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An Algorithm to Assess the Application-specific Risk of Tin Whisker induced Failures.

Abstract

The use of pure tin finishes has become widespread among suppliers of a wide variety of commercial electronic components, despite the well-documented risk of tin whisker formation on pure tin finishes, and the attendant risk of latent electrical failure. This situation creates a recurring need for component application engineers throughout the military and aerospace industry to assess the level of risk posed by tin whiskering on an application by application basis. Such assessments are a required element of tin control plans compliance with GEIA-STD-0005-2, Level 2.

Tin whisker risk assessments used to be performed by a small group of SMEs, are now being performed by thousands of engineers across the entire industry. Methods are therefore required to standardize and streamline the assessment process. In response to this need, the author has developed an algorithm tool for use in performing standardized application-specific tin whisker risk assessments. The original version of this tool was developed and published in 2003. Subsequent revisions have been published in 2005 and 2007.

The algorithm is designed to rate the level of risk that a whisker could form and bridge a specific gap. The effects of a whisker bridging any given gap are beyond the scope of the algorithm, and will depend upon the details of the circuit in question. In practice, many applications in military or aerospace electronics exhibit a very low risk of such bridging, so that a subsequent, detailed electrical review is not required.

The algorithm uses as input 13 different factors. These factors were chosen not only because of their reported contribution to the whiskering phenomenon, but also because they were likely to be discoverable by an applications engineer. The output is a number that falls roughly between 1 (very low risk) and 10 (very high risk) on a scale based upon a base 10 logarithm. The numerical result is a figure of risk for tin whisker bridging. This number is for comparative purposes only. No absolute probabilities are currently ascribable to a particular score.

The algorithm has been calibrated in two ways. All documented tin whisker induced failures in the literature have been assessed to assure that they receive sufficiently high scores. A wide range of candidate applications have been assessed, and their acceptability has been reviewed by a panel of engineers. The algorithm has been calibrated so that all of the documented failures receive high scores, and that the opinions of these engineers are reproduced when specific threshold recommendations are employed. This calibration insures that everyone who properly employs the algorithm will reproduce the opinions of the engineers against whom the calibration was performed, and that applications similar to documented failures were received high failing scores.

Versions of this tool have been in use at Raytheon and at other aerospace companies for several years. The tool is available publicly free of charge, however the author and Raytheon accept no responsibility for the results of its use. Some users have modified the parameters of the tool to suit their own needs.

The author welcomes all constructive criticism from users of the tool, and will seriously consider recommendations for modifications to be incorporated in future released versions.

Background

Manufacturers of high reliability electronics must manage the risks associated with tin whiskers, while continuing to meet other important customer-driven requirements such as performance, cost, and delivery schedule. Standardized approaches for managing these trades are in use in the industry and have been embodied in standard GEIA-STD-0005-2. A documented process for performing detailed risk assessments is required for compliance to this standard, and also to satisfy the concerns of the customer base.

Several methods are currently used to perform risk assessments. A risk assessment algorithm tool has been developed to provide a standardized method for performing application-specific tin whisker risk assessments. This tool was first published in 2003 and has been revised twice. This paper describes the current revision of the algorithm. Also discussed is how this knowledge may be incorporated into broader risk assessment methodologies.

Algorithm Description

The intent of the algorithm is to assess the risk that for a given application of tin plating, that tin whiskers will bridge between conductors. The term "overall mechanical risk" is used to describe this risk of whisker bridging. This algorithm does not address the consequences of the formation of such a bridge (electrical risk). Experience indicates that for many applications to be assessed that the risk of a whisker bridging is so negligible that further assessment of the consequences are unnecessary. Experience has also shown that in a sizable fraction of the assessments where the mechanical risk is high, the consequences of a bridge are so evident that no further risk assessment need be performed. For these reasons it is anticipated that the vast majority of risk assessments need only consist of the evaluation of the mechanical risk.

The approach taken in formulation of the algorithm is that the mechanical risk is a product of the probability that whiskers will form, and the probability of these whiskers bridging between conductors. The factors that affect whisker growth relate to the properties of the plating and substrate onto which it is plated. The factors that affect the bridging risk relate to geometry of the assembly and the presence or absence of insulating coatings on the conductors.

Note: This algorithm is based upon the premise that failure only occurs if a whisker bridges the entire gap between conductors. This premise applies to most applications, but *not* to high voltage applications where arcing across gaps is a common failure mode. Therefore, this algorithm may produce misleading results if applied to assess applications where high voltages are present.

The output of the algorithm is a numerical index of relative risk of whisker bridging, and as the levels of risk are anticipated to range over several orders of magnitude, the numerical index will be reported on a log-10 scale. Scaling factors have been selected so that the range of the numerical factor falls between zero and ten. Higher output numbers indicated higher degrees of risk.

There are 13 inputs used for the algorithm, which represent risk and mitigation factors that affect the probability of the formation of a whisker bridging between adjacent conductors. These factors are defined below.

$r_1 = f_1$(conductor spacing)

$r_2 = f_2$(Pb content in plating)

$r_3 = f_3$(Sn deposition process)

$r_4 = f_4$(Sn deposit thickness)

$r_5 = f_5$(composition of material directly beneath Sn deposit)

$r_6 = f_6$(substrate controlling the CTE imposed on Sn deposit)

$r_7 = f_7$(reflow of Sn deposit)

$r_{8a} = f_{8a}$(type of conformal coating applied directly over Sn deposit)

$r_{8b} = f_{8b}$(type of conformal coating applied on the surface of adjacent conductors)

$r_9 = f_9$(use of mechanical hardware that applies stress to the surface of the Sn deposit)

$r_{10} = f_{10}$(vulnerability of the assembly to contamination related failure, as indicated by imposed environmental controls during assembly)

$r_{11} = f_{11}$(use of conformal coating on conductors throughout assembly)

$r_{12} = f_{12}$(airflow within assembly)

The functions f_x are as defined by the table below, and the values have been adjusted during the calibration process for the algorithm.

The Scale factor has been set to K = 8.9, based upon the maximum and minimum values produced by the functions defined below, to set the range of the numerical output to range from zero to ten.

These factors are combined in accordance with the following logic.

Overall Mechanical risk = R_{total}

Total susceptibility risk factor = $R_{susceptibility}$

This represents the effects of geometry on the ability of a whisker to create a bridge

Overall whisker growth risk factor = $R_{formation}$

This represents the risk of forming a whisker of sufficient length to create a bridge.

Scaling constant = K

Equation 1 $$R_{total} = K + \log_{10} (R_{susceptibility} \bullet R_{formation})$$

The susceptibility of the application to whisker induced failures is broken into two parts: primary shorts and secondary shorts. Primary shorts occur when a whisker bridges directly from its origin to an adjacent conductor. Secondary shorts occur when whiskers become dislodged and migrate through the system to a remote site with a bridge between two other conductors. The formation factor is also broken in two parts: the density of the whisker growth and the lengths of the whiskers.

Equation 2 $$R_{total} = K + \log_{10} [(R_{primary} + R_{secondary}) (R_{density} \bullet R_{length})]$$

A simplification is made to formulate the risk that whiskers will grow by assuming that there are four, independent driving mechanisms of concern:

1) Stress induced during initial tin deposition
2) Stress developed in the tin as a result of inter-diffusion with the material below during time/temperature exposure
3) Stress developed over time due to differential CTE between the tin and the controlling substrate, and
4) Stress induced as a result of externally applied forces.

Initial stress risk factor = R_i

Diffusion stress risk factor = R_d

CTE stress risk factor = R_{cte}

External risk factor = R_{ex}

The growth of whiskers across the gap will be diminished by the presence of conformal coating directly on the tin surface. Therefore, the four factors identifying sources of stress are combined with a conformal coat factor defined the overall

Equation 3 $$R_{density} = r_{8a} (R_i + R_d + R_{cte} + R_{ex})$$

Investigations into the distribution of whisker lengths that grow from various deposits of tin indicate that some mitigation techniques are effective not because they necessarily decrease the density of whisker growths, but because they seem to restrict the lengths of the whiskers that do form. Therefore, the length factor is defined as a function of the individual factors representing plating process, substrate composition, and post plate heat treatment as follows:

Equation 4 $$R_{length} = (r_3\ r_5\ r_7)$$

Combing equations 1-4

Equation 5

$$R_{total} = K + \log_{10}\left((R_{primary} \bullet R_{secondary})\ \{(r_3\ r_5\ r_7)\ [r_{8a}\ (R_i + R_d + R_{cte} + R_{ex})]\}\right)$$

Each of the six R_x remaining values in equation 5 are calculated based upon attributes of the application.

$R_{primary} = f\ \{r_1, r_{8b}\}$

$R_{secondary} = g\ (R_{length}, r_{10}, r_{11}, r_{12})$

$R_i = h\ \{r_2, r_3, r_4, r_5, r_7\}$

$R_d = l\ \{r_2, r_5, r_7\}$

$R_{cte} = m\ \{r_2, r_6\}$

$R_{ex} = n\ \{r_2, r_9\}$

Functions f, g, h, l, m,and n, are functions. These functions are simple products. These functions could be redefined later if data indicates a different type of relationship applies.

The values for the 13 input factors as a function of application data are defined in the Excel spreadsheet. Working versions of this algorithm in Microsoft Excel format are available online at https://www.reliabilityanalysislab.com/TechnicalLibraryTinWhisker.asp.

Algorithm Application

The values listed on the selection table have been adjusted for calibration process. This calibration process involved to different steps. Firstly, the widest possible selection of documented tin whisker failures were analyzed using the algorithm to check whether or not these cases would have resulted in uniformly high scores. Secondly, a wide range of actual applications of tin were assessed, and in parallel a range of subject matter experts who had been routinely performing tin whisker risk assessments were asked to provide their opinion on the suitability of tin in each of these applications. The values on the chart for adjusted so that the algorithm would faithfully reproduce the opinion of the SMEs with regard to suitability, while still providing uniformly high scores for the documented failures.

The net result of the calibration process is that all of the documented failures yield a score of 8.99 or higher, while applications where the SMEs generally agreed that tin was suitable for use score below the range of 7.0-7.5.

These scores are typically compared against the threshold value that is agreed upon as appropriate for the reliability requirements of the system in question. In the context of system-level controls in accordance with GEIA-STD-0005-2, a threshold value of 7.5 is recommended for use with Tin Control Level 2B, and a threshold value of 7.0 is recommended for use with Tin Control Level 2C.

Conclusions

The algorithm tool described in this paper provides a method for obtaining standardized tin whisker risk assessments that conform to the opinions of the tin whisker SMEs who provided input for calibration.