PD IEC/TS 62647-2:2012

BSI Standards Publication

Process management for avionics — Aerospace and defence electronic systems containing lead-free solder

Part 2: Mitigation of deleterious effects of tin

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National foreword

This Published Document is the UK implementation of IEC/TS 62647-2:2012.

The UK participation in its preparation was entrusted to Technical Committee GEL/107, Process management for avionics.

A list of organizations represented on this committee can be obtained on request to its secretary.

Published by BSI Standards Limited 2013

ISBN 978 0 580 68760 0

ICS 03.100.50; 31.020; 49.060

This Published Document was published under the authority of the Standards Policy and Strategy Committee on 31 January 2013.

Amendments issued since publication

Amd. No.	Date	Text affected

PD IEC/TS 62647-2:2012

IEC/TS 62647-2

Edition 1.0 2012-11

TECHNICAL SPECIFICATION

colour
inside

Process management for avionics – Aerospace and defence electronic systems containing lead-free solder –
Part 2: Mitigation of deleterious effects of tin

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

PRICE CODE **XB**

ICS 03.100.50; 31.020; 49.060

ISBN 978-2-83220-519-8

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

PROCESS MANAGEMENT FOR AVIONICS – AEROSPACE AND DEFENCE ELECTRONIC SYSTEMS CONTAINING LEAD-FREE SOLDER –

Part 2: Mitigation of deleterious effects of tin

FOREWORD

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- the subject is still under technical development or where, for any other reason, there is the future but no immediate possibility of an agreement on an International Standard.

Technical specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC/TS 62647-2, which is a technical specification, has been prepared by IEC technical committee 107: Process management for avionics.

The text of this technical specification is based on the following documents: IEC/PAS 62647-2 and GEIA-STD-0005-2 Revision A.

This technical specification cancels and replaces IEC/PAS 62647-2.

A list of all the parts in the IEC 62647 series, published under the general title *Process management for avionics – Aerospace and defence electronic systems containing lead-free solder*, can be found on the IEC website.

The text of this technical specification is based on the following documents:

Enquiry draft	Report on voting
107/160/DTS	107/193/RVC

Full information on the voting for the approval of this technical specification can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- transformed into an International standard,
- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

Due to a variety of real and potential health issues, many constituent materials used in the production of electronic products have come under scrutiny. The European Union (EU) has enacted two directives: 2002/95/EC Restriction of Hazardous Substances (RoHS) and 2002/96/EC Waste Electrical and Electronic Equipment (WEEE) that restrict or eliminate the use of various substances in a variety of products produced after July 2006. One of the key materials restricted is lead (Pb), which is widely used in electronic solder and electronic piece part terminations, and printed wiring boards. While these regulations may appear to only affect products for sale in the EU, due to the reduced market share of the aerospace, defence, and high performance industry in electronics, many of the lower tier suppliers are changing their products because their primary market is world-wide consumer electronics. Additionally, several Asian countries and United States (U.S.) states have enacted similar “green” laws. Many Asian electronics manufacturers have recently announced completely “green” product lines.

The restriction of Pb use has generated a transition by many piece part and board suppliers from tin-lead (SnPb) surface finishes to pure tin or other Pb-free finishes. Lead-free tin finishes can be susceptible to the spontaneous growth of crystal structures known as “tin whiskers” which can cause electrical failures, ranging from parametric deviations to catastrophic short circuits, and may interfere with sensitive optical surfaces or the movement of micro-electro mechanical systems (MEMS) for example. Though studied and reported for decades, the mechanism behind their growth is not well understood, and tin whiskers remain a potential reliability hazard. Furthermore, the growing number of piece parts with pure tin finishes means there are more opportunities for whiskers to grow and to produce failures.

It is important to state that that the nature and meaning of ‘risk’ posed by tin whiskers may vary considerably across the range of users of this Specification. As in any assessment of risk, the probability of occurrence and failure and consequence of occurrence and failure should be considered in each application. Potential whisker failure modes for a particular hardware/system application must be carefully considered when making the choice/determination of which control level(s) to apply. For example, whisker-prone leaded parts on circuit card used in a system that is under frequent/continual power may only incur parametric deviations or interrupts as individual whiskers grow and short to an adjacent lead. On the other hand, the same circuit card, employed in a missile subject to years of dormant storage, could grow many long whiskers into potentially catastrophic shorting conditions but the shorts will not occur until the missile is launched toward its target and results in mission failure. For the purposes of this Specification, risk refers to the chance and consequence of a failure due to a whisker, not just the chance of the presence of a whisker.

PROCESS MANAGEMENT FOR AVIONICS – AEROSPACE AND DEFENCE ELECTRONIC SYSTEMS CONTAINING LEAD-FREE SOLDER –

Part 2: Mitigation of deleterious effects of tin

1 Scope

This Technical Specification establishes processes for documenting the mitigating steps taken to reduce the harmful effects of Pb-free tin in electronic systems.

This Technical Specification is applicable to aerospace, defence, and high performance (ADHP) electronic applications which procure equipment that may contain Pb-free tin finishes.

This document may be used by other high-performance and high-reliability industries, at their discretion.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC/TS 62647-1:2012, *Process management for avionics – Aerospace and defence electronic systems containing lead-free solder – Part 1: Preparation for a lead-free control plan*[1]

IEC/PAS 62647-3, *Process management for avionics – Aerospace and defence electronic systems containing lead-free solder – Part 3: Performance testing for systems containing lead-free solder and finishes*[2]

IEC/PAS 62647-21, *Process management for avionics – Aerospace and defence electronic systems containing lead-free solder – Part 21: Program management – Systems engineering guidelines for managing the transition to lead-free electronics*[3]

IEC/PAS 62647-22, *Process management for avionics – Aerospace and defence electronic systems containing lead-free solder – Part 22: Technical guidelines*[4]

ANSI/GEIA-STD-0006, *Requirements for using solder dip to replace the finish on electronic piece parts*

ANSI Z1.4, *Sampling procedures and tables for inspection by attributes*

IPC J-STD-001, *Requirements for soldered electrical and electronic assemblies*

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[1] Previously known as GEIA-STD-0005-1.

[2] Previously known as GEIA-STD-0005-3. IEC/PAS 62647-3 is in the process of being revised and will be issued as IEC/TS 62647-3.

[3] Previously known as GEIA-HB-0005-1. IEC/PAS 62647-21 is in the process of being revised and will be issued as IEC/TS 62647-21.

[4] Previously known as GEIA-HB-0005-2. IEC/PAS 62647-22 is in the process of being revised and will be issued as IEC/TS 62647-22.

IPC-CC-830, *Qualification and performance of electrical insulating compounds for printed wiring assemblies*

JESD201, *Environmental acceptance requirements for tin whisker susceptibility of tin and tin alloy surface finishes*

JESD213, *Standard test method utilizing X-ray fluorescence (XRF) for analyzing component finishes and solder alloys to determine Tin (Sn) – Lead (Pb) content*

MIL-STD-1580, *Destructive physical analysis for electronic, electromagnetic, and electromechanical parts*

3 Terms, definitions and abbreviations

For the purposes of this document, the following terms, definitions and abbreviations apply.

3.1 Terms and definitions

3.1.1
assemblies
electronic items that require electrical attachments, including soldering of wires or component terminations

EXAMPLE Circuit cards and wire harnesses.

[SOURCE: IEC/TS 62647-1:2012, 3.1]

3.1.2
critical
state of an item or function, which if defective, will result in the system's inability to retain operational capability, meet primary objective, or affect safety

[SOURCE: IEC/TS 62647-1:2012, 3.2]

3.1.3
control level
amount of attention that should be paid to the risk of tin whiskers (i.e., no restrictions on tin use, some restrictions on tin use, and prohibition of tin use)

3.1.4
conformal coat
insulating protective covering that conforms to the configuration of the objects coated (e.g., printed boards, printed board assembly) providing a protective barrier against deleterious effects from environmental conditions

3.1.5
COTS
commercial-off-the-shelf
item whose design and configuration is controlled by the manufacturer and on which the user has no control with regard to the design and configuration

Note 1 to entry: An item may be a component, a sub-assembly, an assembly, a system.

3.1.6
COTS assemblies or sub-assembly
assembly or sub-assembly developed by a supplier for multiple customers, whose design and configuration is managed by the suppliers or an industry specification

[SOURCE: IEC/TS 62647-1:2012, 3.4]

3.1.7
customer
entity or organization that (a) integrates a piece part, soldered assembly, unit, or system into a higher control level system, (b) operates the higher control level system, or (c) certifies the system for use

EXAMPLE This may include end item users, integrators, regulatory agencies, operators, original equipment manufacturers (OEMs), and subcontractors.

[SOURCE: IEC/TS 62647-1:2012, 3.5]

3.1.8
EDS
energy dispersive (X-ray) spectroscopy
method for material composition analysis

3.1.9
encapsulation
process which involves the surrounding of (a) component(s) or an assembly with a liquid resin

3.1.10
gap
minimum line of sight distance between tin surface and the nearest adjacent conductor at a different potential.

Note 1 to entry: It refers to any conductors (leads, pads, connectors, contacts, or others).

3.1.11
high voltage
voltage level required to cause a plasma event

3.1.12
high performance
continued performance or performance on demand where an application (product, equipment, electronics, system, program) down time cannot be tolerated in an end-use environment which can be uncommonly harsh, and the application must function when required

EXAMPLE: Examples of high performance applications are life support or other critical systems.

[SOURCE: IEC/TS 62647-1:2012, 3.7]

3.1.13
lead-free
defined as less than 0,1 % by weight of lead in accordance with reduction of hazardous substances(RoHS) guidelines guidelines

[SOURCE: IEC/TS 62647-1:2012, 3.8]

3.1.14
mitigation
method to reduce the risk or consequence of a whisker failure over a period of several years.

Note 1 to entry: This does not imply that the risk is driven to zero, simply that the risk or consequence is reduced in some significant way.

3.1.15
Pb-free tin
pure tin or any tin alloy with $<$ 3 % lead (Pb) content by weight

Note 1 to entry: Some Pb-free finishes other than pure tin, such as tin-bismuth and tin-copper are considered to be “tin” for the purposes of this specification. Many of these alloys have not been assessed for whiskering behaviour.

[SOURCE: IEC/TS 62647-1:2012, 3.11]

3.1.16
Pb-free tin finish

final finishes or underplates either external or internal to a device, board or other hardware, including all leads and surfaces, even those coated, encapsulated, or otherwise not exposed

Note 1 to entry: It may include finishes on electrical piece parts, mechanical piece parts, and boards. It does not include Pb-free bulk solders, assembly materials, solder balls, or those devices where the Pb-free tin finish has been completely replaced (consistent with GEIA-STD-0006).

[SOURCE: IEC/TS 62647-1:2012, 3.12]

3.1.17
plasma event

destructive arcing event that can occur at altitudes from sea level to space depending on voltage and current levels

3.1.18
piece part
piece component

electronic component that is not normally disassembled without destruction and is normally attached to a printed wiring board to perform an electrical function

[SOURCE: IEC/TS 62647-1:2012, 3.14]

3.1.19
potting

encapsulation process which involves the surrounding of a component(s) or an assembly in a container with a liquid resin which is then cured in place

Note 1 to entry: The container usually becomes an integral part of the system such that the critical property that needs to be maintained is the interfacial adhesion between the cured resin system and the container substrate and critical components for an optimum long-lasting reliable package.

3.1.20
rework

action taken to return a unit (SRU/LRU/system) to a state meeting all requirements of the engineering drawing, including both functionality and physical configuration by making repairs

Note 1 to entry: Also used to define the act of reprocessing non-complying articles, through the use of original or equivalent processing in a manner that assures full compliance of the article with applicable drawings or specifications.

[SOURCE: IEC/TS 62647-1:2012, 3.16]

3.1.21
repair

act of restoring the functional capability of a defective article in a manner that precludes compliance of the article with applicable drawings or specifications

[SOURCE: IEC/TS 62647-1:2012, 3.17]

3.1.22
risk

probability of a failure due to a tin whisker

Note 1 to entry: It is not used with regards to the risk of the presence of a whisker or nodule.

3.1.23
sub-contractor
organization, within the given high-reliability industry, that supplies, maintains, repairs, or supports electronic systems, and is not the direct supplier to the customer or user of those systems

[SOURCE: IEC/TS 62647-1:2012, 3.22]

3.1.24
supplier
refers to an entity or organization that designs, manufactures, repairs, or maintains a piece part, unit, or system

Note 1 to entry: This includes original equipment manufacturers (OEMs), repair facilities, subcontractors, and piece part manufacturers.

[SOURCE: IEC/TS 62647-1:2012, 3.23]

3.1.25
system
one or more units that perform electrical function(s)

[SOURCE: IEC/TS 62647-1:2012, 3.24]

3.1.26
tin whisker
spontaneous crystal growth that emanates from a tin (Sn) surface and which may be cylindrical, kinked, or twisted

Note 1 to entry: Typically tin whiskers have an aspect ratio (length/width) greater than two, with shorter growths referred to as nodules or odd-shaped eruptions (OSEs).

[SOURCE: IEC/TS 62647-1:2012, 3.26]

3.1.27
unit
one or more assemblies within a chassis or higher level system to perform electrical function(s)

[SOURCE: IEC/TS 62647-1:2012, 3.27]

3.1.28
XRF
X-ray fluorescence
method for material composition analysis

3.2 Abbreviations

ADHP	Aerospace, defence and high performance
COTS	Commercial off the shelf
EDX	Energy-dispersive X-ray spectroscopy
FMEA	Failure mode effects analysis
FMECA	Failure mode effects and criticality analysis
FOD	Foreign object damage
IMC	Intermetallic compound
iNEMI	international Electronics Manufacturing Initiative

JEDEC	Joint Electron Device Engineering Council
MEMS	Micro-electro mechanical systems
OEM	Original equipment manufacturer
OSD	Odd-shaped eruptions
Pb	Lead
PLCC	Plastic leaded chip carrier
PQFP	Plastic quad flat pack
QFP	Quad flat pack
REE	Rare earth elements
SEM	Scanning electron microscope
Sn	Tin
Sn-Pb	Tin/lead
SOIC	Small outline integrated circuit
TQFP	Thin quad flat pack
TSOP	Thin small outline package
XRF	X-ray fluorescence

4 Technical requirement

This specification is intended for use by those procuring, designing, building or repairing electronic assemblies that will use items with Pb-free tin finishes to document processes they use to assure performance, reliability, airworthiness, safety, and bring credit of certification of those assemblies. It provides a framework to communicate and agree on the processes to be used to control and mitigate the use of Pb-free tin in these applications

This specification is intended to be used in concert with IEC/TS 62647-1, IEC/PAS 62647-21, and IEC/PAS 62647-22. This specification may be referenced in proposals, requests for proposals, work statements, contracts, and other documents. It may be used as a stand-alone specification or as part of compliance with IEC/TS 62647-1.

This specification addresses the risk of tin whiskers. However, the state of research into tin whisker risk still does not allow accurate quantitative estimates of the risk and reliability. It defines three baseline control levels that detail the amount of attention that should be paid to the risk of tin whiskers: no restrictions on tin use, some restrictions on tin use, and prohibition of tin use.

There are five informative annexes in this specification:

- Annex A provides guidance on selecting control levels and performing risk assessments;
- Annex B provides some background on various mitigation methods;
- Annex C provides guidelines for performing tin whisker inspections;
- Annex D provides some additional guidance on tin whisker risk analyses;
- Annex E provides information on whiskers growing from bulk solder and joints.

4.1 Control level requirements

4.1.1 General

The supplier shall clearly state the control levels and shall document agreement by the customer in appropriate requirement or lead-free control plan documents. Customers are responsible for determining the control level they are seeking and identify it in their request for proposal and contract when this specification is imposed.

Higher control levels impose tighter controls and thereby reduce exposure to tin whisker risk. However, tin whisker risks are just one of many types of risks associated with component selection and assembly design. Controls imposed on tin whiskers should be commensurate with controls imposed to manage these other risks. Each program or system has the responsibility of determining the appropriate control level for their product. This document is not intended to imply that any category of ADHP application is more or less reliable or critical than any other category nor is it intended to imply that any ADHP system will be more or less reliable, depending on the control level that is selected. Reliability is assured by a wide range of design, production, use, and support decisions and activities, of which tin whisker mitigation is only one. It is expected that, whatever control level of mitigation category is used, the system reliability will be assured by the totality of all the methods available to the producer and user of the system.

In particular, it is recommended that the selection of control level involves consideration of the following questions:

- What are the consequences of performance anomalies in your system?
- Do we antipate that the whiskers will produce a plasma event?
- Do local anomalies affect top-level system performance?
- Could a failure cause a critical failure or defeat redundancy?
- Are anomalies detectable and repairable?

More information on how these questions can be used to select an appropriate control level is provided in Annex A.

Overall, there are three approaches to tin whisker control:

- tin part avoidance;
- whisker risk mitigation;
- whisker risk acceptance.

Different control levels represent different emphasis on each of these approaches.

Control level 1:	Under control level 1 tin whisker risks are accepted. It is expected that this control level will primarily apply to developmental models, test equipment, and other units that will not be fielded.
Control level 2:	Under control level 2, Pb-free tin is sometimes acceptable. Tin whisker risk is managed primarily by a combination of design rules, mitigations, and avoidance. The sub-control level under control level 2 determines the emphasis given to each of these strategies. If only control level 2, with no sub-control level, is identified in a control document, the default level shall be assumed to be control level 2A.
Control level 2A:	Under level 2A, tin whisker risks are managed primarily through the acceptance of tin whisker risk, and to a lesser extent upon the use of design rules. This control level was designed primarily for lower criticality applications. Tin is permitted for use in all applications except where specially restricted.
Control level 2B:	Under control level 2B, tin whisker risks are managed primarily through the use of design rules, and to a lesser extent upon tin avoidance. This control level was primarily designed for non-critical boards or units or boards and units with good redundancy used in systems with moderate to high failure consequences.
Control level 2C:	Under control level 2C, tin whisker risks are managed primarily by tin avoidance, and in exceptional cases, by design rules. This control level was primarily designed for critical boards with limited redundancy used in systems with moderate to high failure consequences.

Control level 3: Tin whisker control is managed strictly by tin avoidance. This level was designed for units and boards where failures cannot be tolerated.

For units or boards that apply a mix of design rules and individual Pb-free tin evaluations, the unit or board shall be defined as control level 2B, with the rules defining the circumstances requiring control level 2C-like evaluations clearly called out. Applications falling within the control level 2C-like requirements shall be documented and mitigated per the requirements of control level 2C.

Control levels are expected to be applied at the unit or board control level, consistent with the overall risk strategy for that unit or board. However, an overall strategy for higher control levels of integration may be appropriate and is discussed in 4.1.2 below.

4.1.2 Control levels and levels of integration

Control levels were designed to be applied at the unit or board control level, but customers may want to have an approach to control levels and level selection at the subsystem, product, or system control level. Some approaches at higher control levels of integration and in system lead-free control plans:

- define the criteria that are to be used to evaluate unit control levels, preferably with some general statements about what control levels are expected on most units and boards;
- define control levels based on unit criticality, function, or some other design rule;
- define the system level control level based on the expected control level of most units and define when the program will require higher control levels. A discussion of this process for requiring higher or allowing lower control levels should be included.

4.1.3 COTS and level selection

The imposition of control levels 2C and higher will generally preclude the use of COTS assemblies and systems, unless directed or authorized by their customer. If COTS assemblies are used in a program or system that is defined as control level 2C or 3, they shall be identified and treated as exceptions or a comprehensive material control and analysis plan shall be implemented or the material and mitigations requirements will be flowed down to and accepted by the COTS supplier. In a control level 2B situation, the treatment of COTS shall be addressed in the list of families where Pb-free tin alloys will be used or the materials and mitigations requirements will be flowed down to and accepted by the COTS supplier.

COTS parts may be used under any level but need to be evaluated as any part or finish and meet the requirements of the control level. This will likely involve at least one of the following:

- working with the part supplier to understand the material and mitigating as necessary;
- managing material identification for any lot or subset of parts with known uniformity of finish and mitigating materials as necessary;
- treating all COTS material as Pb-free tin and performing mitigations on all as required.

4.1.4 Other level selection information

Annex A provides additional guidance on level selection.

Note that these levels are different than the IPC Product Classes described in IPC J-STD-001E-2010 (IEC 61191). In general, it is expected that most users of this specification are IPC Class 3 due to the types of final end applications their products support.

There will be cases where errors will be made in the finish determination or in the application of mitigation methods. Customers and suppliers should have processes in place to document and assess the impact of these errors. Already existing deviation or waiver processes may be acceptable if technical experts on tin whiskers are consulted.

4.2 Requirements for control levels

4.2.1 Control level 1 requirements

4.2.1.1 Control level 1 requirements for documentation of uses of Pb-free tin

There are no requirements. The supplier should provide general information regarding types of platings, finishes, and solder used and plans for process controls on those processes.

4.2.1.2 Control level 1 requirements for detecting and controlling Pb-free tin finish introduction

There are no requirements.

4.2.1.3 Control level 1 requirements for tin whisker risk mitigation

There are no requirements.

4.2.1.4 Control level 1 requirements for parts selection

There are no requirements.

4.2.1.5 Control level requirements for analysis and documentation of risk and mitigation effectiveness

There are no requirements.

4.2.2 Control level 2A requirements

4.2.2.1 Control level 2A requirements for documentation of uses of Pb-free tin

The supplier shall document the design rules that are in place for determining when Pb-free tin is not acceptable or when mitigations are required.

The customer is responsible for listing any applications where Pb-free tin is not allowed.

4.2.2.2 Control level 2A requirements for detecting and controlling Pb-free tin finish introduction

There are no requirements.

4.2.2.3 Control level 2A requirements for tin whisker risk mitigation

The plan should indicate any mitigation that is applied as part of the general process at the supplier.

The customer is responsible for defining any mitigation measures that are required.

4.2.2.4 Control level 2A requirements for parts selection

Unless the parts list or vendor list is provided by the customer, the supplier should have a part selection process that encourages the use of parts that have lower tin whisker risk, consistent with the requirements presented in 4.5.

4.2.2.5 Control level 2A requirements for analysis and documentation of risk and mitigation effectiveness

This analysis is expected regardless of whether mitigations are applied.

For control level 2A, these analyses may be performed at the process control level. For example, the analysis might address all devices with a particular mitigation technique employed.

4.2.2.6 Control level 2A exceptions

Specific piece parts, soldered assemblies, units, or applications may be required to meet a higher control level. These requirements shall be specified in contractual documents.

4.2.3 Control level 2B requirements

4.2.3.1 General

If the control level is defined at a system or assembly control level, this is the control level that will most likely be selected if the use of Pb-free tin will be dependent on function or criticality of elements of the assembly or system.

4.2.3.2 Control level 2B requirements for documentation of uses of Pb-free tin

For control level 2B hardware, the control plans may cover families of piece part types or applications or individual uses. Separate assessments and control plans for each individual item are NOT required for items within these classes. For example, one assessment might allow use of tin-plated capacitors in a variety of applications. For Pb-free tin items not within the classes, specific plans and assessment are required.

The supplier shall provide lists of families of tin-finished piece parts and/or location and material information for categories of applications where they would like to use Pb-free tin in accordance with 4.6. If there are other individual uses of tin, the supplier shall provide a list of additional specific applications of Pb-free tin that fall outside these families. If the supplier is unable to determine some materials, this shall be stated.

The customer is responsible for listing any applications where Pb-free tin is not allowed.

The definition of high voltage applications shall be documented. Pb-free tin usage in high voltage applications and their mitigations shall be documented separately and identified as high voltage.

4.2.3.3 Control level 2B requirements for detecting and controlling Pb-free tin finish introduction

The supplier should provide a plan for monitoring materials on a sample basis, including method of test and sampling scheme, in their product in accordance with 4.3.3.

4.2.3.4 Control level 2B requirements for tin whisker risk mitigation

Uses of Pb-free tin require mitigation. For non-high voltage applications, mitigation requirements shall be fulfilled by any one of the following:

- Hard potting or encapsulation
- Physical barriers
- Circuit design and analysis showing low impact of tin whisker short or FOD
- Circuit design and analysis showing that areas sensitive to tin whisker shorts or FOD have at least a 1 cm gap
- Conformal coating with validated coverage and gap size greater than 250 microns
- Pb-free tin electronic components with gaps greater than 2 000 microns that have been installed with SnPb and are physically isolated from any Pb-free tin mechanical piece parts

- SnPb soldering process with validated complete coverage
- Mitigation or combination of mitigations approved by the customer

Specific requirements for each mitigation listed above are presented in 4.4.

High voltage applications shall have a mitigation or a combination of mitigations approved by the customer or customer representative.

4.2.3.5 Control level 2B requirements for parts selection

Unless the parts list or vendor list is provided by the customer, the supplier shall have a part selection process that encourages the use of parts that have lower tin whisker risk. The parts selection process shall document what specific part control level characteristics are considered to be preferred. The process should describe how risks are weighed when deciding if part control level mitigations are applied or not. The documentation of the process shall be made available to the customer upon request.

Recommendations about characteristics of lower risk tin parts are presented in 4.5.

4.2.3.6 Control level 2B requirements for assessment and documentation of risk and mitigation effectiveness

The supplier shall provide an analysis addressing the risk of tin whiskers in accordance with 4.6, including rationale for the selection of control level 2B, unless the control level selection was dictated by the customer.

The supplier shall have documentation covering the following elements:

- Methods of controlling vendor use and introduction of Pb-free tin
- Mitigation measure(s) taken for each family of piece parts or applications of Pb-free tin finish in the product
- Tests or analyses performed for each family of piece parts or applications using Pb-free tin finishes, to determine risk of whisker growth in accordance with 4.6
- If there are other uses of Pb-free tin outside the families, the mitigation measures taken for each piece part or application of Pb-free tin finish in the product outside the families
- If there are other uses of Pb-free tin outside the families, the tests and analyses performed for each of these piece parts or applications to determine risk of whisker growth in accordance with 4.6
- Verification methods, including inspections and tests, that show their processes are under control
- Risk assessment and mitigation measures to the customer for their review, as requested or required by customer

This documentation shall be made available for review, as requested or required by the customer.

4.2.4 Control level 2C requirements

4.2.4.1 General

Applications of tin shall be reviewed and approved individually by an authorized customer representative in accordance with established design rules. Approval of exceptional cases can occur within the requirements of the plan. For example, instead of one assessment and mitigation plan covering all tin-plated capacitors, each capacitor type and application shall be reviewed and approved, even if the same strategy is applied to each situation.

4.2.4.2 Control level 2C requirements for documentation of uses of Pb-free tin

The supplier shall avoid use of Pb-free tin whenever possible. Individual uses of Pb-free tin shall be documented and mitigated and require approval by the customer or customer designee.

The definition of high voltage applications shall be documented.

The supplier shall provide a plan for passing the requirement to lower control level suppliers in accordance with 4.3.1.

4.2.4.3 Control level 2C requirements for detecting and controlling Pb-free tin finish introduction

The supplier shall provide a plan for monitoring materials in their product in accordance with 4.3.3. The supplier and customer shall reach an agreement regarding this plan.

For critical piece parts, assemblies or systems, the plan should include sampling at least one part per lot of all piece parts not approved for tin.

4.2.4.4 Control level 2C requirements for tin whisker risk mitigation

For non-high voltage applications, mitigation requirements shall be fulfilled by at least one of the following:

- Hard potting or encapsulation
- Physical barriers
- Circuit design and analysis showing low impact of tin whisker short or FOD
- SnPb soldering process with validated complete coverage
- Conformal coat with validated coverage and gap greater than 500 μm
- A combination of mitigations approved by the customer

Specific requirements for each mitigation listed above are presented in 4.4.

High voltage applications shall have a mitigation or a combination of mitigations approved by the customer or customer representative.

4.2.4.5 Control level 2C requirements for parts selection

Unless the parts list or vendor list is provided by the customer, the supplier shall have a part selection process that encourages the use of parts that have lower tin whisker risk. The parts selection process shall document what specific part control level characteristics are considered to be preferred. The process should describe how risks are weighed when deciding if part control level mitigations are applied or not. The documentation of the process shall be made available to the customer upon request.

Recommendations about characteristics of lower risk tin parts are presented in 4.5.

4.2.4.6 Control level 2C requirements for assessment and documentation of risk and mitigation effectiveness

The customer is responsible for describing the risk algorithm or other methods for evaluating mitigation measures in the request for proposal, if applicable. The customer is also responsible for communicating any documentation review or oversight requirements to the supplier.

The supplier shall have documentation covering the following elements:

- The mitigation measures taken for each piece part or application of Pb-free tin finish in the product.
- The tests and analyses performed for each piece part or application using Pb-free tin finishes, to determine the risk of whisker growth in accordance with 4.6.
- Provide the risk assessment and mitigation measures to the customers for their review, as requested or required by customers.

4.2.5 Control level 3 requirements

4.2.5.1 General

The supplier shall not allow use of Pb-free tin finish.

No Pb-free finishes may be designed into the product or knowingly purchased without a plan to replace the finish. Any uses of Pb-free tin are considered a deviation from the requirements and require deviation, waiver, or other non-conformance documentation.

4.2.5.2 Control level 3 requirements for documentation of uses of Pb-free tin

The supplier shall provide a plan for passing the requirement to lower control level suppliers as per 4.3.1.

Any use of Pb-free tin finish would represent a violation of requirements, which would require a waiver process based on program requirements, including risk management requirements.

4.2.5.3 Control level 3 requirements for detecting and controlling Pb-free tin finish introduction

The supplier shall monitor the material in their product as per 4.3.4.

4.2.5.4 Control level 3 requirements for mitigation of tin whisker risk and mitigation effectiveness

This is not applicable, as Pb-free tin finish is not allowed.

4.2.5.5 Control level 3 requirements for parts selection

This is not applicable, as Pb-free tin finish is not allowed.

4.2.5.6 Control level 3 requirements for assessment and documentation of risk and mitigation effectiveness

This is not applicable, as Pb-free tin finish is not allowed.

4.2.6 Requirements for mitigating tin whisker risk for solder joints

The majority of requirements in this specification apply to Pb-free tin finishes, not Pb-free solders. This is because the control level of understanding for tin whiskers growing from finishes is much higher than from solders. However, the data on the dangers of tin whiskers growing from Pb-free and SnPb solders when there are rare earth elements (REE) present is sufficient to consider these solders a risk.

For control level 2, use of Pb-free or SnPb solders with intentionally alloyed REE shall be disclosed to the customer and a risk assessment performed with regards to tin whiskers.

For control level 3, use of Pb-free or SnPb solder with intentionally alloyed REE shall be prohibited.

Additional information and recommendations for tin whisker inspection are presented in Annex C. Information and recommendations for preventing tin whiskers growing from Pb-free solder joints are presented in Annex E.

4.3 Implementation methods

4.3.1 Flowing requirements to lower level suppliers (applies to control level 2B, control level 2C, and control level 3)

Requirements for tin whisker control, analysis, and mitigation are applicable to all purchased and subcontracted elements and materials for the program. This may require flowing down these requirements to the lower level suppliers or performing extensive analysis of the purchased material. The supplier should be prepared to document how they addressed the risk from the purchased equipment if requested or required by the customer.

4.3.2 Detecting and controlling Pb-free tin finish introduction

The use of screens to monitor Pb-free tin finish depends in part on the lot uniformity requirements. Many standard lot definitions do not address finishes, only internal features. The sampling or lot monitoring plan should take the finish uniformity requirements into consideration.

4.3.3 Sample monitoring plans (applies to control level 2B and control level 2C)

A monitoring plan, including method of test and sampling scheme, should be documented for control level 2B and shall be documented for control level 2C.

For control level 2B, the monitoring plan and sampling scheme should focus on critical hardware where Pb-free tin is not allowed.

For critical hardware following control level 2C where approvals for use of Pb-free tin have not been obtained, the monitoring plan described in 4.3.4 should be used.

COTS parts may lack finish uniformity requirements, and thus may require higher sample sizes during material identification testing.

If X-ray fluorescence (XRF) spectroscopy is used for detection, the methods shall be consistent with JESD213. If energy dispersive (X-ray) spectroscopy (EDS) is used for detection, the methods shall be consistent with MIL-STD-1580:2010, notice 2, revision B. Other methods may be used with customer approval.

4.3.4 Lot monitoring requirements (applies to control level 3)

A lot screening program is required for all items with metallic finishes. Items containing metallic finishes shall be tested, at least one sample per lot or batch received, unless otherwise specified by the customer. A minimum of 3 % Pb by weight is required. The requirements for lot or batch uniformity should be documented to confirm that the monitoring plan is adequate. COTS parts may lack finish uniformity requirements, and thus may require higher sample sizes during material identification testing. If finish uniformity is not adequately addressed in lot or batch uniformity requirements, a sampling plan consistent with ANSI Z1.4 should be used.

If X-ray fluorescence (XRF) spectroscopy is used for detection, the methods shall be consistent with JESD213. If energy dispersive (X-ray) spectroscopy (EDS) is used for detection, the methods shall be consistent with MIL-STD-1580:2010, notice 2, revision B. Other methods may be used with customer approval.

The customer may allow an exception for monitoring if the material specification defines all finishes as gold with no Pb-free tin finishes and a visual inspection of the device shows it to be gold-coloured. This exception should be documented if used.

4.4 Methods for mitigating impact of Pb-free tin (applies to control level 2B, control level 2C)

4.4.1 General

Since the failure mechanisms for whisker growth are not fully understood, no single method is an assurance against whiskers in all applications, environments, and lifetimes. Mitigations, part selection and analyses are all aspects of a general tin whisker risk mitigation system.

The following subclauses define the requirements for specific mitigations listed as options in 4.2.3.4 and 4.2.4.4.

4.4.2 Hard potting and encapsulation

Potting and encapsulation can be a very effective means of reducing tin whisker risk, but the properties of the material shall be analyzed. For the purposes of this specification, there shall be a documented process for evaluating the effectiveness of the potting or encapsulation and for evaluating risks associated with the use of material in applications.

For potting or encapsulation to be effective it shall be hard over the application temperature range and remain hard over the product life. Attention should be paid to the types of fillers, in addition to the matrix material. The process of forming the potting or encapsulation should ensure that it is unlikely to have voids or bubbles that would reduce its effectiveness at encapsulating whiskers. Issues such as induced stress, thermal mismatch, and outgassing should also be reviewed as part of a general design and risk review before taking this mitigation approach.

4.4.3 Physical barriers

Placement of a physical barrier can prevent whiskers from growing from one conductive surface to another. For the purposes of the specification, barriers are walls, cases, shields or other hard material that whiskers will not penetrate and not applied as a coating to the part. While a barrier may prevent a whisker growing from one conductive surface to another, it cannot mitigate the risks associated with free-floating whiskers unless a combination of barriers fully encase the tin-finished area.

There shall be a documented process for reviewing the hardness of the barrier, examining the possibility and impact of whisker shorts within the enclosed area, and evaluating the risk and impact of free-floating whiskers escaping from the enclosed area.

4.4.4 Conformal and other coats

Unless there is compelling evidence that the coating fully encapsulates whiskers, the coating shall be applied to the Pb-free tin finished surfaces and all adjacent conductors, whether or not they are finished with Pb-free tin. If the coating can be demonstrated to fully encapsulate whiskers, it may be treated as hard potting and encapsulation, as described in 4.4.2.

Conformal coat is used in conjunction with spacing requirements in mitigations in order to make sure there is an adequate air gap for whiskers to buckle upon contacting conformal coats on adjacent surfaces. The specific spacing requirement is given in 4.2.3.4 or 4.2.4.4.

As a minimum, the conformal coat shall meet the applicable requirements of IPC-CC-830 and J-STD-001 for Class 3 hardware.

In addition, there shall be a process for evaluating the following aspects of the conformal coat:

a) likelihood of coating bridging between the conductive surfaces, eliminating the air gap that promotes whisker buckling;
b) ability of the conformal coat process to achieve adequate coverage and thickness on a particular assembly to provide tin whisker mitigation, including an assessment of thinning of the coating on corners, amount of coverage on back or undersides of leads or other complex geometries, and the likelihood of bubbles;
c) strength of the conformal coating material with regards to whisker entrapment (if opposing surfaces are uncoated) and penetration on opposing surfaces (e.g., buckling studies), considering possible degradation from the temperature and humidity environments of the planned application. Industry or other published information may be used to meet this requirement.

It is expected that other aspects of the conformal coat, such as possible stresses that may be induced by the coating or impact of the curing requirements on the underlying hardware, will be addressed in the general engineering for the product.

4.4.5 SnPb soldering process with validated coverage

As stated in the definition, if all Pb-free tin finishes on the device have been replaced through replating or solder-dipping, following GEIA-STD-0006 or equivalent, then the device is no longer considered to be tin-finished.

However, if only some tin-finished surfaces have been reworked, then the actions are considered to be equivalent of SnPb coverage as part of an SnPb soldering process.

The solder process shall be qualified for each package style, either by test or by similarity, where it will be used as a mitigation. For qualification, the following are required:

- Tin or tin alloy finishes and soldered areas shall be evaluated for > 3 % Pb content using XRF, consistent with JESD213, SEM EDS, consistent with MIL-STD-1580:2010, notice 2, revision B, or other methods approved by the customer.
- Adequate consumption of the Pb-free tin into the solder shall be demonstrated through microsectioning or other validated methodology.
- The qualification shall take into account variability in the solder process controls.

The solder process shall be controlled or monitored to ensure that the qualification continues to apply. This may be accomplished through statistical process controls or statistical sample testing.

4.4.6 Circuit and design analysis

This mitigation may not be practical in units where tin is used extensively. The level of detail needed for the analysis may likely make it too onerous an approach.

It is expected that this approach will not be taken for applications at risk for plasma events. Guidance on evaluating the risk of plasma events is provided in Annex A.

For the purposes of this specification, the circuit and design analysis shall demonstrate that a whisker growing from a Pb-free tin surface and bridging a gap to cause a short will not impact the reliability and performance of the unit containing the surface. In high voltage applications, the analysis shall also address non-bridging failure modes. In cases where current is greater than 50 mA, and arcing or plasma event has been shown to be unlikely, it may be assumed that the whisker will fuse and the assessment only needs to be done for an intermittent short lasting 50 microseconds.

This analysis may be addressed as an element of the overall failure modes and effects analyses (FMEA) or failure mode, effects, and criticality analyses (FMECA). This is not intended to include the probability of a whisker growing or of a whisker touching a particular surface; it is intended to focus on effects.

The risk of a whisker breaking free and becoming a foreign object debris (FOD) is less than the risk of whiskers shorting to an adjacent surface. Applications with optical or electro-mechanical requirements should be evaluated for FOD risk. Applications that are likely to be extensively handled or will repeatedly be exposed to very high vibration environments, both of which would increase the chances of whiskers being knocked free, should also be evaluated for FOD risk.

If the SnPb soldering process, consistent with 4.4.5, or the conformal coat, consistent with 4.4.4, can be shown to consistently cover some areas of tin, circuit analysis is only required for areas that are at risk for remaining exposed.

4.5 Part selection process

Part selection is an important part of an overall tin whisker mitigation strategy, but no part level mitigation is without risk. There have been whiskers reported with virtually every part control level practice proposed by the electronics industry. In addition, because part manufacturing and finishing is outside the control of the ADHP industry and verification of the processes is difficult, there may be too much process variability for the practices to be consistently effective. For those reasons, part control level practices do not fulfill the mitigation requirements of 4.2.3.4 or 4.2.4.4 of this specification. Instead, a strategy for encouraging the use of lower risk parts is required, in addition to those requirements.

Some sources of information about lower risk finishes are available from papers in the literature or industry groups, such as iNEMI (iNEMI web sites can be a source for information – http://www.inemi.org/; http://thor.inemi.org/webdownload/projects/ese/tin_whiskers/Pb-Free_Finishes_v4.pdf). In general, process knowledgeable ADHP customers have a preference for parts with at least one of the following (shown in alphabetical order):

- annealing or fusing at part manufacturer, close to the time of plating;
- hot dipped tin finishes (as opposed to plated finishes);
- immersion tin (for boards only; not applicable to component / part finish);
- low profile parts, parts with short leads, or other geometries that have lower risk of whisker shorting;
- nickel under-plate (so long as not under bright tin);
- SnAg finishes (with 1,5 % to 4 % Ag), particularly when hot dipped;
- SnBi (with 2 % to 4 % Bi);
- SnPb (with minimum 1 % Pb);
- successful passage of JESD201 testing at Class 2 control level.

Annex B should be consulted for more information on the effectiveness and possible reservations about each of these methods.

4.6 Assessment and documentation of risk and mitigation effectiveness

4.6.1 General

The customer and supplier should evaluate their products, applications, and environments and evaluate how test data and mitigation strategy apply to those conditions. A number of different analyses might be appropriate for this requirement. Determination of the specific analysis should be made by the supplier and customer.

Any detailed material analyses, qualification reports, process monitor reports, tests or other documentation related to mitigations shall be made available to the customer upon request for mitigations applied to their products.

4.6.2 Elements of assessment

The analysis shall address the rationale for the selected control level, unless the control level was dictated by the customer. The rationale may consist of an analysis that indicates that the consequences of a tin whisker induced failure are acceptable. The rationale may consist of an analysis of the demonstrated reliability of the affected hardware as compared with the requirements.

The supplier shall have documentation of their methods of controlling vendor use and introduction of Pb-free tin.

For control levels 2B, 2C, and 3, the supplier shall have documentation of their methods of verifying Pb content.

For control level 2B and 2C, the supplier shall also document:

- the mitigation measure(s) applied (generally documented at family control level for 2B and piece part control level for 2C);
- the processes and analyses required for the mitigation measures selected, consistent with the requirements of 4.4, including qualification processes and process monitoring processes, if applicable.

For products containing COTS assemblies or sub-assemblies, the program should include COTS tin whisker risk assessment and mitigation in make-buy and equipment selection decisions. This should include an assessment of the COTS design and supplier practices to identify risk from tin whiskers. The assessment should include determination of the supplier’s policies and processes related to tin whisker mitigation, when possible. The results of the assessment should be documented, including any planned system control level mitigation. Hardware that is identified as RoHS compliant will not contain any tin-lead terminal finishes, and will likely contain pure tin finishes. Hardware that is not identified as RoHS compliant may contain pure tin finishes. Higher assembly control levels of COTS equipment will be the most difficult to assess for tin whisker risks. Some COTS suppliers, especially those that supply to defence contractors, may have options available for managing and controlling the use of pure tin. Possible options should be explored with the supplier during COTS implementation decisions.

4.6.3 Other risk analysis issues

If some Pb-free tin finishes have been replaced, the analysis shall address the replacement process, risk of secondary damage, and risk of tin remaining.

Analyses might also include use of a risk algorithm. Although there is no industry consensus on a specific algorithm to be called out in this specification, more information regarding these evaluations is provided in Annex D.

Annex A
(informative)

Guidance on control levels, risk assessment, and mitigation evaluation

A.1 General

The determination of the suitability of the use of Pb-free tin should be performed on an application-by-application basis. Unfortunately, the current state of our understanding of the tin whisker phenomenon does not permit the quantification of the probability of failure due to tin whiskers for any particular application, even under extremely well controlled circumstances. Nonetheless, customers and supplier should choose tin control levels and mitigation strategies and weigh those decisions against the risk of tin whiskers.

Potential applications of high reliability electronic systems vary from "single thread" systems where no failures can be accepted for very long periods of time, often exceeding 20 years, to systems where it is necessary to be single failure tolerant and it is necessary to mitigate the effects of single failures utilizing multiple techniques including redundancy and field support actions. A guiding principal should be that it is not possible to have a single channel electronic system that will never fail. Thus, for high reliability electronic systems, multiple provisions and techniques are required to achieve application specific reliability and availability. These principles apply to both the risk from tin whiskers as well as other failure mechanisms that have long been considered in risk and reliability assessments.

A.2 Control level determination

There are three basic control levels: no controls on tin finishes, some controls on tin finishes, and prohibition of tin finishes. Control level 2, some controls on tin finishes, has three sub-control levels. The differences between the three sub-levels may seem subtle, but the differences were carefully established to allow flexibility between different program types. Full requirements are provided in the normative clauses/subclauses of this specification, but it may be helpful to review the following summary of requirements when selecting a program’s level.

As part of the determination of which tin whisker control level is appropriate for a specific application, it is recommended that the following Figures A.1, A.2, A.3 (“Decision tree”, “Decision tree, sub-tree 1” and “Decision tree, sub-tree 2”, respectively) be used for decision. There are clarifying questions and information following these figures. Table A.1 provides a summary related to the different control levels.

Note that control level 1 does not appear on the decision tree. It is generally applicable to non-fielded hardware, such as engineering models, or applications with no risk of tin whisker impact.

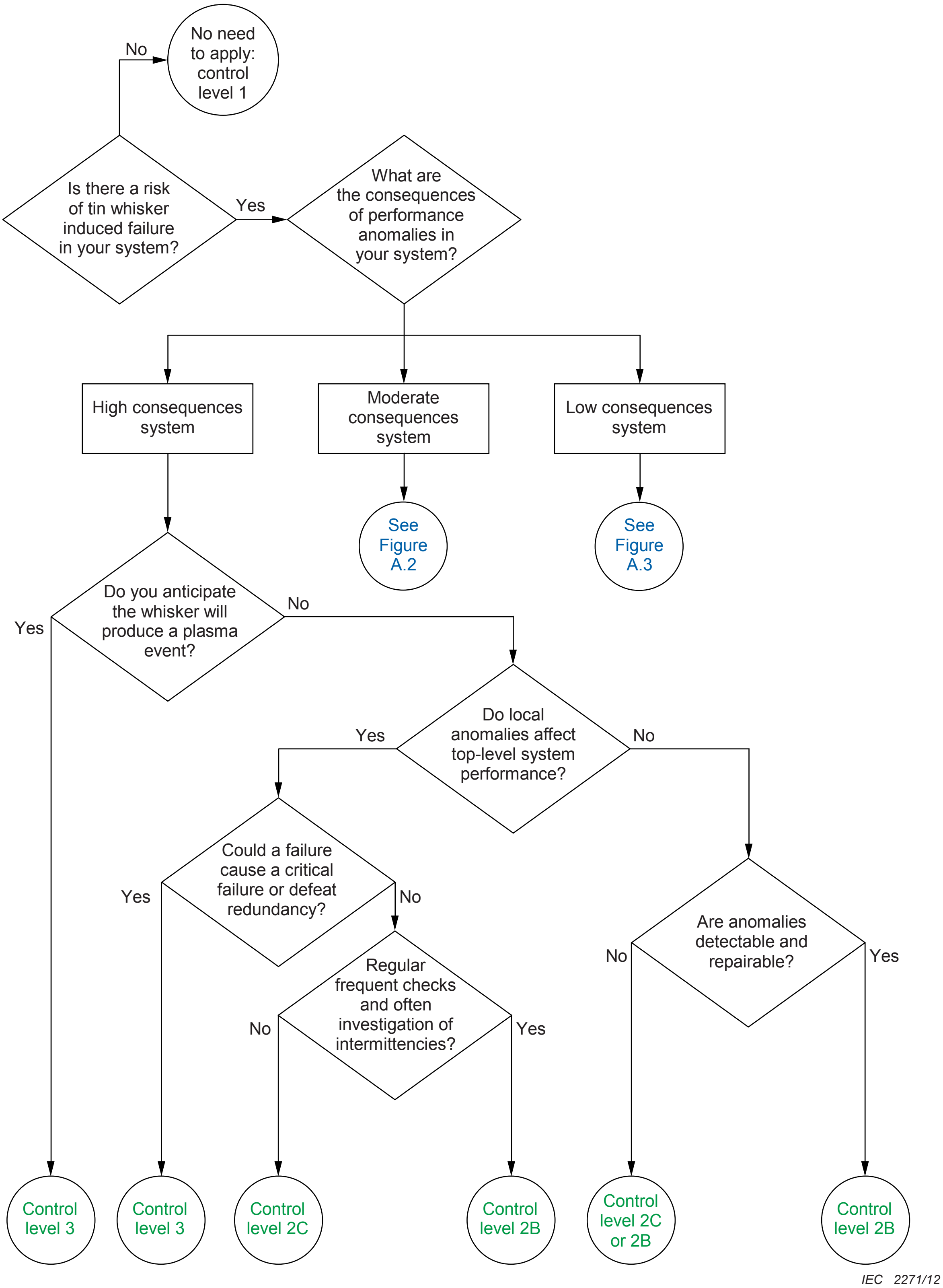

Figure A.1 – Decision tree

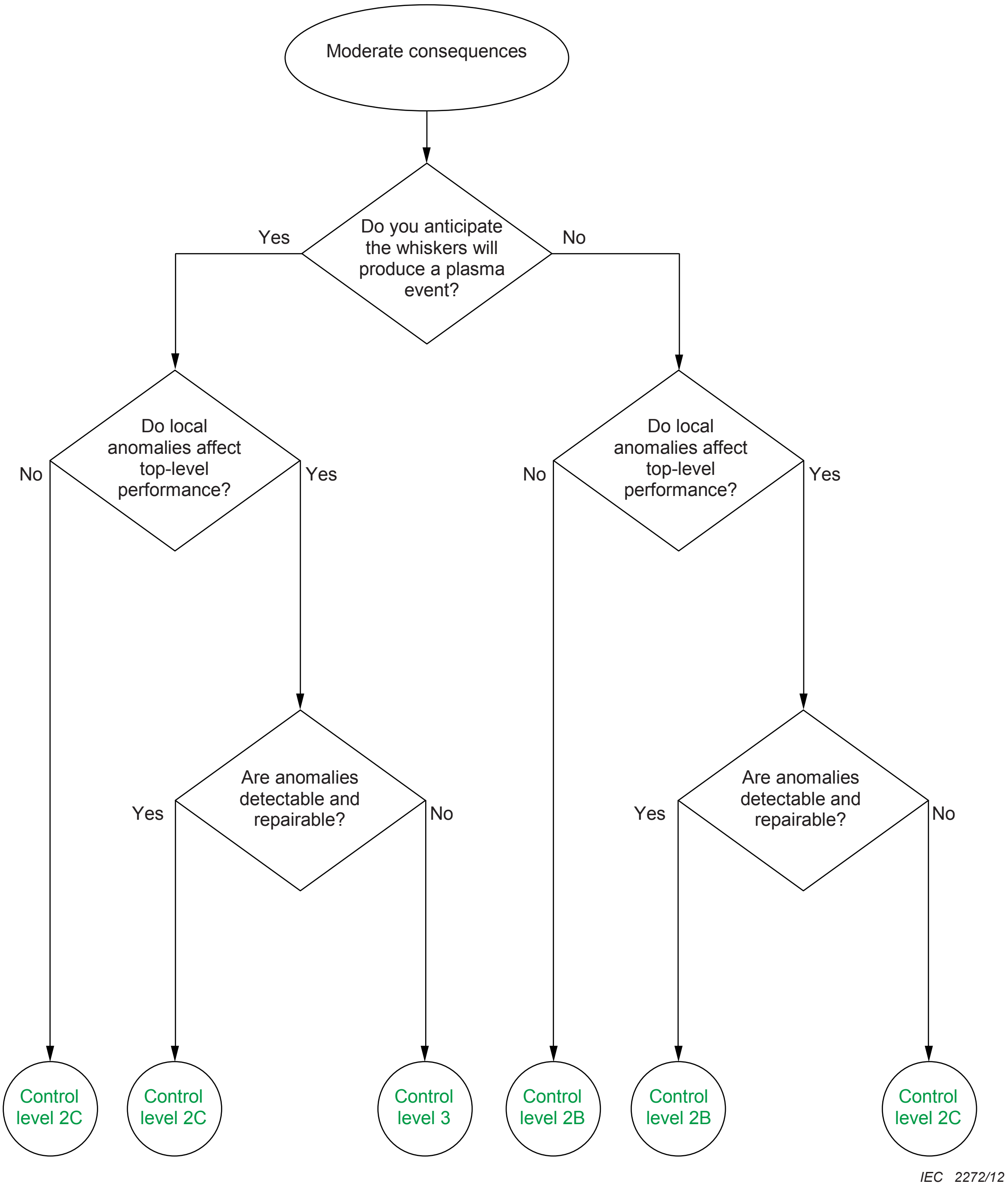

Figure A.2 – Decision tree, sub-tree 1

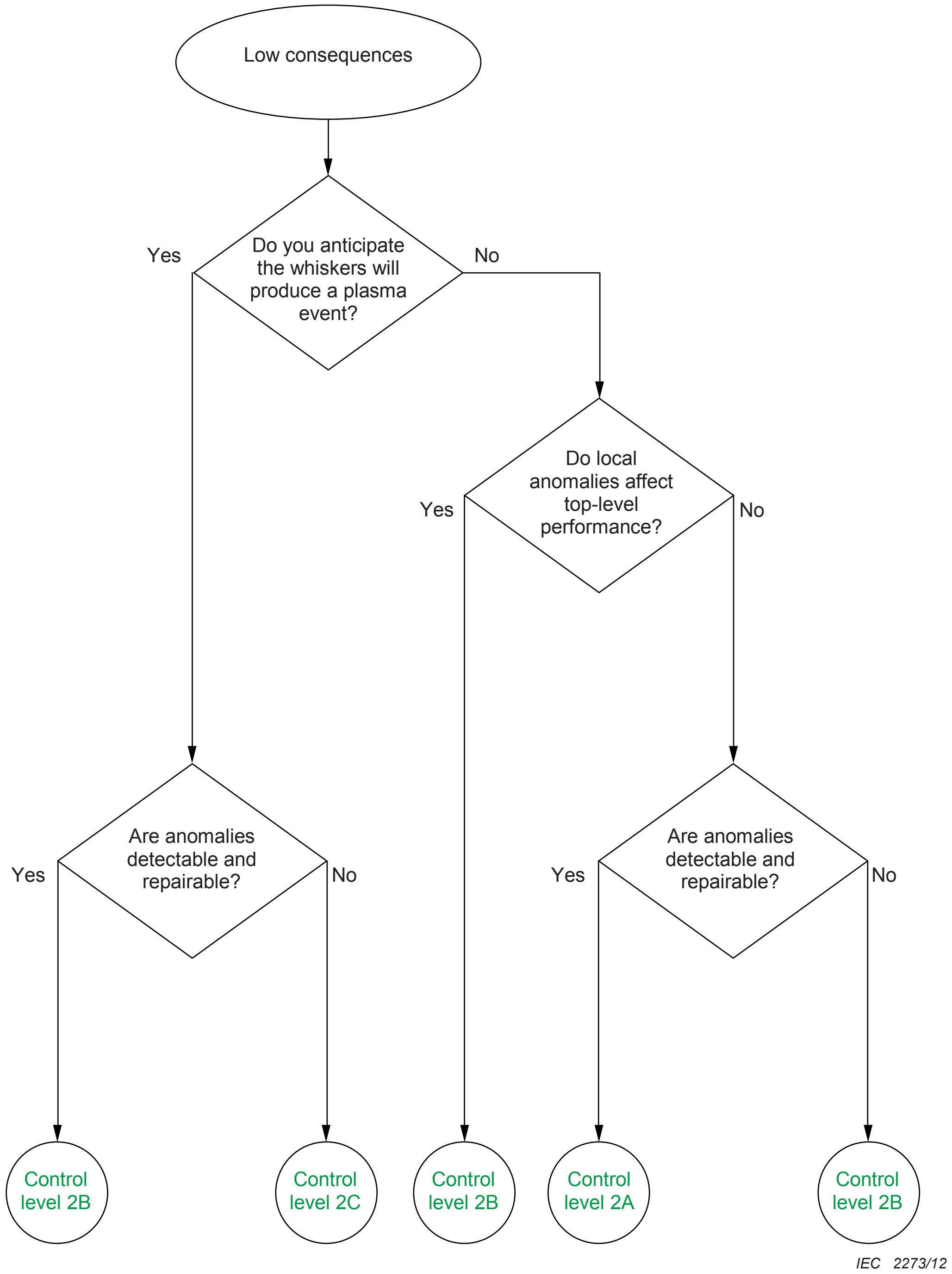

Figure A.3 – Decision tree, sub-tree 2

A.3 Decision tree questions

The following questions provide guidance for evaluating the decision tree.

What are the consequences of performance anomalies in your system?

This question is about the type of system that you are building for.

High consequence systems are those that have an immediate human life implication, are critical strategic assets, or have a high monetary value, such as large unmanned space vehicles and satellites.

Moderate consequence systems are those that have a low or intermittent risk to human life. It may also include systems which have to work for short periods of time when demanded (intermittent use). This category is likely to include many single or limited use items.

Low consequence systems have no risk to human life and/or have low monetary value.

Do we antipate that the whiskers will produce a plasma event?

In low pressure or vacuum environments, applications at greater than about 13 V are considered at risk with those greater than 25 V being considered high risk.

In 1 atm or more, the risk should be considered for applications at greater than 28 V. Voltages greater than 130 V are generally considered high risk.

Do local anomalies affect top-level system performance?

This question is about the unit or board being evaluated.

Is this a critical unit or a unit with limited redundancy whose failure would cause mission failure? If so, then a local anomaly is assumed to impact top-level performance. If not, then a local anomaly is assumed to not impact top-level performance.

If there is good unit redundancy or internal redundancy or if the unit is not critical, then the local anomaly will likely not impact top-level performance.

Could a failure cause a critical failure or defeat redundancy?

Can a single failure defeat redundant systems?

Can a single failure inhibit a common mode voting function or a safety tripping mechanism?

Can a failure initiate a tripping mechanism which defeats voting and could cause a loss of function?

Are anomalies detectable and repairable?

This is primarily focused on the unit or board being evaluated.

Is your mission, including storage and down-time, a short one (< 5 years)? Or are units planned on being replaced or extensively maintained frequently (< 5 years)? If so, then you can treat your product as being frequently repaired for the purposes of this question.

Are troubleshooting and repair part of your normal operational plan? Are intermittent anomalies troubleshot regularly? How frequently and thoroughly will the unit be checked for problems (at least annually)? Is performance tested or demonstrated on a defined periodic basis? Will unit or system be tested just prior to use? Will problems be able to be repaired in a timely fashion?

Table A.1 – Control level summary table (*1 of 2*)

	Documentation	**Detecting and controlling introduction**	**Mitigation**	**Parts selection**	**Analysis and documentation of effectiveness**
Control level 2A	Shall document design rules for when Pb-free tin is not allowed.	None	Should document any standard mitigation practices.	Should have a part selection process that encourages use of lower risk parts.	Analysis of why processes produce a control level 2A product.
Control level 2B	Shall document lists of families where Pb-free tin may be used. If there are other individual uses of Pb-free tin, those parts and applications shall be documented. Unknown materials shall be documented.	Should provide a plan for monitoring materials on a sample basis.	For non-high voltage applications, mitigations shall be fulfilled by any one of the following: • Hard potting or encapsulation. • Physical barriers. • Circuit design and analysis showing low impact of tin whisker short or FOD. • Circuit design and analysis showing that areas sensitive to tin whisker shorts or FOD have at least a 1 cm gap. • Parylene conformal coating with valid coverage and gap size, prior to coating, greater than or equal to 150 µm. • Conformal coating with validated coverage and gap size greater than 250 µm. • Pb-free tin electronic components with gaps greater than 2 000 µm that have been installed with SnPb and are physically isolated from any Pb-free tin mechanical piece parts. • SnPb soldering process with validated complete coverage. • Mitigation or combination of mitigations approved by the customer.	Shall have a part selection process that encourages the use of parts that have lower tin whisker risk. Shall document what specific part control level characteristics are considered to be preferred.	Shall provide an analysis addressing the risk of tin whiskers. Shall have documentation covering the following elements: • Methods of controlling vendor use and introduction of Pb-free tin. • The mitigation measure(s) taken for each family of piece parts or applications of Pb-free tin finish in the product. • The tests or analyses performed for each family of piece parts or applications using Pb-free tin finishes, to determine risk of whisker growth in accordance with 4.6. • If there are other uses of Pb-free tin outside the families, the mitigation measures taken for each piece part or application of Pb-free tin finish in the product outside the families. • If there are other uses of Pb-free tin outside the families, the tests and analyses performed for each of these piece parts or applications to determine risk of whisker growth in accordance with 4.6. • Verification methods, including inspections and tests, that show their processes are under control.

Table A.1 (*2 of 2*)

	Documentation	Detecting and controlling introduction	Mitigation	Parts selection	Analysis and documentation of effectiveness
Control level 2C	Shall avoid use of Pb-free tin whenever possible. Individual uses of Pb-free tin shall be documented and mitigated and require approval by the customer or customer designee.	Shall provide a plan for monitoring materials in their product. Shall reach an agreement regarding this plan.	Mitigation requirements shall be fulfilled by at least one of the following: • Hard potting or encapsulation. • Physical barriers. • Circuit design and analysis showing low impact of tin whisker short or FOD. • SnPb soldering process with validated complete coverage. • Parylene conformal coating with valid coverage and gap size, prior to coating, greater than or equal to 150 µm. • Conformal coat with validated coverage and gap greater than 500 µm. • A combination of mitigations approved by the customer.	Shall have a part selection process that encourages the use of parts that have lower tin whisker risk. Shall document what specific part control level characteristics are considered to be preferred.	Shall have documentation covering the following elements: • The mitigation measures taken for each piece part or application of Pb-free tin finish in the product. • The tests and analyses performed for each piece part or application using Pb-free tin finishes, to determine risk of whisker growth in accordance with 4.6. • Provide the risk assessment and mitigation measures to the customer for their review, as requested or required by customer.

Annex B
(informative)

Technical guide on detection methods, mitigation methods, and methods for limiting impact of tin

B.1 General

Below is a discussion of individual methods and other information to help reduce the risk of failure due to tin whisker formation. The effectiveness of the mitigation strategies presented here has been demonstrated to varying degrees, but their relative effectiveness has not been quantified. Until the growth mechanisms are understood, no accelerated test for whiskers can be developed. A reliable, repeatable accelerated test will be needed before the risk to a system or the effectiveness of a mitigation strategy can be accurately and quantitatively calculated. The only sure strategy to prevent tin whisker induced failure is to avoid using Pb-free tin, but a mixture of mitigation strategies may allow for the use of Pb-free tin finishes for some applications or lifetime requirements. Strategies, along with references to research evaluating them, are presented in B.2 to B.8.4 to help users qualitatively evaluate their particular circumstances.

B.2 Hard potting, encapsulation, and physical barriers

Perhaps the most obvious method to prevent whiskers from shorting out adjacent conductors is creation of an insulating physical barrier between them. Placement of non-conductive washers, spacers, staking compound materials, etc. as a physical barrier can prevent whiskers from growing from one conductive surface to another. Because whiskers can grow through oils, greases, and the softer lacquers, care must be taken in selecting the material of the barrier. In this context, the harder or more durable materials (e.g., epoxies) are much more effective, provided they remain intact [1] [2] [3][5]. While a barrier may prevent a whisker growing from one conductive surface to another, it cannot mitigate the risks associated with free-floating whiskers.

B.3 Conformal and other coats

If piece parts with Pb-free tin finish are used, government and industry subject matter experts strongly recommend the application of a conformal coating. Conformal coat reduces the risk of whisker failure by retarding possible tin whisker growth and containing many whisker growths within the coat. However, whiskers have been shown to escape most coatings. So perhaps the more important feature is that conformal coating prevents whiskers from shorting exposed conductors, as whiskers typically buckle before penetrating coatings on adjacent surfaces. [1] [4] [5] [6] [7] [8] [9]

The published literature on the physical and mechanical properties of conformal coating materials is a scarce commodity. The electronics industry has primarily utilized conformal coating materials for their ability to provide product use environmental protection, thus material properties such as elongation or elastic modulus were a special interest topic. However, with the use of conformal coating as a tin whisker risk mitigation strategy, the mechanical properties of the various conformal coatings are now a topic of significant industry interest. Meschter et al [10] characterized various conformal coating physical properties as part of an investigation of deflecting or buckling a tin whisker by a conformal coating surface. Table B.1 illustrates the calculated physical properties of various conformal coating materials from the investigation.

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[5] Numbers in square brackets refer to the Bibliography.

Table B.1 – Conformal coating material physical properties from S. Meschter [10] [6]

Coating	Durometer	Critical stress (MPa)	Stiffness constant (MPa)	Deflection/Diameter	
				linear	durometer
Uralane 5750 [6] [10]	A50	3,39	3,05	0,87	1,00
Dymax 984 [7]	D80	324	455	0,56	1,36
Dymax 9 -20557 [7]	D60	81,4	265	0,24	1,57
Dymax 9-986 [7]	A65	4,28	5,88	0,57	0,70
Aptex 7503 [8]	A55	3,69	6,44	0,45	0,90
Humiseal 1B31 [9] [14]		11,6	65,77	0,14	0,18

The 250 μm gap in conjunction with conformal coat mitigation requirements of control level 2B is to try to allow adequate space for the conformal coat and a sufficient air gap to ensure buckling of the whisker will occur. The 500 μm gap with conformal coats for control level 2C adds more conservatism to allow for a wider range of whisker growth directions, whisker diameters, and conformal coat strength. [10]

Woodrow published a table of conformal coating physical properties (Table B.2) as part of an investigation of various conformal coatings to mitigate the formation and growth of tin whiskers [9] [12]. Woodrow initiated the study of conformal coatings because they were one of the few processes that were under the control of OEMs that manufacture high reliability electronics. Unfortunately, Woodrow found no direct relationship between conformal coating properties and their ability to contain tin whiskers [12]. However, there is no direct examination of buckling.

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[6] Reproduced with permission of Mr S. Meschter, August 13th 2012.

Table B.2 – Conformal coating physical properties from T. Woodrow [12] [7]

Properties	**Coating A (urethane acrylic)**	**Coating B (silicone)**	**Coating C (acrylic)**	**Coating D (urethane acrylic)**	**Coating E (urethane acrylic)**	**Parylene C**
Young's modulus (N/cm^2)	483	621	689	41 369	122 727	275 790
Tensile strength (N/cm^2)	172	300		4 137	2 413	6 895
Elongation to break (%)	200	30		5	10	200
Hardness	Shore A55	Shore D24		Shore D80	Shore D70	Rockwell R80 (approx. Shore D75)
Oxygen permeability at 25 °C (cm^3 (STP) × mm/ (2 540 mm^2/ day × atm)	200	50 000		200	200	7,2
Water vapor transmission at 90 % RH, 37 °C (g × mm/ (2 540 mm^2 × day)	2	5		2	1,8	0,21

Kumar included a table of conformal coating physical properties as part of his investigation into the use of Parylene conformal coating as a tin whisker risk mitigation strategy [13].

Table B.3 lists the various conformal coating material types and properties from the investigation.

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[7] Reproduced (with conversion to SI units) with permission of Mr T. Woodrow, August 10th 2012.

Table B.3 – Conformal coating physical properties from R. Kumar [13][8]

Properties	Parylene N	Parylene C	Parylene D	Parylene HT	Acrylics (AR)	Epoxy (ER)	Silicones (SR)	Polyurethanes (UR)
Young's modulus (N/cm^2)	241 317	275 790	262 001	255 106	1 379 - 6 895	241 317	621	689 - 68 948
Tensile strength (N/cm^2)	4 137 – 7 584	6 895	7 584	5 171	4 826 - 7 584	2 758 - 8 963	241 - 689	121 - 6 895
Dielectric strength V/mil	7 000	5 600	5 500	5 400	3 500	2 200	2 000	3 500
Elongation to break (%)	20 - 250	20 - 200	10	10	2 - 5,5	3 - 6	100 - 210	>14
Density (g/cm^2)	1,10 - 1,12	1,289	1,418	1,506	1,19	1,11 - 1,40	1,05 - 1,23	1,10 - 2,50
Water absorption (% after 24 h)	<0,1	<0,1	<0,1	<0,01	0,3	0,5 - 1,0	0,1	0,6 - 0,8
Rockwell hardness	R85	R80	R80	R122	M68 - 105	M80 - 110	40A – 45A (Shore)	68A – 80D (Shore)
LCTE at 25 °C (ppm)	69	35	30 - 80	36	55 - 205	45 - 65	250 - 300	100 - 200
Gas permeability at 25 °C								
N_2	3,00	0,40	1,80	4,80	No data	160	No data	31,50
O_2	15,40	2,80	12,60	23,50	No data	2,00 - 3,90	19 685	78,70
CO_2	84,30	3,00	5,10	95,40	No data	3,10	118 110	1 181
WVTR at 37 °C, 100 % RH, (cc-mm)/(m^2-day)	0,59	0,08	0,09	0,22	13,90	0,94	1 747	0,93 - 3,40

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[8] Reproduced (with conversion to SI units) with the permission of Mr R. Kumar, August 2nd 2012.

It is anticipated that the renewed interest in the physical properties of conformal coating materials will result in a broader and more complete compilation of values with industry consensus agreement. In the short term, the use of the published literature on conformal coating physical properties should be used cautiously as part of any due diligence actions for tin whisker risk mitigation strategy.

In general, it is believed by the ADHP industry that Parylene conformal coats, particularly Parylene C, are the most resistant to tin whisker growth. This is due to the physical properties of the coating as well as the ease of achieving even and complete coverage. However, the expense of the process and the difficulty of performing repair and rework on the boards after coating make this a less appealing option in many cases. Uralane is a common ADHP industry selection and while not completely effective at containing whiskers, has been shown to reduce the number and length of whiskers, particularly when thickly applied [14] [15]. Woodrow’s work [9] [12] has raised some concerns in the industry about non-Urethane acrylic coatings and silicone coatings. These coatings should be approached with more caution.

Obvious limitations of using conformal coating over Pb-free tin finish are the possible variability in the quality and thickness of the coating coverage. Experts warn that when applying conformal coating to dense assemblies, the coat should not bridge the gap from one surface to another, providing a direct path for potential whiskers. Coating fully under-mounted piece parts such as pin grid arrays (PGAs), ball grid arrays (BGAs), and chip scale packages (CSPs) may also be difficult. When conformal coating is applied in a spray process, the coat must be sprayed from several angles to prevent shadow areas created by high profile piece parts [6] [16]. Achieving adequate coating can be very difficult. [10]

Thus, conformal coat as a whisker mitigation technique depends on the workmanship of the coating. It is also possible to induce other problems with the use of a conformal coat. It is recommended that industry standard or carefully created company standard conformal coat application methods be used. There is worked planned at IPC to address the issue of conformal coat applications and inspection requirements for tin whisker mitigation but the work is ongoing. Some currently existing industry methods include:

- Adjunct pictorial reference for assorted NASA Workmanship Standards (including conformal coat) [100] (web site http://workmanship.nasa.gov/lib/insp/2%20books/frameset.html);
- IPC-CC-830: Qualification and performance of electrical insulating compound for printed wiring assemblies [101];
- MIL-I-46058C: Insulating compound, electrical (for coating electrical circuit assemblies) [102];
- IEC 61086 series: Coating for loaded printed wire boards (conformal coatings) [103].

There is some evidence that whiskers may be attracted to each other through electrostatic forces, increasing the likelihood of whiskers shorting to other whiskers [14] [7] [16]. However, whisker to whisker shorts are estimated to be quite rare [17].

There are a number of new coating techniques that are currently under investigation, such as atomic layer deposition (ALD) and new tougher sprayed or painted coatings. Many of these are showing a lot of promise. However, at the time of this specification’s publication, there was insufficient data for the ADHP industry to fully evaluate the techniques and materials. These materials may be adequate if additional data is gathered and reviewed with the customer.

B.4 Tin finish replacement and SnPb soldering processes

B.4.1 General

The most effective solutions, if SnPb finishes are not available, involve completely replacing the Pb-free tin finish, not merely covering it, and ensuring that no Pb-free tin remains exposed. However, replacing the Pb-free tin finish may lead to suppliers no longer guaranteeing the performance of piece parts. Therefore, analysis and possibly qualification of the re-processed piece parts may be needed to verify that they will function as intended.

B.4.2 Solder dip tin-finished surfaces

Hot solder dipping (sometimes referred to as HSD) of tin-finished leads and surfaces using an Sn-Pb-based solder will help reduce whisker formation by relieving stress in the tin. The heat can increase grain size, and the SnPb alloy is less prone to whisker formation. Under ideal practices, solder dip of tin-finished terminations, using SnPb solder, will virtually eliminate whisker formation by dissolving and replacing the tin-finish with an SnPb alloy.

GEIA-STD-0006 describes the process controls, qualification, and test requirements for automated HSD intended to fully replace Pb-free tin finishes on electronic piece parts. The process in that document differs from traditional solder dip in that the lead must be coated over its entire length, right up to the package interface. During hot solder dip, the piece part undergoes an unavoidable amount of thermal shock. Differential temperatures during solder dip are significantly greater than those present during typical board-level assembly. In addition, the fluxes used during the dipping process can be drawn into minor delamination commonly found in plastic piece parts, which can lead to reliability issues [9]. GEIA-STD-0006 is the best available method of confirming that the Pb-free tin finish is replaced and that the parts are not damaged by the process.

If the device cannot be dipped all the way to the body, the standoff distance, usually between 254 μm and 1270 μm, would still be at risk for whisker growth. There is also a risk of whiskers on any Pb-free tin inside the device that could not be solder dipped. [1] [4] [5] [6]. These cases should be handled like the SnPb soldering process described in the main body of this document.

B.4.3 Re-plate whisker prone areas

Some manufacturers may be willing to strip the Pb-free tin plate from finished products and re-plate using a suitable alternative plating material such as SnPb or nickel. Stripping and refinishing is generally not suitable for electronic piece parts, but may be reasonably applied to a range of mechanical piece parts. If applied to electronic piece parts, such processes should be reviewed to determine the potential for affecting the reliability of the original product (e.g., chemical attack on piece part materials). [4] [5] [6]. Stripping and replating is a common process performed by the metal finishing industry.

B.4.4 Pb over-plating

Another option for replacing the pure tin finish involves plating of Pb on the surface of the tin and then baking the part to promote complete inter-diffusion. This option may be most suitable for use on small chip-style passive devices.

B.4.5 Soldering with SnPb solder

The electronics industry has conducted extensive investigation into the use of the tin/lead soldering process to “self poison” the resulting solder joint with lead thus eliminating the risk of tin whiskers. The success of using an SnPb soldering process as a tin whisker mitigation is understanding the key parameters of solder paste deposition and reflow in order to assure that through either solder coverage of a component termination or the diffusion of lead into a component tin finish can be accomplished. The stencil thickness and stencil aperture design in combination with the reflow process parameters are critical in how much of a component termination can be “poisoned”. Figure B.1 illustrates a component in which the soldering process was not sufficient to flow solder onto or diffuse solder into the existing component lead surfaces. The height of the component termination is too great for the specific soldering process used to implement effective tin whisker mitigation. Areas of exposed tin have been shown to grow whiskers and could cause failures. [18] There have been studies suggesting that hand soldering processes may be particularly difficult to understand and control to the control level needed to mitigate tin whisker risk. [19]

The use of an SnPb soldering process as a tin whisker mitigation practice is dependent on the availability of objective evidence demonstrating use of key solder paste deposition/reflow processes.

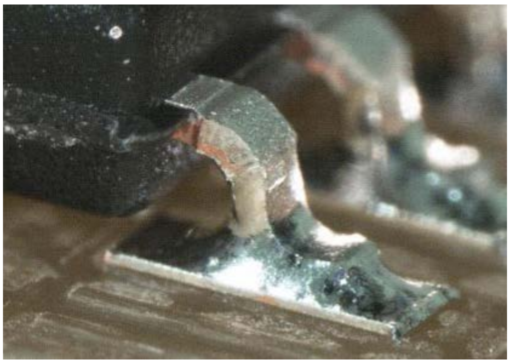

IEC 2274/12

Figure B.1 – Insufficient solder flow

B.5 Circuit design and analysis

In general this “mitigation” technique is specific to the circuit involved, not to the characteristics of the whisker. However, there are some assumptions that should be made in these analyses.

Some industry investigations have focused on the voltage required for a tin whisker to cause an electrical short. [20] [21] investigated the voltage breakdown of actual tin whiskers using various metal plated probes. Their test results revealed that the voltage required to break through the oxide layer of a tin whisker was in the range of 5 V DC to 8 V DC.

The analyses may also depend on some assumptions regarding the likelihood of the whisker short to be permanent versus intermittent, based on the likelihood of the whisker to fuse. There appears to be surprisingly little data available on this subject. Most of the reports seem to suggest that whiskers may fuse with as little as 5 mA or 10 mA of current, but to be conservative, more than 50 mA should be assumed to be needed to fuse thicker whiskers. [21] [22] [23] [24] Truly conservative analyses may want to assume that 75 mA or 100 mA will be needed since [25] may have observed some outlier whiskers needing 75 mA to fuse.

Shorting time of whiskers has been reported even less. Fifty microseconds was chosen to be a very conservative estimate. Hade [24] reports even less than 1 μs.

FOD analysis is likely only needed in special circumstances because whiskers are generally unlikely to break free. Their crystalline structure makes tin whiskers surprisingly strong in the axial direction. High forces in vibration and mechanical tests may be needed to damage or break free whiskers [24]. Even concentrated airflow was reported to be ineffective in removing all but long whiskers. These experimental results may not match all experiences, however, as there are known examples of whiskers detaching and creating short circuits or jamming mechanical mechanisms. [1] It is thought that as the whisker ages, it may be more prone to breakage.

For control level 2B, the analysis may show tin whisker sensitivity so long as those areas have at least a 1 cm gap from the Pb-free tin (whisker origination point). This is based on studies that have shown that whiskers are very unlikely to grow that long. There have been cases of whiskers growing longer than 1 cm, for example on the space shuttle card guides, [26] but even in that case, it was only outlier whiskers that were longer than 1 cm, with the vast majority being several millimetres in length. Based on all available data, it is felt the risk of whiskers greater than 1 cm is very low. Since control level 2B is designed for non-critical applications or applications with good redundancy, it is believed that sensitivity to whiskers with greater than a 1 cm gap is justified. See Clause B.6 below for additional discussion about whisker length models and assumptions.

B.6 Gap distance rules

One of the challenges in quantifying tin whisker risks is that so many studies only report the longest whisker observed, or perhaps a mean whisker length and the longest whisker length. These summary statistics are dependent on the sample size and do not allow for a more in-depth assessment of the distribution and the length distribution. It is unclear whether the longest whisker is a single outlier and not representative of the general performance, whether there is a subpopulation of long whiskers, or whether the sample size is so small that there is still a reasonable chance of much longer whiskers in the larger population. Furthermore, many of the results are derived from limited samples that have only been aged a limited amount of time. Trying to extrapolate those results to field life is also challenging without agreed upon acceleration factors or growth rates.

Some of the studies that have more complete distribution data on whisker lengths include [25] [27] [28] [29] [30] [31].

Dunn’s data on long term whisker growth [32] [33] are also valuable for evaluating limits, even though they don’t include distributions.

In general, whisker lengths are believed to follow approximately a log-normal distribution. Hilty [30] proposed a Johnson’s Transformation model, which puts some additional weight in the tails of the distribution, but which is more complicated to implement and only provides a small amount of additional conservatism. The results of the papers suggest means of between 5 μm and 2 000 μm, depending on the length of the experiment and the types of platings involved. (Median in log scale of 1,5 to 7,5.) Standard deviations range from about 2 μm to 500 μm (shape parameters for log-normal of about 0,25 to about 1).

In almost every case the 90th percentile from the distribution is less than 0,5 mm and a 99th percentile of less than 1 mm. Hada [25] had a case of bright tin over copper after 500 days that had a 90th percentile of about 2,7 mm and a 99th percentile of about 3,5 mm. Dunn [33] also has a few samples with the longest whiskers greater than 1mm, but primarily on abnormal or contaminated tin platings.

In general, it has been observed that longer whiskers have appeared on mechanical piece part components than on electronic piece parts. This may be because of greater process control in the electronics industry or because electronic piece part manufacturers have attempted to implement part control level mitigations. The cases with the longest whiskers above correspond more closely to mechanical parts.

Even though these studies do not represent 15 or 20 years of field operation, most growth models show a decreasing or saturating growth rate. Although they will not capture the total growth at end of life, the studies have other conservative elements in them.

Based on these results, it was felt that for electronic components in control level 2B hardware, 2 000 μm (2 mm) gaps were sufficient to provide tin whisker mitigation. This is primarily based on 1 mm being at least a 99th percentile in the studies above with margin to allow for growth over time and uncertainty about the whisker density and other contributors to variability. This value is also consistent with Rev D of the “Pinskey Model”. [35]

B.7 Part control level strategies to be considered in part selection

B.7.1 Annealing, fusing, and other heat treatments

In general, data support a variety of heat treatments increasing the incubation time, delaying the onset of tin whiskers, but not necessarily preventing them permanently. For this reason, heat treatments are considered somewhat controversial. They may greatly reduce risk for some period of time, but may lead to false confidence for most ADHP mission lengths.

There are two basic categories of heat treatments, those performed below the fusing temperature, such as most annealing, and those above the fusing temperature, usually accomplished by dipping parts in a hot oil bath. There is also variation in when the treatments are performed.

iNEMI recommends a 150 °C anneal for 1 hour within 24 hours of plating, but suggests accompanying data be provided to show the anneal's effectiveness. It also recommends fusing within a few hours of plating as an alternate method. The writers of this specification agree with iNEMI that these kinds of heat treatments, close to the time of plating, are considered to be more effective than heat treatments performed at higher levels of assembly. While iNEMI prefers annealing over fusing, the writers of this specification believe the current tin whisker growth theories should support treatments above the fusing temperature being more effective than those below.
[1] [2] [4] [5] [6] [8] [36] [37] [38] [39] [40] [41] [42] [43] [44] [45] [46] [47] [48] [49]

B.7.2 Plated versus "hot dipped" tin

In general, plated tin is thought to have a slightly higher propensity to whisker than dipped tin. Process controls on the plating baths can help reduce the risk of whisker formation. Contamination in the bath creates nuclei for internal stresses promoting whisker growth. By controlling contamination and refreshing the baths often, these stresses can be limited. Process control is also recommended for current density, temperature, and plating speed. Higher current densities, and therefore quicker plating, may be more prone to greater whiskering. [19]

Hot-tin dipping is not typically performed on lead-frame parts but may be available on other electronic or mechanical components. These parts may be better than plated parts with regards to whiskers, but are known to have whiskering problems. The parts should come from controlled production lines to avoid contamination which is believed to increase whisker growth. [9] Even though the layer of tin during dipping, theoretically, should be less stress inducing than electroplating, variation in plating thickness and handling damage from multiple processing steps can introduce stresses. [8] [51]

B.7.3 Immersion tin for boards

Immersion tin surface finishes for printed wiring board applications are a significantly different electroplating process than that used for the plating of electronic components. The process is much slower and is based on a one-to-one atom exchange between the plating solution and the target surface. The process is self-limiting and has a much lower as-plated stress in comparison to electroplated tin processes for components. The immersion bath's chemical composition is different due to the plating process kinetics, which also has an impact on the propensity of the resulting plating to produce tin whiskers. The electronics industry's published reports are a mixed bag, with both reports of no tin whiskering and reports with significant tin whiskering of immersion tin finishes. A key parameter differentiating the reports is the specific immersion tin plating chemistry formulation used in the industry investigations. The user of immersion tin surface finishes for printed wiring boards is cautioned to conduct due diligence prior to the implementation of an immersion finish. [52]

B.7.4 Nickel underplate

A thin layer of nickel over the copper substrate should reduce intermetallic compound (IMC) diffusion and stress. Studies investigating the effectiveness of nickel underplating on whisker growth have been mixed. Some studies have shown a reduction in number and length of whiskers on tin plated nickel than on tin plated copper. [42] [53] [54] [55] [56] However, studies have also shown that whiskers will grow despite a nickel barrier. [57] [58] [59] [60] [61] The effectiveness of nickel barriers to prevent whiskers may depend on the properties of the base material and the process used for depositing the tin, explaining the differences in the experimental effectiveness of the barrier. A minimum layer thickness of 0,5 μm is recommended for devices subjected to Pb-free reflow assembly conditions. [62]

Silver underplate (> 2 μm) may also be a mitigating feature, but data is much more limited. [63] There is, however, the potential for this mitigation practice to be effective, and further investigation of the effectiveness of this technique should continue.

B.7.5 SnAg finishes

The electronics industry has historically had widespread use of the Sn96,5Ag3,5 eutectic tin/silver alloy for electronics in harsh use environments such as sour gas well, automotive and in high temperature applications. There have been limited studies on SnAg finishes with regards to whiskers, but the results have been promising. Without additional studies on a wider variety of processes, it is difficult to draw a final conclusion about SnAg. [64] [65]

B.7.6 SnBi finishes

The electronics industry has compiled significant investigated results for SnBi surface finishes. The primary focus of SnBi industry investigation has been on electronic component solder joint integrity but secondary results covering the topic of tin whisker initiation/growth has been included in the reports. The reported bismuth content for electroplated SnBi surface finishes has been in the 1 % to 6 % range. The industry reports show a variety of results from no evidence of tin whiskers to modified tin whisker initiation/growth.

JEITA studied SnBi (2 %) parts for 10 000 hours at 55 °C and 85 % RH. The maximum whisker length was less than 50 μm (the whiskers on pure tin were over 100 micrometers). Thermal cycling tests from them and other Japanese companies showed very good performance of SnBi under thermal cycling tests, in some cases with the SnBi performing as well as SnPb.

The NASA DoD Electronics consortia conducted testing of components with an SnBi surface finish, TSOP components subjected to 4 066 cycles of –55 °C to +125 °C thermal cycle conditioning with no evidence of tin whiskers from the SnBi surface finish. Caution should be used when implementing SnBi surface finishes as part of a tin whisker mitigation plan. Additional industry investigation for the SnBi finishes is warranted as the electronics industry has not yet consensus on the topic. [64] [65] [66] [67] [68] [69]

B.7.7 Non-compliant SnPb (1 % to 3 % Pb)

Industry consensus and investigation have demonstrated that a tin/lead surface finish eliminates the initiation and growth of tin whiskers. The industry tin whisker mitigation practice of alloying 1 % to 10 % lead in a tin surface finish was primarily due to investigations conducted by Bell Laboratories in the 1950s. Investigations have shown that as little as the addition of 1 % or 2 % lead to a tin finish will greatly reduce tin whisker initiation. [70] [71] The electronics industry has adopted the use of a minimum of 3 % lead as a minimum standard lead content based on additional margin, the metallurgical properties of the alloy, and general plating practices. Although whiskers have been known to grow occasionally even on very high lead content alloys [69], there have been no reported cases of very long whiskers, and the practice of using SnPb alloys has been successful in the field.

Parts with 1 % to 3 % Pb in the alloy are likely the result of processing problems at a supplier, rather than an intended plating. These are especially likely to arise on control level 3 products where testing of Pb content on each lot is required. It is particularly common in codeposited SnPb barrel plating processes where the plating can be particularly nonhomogeneous and there can be small areas of pure tin and islands of Pb. Even after annealing or other heat treatments, there may still be inadequate mixing of Sn and Pb. Cases with less than 3 % Pb, even if more Pb was intended, require waivers or other non-compliance documentation for control level 3 products, but are in general considered low risk. The gap sizes and plasma likelihood should be considered, along with whether conformal coat or other mitigation is applied.

B.7.8 Successful passage of JESD201 testing at Class 2 control level

Although the mechanisms for tin whisker growth are still unknown, there are several test methods being used by suppliers in the industry. Industry standard tests do provide a common method and comparable data.

Many piece part suppliers are involved with developing tin whisker test methods and finish qualification methods. Some examples include JESD22-A121 “Test Method for Measuring Whisker Growth on Tin and Tin Alloy Surface Finishes” and JESD201 “Environmental acceptance requirements for in whisker susceptibility of tin and tin alloy surface finishes.” Tests typically include aged samples being put through thermal cycling, humidity, high temperature, and ambient testing. Because these tests are developed for the commercial community and most commercial products have an expected lifetime of 3 to 7 years, it is expected that without other mitigation steps, positive results on these tests would generally only be applicable to products with those lifetimes or those products with thorough inspections in that time-frame. Thus, there is a preference for parts that have passed the tests over those that have not, but testing alone does not mitigate or even quantify the risk to ADHP systems.

There is very limited data on the relevance of the test results to field performance. There have been reported cases of parts with tin whisker field failures that previously passed JESD201, but most have been unofficial reports with little detail.

The use of JESD201 in the ADHP community is controversial. Some believe that vendors using the test method are at least considering the tin whisker problem, likely applying other part control level mitigations, and that these parts are thus preferable to parts from suppliers that are not addressing tin whisker issues at all. Others feel that the test creates too easy a solution for suppliers in that they will perform the short test and think they are done. However, 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 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. Note 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. This is particularly true for systems with greater than 20 or 30 years of storage and mission life, harsh temperature cycle environments, or harsh humidity environments. Even tests that show whisker growth rate slowing should be applied with caution as periods of dormancy have been observed on whiskers.

B.8 Part control level mitigations with less ADHP industry support or consensus

B.8.1 “Matte” tin

“Bright” tin finish usually contains additives that can cause internal stresses in the tin. A “matte” tin finish, or a relatively dull finish, may be preferred because it does not contain these additives. [1][6] Generally, matte tin is a tin film with lower internal stresses and larger grain sizes than bright tin. Matte tin is defined by iNEMI and JEDEC to have carbon content of 0,005 % to 0,05 % and grain size of 1 μm to 5 μm.

Many groups have defined matte tin as a lower risk finish. However, the definition of bright and matte tin is vendor dependent. There is little attempt to verify that a vendor's product conforms to the iNEMI, or any other, definition. Categorization is very difficult and purchase on the basis of these descriptive terms can be misleading. For this reason, this specification does not recommend a differentiation between the risk on bright and matte tin for the purposes of defining lower risk finishes without substantial supporting data specific to the parts and process in question.

Furthermore, data on matte tin has been inconsistent, perhaps because of the lack of control on its definition. One study found whiskers up to 2 mm long on matte tin-plated steel. [57] [58] [59] Other researchers have suggested that matte tin may be very effective, particularly when combined with other mitigations. [1] [54] [73] The effectiveness of matte tin may be dependent on process controls during plating and the particular environment during use.

B.8.2 Choice of substrate material

The formation of intermetallics between the base metal and the Pb-free tin finish may create stresses that promote tin whisker growth. By controlling the underplate or substrate, the risk of whiskers may be reduced.

The chemistry, thickness, surface finish, grain size, surface cleanliness, and internal stress of the substrate are all factors that may affect intermetallic compound (IMC) formation and growth. The diffusion of the materials and the IMC create compressive stresses in the Pb-free tin finish, particularly along tin grain boundaries. If the stress reaches a critical level, tin may be extruded from the surface, relieving the stress and creating a whisker. Alloy 42 lead-frames with tin finish are believed to be particularly prone to grow whiskers under thermal cycling due to the CTE mismatch between the alloy 42 and tin. [1] [33] [51] [54] [73] [74]

B.8.3 SAC finishes

The propensity of SAC finishes on components is not a heavily investigated topic as the surface finish is relatively new for the electronics industry. The general consensus within the electronics industry is that the SAC surface finishes will not initiate and grow tin whiskers primarily due to the fact that these finishes are applied in "hot dipped" processes rather than as electroplated processes (see B.7.2). Additionally, it has been proposed that the silver content of the SAC finishes reduces and/or eliminates the propensity of tin whiskering due to the lowering of the overall surface finish tin content. The Joint Council on Aging Aircraft (JCAA)/Joint Group on Pollution Prevention (JGPP) Pb-free Soldering project conducted a series of harsh environment thermal cycle and mechanical tests using a SAC solder alloy and a SAC solder finish. No evidence of tin whiskers was observed after the testing was completed. [75]

Mathew [76] concluded that SAC finishes, particularly over alloy 42, may have problems with whiskers under thermal cycling. SAC performed better under ambient conditions, but whiskers were observed and there were more whiskers > 10 μm observed on SAC parts than on SnPb.

B.8.4 Thick tin

There is some data suggesting that thicker Pb-free tin finishes show a lower propensity for tin whiskers and/or a greater incubation time before tin whiskers occur. It is recommended that the tin thickness for piece parts without a nickel or silver underlayer be 7 μm minimum with 10 μm nominal or thicker preferred. When a nickel or silver underlayer plating is used, the minimum tin thickness should be 2 μm. [41] [77]

Annex C
(informative)

Tin whisker inspection

C.1 General inspection guidance

Optical inspection of electronic assemblies and electronic products present a significant examination challenge. It is recommended that use of multiple light sources (such as ring, flood and flexible wands) and multiple magnification ranges from 1X to 100X be employed during a tin whisker inspection process. The use of multiple angles of incident light is incorporated into the tin whisker inspection protocol for maximum effectivity of whisker observance. Concentrated beams of light can be very effective if they can be easily moved to different angles.

A number of videos demonstrating how critical the light source, magnification and angle of light incident choices can be for tin whisker inspection process can be found at the following web site address: http://nepp.nasa.gov/whisker/video/inspection/index.html.

Although primarily written for reviewing coupon and qualification test results, JESD22-A121 provides some additional recommendations for inspecting for whiskers that are applicable for hardware.

C.2 Inspection of installed hardware

The optical inspection of electronic products in the field may not be feasible due to inadequacies of lighting and magnification. It is likely that only the most severe whisker effects will be observed in this setting. Thus, if whiskers are suspected on field hardware, it is recommended that a sample part, board, or unit be removed to a more controlled setting for further investigation.

C.3 Inspection of removed units and/or inspection during failure analysis or in other laboratory situations

C.3.1 Inspection using stereo-microscope

The first significant inspection for tin whisker should be performed using a stereo-microscope, at about 50x using at least one flexible light source. Details of a recommended inspection procedure are given below.

Equipment:

Multi-angle vise or gimbal

Stereo-microscope (at least 50X)

Flexible goose-neck light

Examination procedure:

Hold specimens using equipment that can allow for a multi-angle examination such as a multi-angle vise. Use the vise to tilt the specimens in the appropriate direction for examination of whisker formation as shown in Figures C.1 and C.2.

Provide side-illumination using a flexible goose-neck light, which can improve contrast against the background as shown in Figure C.3. During examination, change the direction of the light source to find the light reflection from the whiskers. Conformal-coated specimens sometimes have coating residuals and dust on the lead-frame as shown in Figure C.4. It is not easy to distinguish these things from whiskers, but there a slight difference can be seen in their light reflection compared to the reflection from whiskers through changing the direction of the light source.

Examine all the surfaces from the shoulder of the lead-frame where the leads exit the package body to the solder joint, including the non-wetting area across the lead-frame. Especially, any corroded areas on the lead-frame should be examined carefully. The corroded areas are heavily concentrated near the dam bar cuts and the tips of the leads. A study by Su et al. has shown that whiskers are most likely to grow in the corroded areas on the shoulder and tip of the lead-frame. [31]

Capture and document the images where a whisker is observed or suspected in order to conduct scanning electron microscopy (SEM) observation. Documentation should include a description of the lead-frame location where the whiskers have grown.

C.3.2 Comparisons between optical microscope and SEM observation

There are some limitations when observing whiskers using an optical microscope because its magnification is limited and there is reflection from the background, such as the lead-frame surface. Compared to an optical microscope, an SEM has high magnification and can take very clear pictures of the observed sites.

Straight whiskers with a length of more than 100 µm can be easily observed by an optical microscope using a flexible light as shown in Figure C.5. However, nodule whiskers are not easy to locate as it is difficult to detect a light reflection from whiskers using a flexible light because these whiskers can be easily confused with the surface morphology of a lead-frame. Figure C.6 shows that two kinds of whiskers (left: straight whisker; right: nodule whisker) and the right nodule whisker cannot be clearly distinguished in the microscope observation.

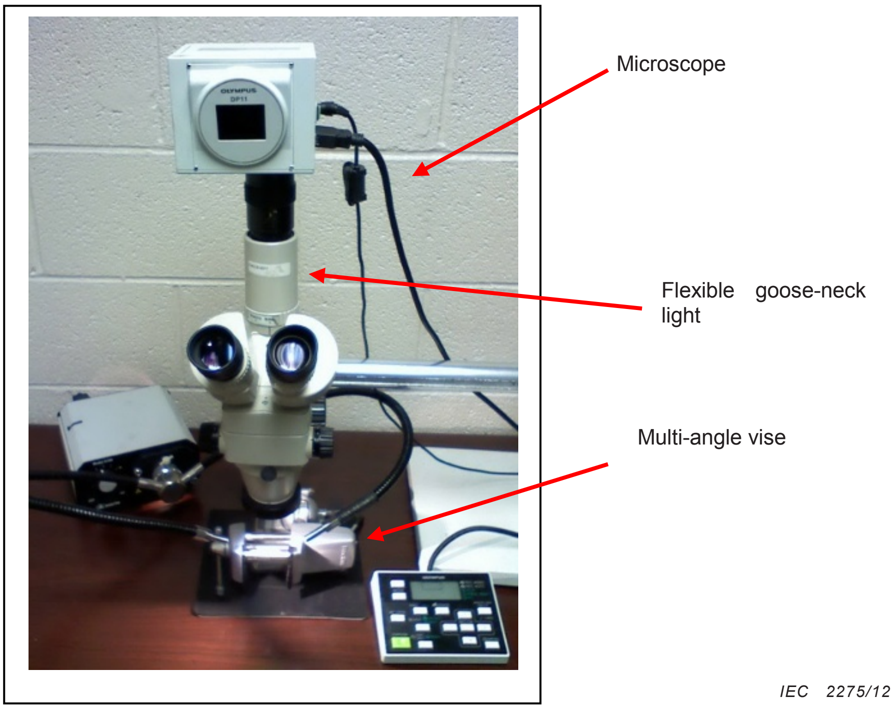


Figure C.1 – Equipment setup for whisker examination

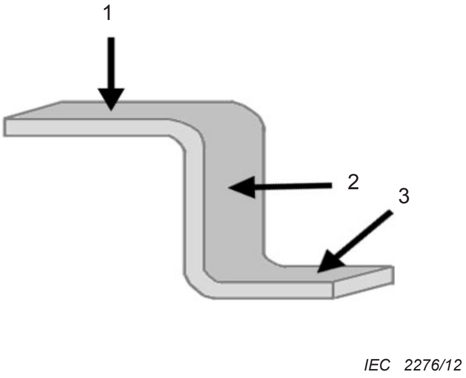


Figure C.2 – Whiskers examination areas and direction

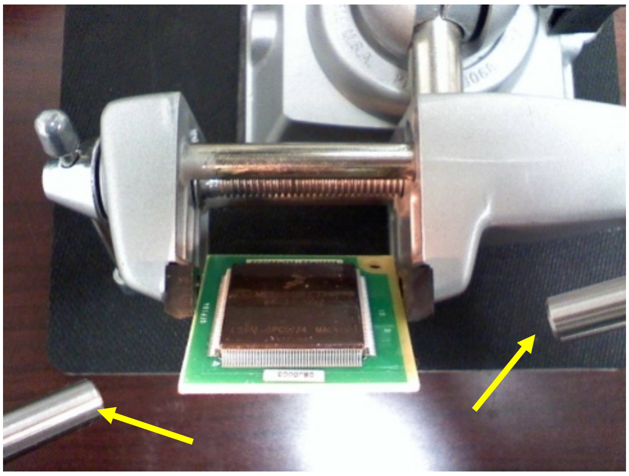


Figure C.3 – Side-illumination by flexible light

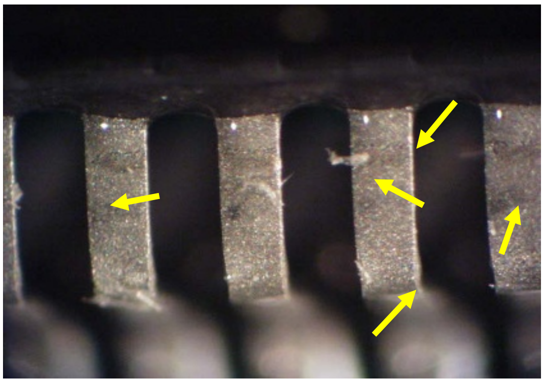
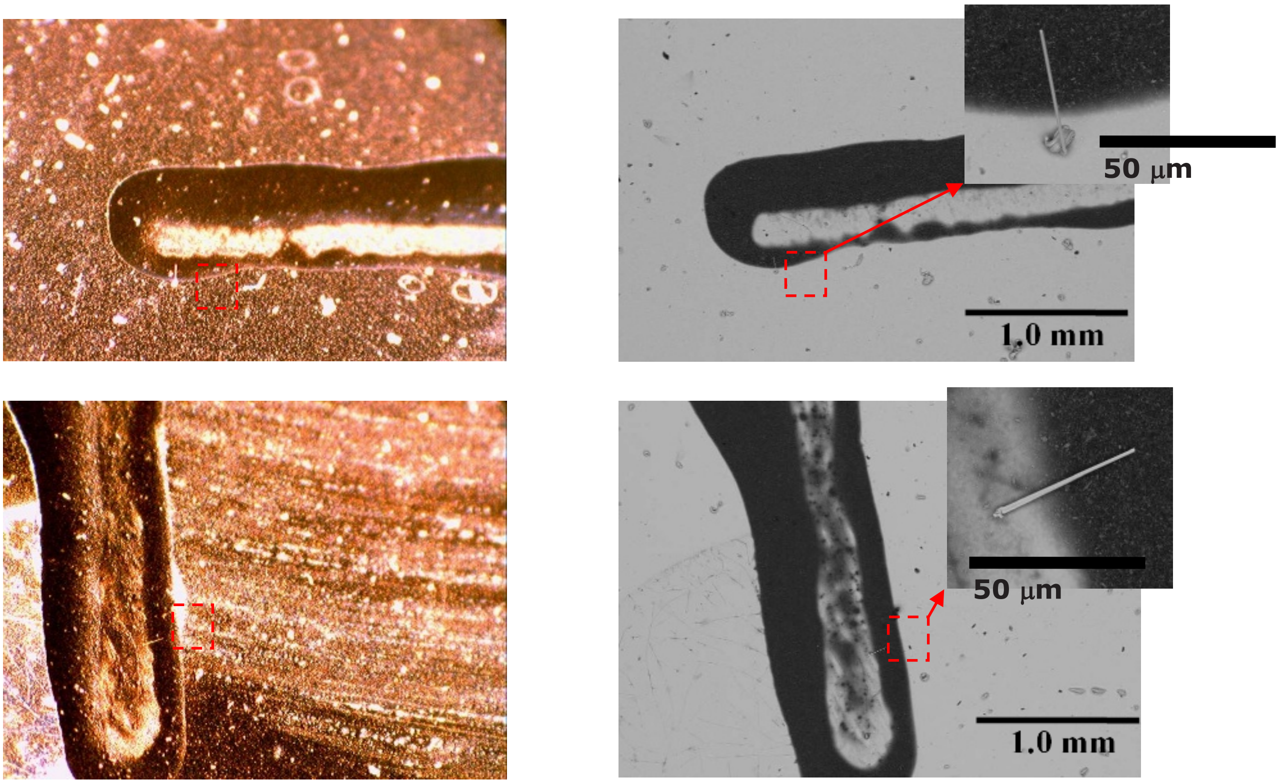


Figure C.4 – Coating residuals and dusts attached on lead-frame with conformal coating



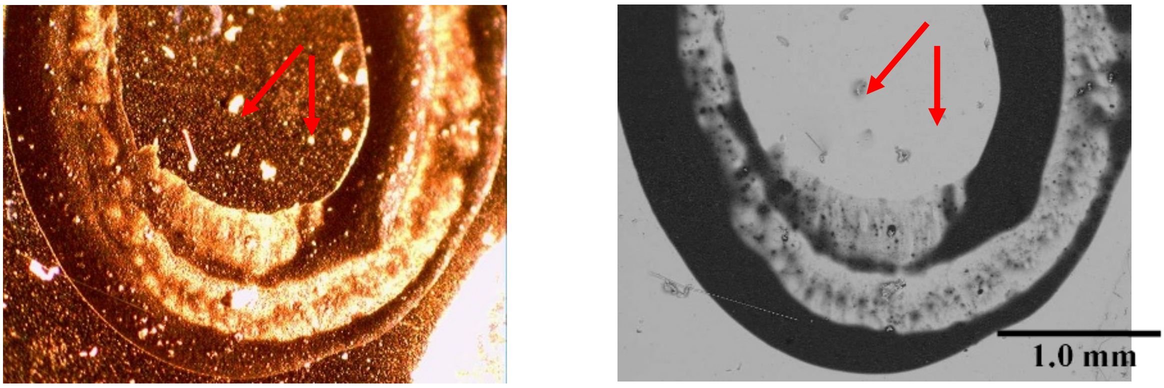
IEC 2279/12

IEC 2280/12

a) Optical microscope

b) SEM

Figure C.5 – Comparisons between whisker observations by microscope and SEM



IEC 2281/12

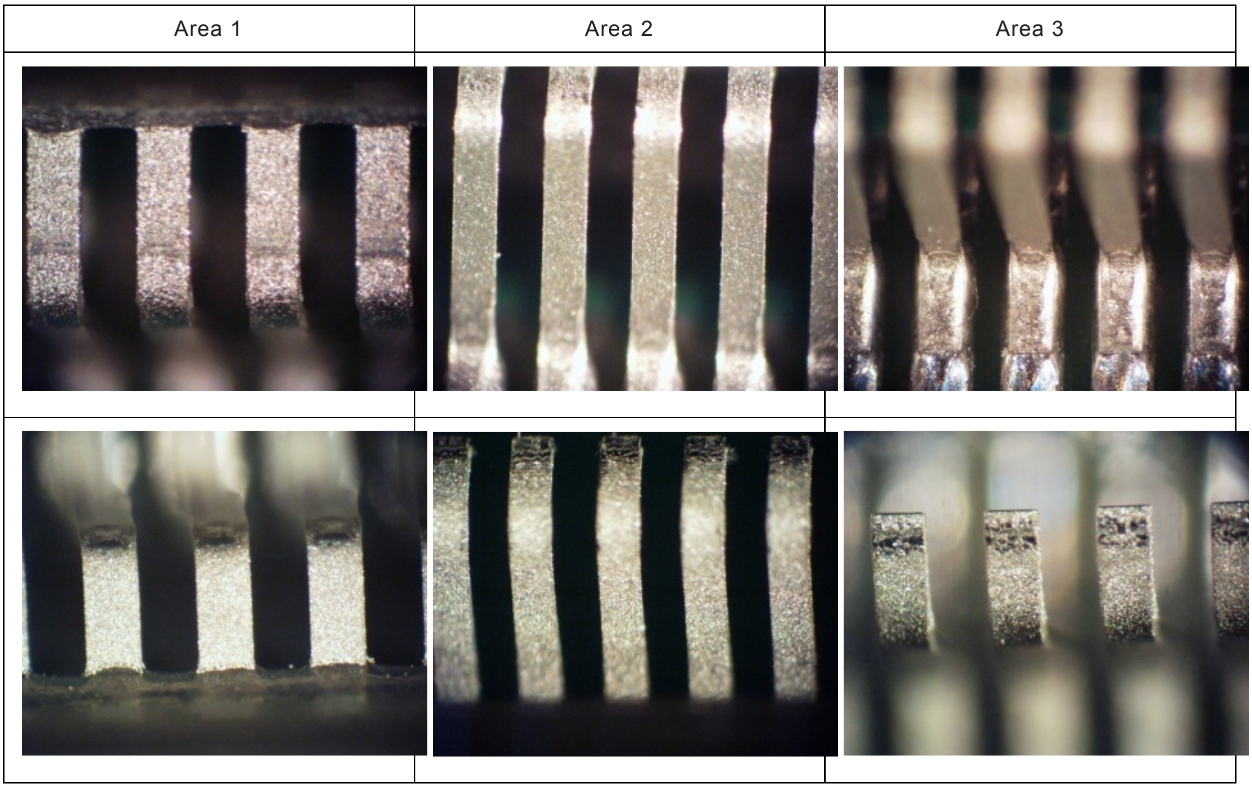
IEC 2282/12

a) Optical microscope

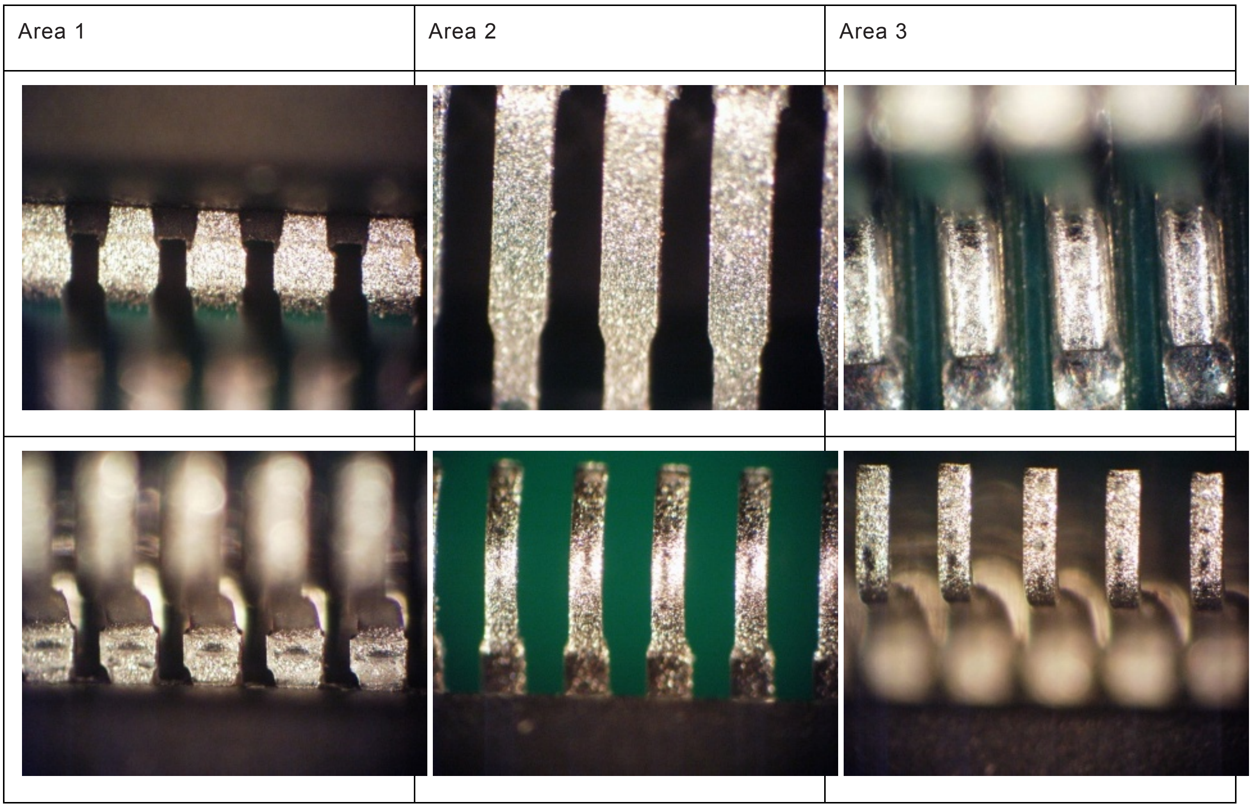
b) SEM

Figure C.6 – Limitation of microscope observation

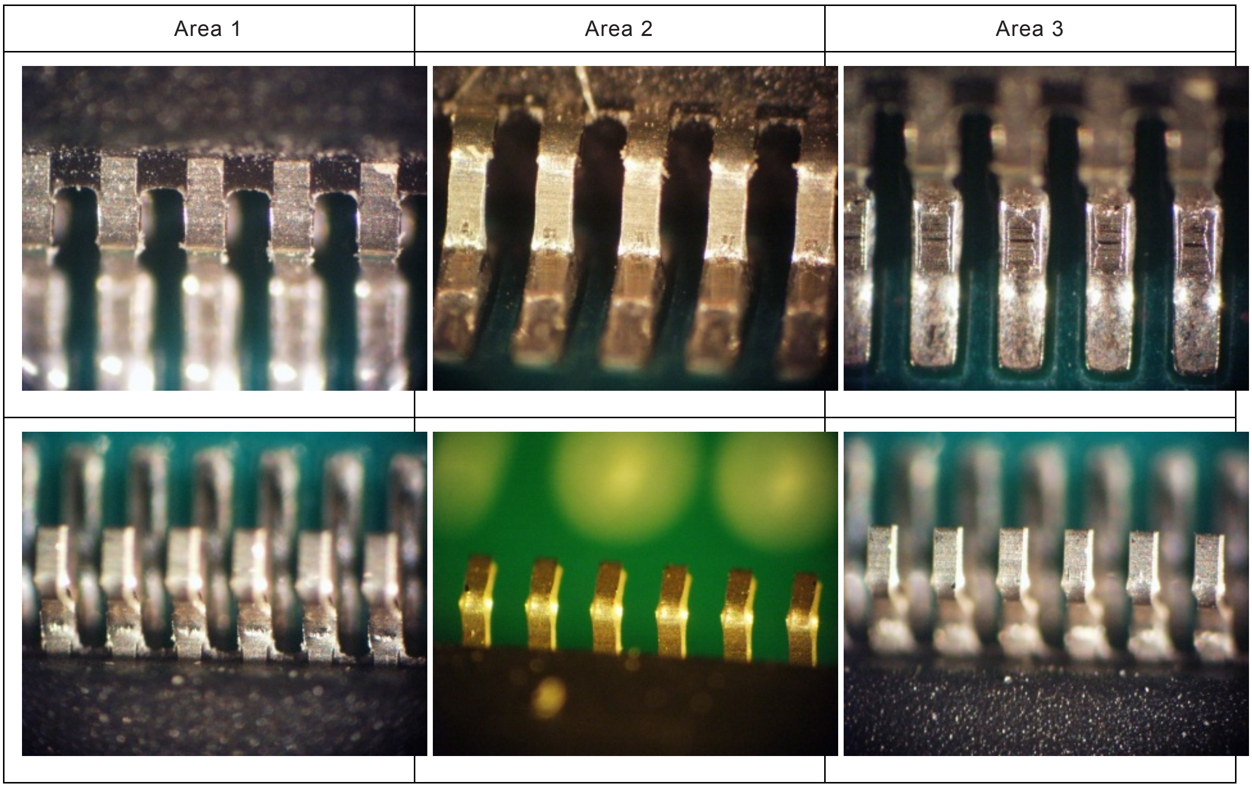
Figures C.7a) through f) describe preliminary whisker examination in non-coated test specimens.



a) QFP package

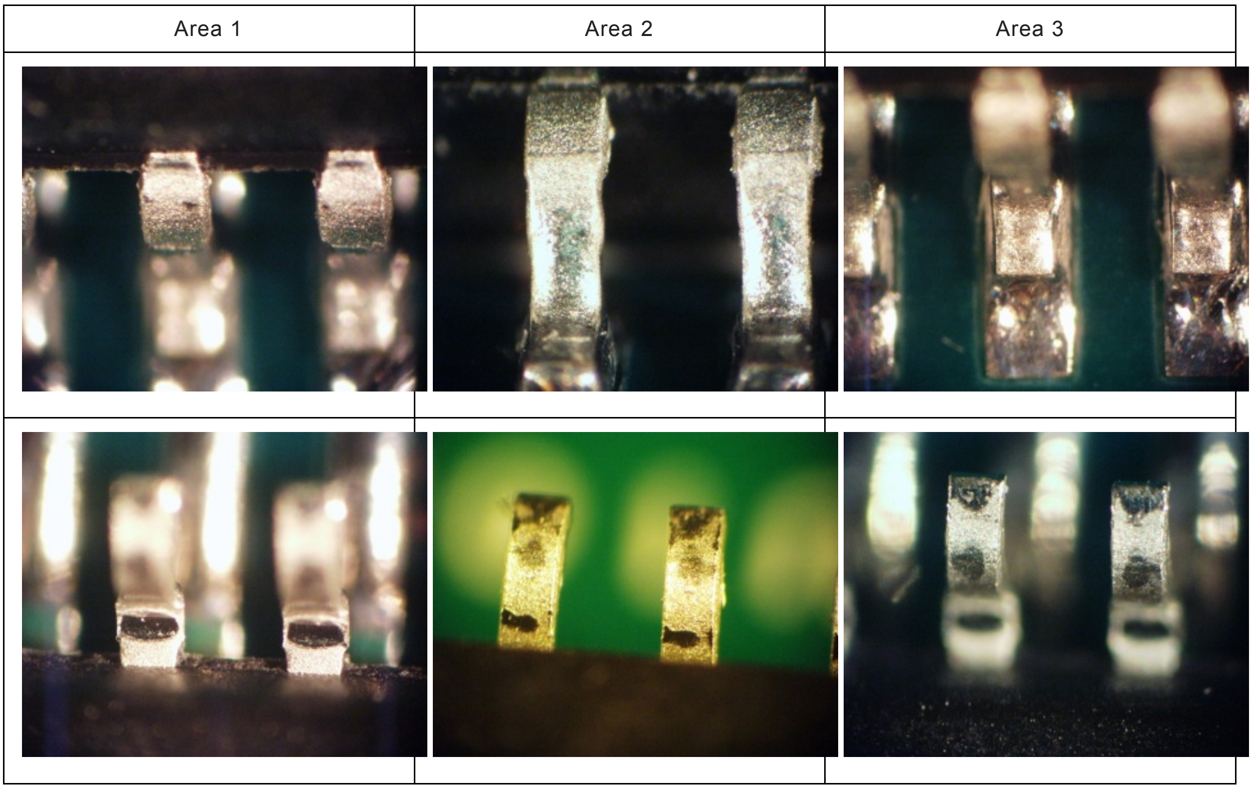


b) PQFP package



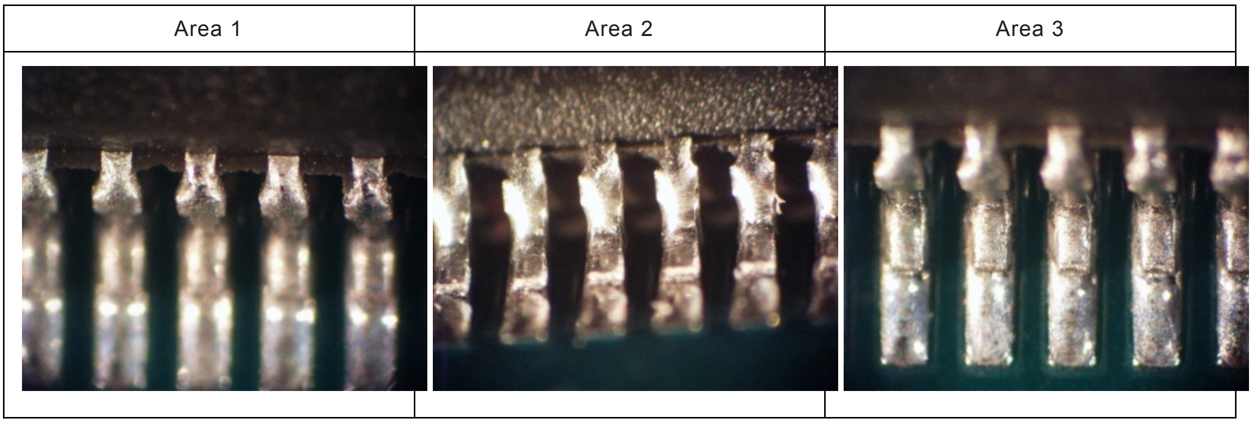
c) TQFP package

IEC 2285/12



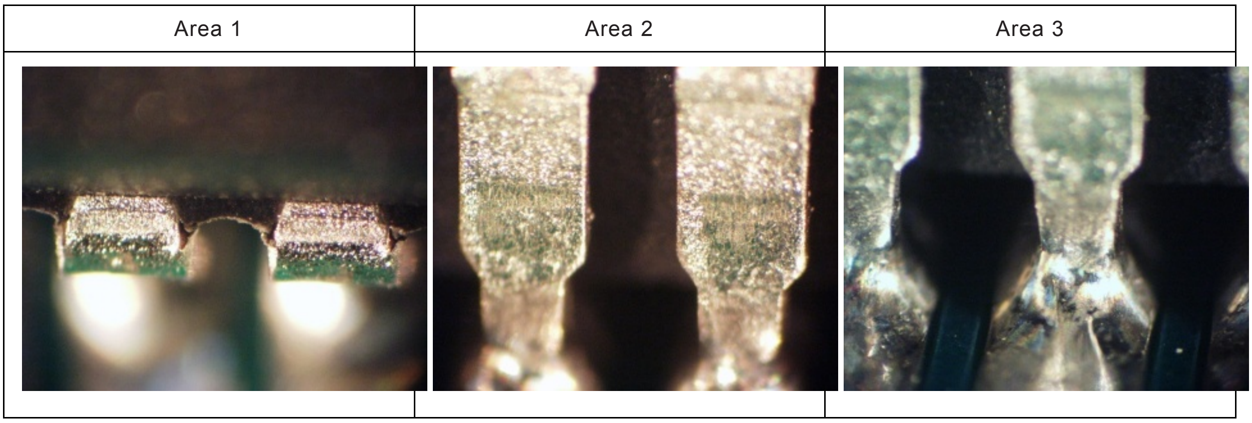
d) SOIC package

IEC 2286/12



e) TSOP package

IEC 2287/12



f) PLCC package

IEC 2288/12

Figure C.7 – Preliminary whisker examination in non-coated test specimens

C.3.3 Inspection using scanning electron microscope

Full characterization of lengths and densities will likely need to be made using a scanning electron microscope (SEM) using a minimum of 250X magnification.

Annex D
(informative)

Analysis and risk assessment guidance

D.1 General

In order to make a final determination of a control level or a particular mitigation strategy, many programs will require a risk assessment. Although quantitative risk calculations and probabilities may not be possible, qualitative risk assessments will need to be performed if reasoned decisions are to be made concerning the use of tin.

Tin whiskers can induce failures by various mechanisms. All mechanisms that are applicable to the circumstances under assessment should be considered.

a) The vast majority of reported tin whisker-induced failures have resulted from the growth of the tin whisker from one conductor so that it bridged the gap to an adjacent conductor at a different electrical potential, including the possibility of whisker-to-whisker shorts. The bridging creates a short circuit between the two conductors, often resulting in destruction of the whisker in the manner of a fuse element. For low pressure or high voltage applications, plasma events may result from the shorting.
b) A second failure mechanism has also been reported. With this mechanism a whisker grows in one location, becomes dislodged, and is transported to another location where it bridges between two conductors creating a short circuit. (This failure mechanism has been widely reported to have been induced by zinc whiskers.)
c) Whiskers that become loose within an assembly that is highly sensitive to contamination can pose a variety of risks, depending upon the system including: disruption of optics, disruption of micromechanical function, blockage of extremely small orifices, etc.
d) Whiskers that grow from the surfaces of RF waveguides into the region of space where the RF fields are propagating can affect the performance of the device, without necessarily contacting a second surface.
e) In high voltage applications, whiskers that grow from surfaces into regions of high electric field strength could result in failures without whiskers necessarily contacting an adjacent conductor.

The performance of these assessments should take into account the various factors that affect the risk of occurrence of these tin whisker-induced failures. There are five principal factors that should be considered in assessing such risks. These are:

a) The propensity of the Pb-free tin surface in question to grow whiskers of a given length, in a given abundance, in a given time frame.
b) The ability of whiskers growing from that surface to create an electrical short directly to an adjacent metallic surface. The principal factors for consideration here are the distance between conductors and the existence and nature of any intervening barriers.
c) The ability of whiskers to break off and to migrate to a different location in the system, where they could create electrical shorts or act as general contaminants in especially sensitive assemblies.
d) The vulnerability of the system to suffer performance degradation due to electrical shorts such as might be created by tin whiskers.
e) The vulnerability of the system to suffer performance degradation to the presence of whiskers as general contamination.
f) The vulnerability of the circuit to non-contacting failure modes due to RF or high voltage considerations.

The detailed contributors to these factors are discussed in reference [78].

It is important to note when performing risk assessments that the certainty that a whisker will fuse open does not imply that there is zero risk of failure. Certainty of fusing only implies that any failure condition is likely to be intermittent. There are numerous examples and literature of whiskers which fused, but still cause the system-level failure (see [79] [80]).

The rationale supporting risk assessments will need to be recorded, to preserve traceability for audit purposes. This requirement, together with typical industry quality requirements (such as ISO 9000) creates a strong incentive for the establishment of standardized approaches for risk assessment within each organization, at the minimum.

There are three basic approaches to standardized risk assessment in this context:

a) Assignment of "cognizant subject matter experts" to review, record rationale, and signoff each risk assessment.
b) Establishment of a set of rules-based criteria that define conditions under which the risks are deemed to be acceptable.
c) Development of an algorithm that encompasses risk factors of concern that can be used to define a metric of risk on a standard basis.

In practice, some combination of these three approaches may be used in concert.

An example of a rules-based criterion that might be used for establishing a risk threshold could be: circuit cards which are 100 % covered by a urethane conformal coat to a thickness of 100 μm minimum shall be considered to provide acceptable mitigation against tin whisker risks for whisker mitigation control level 2B hardware. This is an example and is not intended as a recommendation.

Examples of algorithms for use in calculating a risk metric are described in reference [35] and [78]. Users may consider applying these existing algorithms without modification, modifying them to suit specific needs, or using them as a basis for the development of new algorithms. (The algorithms described in these references are available for use in the public domain, without restriction.) There have also been examples of Monte Carlo approaches being taken to assess risk. [17] [30] [82]

D.2 Data relevant to tin whisker risk assessment

The information relevant to a tin whisker risk assessment is, in some cases, different than what is normally provided in a reliability or risk report. For example, unlike many failure mechanisms, tin whiskers grow equally well, if not better, under storage conditions as compared to application environments. If the application is likely to have a long period of storage, it is recommended that customers require suppliers to address risk from this period or include it in any life-time calculations.

The following list represents information that is recommended to be gathered and provided in the documentation, to the degree reasonable, particularly in a control level 2C assessment:

Component control level information

- type of finish (pure tin or tin alloy, plated or dipped);
- substrate and underplate materials;
- type of component;
- approximate area of Pb-free tin surfaces;
- encapsulant, potting, or coating over the Pb-free tin material and other surfaces, if applicable;
- internal gap distances.

Process information

- installation process (kind of solder, epoxy attach, or other material attach; hand or automated process);
- temperature exposures during installation and processing;
- encapsulations, potting, conformal coats or other coatings applied (including thicknesses);
- methods of examining coverage of solder or other installation material and coatings, including photos, if available.

Application control level information

- gap distance if whisker attached to Pb-free tin surface;
- gap distance for free-floating whisker;
- current and voltage available if a whisker were too short to an adjacent surface;
- current and voltage available if a free floating whisker were too short;
- level of concern about FOD in general for unit;
- planned test, repair, and replacement schedule.

Environmental information

- storage temperature (keeping in mind that whisker grow best at just above room temperature), humidity, atmosphere (pressure and corrosion), and lifetime;
- field temperature (keeping in mind that whisker grow best at just above room temperature), humidity, atmosphere (pressure and corrosion), and lifetime;
- temperature cycling expectations;
- expected airflow (possibility of breaking whisker free);
- expected vibration (possibility of breaking whisker free).

D.3 Role of whisker propensity tests

Although the mechanisms for tin whisker growth are still unknown, there are several test methods being used by suppliers in the industry. Industry standard tests do provide a common method and comparable data.

Many piece part suppliers are involved with developing tin whisker test methods and finish qualification methods, examples include JESD22-A121 or JESD201. Tests typically include aged samples being put through thermal cycling, humidity, high temperature, and ambient testing. Because these tests are developed for the commercial community and most commercial products have an expected lifetime of 3 to 7 years, it is expected that positive results on these tests would generally only be applicable to products with those lifetimes or those with thorough inspections in that time-frame. Thus, there is a preference for parts that have passed the tests over those that have not, but testing alone does not mitigate or even quantify the risk to ADHP systems.

For products with longer lifetime requirements or without thorough inspections in less than 7 years, if qualification or other test data is included, 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. Note 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. This is particularly true for systems with greater than 20 or 30 years of storage and mission life, harsh temperature cycle environments, or harsh humidity environments. Even tests that show whisker growth rate slowing should be applied with caution as periods of dormancy have been observed on whiskers.

D.4 Analyses of field data

Suppliers' field data of historic reliability on hardware using tin piece parts may provide insight into the risk of tin whiskers. Historic failure databases of these tin piece parts in these applications might include some tin whisker failures, if failures were possible, but their cause may not have been traced to a whisker.

However, care should be taken in extrapolating field data results. Different plating processes, from different suppliers, may have different propensities for whiskering. A growing number of piece parts with Pb-free tin finishes means there are more opportunities for whiskers to grow and to produce failures. The similarity of the field data to future use should be addressed in any analysis taking this approach.

Several things should be kept in mind when a supplier claims they have never experienced field failures due to tin whiskers. First, past failure analyses (if conducted) most likely did not consider whiskers as a possible failure mode and did not look for whisker presence. Secondly, a failure due to a whisker-induced short circuit usually results in the vaporization of the whisker, making it difficult to prove that the failure was caused by a whisker. Thirdly, some very knowledgeable authorities on metal whisker feel strongly that many ‘cannot duplicate’ or ‘no fault found’ failures have been due to whiskers.

D.5 Risk of plasma events

Once a whisker is long enough to form a mechanical contact between two electrically conductive surfaces, its insulating oxide coating may break down to start conducting current (this dielectric breakdown was demonstrated by Karim Courey to be in the range between 0,2 V and 50 V). While conducting electrical current, the whisker is heating up due to joule heating, and if the current is high enough then the tin in whisker will melt. Depending on the voltage between the two surfaces that the whisker is bridging, the current (and subsequently joule heating) may be high enough to vaporize the whisker into a neutral gas before the molten tin beads up and disrupts the electrical circuit. This process forms a flash of incandescence referred to as a 'spark'. When the voltage potential between the two surfaces that a whisker bridges is large enough (typically greater than 12 V) the neutral vapor of tin can ionize (removing electrons from atoms) and ignite into a plasma. If sufficient current is flowing through the plasma and feeding metal into it by boiling off surrounding metal, a sustained metal vapor arc is created. The arc will continue until either:

- the voltage supply is terminated by the circuit, or
- the arc is starved for ionized gas if no more material is being supplied and the gap between conductors becomes too large, breaking up the conductive plasma, or
- the presence of materials with higher ionization energy than tin, such as air, or polymers, that are not able to ionize under a given potential and as a result quench the arc.

A metal vapor arc is capable of carrying currents up to several hundred amperes. As determined experimentally, a minimal voltage required for sustaining a tin metal vapor arc is 12 V with a minimum current of 0,75 A. [83] However, a short spark event may occur even in circuits at low voltages, when inductance and capacitance in the circuit can kick up the voltage and current to needed values.

Annex E
(informative)

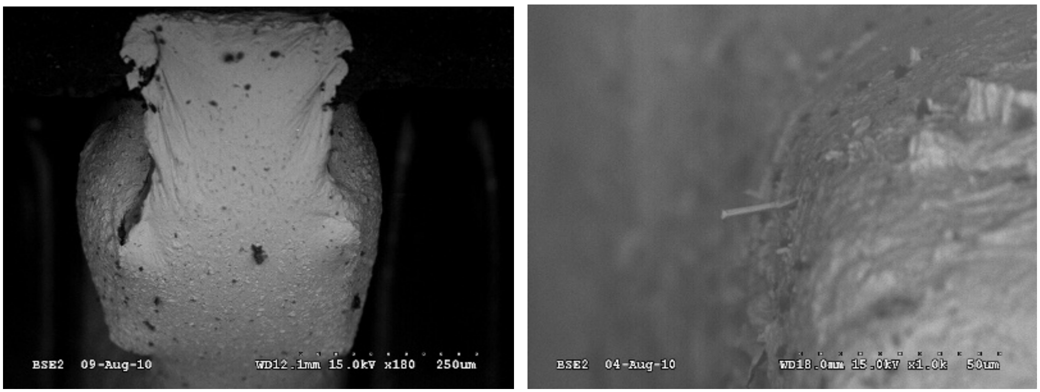
Whiskers growing from solder joint fillets and bulk solder

E.1 General phenomenon of Sn whisker formation in SnPb and Pb-free solder

Tin whisker formation is a general phenomenon that may occur under certain conditions to pure tin and tin alloys including solder. [84] [85] The limited length of tin whiskers growing from SnPb generally does not raise concerns with respects to electrical short circuits. In addition, Sn-based Pb-free solder fillets are also not a concern in non-corrosive environments. An example of whisker formation on solder fillets after testing in the Celestica Laboratories is shown in Figure E.1. Figures E.1a) and E.1b) show a scanning electron microscope (SEM) photograph of whiskers growing from a 63Sn-37Pb alloy solder joint at 85 °C/85 % RH, 500 h followed by –55 °C to 85 °C air to air cycling, 1 000 cycles. The maximum whisker length growing from the Sn-rich phase of SnPb solder fillet does not exceed 6 μm. The whiskers formed from SAC305 solder joints tested in parallel with SnPb assemblies are 3,5 times longer (Figures E.1c), E.1d)). The longest whisker detected in this testing is 21 μm and still is not a significant reliability concern when corrosive conditions are mitigated.

IEC 2289/12 IEC 2290/12

a) SnPb solder joint, SEM, 200X, b) SnPb solder joint, SEM, 3 000X



IEC 2291/12 IEC 2292/12

c) Pb-free solder joint, SEM, 180X d) Pb-free solder joint, SEM, 1 000X

Figure E.1 – Whiskers and hillocks formed after 500 hours of storage at 85 °C / 85 % RH followed by –55 °C to 85 °C air to air cycling, 1 000 cycles

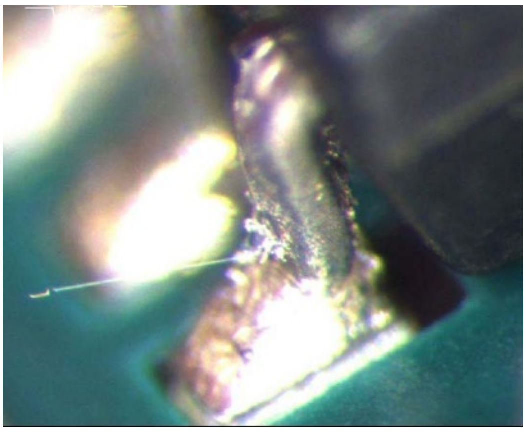
E.2 Long Sn whiskers in Pb-free solder

E.2.1 General

Since the widespread introduction of Pb-free solder to electronics assembly, there have been several observations of long whiskers growing from the bulk solder of leaded and ball grid array joints. The reported cases may be divided into two groups: (1) Sn-Ag-Cu solder with ionic contamination and (2) Sn-Ag-Cu alloys with additions of rare earth elements (REE) such as Ce, La, Er, and Y.

E.2.2 Long Sn whiskers in Pb-free solder with ionic contamination

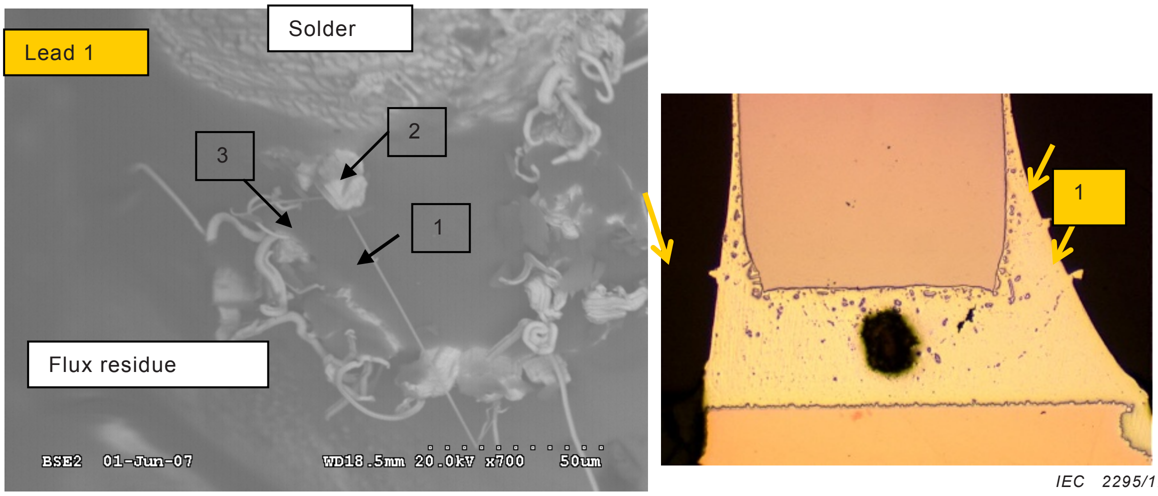
In 2007, the first failure related to long whisker growth from SAC405 solder was reported by Terry Munson (Foresite). [86] The whisker grew from a solder fillet of a MOSFET device (Figure E.2) The device had an alloy 42 lead-frame with matte Sn finish and was assembled using no-clean SAC405 solder paste. The assemblies were subjected to 20 days of life testing at 65 °C and 25 % RH with blowing air. The failure occurred due to two separate whiskers touching. The possible root cause of long whisker formation was attributed to flux residue that may promote corrosion.



IEC 2293/12

Figure E.2 – Long whisker growing from SAC405 no-clean assembly reported by Terry Munson (Foresite)

In 2008, whisker growth was observed on SAC solder in the presence of contamination. [87] The whiskers appeared after life testing for 10 days at 60 °C and 20 % to 30 % RH with voltage cycling. Optical and scanning electron microscopy (SEM) with EDX following by cross-sections through whiskers were performed. The detailed metallurgical analyses revealed that Sn whiskers originated not from the component lead plating as was expected, but from bulk SAC405 or SAC305 solder (Figure E.3). A high precision metallographic technique using progressive polishing was developed to examine the details of whisker formation. The paper discussed the microstructural relationship between the whiskers and the following factors: solder microstructure and its modification during oxidation and corrosion, alloy 42 lead-frame material, lead plating quality, component contamination and flux on solder.

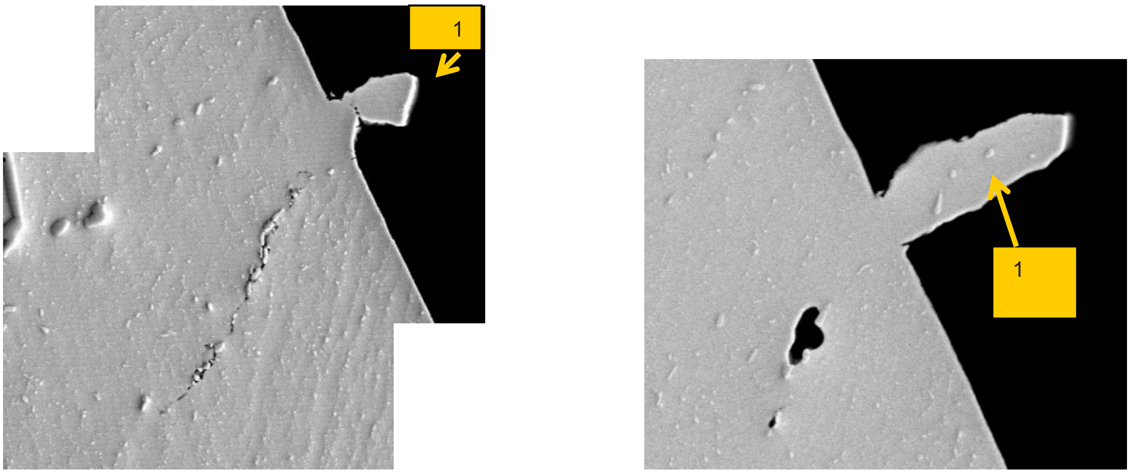


IEC 2294/12

IEC 2295/12

a) SEM, 700X

b) Cross-section, 200X



IEC 2296/12

IEC 2297/12

c) Whisker 1 shown with arrow on cross-section b

d) Same whisker as in c) after next sequential polishing, SEM, 1 800X

Key

1 thin long filaments (tin whisker)

2 thicker and shorter rods

3 hillocks

Figure E.3 – Whiskers and hillocks protruding through flux residue and growing from solder free of the flux residue [87]

It was concluded that the whisker formation origin from Pb-free solder is corrosion related. Corrosion propagates through the eutectic regions in the interdendritic spaces of the solder accompanied by intensive diffusion in the bulk solder that causes the solder to be depleted of Ag and Cu. The depleted solder area may experience compressive stresses from the rest of the solder, which may result in recrystallization, (and possibly dynamic recrystallization [84]) along with hillock and whisker formation. As a result of this study the relationship between ionic contamination of virgin piece parts and whisker growth propensity was revealed.

Although not focusing on solder joints, a 2009 investigation was initiated to evaluate of the potential of tin whisker growth induced by ionic contamination exposure [88] Samples of electroplated tin on a stressed copper substrate were subjected to three different chlorine solutions for a period of 72 hours, after which high temperature/high humidity conditioning (85 °C / 85 % RH) for 4 000 hours was conducted. Optical and scanning electron microscopy (SEM) inspection at 500 hours intervals for five designated locations was conducted with all anomalies, tin whisker lengths and population densities being documented. The test results revealed that both tin whisker length and population density were impacted by the ionic contamination (see Figures E.4 and E.5).

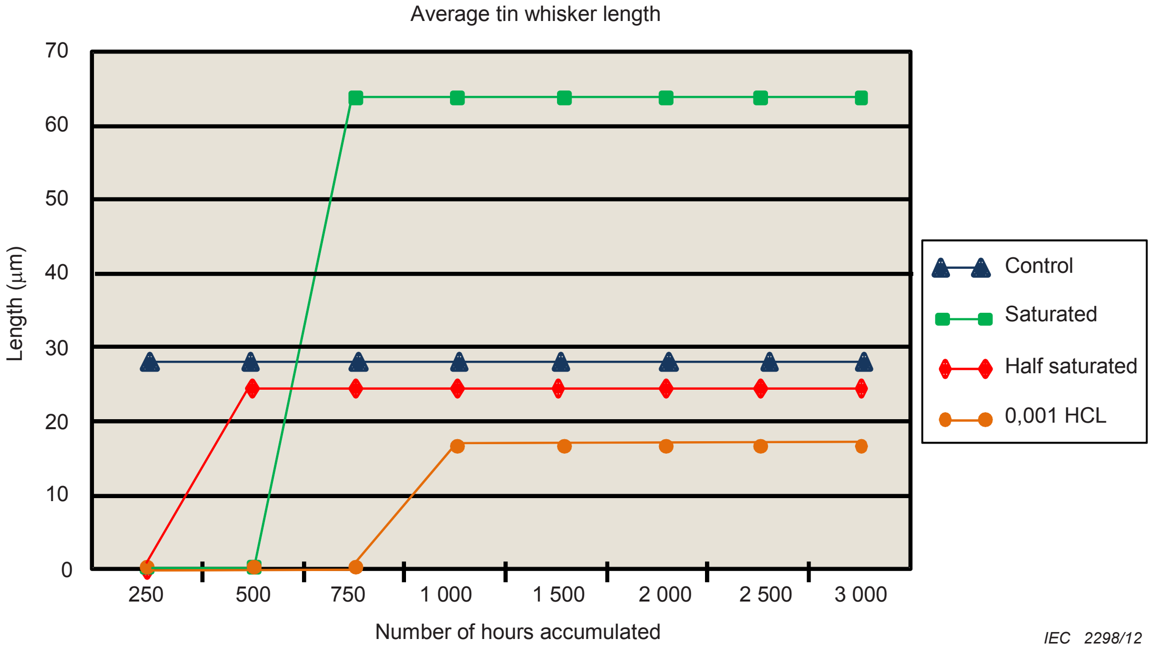


Figure E.4 – Tin whisker length impact by ionic cleanliness

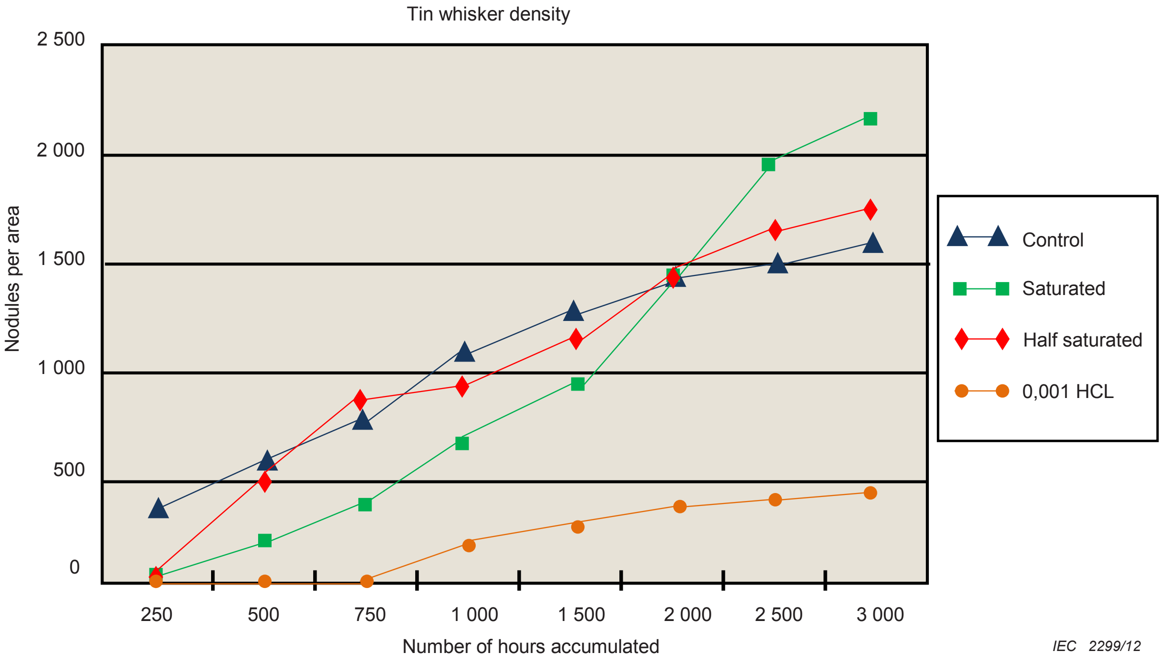


Figure E.5 – Tin whisker density impact by ionic cleanliness

The recent data by Snugovsky [89] fully confirmed the importance of cleanliness in whisker mitigation for solder joints. Assemblies with components cleaned before soldering to achieve a level of ionic contamination 10 times below acceptable level and with post assembly cleaning, did not create whiskers after 500 hours in a 85 °C / 85 % RH environment. Long whiskers were formed on assemblies with as-received parts, and on systematically contaminated parts with the ionic contamination above the acceptable level. Additional flux residue promotes whisker formation further even if the flux was halide free ROL0 (a rosin flux containing 0 % Halide by weight with a low flux/flux activity level) containing only adipate (Figure E.6).

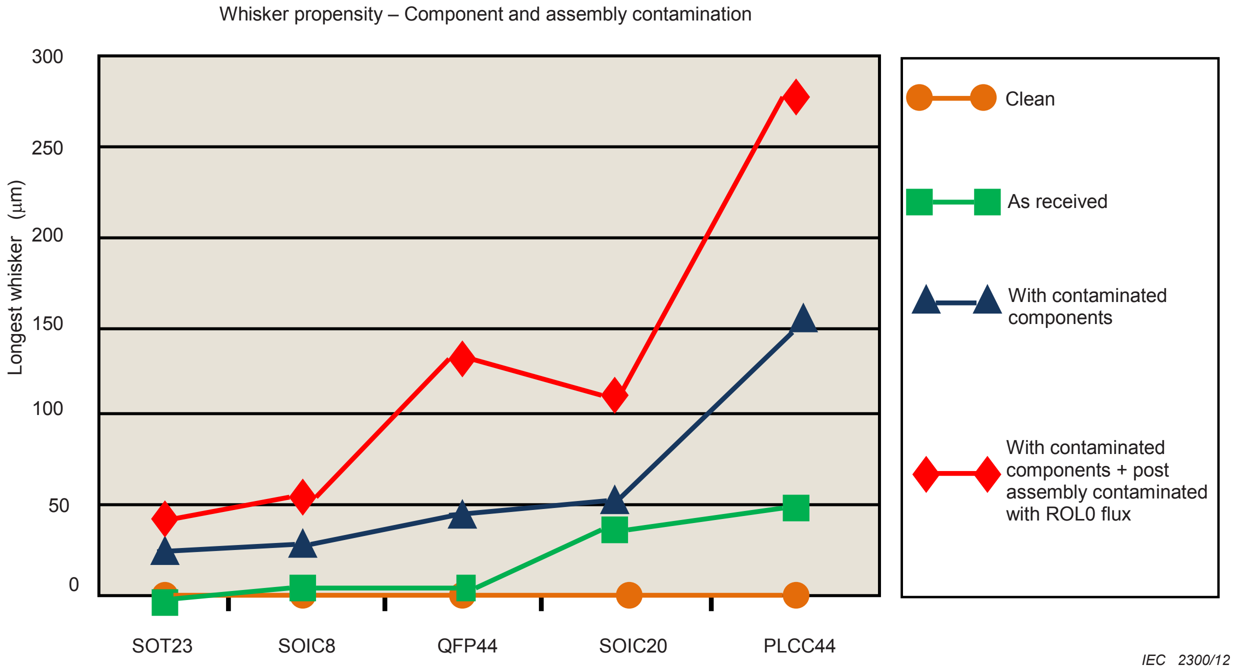
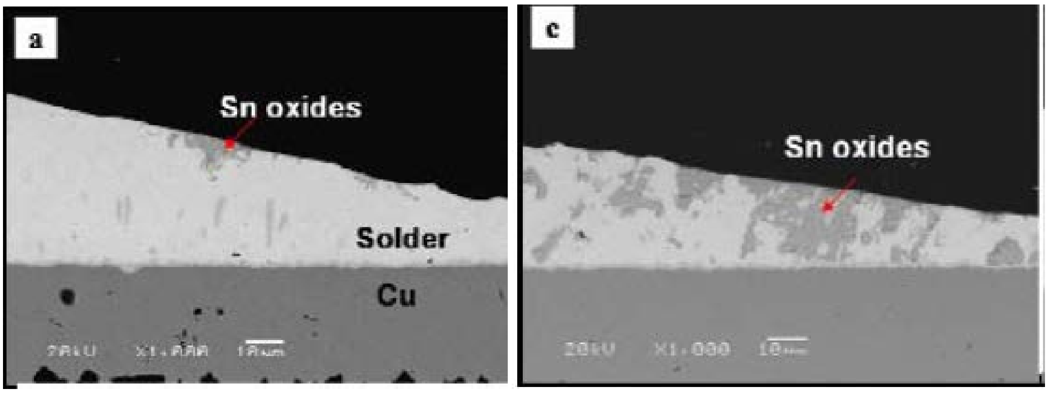


Figure E.6 – Whisker length depending on component and assembly cleanliness

Nihon Superior Co., Ltd [86] investigated the relationship between whisker growth in conditions of heat and humidity and surface corrosion accelerated by the residues of the fluxes typically used in the three common soldering processes, wave soldering, hand soldering and reflow soldering. They analyzed Sn-3,0Ag-0,5Cu (SAC305) and Sn-0,7Cu-0,06Ni-0,1Ge solder alloys that were applied to the test vehicle, an interdigitated comb pattern by dip soldering, hand soldering and reflow soldering with a variety of commercially available fluxes. Under conditions of 60 °C / 90 % RH and 85 °C / 85 % RH, corrosion that appears to be related to the character of the residues used in the soldering process can cause solder to produce whiskers long enough to compromise circuit reliability. The authors suggested that the likelihood of whisker growth occurring on Pb-free assemblies soldered using no-clean technologies can be significantly reduced by using a flux which does not promote the sort of corrosion that can generate compressive stress in the solder.

The JEITA Activity report of solder whisker growth [87] indicated that Sn whiskers also form on solders and not only electroplated Sn. The wetting behavior of Pb-free solders is worse than is the case for SnPb solders. High flux activity is thus required to enforce good wetting, but the active agents used for this contain Cl or Br and cause corrosion when used; the corrosion of solder may be a trigger for whisker formation. Consequently, processing conditions need to be controlled during reflow, as does the flux composition, to prevent the formation of Sn whiskers on Pb-free solder joints.

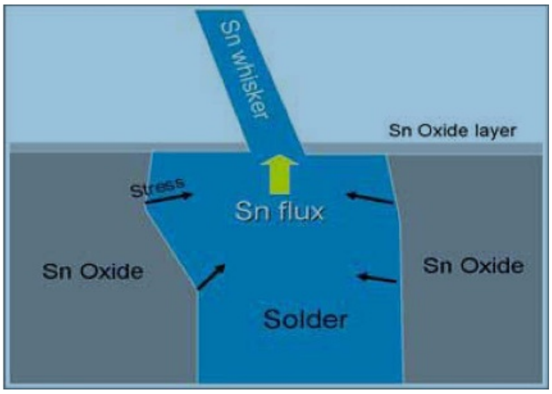
Another recent work [92] reports on Sn whisker formation on solder during 85 °C / 85 % RH testing by looking at the effects of process atmosphere – a nitrogen atmosphere and an air atmosphere, during reflow and the effect of three fluxes with different concentrations of HBr activators. It was found that Sn whiskers were not formed on solder fillets when using a halogen free flux or a nitrogen atmosphere. Both suppressed the oxidation of solder. Solder joints reflowed in an air atmosphere using halogenated flux examined a large amount of Sn-oxide penetrated into the solder fillet (Figure E.7). The formation of Sn oxide results in a volume expansion of about 29 % to 34 %. Consequently, the formation of Sn oxide can be a source of compressive stress that acts on Sn grains. To release this stress, Sn whiskers grow from the Sn surface (Figure E.8).



IEC 2301/12 IEC 2302/12

a) QFP with Cu lead-frame b) QFP with alloy 42 lead-frame

Figure E.7 – Microstructures of solder fillet with 0,8 % HBr activated flux assembled in air after 1 000 hours at 85 °C / 85 % RH



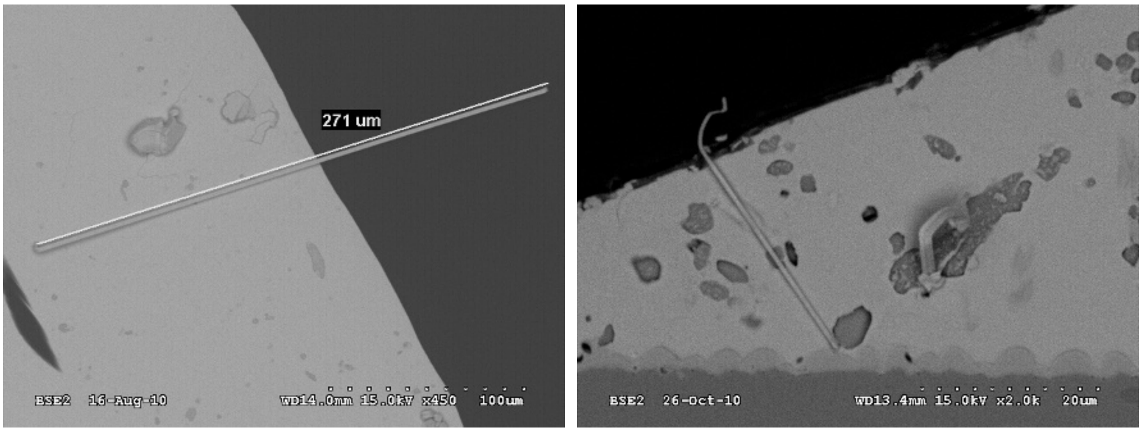
IEC 2303/12

Figure E.8 – The mechanism of Sn whisker formation on solder fillet induced by oxidation

E.2.3 Long Sn whiskers in Pb-free solder with rare earth elements

Recently there were several publications discussing whisker growth from Pb-free solder with additions of REE [93] [94] [95] [96]. REE additions are used to improve mechanical properties and wetting of SAC alloys. Tung-Han Chuang and Shiu-Fang Yen discovered that Sn whiskers appeared in Sn3Ag0,5Cu0,5Ce solder joints of ball grid array packages after storage at room temperature. [90] The high propensity to whiskering was attributed to the $CeSn_3$ particles that exist in solder after reflow and oxidize rapidly during natural aging. The surface oxide of the $CeSn_3$ consumes more Ce than Sn. The Ce depleted layer that contains almost pure Sn is left behind the oxide layer. The abnormal whisker growth was attributed to the compressive stress in the Ce depleted Sn layer. Similar conclusions were drawn by authors [93] who studied oxidation-induced whisker growth on the surface of Sn and rare-earth-containing alloys. The driving force for whisker growth was, as the authors concluded, the compressive stress induced by the volume expansion of $(La0,93Ce0,07)Sn_3$. The Sn atoms released by the oxidation reactions were extruded through the oxide film. In addition, the huge compressive stress accumulated by the volume expansion of the drastically oxidized intermetallics extruded the Sn-La-Ce matrix around the oxides to form the coarse hillocks.

Whiskers growing from bulk SAC105 solder with REE during 85 °C / 85 % RH exposure were detected in some projects. [97] Long whiskers were also observed forming from the surface of cross-sectioned samples of bulk solder and solder joints stored in a nitrogen atmosphere and ambient temperature for 121 and 194 days (Figure E.9).



IEC 2304/12

IEC 2305/12

a) SAC105 with 0,5 % Ce, bulk solder, ambient T in nitrogen chamber, SEM, 450X

b) SAC105 with 0,5 % La, bulk solder, ambient T in nitrogen chamber, SEM, 2 000X [34]

Figure E.9 – SAC105 bulk solder at ambient T in nitrogen chamber [34]

It is believed that whiskers on Pb-free solder form because of local stresses built up during oxidation and corrosion, resulting in deformation of Sn-rich phase and stress relaxation at the surface, presumably by dynamic recrystallization. Stresses from oxidation and corrosion may be coupled with those from intermetallic growth and coefficient of thermal expansion differences.

The selection and control of materials and process parameters in Pb-free assembly is vital in terms of whisker mitigation, which is fundamentally different from SnPb assembly.

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[9] Previously known as GEIA-HB-005-3. IEC/PAS 62647-23 is in the process of being revised and will be issued as IEC/TS 62647-23.

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