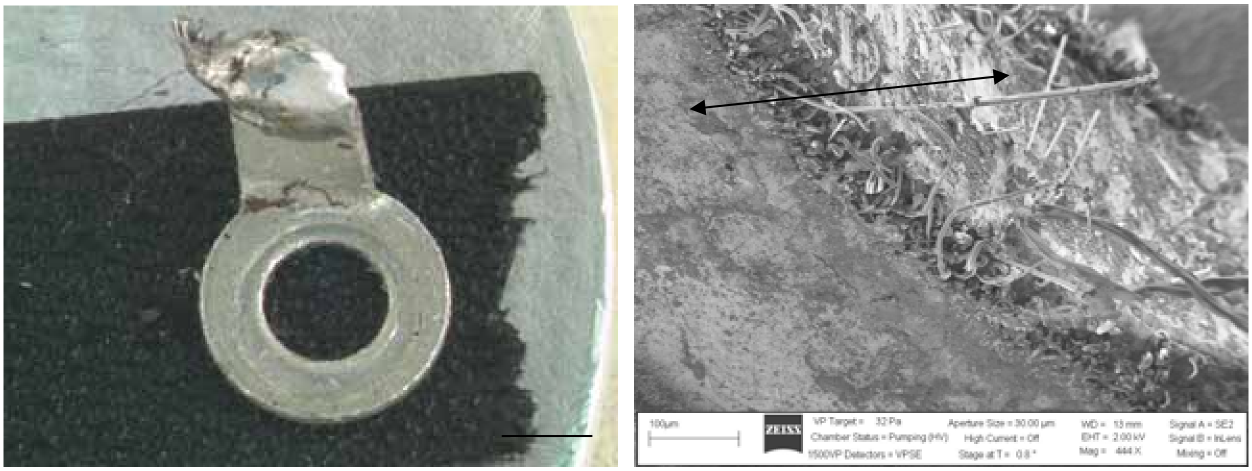


Figure 13: Photo documentation of whisker growth on tin-plated solder terminals stored for twenty years. Maximum whisker length is approximately 18 mils (450 microns)

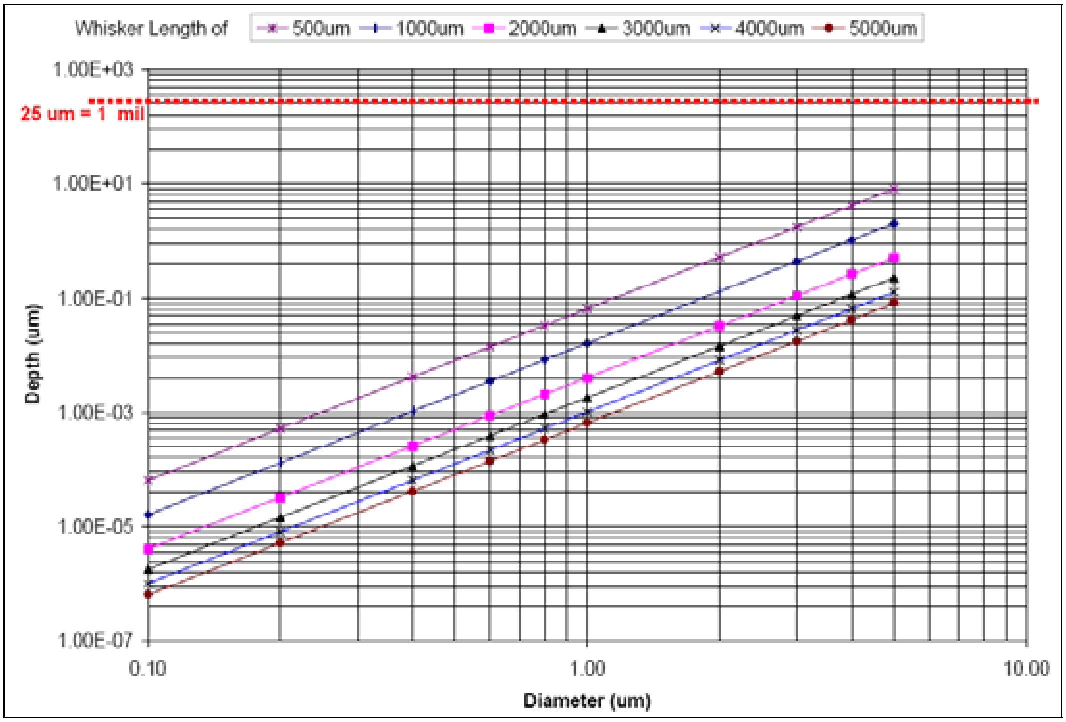


Figure 14: Penetration depth of a tin whisker as a function of diameter and length

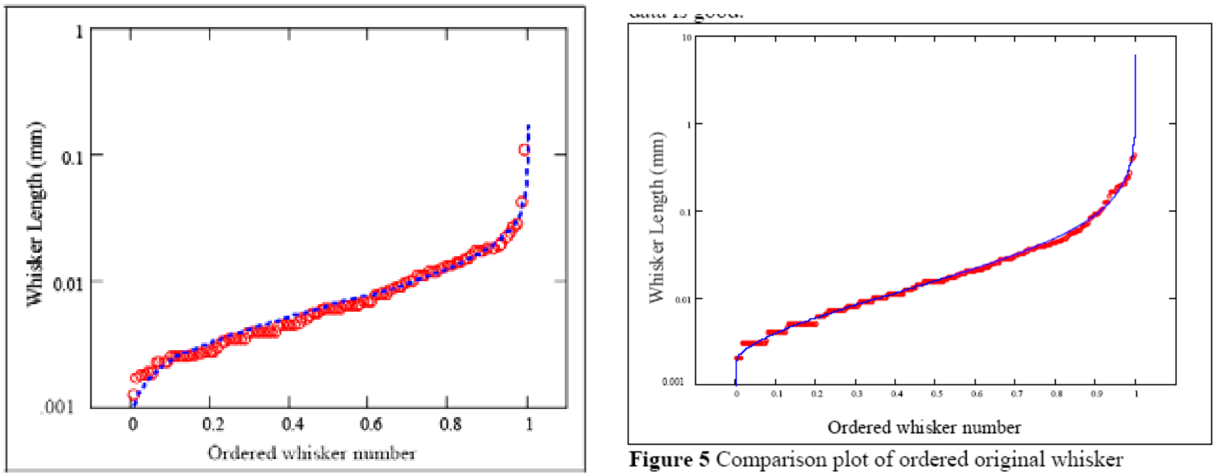


Figure 4 Comparison plot of ordered original whisker length data (circles) and S_B simulated data (dashed line) for the whisker mitigated, low whisker density plating.

Figure 5 Comparison plot of ordered original whisker length data (squares) and S_U simulated data (dashed line) for the non-whisker mitigated, high whisker density plating.

Figure 15: Distribution behavior of whisker length for mitigated (left) and unmitigated (right) tin plating

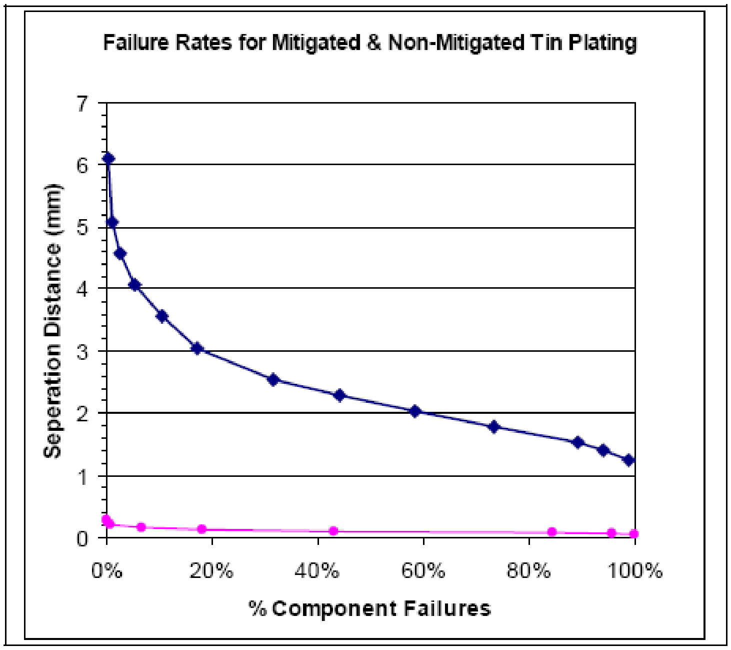


Figure 7. Simulated component failure rate as a function of terminal separation distance for a non-whisker mitigated tin plated component (blue line) versus whisker mitigated tin (pink line).

Figure 16: Probability of failure as a function of separation distance

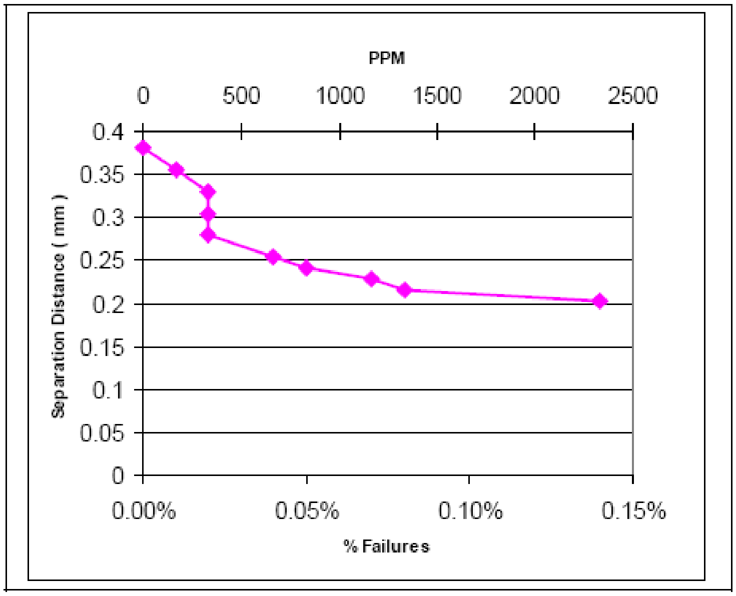


Figure 9. Simulated failure rate chart for whisker mitigated tin showing greater resolution at low defect levels. A separation distance of about 380 µm is required to get to 0ppm failure rates.

Figure 17: Probability of failure as a function of separation distance (mitigated tin)

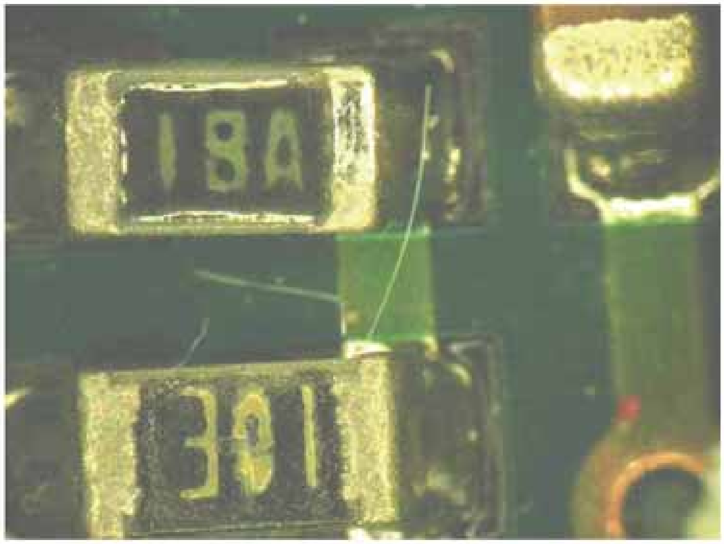
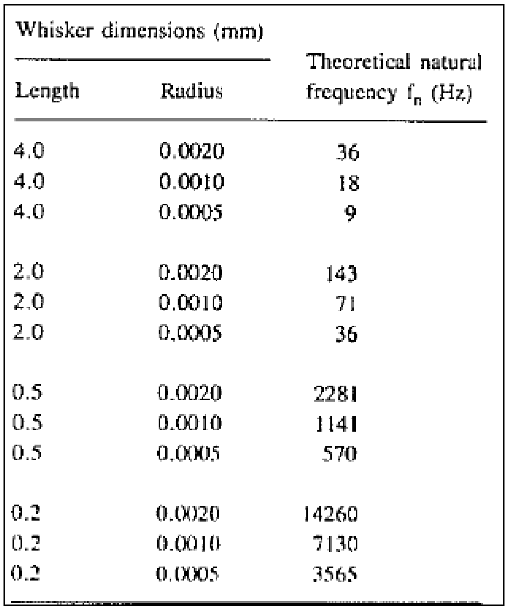


Figure 18: Observation of tin whisker debris as reported to NASA from Sanmina-SCI



Whisker dimensions (mm)		Theoretical natural frequency f_n (Hz)
Length	Radius	
4.0	0.0020	36
4.0	0.0010	18
4.0	0.0005	9
2.0	0.0020	143
2.0	0.0010	71
2.0	0.0005	36
0.5	0.0020	2281
0.5	0.0010	1141
0.5	0.0005	570
0.2	0.0020	14260
0.2	0.0010	7130
0.2	0.0005	3565

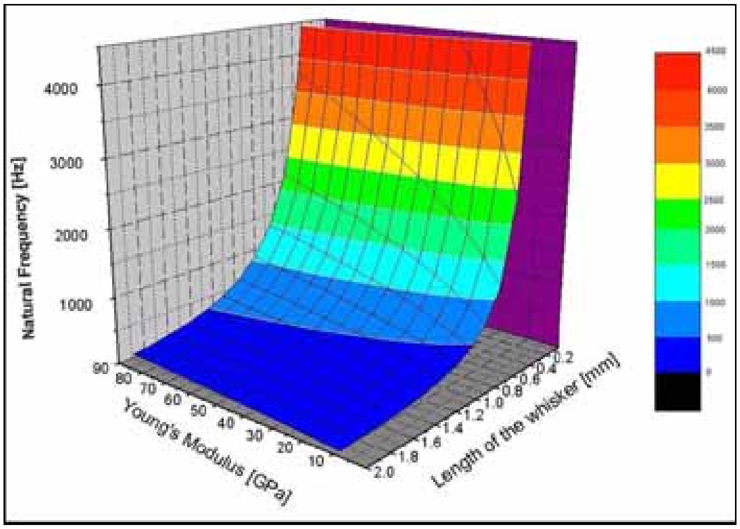


Figure 19: Natural frequencies of tin whiskers calculated by Dunn (left) and Hashemzadeh (right). The formula for natural frequency is $f = \frac{1.88^2}{8\pi\sqrt{\rho}} \frac{\sqrt{Ed}}{L^2}$, where E is modulus, L is length, d is diameter and is density.

Table 4: Parameters of mechanical testing performed on tin whiskers

References		Ando	Dunn	Hashemzadeh
Resonance Sweep	Type	Sinusoidal	Sinusoidal	Random
	Frequency (Hz)	10 – 2000	10 – 2000	10 – 4500
	Maximum Acceleration	20 G	20 G	3.5 Grms
	Duration	N/A	N/A	5 minutes
Extended Duration	Type		Sinusoidal	Random
	Frequency (Hz)		50, 100, 200, 250	10 - 2000
	Maximum Acceleration		6 G	18 Grms
	Duration		60 sec / frequency	22 hours
Mechanical Shock	Maximum Acceleration	3000 G	2000 G	500 G 1000 G
	Pulse Width (ms)	0.3	1	6
	Events	18	50	100

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