iNEMI Recommendations on Lead Free Finishes for Components Used in High-Reliability Products

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Abstract
This document is intended to help manufacturers minimize the risk of failures from tin whiskers. It is the consensus of the iNEMI User Group that pure tin electroplating presents a risk in high-reliability applications, and that there are cost-effective alternatives available to minimize this risk. This paper presents recommendations for Lead Free finishes for a variety of applications and reflects the best judgment of the iNEMI User Group members, based on their own experiences and the available data. The group has defined methods and tests intended to minimize the risk of tin whiskers creating functional or reliability problems in electronic products. These recommendations include a combination of known mitigation practices, process controls and some level of testing. Recommendations have been organized to provide easy-to-follow guidance on the various Lead Free finish options. There are tables addressing every finish and base material offered commercially and provides user acceptance guidelines for the various combinations. Also included are finish recommendations for separable connectors and for buss bars and heat sinks.

Executive Summary
The iNEMI Tin Whisker User Group consists of eleven large manufacturers of high-reliability electronic assemblies. These companies, which annually purchase many millions of dollars of components, formed the User Group to develop recommendations for Lead Free surface finishes for high-reliability electronic applications. These recommendations are intended to minimize the risk of failures from tin whiskers. It is the consensus of the iNEMI User Group that pure tin electroplating presents a risk in high-reliability applications, and that there are cost-effective alternatives available to minimize this risk.

The lack of standards for tin whisker mitigation and acceptance testing is creating problems in the industry. (JEDEC JESD22A121 Measuring Whisker Growth on Tin and Tin Alloy Surface Finishes released in early 2005. At this writing JESD-201, Environmental Acceptance Requirements For Tin Whisker Susceptibility of Tin and Tin Alloy Surface Finishes, is in formal ballot with JEDEC). Suppliers have had no choice but to push forward with Lead Free solutions. However, end-user requirements for plating types, tin whisker mitigation practices and tin whisker qualification testing vary greatly. Suppliers are pushing for low-cost solutions, while high-end users are demanding high reliability. Communication and interaction among suppliers and users is critical to ultimately arrive at products that are acceptable to all.

This document updates the report originally published by the group in June of 2003 and last updated in March 2004. It presents recommendations for Lead Free finishes for a variety of applications and reflects the best judgment of the iNEMI User Group members, based on their own experiences and the available data. Twenty whisker mitigation guidelines have been used in developing these recommendations. The iNEMI Tin Whisker User Group has also issued a document "Tin Whisker Acceptance Test Requirements" (available on the iNEMI website at http://www.nemi.org/projects/ese/tin_whisker_activities.html) that has been adopted by many users and has also been submitted to JEDEC and IPC for formal standards creation (JESD-201 in work as of this writing). Note that neither this document, nor the Tin Whisker Acceptance Test Requirements document is intended to address mission critical applications such as aerospace. These guidelines are generally inadequate for those types of applications.

The goal of the User Group is to define methods and tests that minimize the probability of tin whiskers creating functional or reliability problems with our products. This result is achieved by a combination of known mitigation practices, process controls, and some level of testing. The tin whisker issue is a critical one for high-reliability products. Billions of components are used annually, but it takes only a single defect to create a problem.

Background Statement

Unalloyed tin electroplating has a long history of whisker formation and growth that has resulted in reliability problems for various types of electronic equipment[1]. The predominant whisker mitigation strategy for more than 50 years has been the addition of lead (Pb) to the tin plating. Legislation that will eliminate the use of lead in electronic products sold in the European Union (due to be implemented on July 1, 2006) has led many electronic component suppliers to propose the removal of Pb 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 community, the pure tin strategy presents reliability risks due to the whisker forming tendencies of pure tin and tin alloy plating.

This report lists viable Pb-free finish alternatives for various applications. The positions presented are based on the personal experiences of the members taken in conjunction with the available technical literature on tin whisker formation and growth. The User Group also recognizes the ongoing work on whisker formation and growth carried out under the auspices of several consortia, including the iNEMI Modeling Project, the iNEMI Tin Whisker Accelerated Test Project, and the University of Maryland's Computer Aided Life Cycle Engineering (CALCE) group (http://www.calce.umd.edu/Lead Free/tin-whiskers/). Particular acknowledgement is made to the NASA Goddard Space Center website (http://nepp.nasa.gov/whisker/), which lists considerable background information on tin whisker problems and research.

It is the position of the iNEMI User Group that there is no scientific consensus on whisker formation and growth fundamentals at this time. Nor is there a standard set of tests that can accelerate whisker formation and growth with any reasonable degree of certainty and correlate these directly to use environment and service conditions. Therefore, any claims for "whisker-free" tin-plating processes, or guaranteed lifetimes without a whisker failure, must be regarded with skepticism at this time.

General Guidelines for Migrating to Pb-Free Finishes

There is a great deal of new information in the public domain on tin whisker formation and strategies for migrating to lead free surface finishes[2]. It is advisable to be fully aware of the available data and alternatives before making any decision. Each firm needs to evaluate the alternatives in terms of reliability risk and cost benefits for the market application.

The user should be advised that whisker experimentation has been notoriously inconsistent relative to growth rates, incubation times, and many other parameters. Nevertheless, certain whisker mitigation guidelines have been supported by the iNEMI User Group. It is important for the reader to understand that the various mitigation practices and techniques discussed here are not always effective in reducing tin whiskers and should not be construed as whisker prevention methods, but rather as whisker risk reduction methods. Other material sets and combinations will be considered if they are provided along with strong technical arguments as to why they are efficacious in reduction of tin whiskers, and are backed up with tin whisker test data. The whisker test procedures used by the supplier shall also be specified.

1) Non-tin plating: Nickel-palladium-gold (or just plain nickel-palladium) should be strongly considered for lead-frame applications. This plating has more than a ten-year history (1992-2004+) of field application[3]. Early solderability issues have been resolved. In addition, NiPdAu is not prone to whisker growth in most environments (gold has been observed to grow whiskers in certain environments). The iNEMI User Group strongly recommends this plating for most lead-frame applications to retard whisker growth. However, users should be aware that molding compounds do not adhere as well to noble metals such as Pd and Au as they do to copper. As such, it may be more difficult for NiPdAu packages to achieve MSL 1 and 2 performance at the higher temperatures associated with SnAgCu Pb-free assembly. NiPdAu has also had corrosion in accelerated tests using high hydrocarbon and sulfur atmospheres. This corrosion has not been noted in actual field conditions.

2) Adding Pb to Sn plating mitigates whisker formation[4]. This strategy, however, will no longer be viable for most products after July 1, 2006 due to pending EU, California, and Chinese regulations.

3) Adding a nickel (Ni) underlay between tin plating and a copper (Cu) base metal mitigates whisker formation (this is a key User Group recommendation). The underlayer plating may alleviate the compressive stress in the tin film, which is thought to be one of the driving forces for tin whisker growth. The thickness, porosity and ductility of the nickel plating are also very important to ensure an effective barrier layer for the copper. It is important to ensure these parameters are met even after lead forming. Similarly, the control of the tin bath impurities, particularly copper, is important to make this underlayer effective[5,6,7].

4) 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 noted above. However, there is limited whisker test data supporting the

effectiveness of an Ag underlay for whisker mitigation[8]. The User Group acknowledges the potential for this mitigation practice to be effective, and encourages further investigation of this technique.

5) Silver finishes are not prone to whisker growth in most environments. However, rapid growth of silver whiskers or dendrites may form in the presence of H_2S (found in some cases where the environmental air pollution contains SO_2). Additionally, users sometimes avoid silver finishes due to potential issues with electromigration and solderability shelf life.

6) Fusing tin plating shortly after plating mitigates whisker formation[9,10]. Fusing is a reflowing operation usually done by dipping the tin-plated surfaces into a hot oil bath. Some User Group members recommend fused tin based on excellent field history. Fusing done as part of the printed circuit board (PCB) assembly process has not shown to be an effective mitigation practice and may in some cases increase the growth of whiskers[11,12].

7) Immersion tin is a chemical displacement process that results in a relatively thin (<40 micro-inches or 1µm) and stress-free tin film. Whiskers have been grown on immersion tin by iNEMI team members, but the whisker lengths are typically limited to <20 microns. For some applications, immersion tin is a suitable minimum risk selection that has been successfully used by some of the iNEMI User Group companies. Solderability shelf life considerations generally make this finish inappropriate for electronic components. It is, however, one of the Lead Free finish options for printed circuit boards[13].

8) Hot dip tin is a molten tin bath process that is not prevalent in lead-frame construction intended for electronic components, but it has been used for structural steel parts, connectors and devices such as relays. Hot dipping is considered to be whisker-free. There is evidence that this mitigation process may not be effective with pure tin[14]. Hot dipping with Sn4Ag or SnAgCu is generally an effective mitigation practice[15].

9) Annealing/heat treating (150°C for 1 hour) of matte tin-plated copper alloy lead-frames has shown promise as a tin whisker mitigation technique[16,17,18,19]. However, the data is still not at the level that the User Group is ready to provide blanket endorsement of this technique. The data provided today has not given consistent results. It may be accepted by users once more significant test data is compiled.

10) Matte tin is a tin film with lower internal stresses and larger grain sizes than so-called bright tin. Many current suppliers tout a proprietary version of this type of tin as whisker-free. The iNEMI User Group does not support these claims at this time. The claims are at best premature and should be considered with skepticism. This is also the position of the iNEMI Modeling Project. Matte tin films are less prone to whisker formation and growth than so-called bright tin films. For the purposes of this document, matte and bright tin finishes are defined by the following:

11) Parameter	**12) Matte Sn**	**13) Bright Sn**
14) Carbon Content	15) .005%-0.050%	16) 0.2%-1.0%
17) Grain Size	18) 1µm-5µm	19) 0.5µm-0.8µm

20) Tin-bismuth (SnBi) alloy finishes are controversial when used in conjunction with eutectic SnPb solder. When added to tin in amounts of 2-4% by weight, bismuth may aid in suppressing whisker growth[20,21,22]. There is a low melting point ternary eutectic formed between tin-lead-bismuth with a melting point at 96°C. However, it is not thermodynamically possible to form this ternary eutectic with small (1-5% by weight) additions of Bi to Sn finishes when soldered with SnPb. There is a ternary SnPbBi peritectic that is thermodynamically viable for small additions of Bi and this peritectic has a melting point of 135°C. With Lead Free solder, SnBi is a viable candidate for component finishes. With eutectic tin-lead solder, it will be 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 Bi content low is required to retain solderability of formed leads.

21) Plated SnAg (2-4% Ag) alloys in limited testing have shown promise in reducing tin whisker growth[22]. The User Group encourages further investigation of this finish as a possible tin whisker mitigation practice.

22) Industry data indicates that thicker tin finishes show a lower propensity for tin whiskers and/or a greater incubation time before tin whiskers occur[17,23] . The User Group recommends tin thickness for components without a nickel or silver under-layer be at least 10µm nominal or thicker (8µm minimum preferred). When a nickel or silver under-layer plating is used, the minimum tin thickness should be 2µm to ensure solderability shelf life. Components that use nickel under-plating should have a porosity-free nickel thickness of a minimum of 0.5µm. Components using silver under-plating should have a minimum silver thickness of 2µm.

23) The macro stress level of the tin deposit has an impact on tin whisker growth[24]. Tin deposits that have tensile stress as plated and remain tensile with aging are preferred. Tin deposits that are compressive during service life are not preferred.

24) In limited testing thus far, bias voltage (and/or current flow) has been shown to have an impact on tin whisker growth[25,26,27]. The extent and impact of bias is yet to be fully understood and, at this point, is an area of concern for the User Group members.

25) An acceptable plating for alloy 42 (Fe-42Ni) lead-frames has not been proven at this time. Some alternatives that show promise are low porosity NiPdAu and Sn(1-4%)Bi plating.

26) Since a full understanding of the tin whisker growth mechanism is still lacking, collecting data on the characteristics of tin plating is critical to help increase the knowledge level on parameters affecting tin whisker growth. JEDEC JESD22A121 Measuring Whisker Growth on Tin and Tin Alloy Surface Finishes defines data collection requirements for tin finishes. The User Group recommends data collection in accordance with that document.

27) Tin-copper alloys are not satisfactory finishes because copper enhances whisker formation and growth when included as an alloying element in tin plating[28].

28) Surface chemical etching prior to plating of copper-based alloys in limited testing has shown promise in reducing tin whisker growth when the etching depth is in the range of 3 to 4µm[29]. The User Group encourages further investigation of this technique as a possible tin whisker mitigation practice.

29) The use of conformal coating after assembly has shown some promise in reducing the rate of whisker growth. This appears to be specific to the material types used and the environment. Data does not support conformal coating to be a cure for whisker growth. However, it does add an insulation barrier that may prevent shorting should long whisker growth occur[30,31].

Electronic Component Lead and Terminal Finishes

Electronic component lead and terminal finishes refer to the solderable finishes applied to electronic components. These include lead-frames for ICs, leads for other solderable components, terminations for discrete components, and solderable finishes applied to plated covers on electronic components. Lead-frames are the metal tabs that electrically connect the chip die to the printed circuit board. The majority of current lead-frames are made of copper or a copper alloy. In addition, some lead-frames are still made of an iron-nickel alloy (e.g. alloy 42). Typically, the lead-frames are purchased without a finish (or plating) and processed at the manufacturing site into a package. Tin lead-frame plating is done after the molding operation. The predominant lead-frame finish today is a tin-lead alloy with typical nominal Pb content ranging from 7% to 37% Pb. About 10% of the lead-frame finishes are NiPdAu, which is purchased in a pre-plated form by the assembly manufacturer.

Table 1 (below) lists all the Lead Free finishes that the User Group has identified as offered or proposed finishes for electronic components. For each finish, which includes under-layer plating if applicable, and associated base material, the finishes are placed in one of three categories. This table is specific to tin whiskers and does not directly address other possible issues and concerns with these finishes. Category 1 indicates that the proposed solderable finish will be accepted by the User Group without any tin whisker testing. Category 2 indicates that the finish will only be accepted with acceptable tin whisker testing (see "Tin Whisker Acceptance Test Requirements" at http://www.nemi.org/projects/ese/tin_whisker_activities.html). A category 3 rating indicates that User Group members consider this finish a high risk for tin whiskers and will not accept it in any case, regardless of tin whisker test data provided. Since the user companies do not all have the same requirements, each listing is provided as a percentage of the companies that fit into each category.

Table 1 - Component Lead Free Finishes (Tin Whisker Test Requirements)

Solderable Finish	Base Material								
	Cu (7025, 194, etc)			Low Expansion Alloy (Alloy 42, Kovar)			Ceramic (such as resistors and capacitors) – no lead-frame		
	Cat 1 %	Cat 2 %	Cat 3 %	Cat 1 %	Cat 2 %	Cat 3 %	Cat 1 %	Cat 2 %	Cat 3 %
NiPdAu	100			100			100		
NiPd	100			100			100		
NiAu	100			100			100		
Matte Sn w/ Nickel underplate	9	91		NA			100% are 1 or 2 [1]		
Reflowed Sn	18	82		9	82	9	10	90	
Hot Dipped SnAgCu	55	45		50	50		56	44	
Matte Sn w/Silver underplate		100			100			100	
Hot Dipped SnAg	9	73	18	22	78		25	75	
Hot Dipped Sn	18	82		9	91		10	90	
Hot Dipped SnCu	9	73	18		82	18	10	70	20
SnAg (1.5-4%Ag)	10	90			100			100	
Matte Sn – 150C anneal	10	90		10	70	20		50	50
Matte SnCu – 150C anneal		73	27		46	64		50	50
SnBi (2-4% Bi)[2]	9	64	27		73	27		70	30
Matte Sn		36	64[4]		60	40[4]		44	66[4]
Semi-Matte Sn		36	64[4]		55	45[4]		45	55[4]
SnCu		27	73[4]		18	82[4]		20	80[4]
Bright Tin w/Nickel underplate	9	36	55	9	36	55	9	36	55
Bright Tin		9	91[4]		9	91[4]		9	91[4]
Ag (over Ni)[3]	100			100			100		
AgPd (over Ni)[3]	100			100			100		
Ag [3]	100			NA			100		

Category 1: No tin whisker testing required
Category 2: Finish must pass tin whisker testing
Category 3: Do not accept this finish in any case

Color Coding for Table 1:

- (green) Preferred finishes
- (light blue) Finishes with preferred tin whisker mitigation practices
- (yellow) Finishes with tin mitigation practices that are less desirable than preferred practices
- (orange) Finishes without tin whisker mitigation that are often not acceptable to users
- (red) Finishes to avoid

Notes for Table 1:

1) In general, tin whisker testing is required. However, users have defined a specific category of discrete ceramic components that are exempt from the tin whisker test requirements (see "Tin Whisker Acceptance Test Requirements" at http://www.nemi.org/projects/ese/tin_whisker_activities.html).
2) A number of users have restrictions on the use of SnBi finishes that are independent of tin whisker concerns.
3) In general, although whiskers on Ag and AgPd finishes are not considered an issue, the User Group is very hesitant to accept these finishes due to a number of concerns including, but not necessarily limited to, electromigration and solderability shelf life.

4) A small number of users may accept these finishes for devices with lead spacing greater than 1mm.

5) The iNEMI User Group specifically advises potential users to realize that component finishes are not always melted into the solder during an assembly operation. Some part of the component lead-frame may remain non-wetted after a solder assembly operation. This is an important fact that users must take into account. A non-wetted (or as-plated) film is susceptible to whisker formation and growth due to the built-in stress state. It is true that whisker formation is inhibited if the finish is completely absorbed or reflowed into the solder; however, complete absorption or reflow of the finish should not be relied upon. In some cases, reflow of the finish during assembly may make the propensity for tin whisker growth worse.[11,12]

Separable Connectors

A separable connector is defined as a make/break connector with a separable interface for interconnection and, typically, a second interface with a more permanent connection, such as a crimp to a wire or a solder joint to a PCB. Separable connectors include compliant pin connectors, bolt-on connectors, PCB connectors and cable connectors, for example. Separable connectors usually have a nickel underlay beneath a film of gold, tin-lead, or pure tin.

Many connectors use tin as a solderable finish and use a precious metal in the separable interface. If the tin plating is completely wet during the soldering process, the likelihood for whiskering after soldering is greatly reduced. Thus, some companies may have different acceptance criteria for tin used only in the solderable interface.

Compliant pins (or press-fit pins) utilize a contact design where a portion of the contact is mechanically inserted into a plated through hole (PTH) of a printed circuit board. The Technical Adaptation Committee for RoHS in the European Union has made a recommendation to make compliant pin technologies exempt from the Lead Free requirements of the RoHS Directive. This exemption looks like it will eventually be approved, but the exemptions are to be reviewed every four years and, thus, may eventually be eliminated.

Compliant pins typically utilize a tin-lead plating to achieve reasonable insertion forces. Members of the User Group have performed testing on Lead Free compliant pins and shown that the insertion forces and retention forces increase when the Pb is removed from the finish. This increase in insertion force is acceptable in most applications. The increase is most strongly linked to the switch from bright tin-lead coatings to matte tin coatings. Bright tin coatings have demonstrated insertion forces that are statistically equivalent or lower than bright tin-lead; however, bright tin is considered more susceptible to whisker growth.

Whisker growth can be accelerated by the high stresses exerted on terminal finishes used on bolted connectors. Bolted connectors are typically annular rings (ring lugs) that are bolted down onto a base metal, often with a Belleville washer assembly to maintain a high torque level over time. Many of these products have used pure tin finish for decades and many of them have generated tin whiskers. Each application must be analyzed relative to possible exposure to sensitive electrical circuitry. For example, bolted connections in the air stream leading to electrical circuitry could be considered a sensitive location. Whisker forming materials should not be used in sensitive locations.

Table 2 (below) summarizes the iNEMI User Group's ratings for connector finishes relative to concerns about whisker formation and growth. The first column tabulates acceptance of finishes for solderable terminations. The second column tabulates the use of surface finishes in a region of the product where the terminal finish is in the stressed separable interface and the connector spacing is fine. We define "fine spacing" as contacts with a spacing less than or equal to 0.5mm. The third column tabulates the use of surface finishes in a region of the product where the terminal finish is in the stressed separable interface and the connector spacing is large. We define "large spacing " as contacts with spacing greater than 0.5mm.

Table 2 - iNEMI Ratings for Whisker Risk on Termination Finishes for Separable Connectors

Finish	Termination finish use only as a solderable finish	Terminal finish use as a separable interface for fine spacing applications	Terminal finish use as a separable interface for large spacing applications
NiAu	1	1	1
NiPd	1	1	1
NiPdAu	1	1	1
Ag (over Ni)*	1	1	1
Hot Dipped SnAgCu	1	1	1
Reflowed Sn	1	2	2
Hot Dipped Sn	1	2	2
Hot Dipped SnCu	1	2	2
Matte Sn w/ Nickel underplate	2	2	2
Matte Sn w/Silver underplate	2	2	2
Matte Sn – 150C anneal	2	2	2
Matte SnBi (2-4% Bi) w/Nickel underplate	2	2	2
Matte SnAg (1.5-4%Ag) w/Nickel underplate	2	2	2
SnCu w/Nickel underplate	2	2	2
Bright Tin w/Nickel underplate	2	2	2
Matte SnBi (2-4% Bi)	2	2	2
Matte SnAg (1.5-4%Ag)	2	2	2
Matte Sn (no underplate)	3	3	2
Bright Tin	3	3	3
SnCu	3	3	3

1) No tin whisker testing required
2) Finish must pass tin whisker testing
3) Do not accept in any case

Color Coding for Table 2:

- Preferred finishes
- Finishes with preferred tin whisker mitigation practices
- Finishes with tin mitigation practices that are less desirable than preferred practices
- Finishes without tin whisker mitigation that are often not acceptable to users
- Finishes to avoid

Note for Table 2:
In general, although whiskers on Ag finishes are not considered an issue, the User Group is very hesitant to accept these finishes due to a number of concerns including, but not necessarily limited to, electromigration and solderability shelf life.

Bus Bars

Bus bars are typically copper or copper alloy. Aluminum may also be used in some applications. These parts are of particular interest because they are usually in close proximity to electrical circuitry. Whiskers on these assemblies can cause problems if they dislodge and short electrical circuitry. It is, therefore, prudent to avoid using plating material that is susceptible to whisker formation and growth. If possible, it is advisable NOT to plate bus bars when the application allows. In non-corrosive environments, the base copper metallurgy will tarnish slightly over time, but the basic function of the piece will be unaffected. Localized plating to enhance solderability or contact resistance should utilize platings other than tin when possible, or utilize tin whisker mitigation practices. Table 3 summarizes the recommendations of the iNEMI User Group.

Table 3 - Bus Bars – Tin Whisker Concerns

Finishes	Solderable (Yes/No)	Base Materials	
		Copper Alloys	**Aluminum**
None (unfinished)	No	OK	OK
Nickel	No	OK	Over Copper Strike Plating OK
Chromium(3)	No	OK	Over Copper Strike Plating OK
SnAgCu Solder Dip	Yes	OK	Over Copper Strike Plating OK
Silver(1) (Immersion or Electroplate)	Yes	OK	Over Copper Strike Plating OK
Matte Sn(2)	Yes	Not Recommended(2)	Over Copper Strike Plating, Not Recommended (2)

Notes for Table 3:

1) Silver (Ag) plating, while frequently used for bus bars, is susceptible to corrosion in sulfurous environments or dendritic growth in the presence of moisture.
2) When utilized on bus bars as a finish, tin whiskers are a concern for this finish, particularly when bus bar connections result in mechanical stresses on the finish. As such, the iNEMI Tin Whisker User Group recommends that this finish not be used for bus bars. If Sn finishes are used, a tin whisker mitigation practice is recommended. This finish has been used on bus bars in many products for years, so the application may still be acceptable even with tin whiskers. It is up to the user to make the final decision as to acceptance of this finish.
3) Chromium finishes should not contain CrVI (Hexavalent Chrome).

Heat Sinks

Heat sinks are commonly aluminum (including anodized aluminum), copper, or graphite. Graphite heat sinks are generally unfinished and tin whiskers are not a concern with graphite. Copper heat sinks generally require a finish, and may require solderability on some portion of the finish. Similarly, if aluminum heat sinks require soldering, they are typically selectively plated or solder dipped to provide a solderable surface. Lead Free plating finishes that utilize Sn are a concern for tin whisker growth as the use of heat sinks is typically associated with electronic components. Tin-based Lead Free finishes should not be used when the heat sink finish is subjected to mechanical mounting stresses. Table 4 summarizes the recommendations of the iNEMI Tin Whisker User Group relative to heat sinks.

Table 4 - Heat Sink Finishes and Tin Whiskers

Surface Finish	Solderable Surfaces (Yes/No)	Heat Sink Base Material		
		Aluminum	Copper	Graphite
None (or anodized for Aluminum)	No	OK	OK	OK
Nickel	No	NA	OK	NA
SnAgCu	Yes	OK (Over Cu Strike)	OK	NA
Matte Sn over Nickel	Yes	(Over Cu Strike) Tin Whisker Testing Required (1)	Tin Whisker Testing Required (1)	NA
Matte Sn	Yes	(Over Cu Strike) Not Recommended(1)(2)	Not Recommended (1)(2)	NA

Notes for Table 4:

1) Tin whisker testing required per "Tin Whisker Acceptance Test Requirements" (see http://www.nemi.org/projects/ese/tin_whisker_activities.html.)
2) This finish is generally not recommended due to tin whisker concerns. However, it may be acceptable if one of the preferred mitigation practices is used (see Table 1). Also, if the matte Sn surface is fully wetted by solder during assembly, the finish is generally acceptable.

Printed Circuit Boards (PCBs)

The surface finish on PCB lands (made of copper) are designed to protect the base metal against oxidation that could result in poor solder joints during the assembly operations. HASL (hot air solder leveled) tin-lead finishes have been the coating of choice for most of the last fifty years. To comply with legislation, alternative Pb-free surface finishes must be considered. These finishes include OSPs, immersion gold over electroless nickel, electroplated gold over electroplated nickel, Pb-free HASL, immersion silver, and immersion tin. Of these surface finishes, immersion tin is susceptible to the formation of pure tin whiskers and immersion silver is susceptible to the formation of silver sulfide dendrites. Both tin whiskers and silver sulfide dendrites can create electrical shorts; however, the formation mechanisms and the required environmental conditions are different. There have been no reported instances of tin whiskers on SnCu HASL finished PCBs. However, it should be noted that the use of SnCu HASL as a board finish has been very limited. For all of these finishes, individual processes vary tremendously relative to film quality, corrosion resistance, shelf life, etc., and the user should work closely with the process provider to evaluate each particular process. Aside from whisker and dendrite growth, other aspects of the surface finishes will affect selection, including cost, shelf life, solderability, manufacturability, corrosion resistance, and technical limitations with certain assembly processes, component types, and board designs.

Table 5 summarizes the assessments of the individual members of the iNEMI Users Group relative to the above PCB finish processes.

Table 5 - Printed Circuit Boards

PCB Finish	Tin Whisker Test Requirements?
SnCu HASL	Yes
Immersion Sn	Limited
Electroless NI/Immersion Au	None
Electroplated NI/Electroplated Au	None
Immersion Ag	None
OSP (e.g. Entek)	None

Future Work

The iNEMI User Group meets regularly to consider implications of new data on tin whiskers. A proposed user acceptance requirements document has been submitted to IPC and JEDEC, and the User Group is working with these groups to create a formal industry standard for tin whisker acceptance (JESD-201 – in ballot as of this writing). Changes and revisions to this position statement will be made as new data that warrants changes becomes available.

iNEMI Contacts

Parties interested in participating in iNEMI activities should contact Ronald W. Gedney (703-834-0330 or rgedney@AOL.com) for information. There are currently three ongoing iNEMI project teams focused on tin whisker issues:

a. Tin Whisker Modeling Project - Chairman: Dr. George T. Galyon, IBM Corp.
b. Tin Whisker Accelerated Test Project - Chairman: Dr. Heidi Reynolds, Sun Microsystems.
c. User Group - Chairman: Joe Smetana, Alcatel

In addition to the project on whisker fundamentals and testing, there are also ongoing iNEMI initiatives dealing with Lead Free assembly operations and materials.

Note:
This is Version 3 (Updated May 2005) of this document – Minor updates and referenced were added October 2005 to reflect changes in the industry since this was first released on the iNEMI website.

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