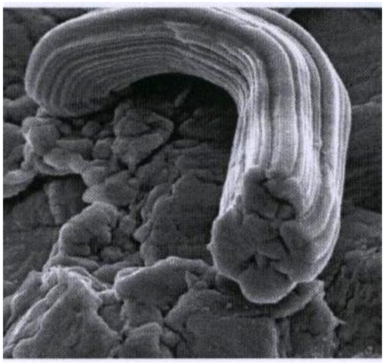
Tin Whisker Formation Test Report

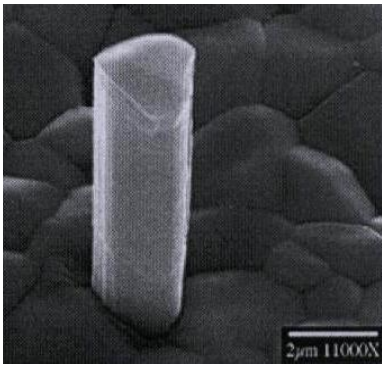
1.0 Background

1.1 Tin Whiskers

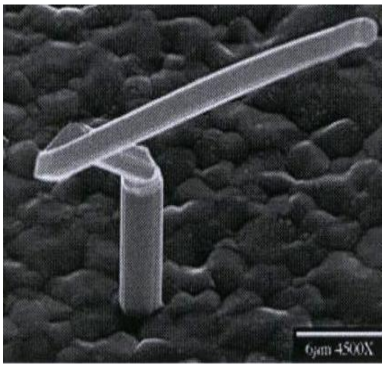
Unalloyed tin (Sn) plating has a long history of whisker formation and growth that has resulted in reliability problems for various types of electronic equipment. Tin whiskers are essentially filaments or fibre-like single crystals of tin which spontaneously grow from a tin surface during storage or use. This process can take anything from a few seconds to several years. As illustrated in Figure 1.1, there are several classified types of whisker. Filament whiskers are needle-like in as much as the length is at least ten times the diameter. Column and spiral whiskers are quite self explanatory. Nodule whiskers are normally defined by their diameter and are often referred to as mounds or hillocks.



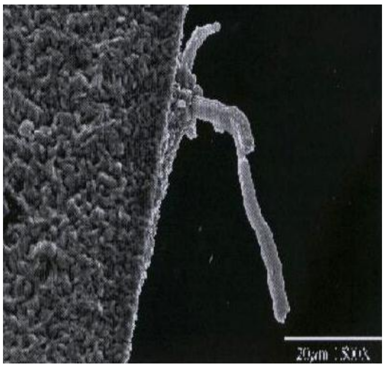
(a) Filament whisker with striations



(b) Column whisker with a consistent cross section



(c) Spiral whisker



(d) Spiral whisker growing from a nodule

Figure 1.1 – Examples of tin whisker appearance [1]

The key reason why tin whiskers are problematic in the electronics industry is evidenced by the list of failures caused by whisker growth. The growth of tin whiskers has resulted in failures in many critical and non critical systems ranging from space and military applications through to failures in medical, industrial and computer applications. In essence it is safe to say that any electrical or electronic application which utilises tin or tin alloys has the potential for tin whisker growth which could, in turn lead to failure.

1.2 Tin Whisker Mitigation

Despite many years of global study, there is presently no definitive explanation as to how or why tin whiskers form. One of the more prevalent theories is that they are the result of stress relief within tin plating, or perhaps form as a result of re-crystallisation and abnormal grain growth within the tin grain structure. It is sufficient to say that until the mechanisms behind the growth of tin whiskers are properly understood prevention remains difficult.

Historically the predominant whisker mitigation strategy has been the addition of lead (Pb) to the tin plating. However recent RoHS legislation that has eliminated the use of lead in most electronic products sold in the European Union has led electronic components manufacturers, including Welwyn Components, to propose the removal of lead from tin-lead (SnPb) plating, leaving essentially pure tin. This approach is the most convenient and least costly lead elimination strategy for the majority of component manufacturers. However, for the high-reliability user, the pure tin presents reliability risks due to the whisker forming tendencies of pure tin and tin alloy plating, which can electrically short across component terminals or break off the component and degrade the performance of electrical or mechanical parts, as shown in Figure 1.2.

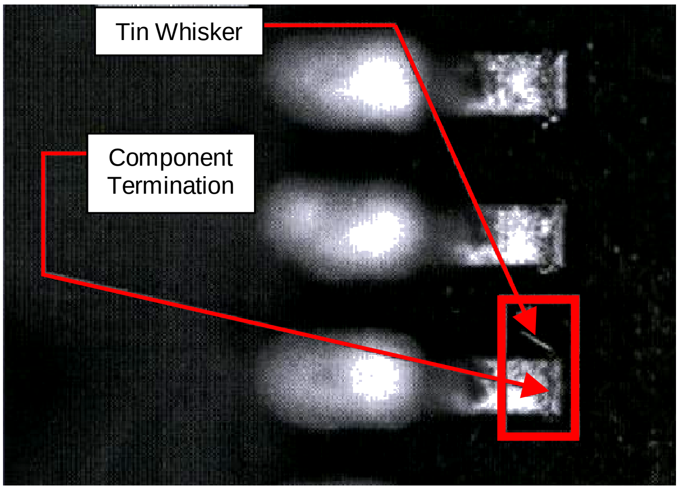


Figure 1.2 – Example of a tin whisker growing from a component termination [1]

There is however a great deal of new information in the public domain on tin whisker formation and strategies for migrating to lead free surface finishes. Moreover the number of accepted methods of mitigation to reduce the risks of whisker growth is constantly growing. Some of the more recognised whisker reduction methods include [2]:

- Adding a nickel (Ni) underlay between the tin plating and a copper (Cu) base metal mitigates whisker formation. The underlying plating may alleviate the compressive stress in the tin film, which is thought to be one of the driving forces for tin whisker growth.
- Adding a silver (Ag) underlay between tin plating and copper base metal has been proposed as a method to mitigate whisker formation, similar to Ni as above.
- Hot dip tin is a molten bath process often used for electronic component terminations, which is considered to be whisker free.
- Hot dipping with tin-silver-copper (SnAgCu) is generally an effective mitigation practice.

- Matte tin is a tin film with lower internal stresses and larger grain sizes than so called bright tin and is therefore less prone to whisker formation. Matte and bright tin finishes are defined by the following:

Parameter	Matte Sn	Bright Sn
Carbon Content	0.005%-0.050%	0.2%-1.0%
Grain Size	1µm-5µm	0.5µm-0.8µm

- When added to tin in amounts of 2-4% by weight, bismuth (Bi) may aid in suppressing whisker growth. With lead free solder, SnBi is a viable candidate for component finishes. With Eutectic tin lead solder, it is necessary to control the bismuth content of the finish between 3-5% so as to have enough bismuth to suppress whisker formation without getting into the compositional range of the ternary eutectic. In addition, keeping the bismuth content low is required to retain solderability of formed leads.

In practice the most common lead free finishes adopted by industry are matte tin on nickel underlay, hot dipped tin and SnAgCu alloy

2.0 Experimental

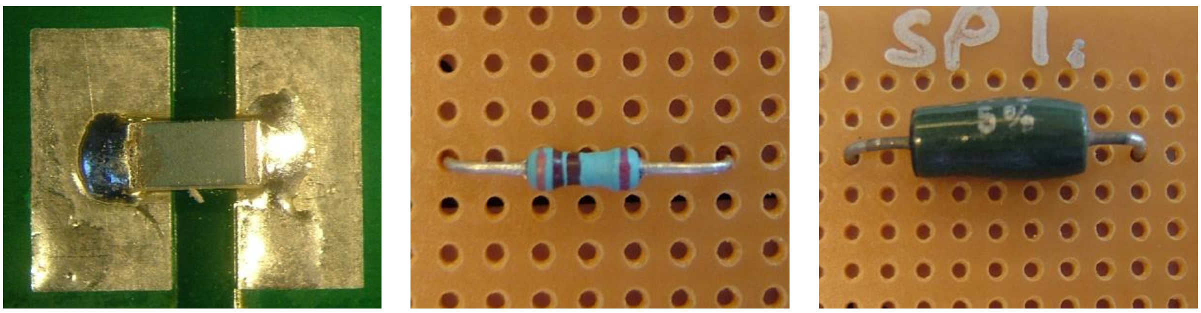
2.1 Test Sample Preparation

Welwyn Components manufacture an extensive range of resistive components. However there are effectively only three main termination materials used in the production of these parts as detailed in Figure 2.1.1.

Termination Finish	**Under Layer**	**Base Metal**	**Products Used On**
Matte Sn plating	Ni plating	Dipped Ag	SMD resistors
Hot dipped Sn	None	Cu wire	Epoxy/cement coated resistors
Hot dipped SnAgCu	Ni plating	Cu clad Steel wire	Vitreous enamel coated resistors

Figure 2.1.1 – Main termination materials used at Welwyn Components

Samples manufactured with each of the above terminations were taken as being representative of a production batch and were then soldered on to circuit boards ready for testing as shown in Figure 2.1.2.



(a) Matte Sn plating (b) Hot dip Sn (C) Hot dip SnAgCu

2.1.2 – Sample mounting for testing

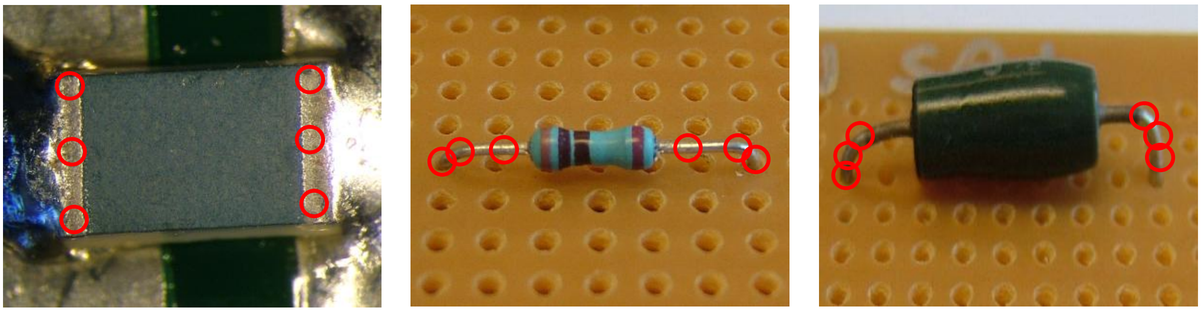
2.2 Testing and Inspection Method

The following tests were conducted in accordance with JEDEC Standards; JEDEC JESD22A121 [1] and JEDEC 201 [3], see Figure 2.2.1.

Test Type	Test Conditions	Interim Inspection	Total Duration
Temperature Cycling	-40 to +85°C, air to air; 30min soak; ~1 cycle/hr	75 cycles	6000 cycles
Ambient Temperature/ Humidity Storage	50 ± 2°C and 60 ± 3% RH	4000 hours	12000 hours
High Temperature/ Humidity Storage	60 ± 2°C and 93 ± 3% RH	4000 hours	12000 hours

Figure 2.2.1 – Testing procedures

Analysis of the terminations took place at the interim inspection interval and after completion of the tests. The areas of inspection on each of the three terminations types are depicted in Figure 2.2.2.



(a) Matte Sn plating (b) Hot dip Sn (C) Hot dip SnAgCu

Figure 2.2.2 – Areas of inspection for the three termination types

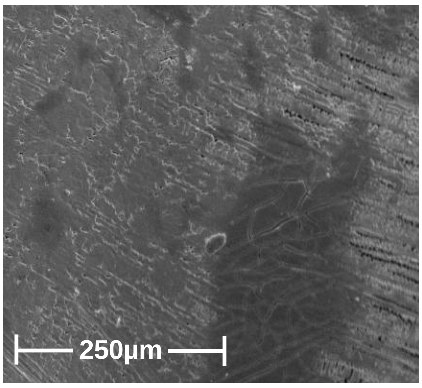
Inspection for tin whiskers was carried out using a scanning electron microscope (SEM). Firstly a screening inspection was conducted at a magnification of x250 followed by a detailed inspection at a magnification of x1000.

3.0 Results

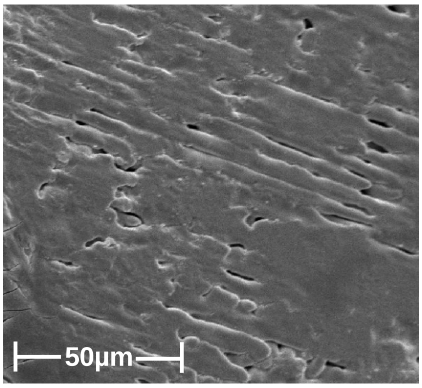
A summary of all results is presented in Figure 3.1 and detailed SEM images of examples from all tests are shown in Figures 3.2 (a) to (r).

Test Description	No. of Tin Whiskers of Length ≥ 5µm Found at Inspection						Maximum Permissible Whisker Length
	Matte Sn plate		Hot dip Sn		Hot dip SnAgCu		
	Interim	Final	Interim	Final	Interim	Final	
Temperature Cycling	0	0	0	0	0	0	45µm
Ambient Temperature/ Humidity Storage	0	0	0	0	0	0	40µm
High Temperature/ Humidity Storage	0	0	0	0	0	0	40µm

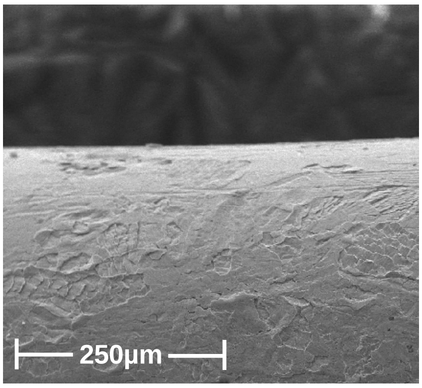
Figure 3.1 – Summary of test results (Note: minimum whisker length detectable at x1000 magnification ≈ 5µm)



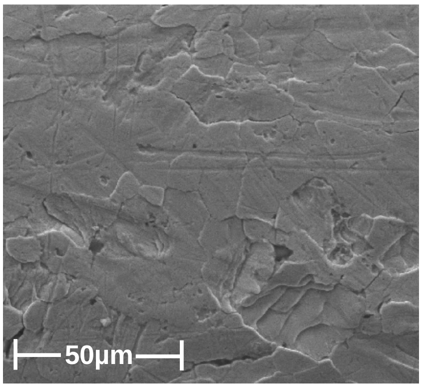
3.2 (a) – Temperature Cycling
Matte Sn Plating, x250



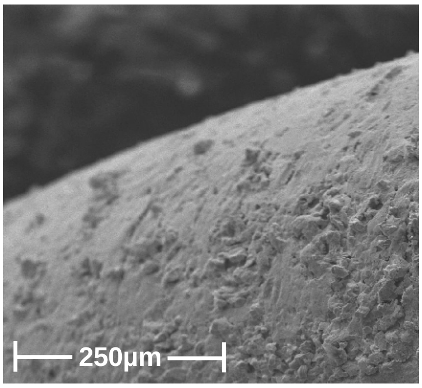
3.2 (b) – Temperature Cycling
Matte Sn Plating x1000



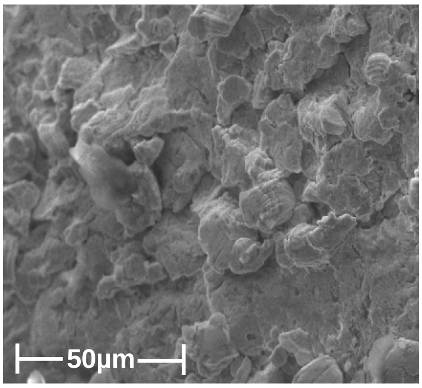
3.2 (c) – Temperature Cycling
Hot dipped Sn, x250



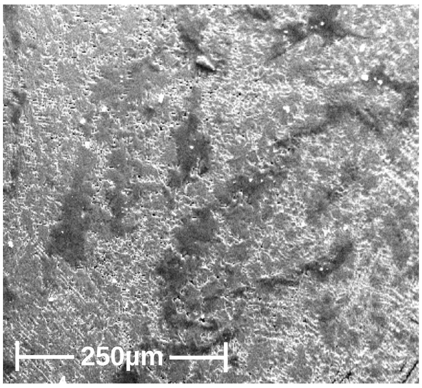
3.2 (d) – Temperature Cycling
Hot dipped Sn, x1000



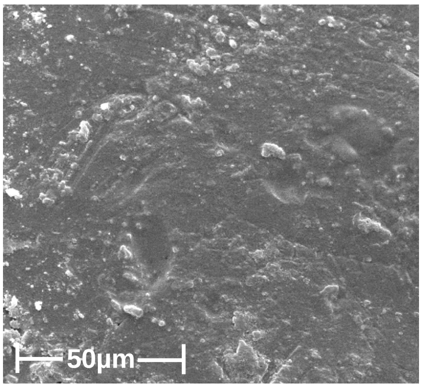
3.2 (e) – Temperature Cycling
Hot dipped SnAgCu, x250



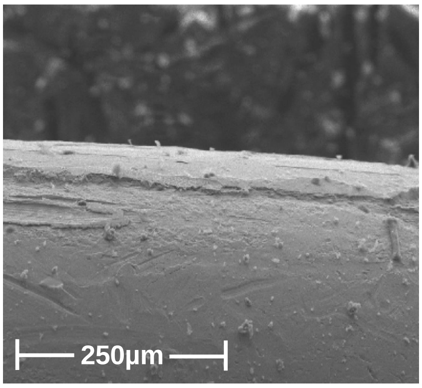
3.2 (f) – Temperature Cycling
Hot dipped SnAgCu, x1000



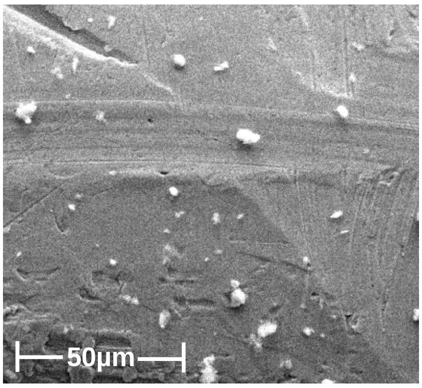
3.2 (g) – Ambient T/H Storage
Matte Sn Plating, x250



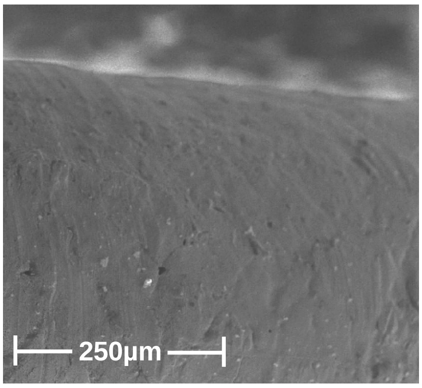
3.2 (h) – Ambient T/H Storage
Matte Sn Plating, x1000



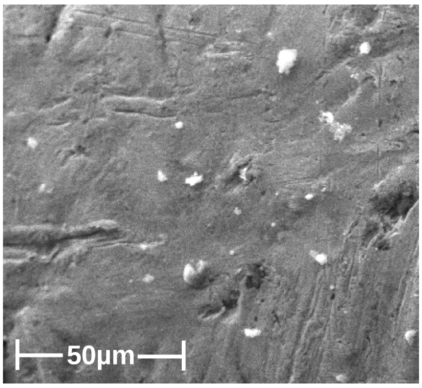
3.2 (i) – Ambient T/H Storage
Hot dipped Sn, x250



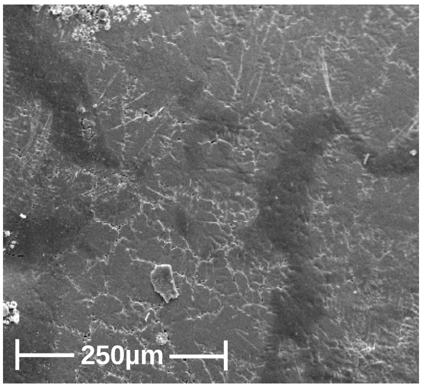
3.2 (j) – Ambient T/H Storage
Hot dipped Sn, x1000



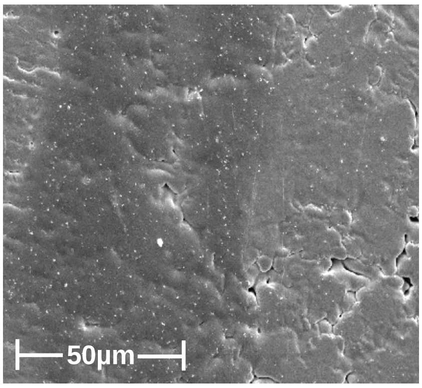
3.2 (k) – Ambient T/H Storage
Hot dipped SnAgCu, x250



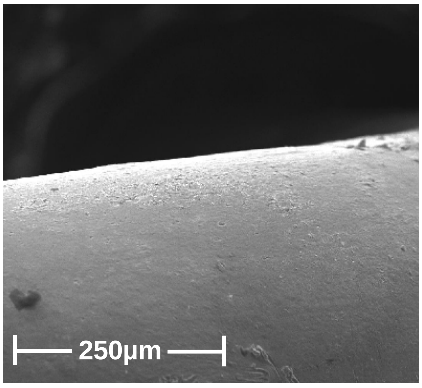
3.2 (l) – Ambient T/H Storage
Hot dipped SnAgCu, x1000



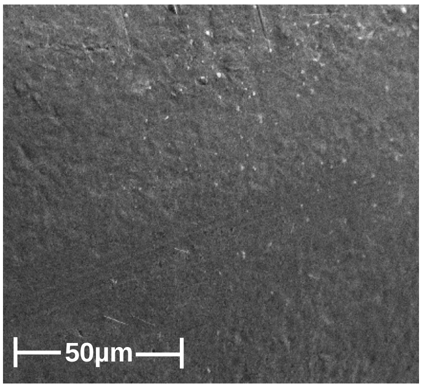
3.2 (m) – High T/H Storage
Matte Sn Plating, x250



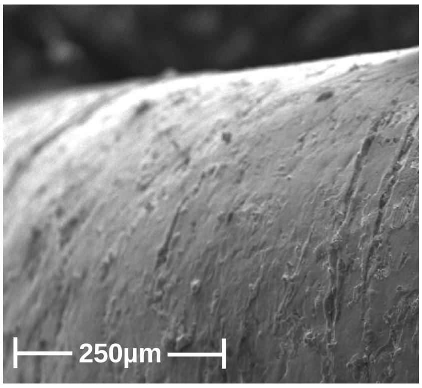
3.2 (n) – High T/H Storage
Matte Sn Plating, x1000



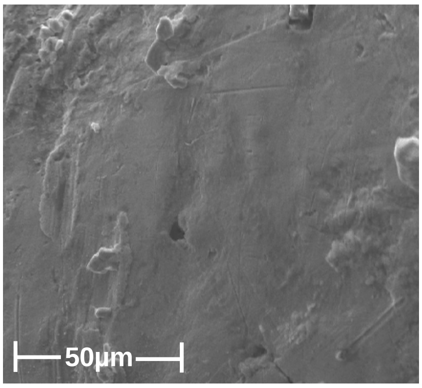
3.2 (o) – High T/H Storage
Hot dipped Sn, x250



3.2 (p) – High T/H Storage
Hot dipped Sn, x1000



3.2 (q) – High T/H Storage
Hot dipped SnAgCu, x250



3.2 (r) – High T/H Storage
Hot dipped SnAgCu, x1000

4.0 Discussion

As can be seen from the above results there was no evidence of tin whisker growth on any of the samples tested. This result is very encouraging and indicative of the success of the mitigation methods applied to Welwyn Components resistor products.

All three of the termination materials tested incorporates one or more of the mitigation methods discussed in Section 1.2; the two termination wire types are hot dipped, a technique which is considered to be whisker free. In addition a SnAgCu finish is applied to the steel core wire to further enhance this measure. The plating applied to the SMD components is matte tin with a nickel underlay, of which both materials are considered to be good mitigation measures.

The result is further supported by the extended test cycle durations undertaken. As can be seen from Figure 4.1 the actual total test durations are much greater than those recommended in JEDEC Standards.

Test Type	Total Test Duration	
	JEDEC	Actual
Temperature Cycling	1500 cycles	6000 cycles
Ambient Temperature/ Humidity Storage	4000 hours	12000 hours
High Temperature/ Humidity Storage	4000 hours	12000 hours

Figure 4.1 – Comparison on JEDEC Recommended and Welwyn Actual test durations

5.0 Conclusions

- No evidence of tin whiskers was found on any of the components tested.
- Mitigation methods used appear to be successful in preventing the growth of tin whiskers on all three termination materials used by Welwyn Components.

6.0 Recommendation

Although Welwyn Components testing to date has found no evidence of tin whiskers, it is a key recommendation that testing be performed using the latest international standards on any new termination finish or in the event of material or process changes.

7.0 References

1. JEDEC JESD22A121 Measuring Tin Whisker Growth on Tin and Tin Alloy Surface Finishes, May 2005

2. iNEMI Recommendations on Lead-Free Finishes for Components in High Reliability Products, Version 3, May 2005

3. JEDEC 201 (proposal) Environmental Acceptance Requirements for Tin Whisker Susceptibility of Tin and Tin Alloy Surface Finishes, September 2005

8.0 Bibliography

Galyon, George T (2004): A history of Tin Whiskers Theory: 1946 to 2004 New York

NASA, NASA Goddard Space Flight Center Tin Whisker (and Other Metal Whisker) Homepage

IEC, (March 2004) 91/443/NP: New Work Item Proposal: IEC 60068-2-82: Environmental testing – Part 2 – 82: Test – Test Tx: Whisker test methods for electronic and electric components.

IEC, (April 2005) 91/517/CD: Committee Draft: IEC 60068-2-82: Environmental testing – Part 2 – 82: Test – Test Tx: Whisker test methods for electronic and electric components.

M. Birkett – December 2006