An updated Application-Specific Tin Whisker Risk Assessment Algorithm, and its use within a process compliant to GEIA-STD-0005-2.

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ABSTRACT

Military and aerospace electronics manufacturers are forced to deal with components that are available only with a pure tin termination. Pure tin is not universally acceptable in all military and aerospace applications due to its propensity to form whiskers. However, pure tin terminations may be acceptable some applications. The recently released industry-standard GEIA-STD-0005-2, "Standard for Mitigating the Effects of Tin Whiskers in Aerospace and High Performance Electronic Systems" establishes a framework within which manufacturers and their customers can establish guidelines for the control of tin usage. One popular method for determining the suitability of pure tin in a given application is the use of a standard tin whisker risk assessment algorithm. The use of an algorithm facilitates standardization of tin risk decision-making across and between organizations.

A widely used tin whisker risk assessment algorithm that was first published in 2003, and was revised in 2004. Tin whisker research that has occurred over the last two to three years has resulted in improved understanding of the factors that affect the risks posed by tin whiskers. These new insights have been used to develop an enhanced version of the existing algorithm. This new algorithm is presented, together with a discussion of how the new insights were used in its development. A discussion of how to use the algorithm within a process compliant to the requirements of GEIA-STD-0005-2 is also provided.

Background

The use of tin plating was long eschewed by military equipment manufacturers because of the risk posed by tin whiskers. Recently however, increasing use of tin plating by component vendors has forced producers of military and other high reliability systems to consider incorporating tin-plated finishes in their products. This situation creates the need for performing numerous risk assessments to determine the acceptability of tin-plated parts for many divergent applications.

The commercial electronics manufacturers have responded the challenge of managing tin whisker risks through the iNEMI consortium, which has produced a set of recommendations and test methods. One of these documents JEDEC JESD 201 states that: "Pure tin and high tin content alloys are not typically acceptable". For: "Mission/Life critical applications such as military, aerospace and medical applications". In other words, these documents are not intended to provide guidance for producers of military and other high reliability systems.

The military and aerospace industry have established their own working group (the Lead-Free in Aerospace Project-Working Group), which has issued a set of documents through GEIA. The document that defines methodologies for tin whisker risk mitigation is GEIA-STD-0005-2. One of the requirements embedded in this standard is that the techniques that are employed to evaluate tin whisker risk mitigation must be described. One possible method mentioned in the standard is to use a risk assessment algorithm.

An application-specific tin whisker risk assessment algorithm was first devised and published in 2003.[1] This particular algorithm was updated and slightly revised version was published in 2004.[2] Since that time there have been advances in the understanding of the tin whisker phenomenon that can now be used to further refine the algorithm. This paper describes this new version of the algorithm together with the rationale for the changes.

Concepts for improvements to Revision B of the existing algorithm.

Recently published work in the area of whisker mitigation, experience with the use of the algorithm locally, and feedback from other users highlight five areas where improvements may be made. These are:
Factors affecting whisker growth densities and whisker length distributions

- The contribution of inter-conductor spacing,
- The mitigating effects of conformal coating,
- The distinction between bright and matte electroplating, and
- The mitigation provided by special-purpose anneal processes validated by testing.

Each of these areas are discussed in detail below.

Conductor spacing-
A comparison was made between the relative risk associated with different inter-conductor spacings as provided by Revision B of the algorithm and that provided by the distribution data from Hilty et al.[3] It was concluded that the whisker data indicate that the risk at spacings below 250 μ was higher than assumed by the algorithm, while the risk above 250 μ was lower. The following changes to the settings for the risk factor r1 are proposed:

Table I Current and proposed settings for factor r1

Spacing in Mils	Less than 10	10-50	50-100	100-500	Greater than 500
Revision B	2	1	0.5	0.25	0
Revision C	5	1	0.25	0.15	0

The risk factors from the two revisions are compared against the risk calculated from the date of Hilty et al. with the risk at 250 μ normalized to 1.0.

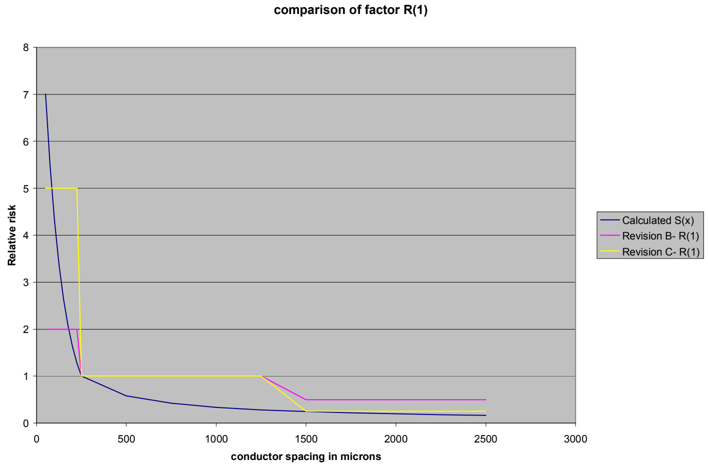

Figure 1. Revisions B and C factor R1 as compared against risk derived from whisker length distribution data for smaller inter-conductor spacings.

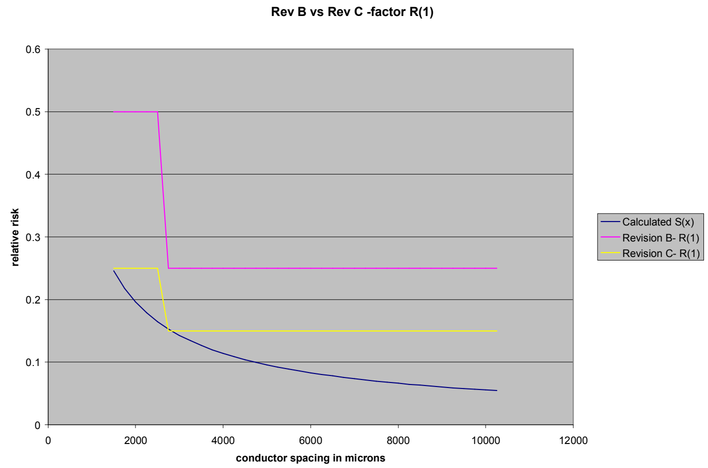

Figure 2. Revisions B and C factor R1 as compared against risk derived from whisker length distribution data for larger inter-conductor spacings.

The mitigating effects of conformal coating

In the instructions for Revision B, adjacent conductors which are covered by conformal coating are not considered to be possible destinations for a whisker-induce short. Therefore, the ability of conformal coating to reduce possible destinations for whiskers is accounted for by increasing the effective conductor spacing. In addition, conformal coating that is present directly on top of the tin is assumed to suppress the growth of whiskers. Finally, the amount of conformal coating that is used throughout the assembly is used to assess the risk of migrating whiskers causing shorts.

A model describing the mitigating effects of conformal coating has been previously presented.[4] This model defines two critical parameters for a conformal coating: E -the coating effectiveness-the ability of the coating to suppress the quantity of whiskers of a given length, and V-void fraction-that fraction of surface area that is not covered by an effective thickness of coating. An overall mitigation factor of V(V+E) was derived. Ideally, each manufacturer would measure values for these two variables for each coating that they apply. In practice we do not yet have these data in hand for the coating effectiveness. Some data is available for the effective void fraction of coatings.

It is proposed that conservative values for E and V the assigned for common coating processes for use in the algorithm, until such time that actual measured data may be used instead. The following values are proposed:

Table II conservative assumptions for conformal coating properties for use in the mitigation model.

Coating material	E	V	E+V
Paralyne	0.10	0	0.10
Urethane	0.10	0.05	0.15
Silicone	0.20	0.05	0.25
Epoxy	0.10	0.05	0.15
Acrylic	0.4	0.05	0.45

There are two values described how conformal coat mitigates risk. The reduction in the formation of whiskers is described by the quantity E+V, and the reduction in possible destinations as provided by the value V. I propose a defining two different risk metrics for each type of conformal coat, r8a = E+V, and r8b = V.

The distinction between "bright" and "matte" electro-deposits.

Data has recently come to light that casts serious doubt as to whether making a distinction between tin electro-deposits that are purported to be "bright" and "matte" is useful for assessing tin whisker risk.

Data was presented by Hilty showing an application where his particular "matte" plating produced far more whiskers then did his particular "bright" plating.[5] He expressed concern that he might be forced to provide a more whisker prone finish to some users if a prohibition of bright tin was enforced.

During a tin whisker workshop in San Diego it was reported that representatives from the chemical suppliers to the electroplating industry agree that there was no technical definition of bright versus matte tin that was universally applied through their industry. Many expressed the opinion that this term only described a cosmetic attribute.[6]

I therefore propose combining or previously separate options (bright and matte) into a single option (electro-deposit) for the purposes of the algorithm.

Special-purpose anneal and whisker resistance validated per the IPC/JEDEC test

Most component vendors that are delivering product that uses electro-deposited tin directly over copper, who were also attempting to pass the IPC/JEDEC tin-whisker test or utilizing a special-purpose anneal process. Vendors who take this level of care with their plating process, and to monitor whiskering tests would seem to be less likely to produce product that will suffer from high densities of particularly long whisker growths.

I therefore propose adding an additional option for factor r7, "plating heated after deposition" to be used for plating that has been subjected to a special-purpose anneal process AND the product has been certified to meet the tin whisker requirements of IPC/JEDEC JESD 22. This factor shall be 0.5.

Tin whisker length and densities

The risks posed by tin whiskers are strongly dependent not only upon the total number of whiskers that grow (density) but also upon how many of these whiskers tend to be long. In fact, whisker length distribution data indicate that the vast majority of whiskers that grow are of an insufficient length to bridge typical inter-conductor spacings. One underlying concept that quantitative approaches use is to treats the whiskering density in the length distribution separately. This approach has also gained some support after the publication of a table by Joe Smetana listing maximum whisker lengths observed under various conditions.[7] Although I am somewhat skeptical of any claim of "maximum possible whisker lengths" there is a body of evidence that indicates that the whisker length distribution can be significantly different depending upon the details of the application.

Detailed analysis of whiskers growing on tin plated over nickel appear to support the idea that one of the principal means by which nickel provides mitigation is through the reduction in the length of whiskers which grow. This fact is likely to be a feature of many effective mitigation strategies.

Separation of the dual contributions of decreasing whisker density and lowering whisker length distributions into the risk assessment algorithm requires changing the form of the algorithm, and cannot be compost by simply fiddling with the r-factors.

In revision B of the algorithm the overall risk is calculated (prior to logarithmic scaling) by multiplication of a growth factor (R_{growth}) and a geometric factor ($R_{geometric}$). I propose that revision C use instead two factors in place of R_{growth}: a whisker density factor ($R_{density}$), and a whiskering length factor (R_{length}). When this approach is combined with the revised factors for r1, the overall effect will be to significantly reduce the scores for applications with whisker-mitigated platings, where the inter-conductor spacing is generous, while maintaining high scores for the tighter spacings.

The density factor will be equal to the old growth factor, with the exception that the new conformal coat growth reduction factor $r8_a$ will be used instead of the old factor r8.

$R_{density} = r8_a\ [R_d + R_i + R_{cte} + R_{ex}]$

The new length factor will be a product of the factors that describe mitigation techniques employed to modify plating.

$R_{length} = (r3\ r5\ r7)$

I propose to modify the geometric factor by multiplying the conductor spacing factor r1 by the new conformal coat destination mitigation factor $r8_b$.

The final form of the total risk is defined by:

$R_{total} = (R_{length}\ R_{density})\ [r1\ r8_b + R_{secondary}]$
(with $R_{secondary}$ remaining unchanged from the prior revision)

Modification of the definition of factor r11, which is used to assess the vulnerability of the assembly to secondary shorts.

The current revision defines this factor in terms of the amount of conformal coating that is utilized on the assembly. Users of the algorithm have commented that this definition is not particularly useful when assessing an application that is in an assembly that does not consist of circuit cards. There are many different types of electronic assemblies that use point-to-point wiring, or other means of the connection. These include: RF assemblies, power regulation in distribution assemblies, and other special-purpose assemblies.

The intent of this factor is to quantify the number of locations where a migrated whisker could create a short. Accordingly, I propose to change the wording associated with this factor to match this intent, without changing the values or how it is used in the algorithm.

The new title of the factor is proposed to be "exposed potential short sites within enclosure". The options to choose from will be: many, some, few, almost none, none. Some explanation will be required so that users can assign these levels with some consistency.

Any enclosure that includes typical circuit card assemblies that are not protected by conformal coat will be instructed to select the option-"many".

The option "none" will be instructed to be selected only when there are no adjacent exposed conductor pairs closer than 1/2" apart anywhere within the enclosure.

Algorithms in context of GEIA-STD-0005-2

GEIA-STD-0005-2 defines a set of standard S This Factor in Terms for use in managing tin whisker risk in military and aerospace programs.

Application-specific risk assessments for the use of tin would typically not be part of a standard process for Whisker Control Level 3, because the use of tin is totally banned.

Whisker Control Levels 1 and 2A do not generally restrict the use of tin in any particular application. Therefore, application-specific risk assessments would typically not be performed as part of standard process.

Application-specific tin was her risk assessments will generally be applicable to Whisker Control Levels 2B and 2C.

Under Whisker Control Level 2C each and every incidence of tin usage must be analyzed, justified, and documented. A standard risk assessment algorithm offers one method of performing these analyses in a well-defined, and easily documented fashion.

Under Whisker Control Level 2B tin may be used under is a set of pre-defined conditions, or blanket exemptions. These conditions must be defined and justified. A standard risk assessment algorithm again can provide a well-defined and documentable method for justifying exemptions. the use of tin may also be justified on a case-by-case bases exactly as with Level 2C.

Quantitative approaches and rules-based approaches can also be used within the context of a process that is compliant with GEIA-STD-0005-2.

CONCLUSIONS

The changes outlined in the paper above should produce results that are consistent with recent understanding of the tin whiskering phenomenon, and also provide some improvements in the ease-of-use of the tool.

The modifications to the current Revision B of the application-specific tin whisker risk assessment algorithm described in this paper, and contained in the accompanying spreadsheet will be considered to be the new current Revision C.

This application-specific risk assessment algorithm can be used as part of a process that is compliant to the requirements of GEIA-STD-0005-2.

References

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