Whisker Risk Model Spreadsheet

User Guide

Center for Advanced Life Cycle Engineering
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Contents

Introduction

The Whisker Risk Model Spreadsheet can be used to calculate the expected number of tin whisker shorts on one or more leaded components, based on user-specified part and lead geometry, whisker density, tin whisker length distribution, applied voltage, and conformal coating coverage. The expected number of shorts is displayed numerically. In addition, graphs depicting the user-specified whisker probability density functions (PDFs), calculated whisker spacing PDFs, and calculated bridge interference PDFs are provided.

This user guide provides a brief overview of the spreadsheet's theory of operation. Next, the spreadsheet's structure is described, including a definition of the data that is to be entered by the user in each of the sheets within the spreadsheet workbook. Finally, two worked examples are presented, including expected results. A list of references is also included for those who would like a more detailed technical description of the spreadsheet model.

Theory of Operation

The spreadsheet can be used to calculate the expected number of tin whisker shorts on a single leaded part, or, optionally, the total number of expected shorts in an assembly consisting of multiple parts. Three independent whisker populations are considered, based on whether the whisker originates at the lead, the solder, or the sides of the PWB pad.

In order to perform the calculation, the user must enter into the spreadsheet the following information:

- **Part and Lead Geometry**. This includes the package height, seating plane, lead geometry, pitch, and number of leads.
- **Applied Voltage**. This is a single voltage applied to all parts. It is used to calculate the probability that a whisker that physically bridges a lead pair will produce an electrical short.
- **Whisker Density**. This is the areal whisker density, i.e. the number of whiskers per mm^2. This is specified independently for lead whiskers, solder whiskers, and pad whiskers.
- **Whisker Length Distribution**. This is the PDF describing the expected distribution of whisker lengths, typically based on the environmental conditions (such as temperature and relative humidity) that the part or assembly experiences, as well as material and finish. The following probability distribution types are supported: *log-normal*, *log-Cauchy*, *Cauchy*, *Weibull*, and *numerical*, which is a table of numerical values describing the cumulative distribution function (CDF). A distribution must be specified for each of the three types of whiskers (lead, solder, and pad).
- **Conformal Coating Effectiveness.** This is a percentage that characterizes the effective conformal coating coverage for the lead, if any.

Note that the spreadsheet is independent of dimensional units, provided that the same units are used consistently. It is recommended that millimeters be used (as in this document).

This user-entered data is first used to calculate the *whisker view factor* and the *whisker bridging probability* (also called the *whisker bridging fraction*) for a whisker growing between adjacent leads.

The whisker view factor is the probability that a whisker growing from a lead will grow in a direction such that it would, if sufficiently long, make contact with the adjacent lead. Note that the probability value used in the spreadsheet has been pre-multiplied by two, so that the expected number of whiskers calculated are for a *lead pair*, accounting for whiskers sourced on *either* lead in the pair.

The whisker bridging probability, on the other hand, is the probability that a whisker which is growing in a direction that points to a target area on the adjacent lead, solder, or pad will grow sufficiently long to in fact make contact.

Thus, for a single lead pair, the expected number of whisker bridges, or *total whisker bridging,* is given by the following equation:

$$\text{Total Whisker Bridging} = \rho_w \times A_w \times VF_w \times P_B \tag{1}$$

where

$$\begin{aligned} \rho_w &= \text{whisker density (whiskers/mm}^2\text{)} \\ A_w &= \text{whiskerable area (mm}^2\text{)} \\ VF_w &= \text{whisker view factor} \\ P_B &= \text{whisker bridging fraction} \end{aligned}$$

This expected number of bridges per lead pair is then multiplied by the number of adjacent lead spaces-per-part to determine the expected number of bridges-per-part.

The spreadsheet does not assume that all bridges result in electrical shorts. The *shorting probability*, which is the probability that a bridge results in a short, is calculated from the user-specified applied voltage in coordination with the shorting probability table in the **Shorting Prob.** sheet. The total whisker bridges-per-part value is multiplied by the shorting probability to determine the expected number of shorts-per-part.

This calculation is performed to obtain the expected number of shorts-per-part for lead whiskers, solder whiskers, and pad whiskers. All three values are summed to arrive at the final number of expected shorts-per-part.

In addition to calculating the expected number of shorts per part, the spreadsheet also calculates the reliability for not shorting, that is, the probability that no shorts form on any of the part's lead pairs.

Using the same definitions as in equation (1), let

$$\begin{aligned} N &= \text{total whiskers generated for lead pair } (= \rho_w \times A_w), \\ L &= \text{total number of lead pairs for the part, and} \\ P_{SHORT} &= \text{probability that a bridging whisker forms an electrical short.} \end{aligned}$$

Then

$$\begin{aligned} P_{WS} &= \text{probability that a single whisker forms a short} = P_B \times VF_w \times P_{SHORT}, \\ R_{NS} &= \text{probability of no shorts forming for a lead pair} = (1 - P_{WS})^N, \\ P_{LPS} &= \text{probability of at least one short forming for a lead pair} = 1 - R_{NS} \\ &= 1 - (1 - P_{WS})^N, \text{ and} \\ R_{NSP} &= \text{probability that no shorts form for part} = (1 - P_{LPS})^L. \end{aligned} \tag{2}$$

This probability that no shorts form for a part (the reliability for not shorting) is calculated for each type of whisker (lead, solder, and pad). The three probabilities are then multiplied to determine the probability that no shorts of any type occur for that part.

By using the **Roll Up** sheet (which is described in the next section), one may optionally specify more than one part (and associated part and lead geometry) for an assembly, including an associated number of parts for each part defined. (This is something like a bill of materials.) In this case, the expected number of shorts-per-part are summed over all parts in the assembly to arrive at an expected overall total shorts for the assembly.

Restrictions

The formulas used in the spreadsheet to calculate the whisker view factors and bridging probabilities are based on previously conducted Monte Carlo simulations for a specific set of package and lead geometries (see Table 1 in [1] and the **Reference Data** sheet). As a result, the use of this spreadsheet should be limited to gull-wing type leads on flat pack or quad flat pack (QFP) packages.

Spreadsheet Structure

The spreadsheet workbook is organized into ten separate sheets which are accessed by selecting the labeled tabs at the bottom of the Excel application window. In general, the sheets contain a combination of data that is to be provided by the user, values calculated by the spreadsheet, default parameters used in calculations, and the final result (total shorts). Spreadsheet cells that require mandatory or optional user data are colored green. Cells that contain hard-coded values or intermediate values calculated by the spreadsheet are colored white. Default parameter values that can be modified are colored light blue. The cells containing the total number of shorts (either for the specified part, or if the Roll Up sheet is used, for the entire assembly) are colored magenta. The spreadsheet also contains figures which describe geometric values entered by the user, as well as graphs showing curves for user-entered and spreadsheet-calculated PDF functions.

The remainder of this section describes the individual sheets in the order they are found within the spreadsheet. The sheet descriptions include an explanation of the calculated values displayed within each sheet. In the interest of time, the reader may wish to skip the calculated values discussion.

User Notes Sheet

This sheet can be used to enter freestyle notes in the spreadsheet. It is not used in the calculation.

Roll Up Sheet

This optional sheet can be used to calculate the total number of expected shorts for an assembly consisting of multiple parts. It may be easier to understand the following description after studying the remaining sheets (especially the Part Data sheet) in the spreadsheet.

The first portion of the sheet displays material, finish, and reference conditions that have been entered by the user in other tabs. It is for informational purposes only and is not used in the calculation. The coating effectiveness percentage entered in the Part Data tab is also reproduced here for convenience.

The main portion of this sheet is a table of parts, with thirteen columns of data to be entered by the user, and four columns of calculated values: **Part Reliability for Not Shorting, Shorts per Part, Overall Reliability for Not Shorting**, and **Total Shorts** (per part). Each row of the table defines a part type, including a reference designator and number of parts of that type in the assembly. The remaining columns of user-entered data are **Package Height**, **Package Seating Plane**, **Lead Span**, **Body Width, Lead Foot Length**, **Lead Thick.**, **Lead Width**, **Lead Pitch**, **Lead Angle From Vertical**, **Number of Leads**, and **Number of Sides with Leads**. These are identical to the attributes entered in the **Part Data** sheet, and are described in the next section.

When the Roll Up sheet is used, the calculation that is normally performed by the spreadsheet using the data in the Part Data tab is instead performed once for each row of part data in the Roll up sheet. The calculation result is available in the Shorts per Part column. This value is multiplied by the value in the **Number of Parts** cell for that row to produce the Total Shorts (i.e. the expectation value for the total number of shorts) for all parts of the type defined in that row.

Two reliability values for each part type are also displayed in this sheet. The Part Reliability for Not Shorting is the probability that a single instance of the part will have no shorting whiskers (even though the expected number of shorts may be non-zero). The Overall Reliability for Not Shorting is the probability that none of the Number-of-Parts instances of this part will have any shorting whiskers (and is therefore equal to the Part Reliability for Not Shorting raised to the Number of Parts power).

The Total Shorts for each part is summed and displayed as the **OVERALL TOTAL SHORTS** field. This is one of the final outputs of the calculation, representing the expectation value for the total number of electrical shorts in the assembly.

The **OVERALL RELIABILITY** is the probability that none of the part instances in the assembly will have a shorting whisker, calculated as the product of the Overall Reliability for Not Shorting in each row. The **OVERALL SHORTING PROBABILITY** is then 1 – (OVERALL RELIABILITY), that is, the probability that there will be at least one shorting whisker in the assembly.

Note that although the data entered in each row of the part table replaces values that would normally be entered in the Part Data sheet, the values entered in the remaining sheets of the spreadsheet (including the whisker length distributions, applied voltage, coating effectiveness, etc.) are still used when calculating the expected number of shorts for each part. This includes data values that must be entered in the Part Data sheet. Thus, when using the Roll Up sheet to evaluate an entire assembly, values in the remaining sheets in the spreadsheet must be provided by the user.

To use the Roll Up sheet, simply leave blank or blank-out those cells outlined in red in the **Part Drawing Dimensions** and the **Manual Lead Dimensions** sections of the Part Data sheet. As described, the dimensions will then be taken from the part table in the Roll Up sheet.

Part Data Sheet

The Part Data sheet is used to enter data describing the part and lead geometry, conformal coating effectiveness, and applied voltage. Additionally, some default values for parameters that control the operation of the spreadsheet can be modified. The following describes the data values, both input values and calculated output values, in the order in which they appear in the sheet from top to bottom.

Default Parameters

This section of blue-colored cells contains default values for parameters that affect how the spreadsheet operates. They can be left as is, or modified if desired.

- **PWB Pad Length over Lead Foot Length**. If the PWB Pad Length is not specified by the user, this value is added to the Lead Foot Length to obtain the PWB pad length.
- **PWB Pad Width over Lead Width**. If the PWB Pad Width is not specified by the user, this value is added to the Lead Width to obtain the PWB pad width.
- **PWB Pad Thickness**. If the PWB Pad Thickness is not specified by the user, this value is used as the default.
- **Fraction for Minimum Whisker Length**, **Fraction for Maximum Whisker Length**. These values are only used when plotting the whisker length distributions to determine the range of the x-axis.
- **Use Geometric Mean for Midpoints**. Can be “TRUE” to specify the use of geometric means, or “FALSE” for arithmetic means. This setting is used when determining the midpoint between adjacent ordinate points in probability distributions. The default, to use the geometric mean, is recommended.
- **Lead Exit Fraction**. If the First Bend Height is not specified by the user, then it is calculated as $\text{Package Seating Plane} + \text{Lead Exit Fraction} \times \text{Package Height}$.

- **Minimum First Bend Distance**. If the First Bend Distance is not specified, then it is calculated using the Lead Span Length, Lead Foot Length, and Lead Angle from Vertical (see below). If the calculated value is less than the Minimum First Bend Distance, however, the Minimum First Bend Distance will be used.
- **Pad Spacing Reduction from Solder Bulge**, **Relative Height of Bulge**. (Note: It is not recommended to change either of these values, unless it is to maintain the pad spacing reduction value after a change in units from millimeters.) These two values are used to model a solder bulge that reduces the pad spacing by the Pad Spacing Reduction (49 microns by default). The bulge is located half-way up the solder joint, by default. See [1] for further details.
- **Rounding Digits for Prompt Display**. This specifies the number of digits to be used for some attribute labels in the spreadsheet.

Part Drawing Dimensions

These twelve values are to be entered only if the Roll Up sheet is not being used to analyze an assembly. The values are **Part Description**, **Package Height**, **Package Seating Plane**, **Lead Span**, **Body Width, Lead Foot Length**, **Lead Thickness**, **Lead Width**, **Lead Pitch**, **Lead Angle From Vertical**, **Number of Leads**, and **Number of Sides with Leads**.

The meanings of these values are accurately described by the drawing located to the right of these cells in the spreadsheet. The numerical values entered should be taken from a part datasheet drawing. The Part Description is optional and not used in calculations.

As previously mentioned, these cells can be blanked-out, which indicates that the Part Roll Up sheet is to be used. Each row in the part table of the Roll Up sheet will then be referenced to supply the dimensions that would otherwise be entered in the Part Drawing Dimensions cells.

Manual Lead Dimensions

The spreadsheet generates a simplified lead model based on the part drawing dimensions entered by the user. The figure located to the right of Manual Lead Dimensions shows the simplified lead and illustrates the meaning of each value in the Manual Lead Dimensions section. See Figure 5 in [1] and the surrounding text for a more detailed examination of the model.

These values can be left blank, in which case a default value is calculated. For each field, this default value, which will be used in calculations, is displayed in parentheses after the cell label. The default value calculations are described below. In the following description, the value names refer to the Part Drawing Dimension cells and to the Manual Lead Dimension cells unless indicated otherwise.

- **Lead Span Length**. The default value is $\frac{1}{2}(\text{Lead Span} - \text{Body Width})$.
- **First Bend Distance**. The default value is $(\text{Lead Span Length} - \text{Lead Foot Length}) - \text{First Bend Height} \times \tan(\text{Lead Angle from Vertical})$. If this value is less than the Minimum First Bend Distance specified in the Default Parameters section, the Minimum First Bend Distance will be used instead.
- **First Bend Height**. The default value is $\text{Package Seating Plane} + \text{Lead Exit Fraction} \times \text{Package Height}$.
- **Lead Foot Length**. The default value is the Lead Foot Length specified in the Part Drawing Dimensions section.

- **Lead Thickness**. The default value is the Lead Thickness specified in the Part Drawing Dimensions section.
- **Lead Width**. The default value is the Lead Width specified in the Part Drawing Dimensions section.
- **Lead Pitch**. The default value is the Lead Pitch specified in the Part Drawing Dimensions section.
- **Total Lead Spaces**. This is the number of adjacent-lead spaces present in the part. The default value is Number of Leads minus the Number of Sides with Leads. For example, a 64-lead QFP would have 64 – 4 = 60 total lead spaces.
- **PWB Pad Length**. The default value is the Lead Foot Length plus the PWB Pad Length over Lead Foot Length value specified in the Default Parameters section.
- **PWB Pad Width**. The default value is the Lead Width plus the PWB Pad Width over Lead Width value specified in the Default Parameters section.
- **PWB Pad Thickness**. The default value is the PWB Pad Thickness value in the Default Parameters section, which is 63 microns by default.

Note that whenever a default value for a Manual Lead Dimension depends on another Manual Lead Dimension parameter, the default value of the parameter is used, unless the user has overridden the value (by entering a number in a green cell).

The two "live" figures located to the right of the drawing show an aerial view and a horizontal projection of the lead based on the values entered by the user.

The final value to be entered in this section is the **Overall Coating Effectiveness**, which defaults to 50%. This value is used to reduce the calculated whisker view factor. As described in the Theory of Operation section, the whisker view factor is the fraction of whiskers which would eventually bridge to the adjacent lead if sufficiently long – that is, the remaining (1 – view factor) fraction of whiskers are growing in the "wrong" direction. The view factor is purely a function of the part and lead geometry. It does not depend on the whisker length distribution.

The whisker view factors calculated in the spreadsheet and displayed in the Whisker View Factors section of the Part Data sheet have been pre-multiplied by (1 – Overall Coating Effectiveness) to incorporate the effect of the conformal coating.

In the Monte Carlo simulations conducted in [1], it was found that a 90% conformal coating effectiveness on the outside of the lead, 50% effectiveness on the lead sides, and 0% effectiveness on the lead back/inside corresponded to an effective reduction in the view factor by 60%, and hence an overall effectiveness of 40%, as indicated in the spreadsheet cell comment for the Overall Coating Effectiveness parameter.

Calculated Parameters

These intermediate values are determined by the spreadsheet and are used in the final result calculations. They are briefly described here.

- **Lead Spacing**. This is the space between the facing sides of adjacent leads, calculated as Lead Pitch – Lead Width.
- **Solder Spacing**. This is the space between adjacent solder bulges, and is effectively $\text{Lead Spacing} - (\text{PWB Pad Width} - \text{Lead Width}$

+ Pad Spacing Reduction from Solder Bulge), where the Pad Spacing Reduction from Solder Bulge is found in the Default Parameters section.

- **Pad Spacing**. This is the space between adjacent PWB pad edges, calculated as Lead Pitch – PWB Pad Width.
- **Lead Thickness/Spacing**. This is the Lead Thickness divided by the Lead Spacing.
- **Lead Thickness/Solder Spacing**, **Lead Thickness/Pad Spacing**. The indicated ratios of values.
- **Lead View Factor Metric**, **Solder View Factor Metric**, **and Pad View Factor Metric**. These three values are metrics used to calculate the corresponding Lead Whisker, Solder Whisker, and Pad Whisker view factors. The metrics depend on geometric parameters and are used in power law relations to determine the view factors. The details of the metric calculation and power law relations can be found in [1].

Calculated Areas

These are areas calculated from the part, lead, and pad geometry of the simplified lead model. The **Whiskerable Lead Area** is used to calculate the Lead View Factor Metric. It is also used to determine the Total Whiskers Generated in the Lead Whisker sheet. The **Whiskerable Solder Area** is used to calculate the Solder View Factor Metric. It is also used to determine the Total Whiskers Generated in the Solder Whisker sheet. **The Whiskerable Pad Area** is used to determine the Total Whiskers Generated in the Pad Whisker sheet. The **Single Side Area** is used to calculate the Lead View Factor Metric.

Whisker View Factors

These are the calculated view factors for lead, solder, and pad whiskers. They depend on the view factor metrics in the Calculated Parameters section, and on the Overall Coating Effectiveness in the Manual Lead Dimensions section. See the Theory of Operation section of this document for details.

Whisker Spacing Limits

These calculated values represent the minimum and maximum spans a whisker growing from the lead, solder, or pad would have to grow in order to make contact with a target area on the adjacent lead, as determined by the whisker spacing distributions described in the next section. They are calculated using formulas found in [1, p. 8]. They are functions of the part, lead, pad, and solder geometries.

Whisker Spacing Distributions

For each type of whisker (lead, solder, or pad), it is necessary to calculate the probability that a whisker will form a bridge between adjacent leads. To calculate this probability, *two* probability distributions are used. One probability distribution is the *whisker length distribution*. This is a description of the length distribution of tin whiskers one expects to find, depending in general on the environment, materials, and finishes. It is entered by the user.

The other probability distribution is called the w*hisker spacing distribution*. For a given part, lead, pad, and solder geometry, consider those whiskers which grow in a direction such that, if sufficiently long, they would eventually bridge to the adjacent lead, pad, or solder. These are the View Factor percent of the whisker population that are growing in the "right" direction for bridging. We imagine for the moment that all the whiskers in this subset grow as long as needed to bridge to the adjacent lead. If we were to measure the lengths of these whiskers, we would arrive at a "spacing" distribution – a PDF that describes the probability that a randomly selected bridging whisker would need to grow a given distance to traverse the space between the adjacent leads.

Note that how long any given whisker must grow in order to bridge will depend upon where on its lead, solder, or pad it originates, and upon what its angle/direction of growth is. This is why the whisker spacing is described by a probability density function. However, it must be emphasized that the whisker spacing distribution is a function of the part and lead geometries only, and is entirely independent of the whisker length distribution.

The whisker spacing distributions used by the spreadsheet are based on three non-dimensional, normalized whisker spacing CDF curves (one curve each for lead, solder, and pad whiskers). These distributions were determined using previously executed Monte Carlo simulations. Using factors that are calculated from the user-entered part and lead geometries, the non-dimensional curve is scaled to produce the whisker spacing CDFs used by the spreadsheet. It is these CDF distributions that are displayed in the Whisker Spacing Distributions section of the Part Data sheet. For example, the lead whisker non-dimensional CDF is scaled using the Lead Spacing value in the Calculated Parameters section of the Part Data sheet, as well as with the Maximum from Lead value in the Whisker Spacing Limits section. For further details, see Table 4 and the preceding text in [1].

This section of the Part Data sheet also contains a **Material/Finish** and **Data/Reference Condition** value for Lead, Solder, and Pad whiskers (six values altogether). These values are displayed for convenience, and are taken from the user-entered values in the Lead Whisker, Solder Whisker, and Pad Whisker sheets, respectively. They are not used in the calculation.

Whisker Shorting Results

This final section of the Part Data sheet contains the primary output value calculated by the sheet – the total expected shorts for this part, and the reliability for not shorting. The values presented are

- **Coating Effectiveness**. This is the Overall Coating Effectiveness value entered by the user in the Manual Lead Dimensions section, and reproduced here for convenience.
- **Total Lead Spaces**. This is the Total Lead Spaces value (either the default or user-overridden value) from the Manual Lead Dimensions section, reproduced here for convenience.
- **Applied Voltage**. This user-entered value is used to determine the probability that a whisker bridge results in an electrical short. It is applied to all parts in the Roll Up sheet when an assembly is analyzed. See the Theory of Operation section for details.
- **Shorting Probability**. This is the probability that a whisker bridge between leads forms an electrical short, based on the applied voltage. See the Theory of Operation section for details.

The next seven values are presented in a table, with one column for each type of whisker: lead, solder, and pad, resulting in nine values.

- **Bridges per lead**. The expected number of whisker bridges per lead space, taken from the Total Whiskers Bridging cell in the corresponding Lead/Solder/Pad Whisker sheet.
- **Bridges per part**. The expected number of whisker bridges per part, calculated as $\text{Total lead spaces} \times \text{Bridges per lead}$.
- **Shorts per part**. The expected number of whisker shorts per part, calculated as $\text{Bridges per part} \times \text{Shorting probability}$.
- **Bridging probability for lead pair.** The probability that *a lead pair* will form at least one whisker *bridge*. This is 1 – (Reliability for not bridging), where Reliability for not bridging is taken from the corresponding Lead, Solder, or Pad Whisker sheet.

- **Shorting probability for lead pair**. The probability that a *lead pair* will form at least one whisker *short*. This is 1 – (Reliability for not shorting), where Reliability for not shorting is taken from the corresponding Lead, Solder, or Pad Whisker sheet.
- **Shorting probability for part**. This is the probability that the *part* will form at least one whisker short. This is 1 – (Reliability for not shorting for part).
- **Reliability for not shorting for part**. This is the probability that the *part* will not form a short on any of its lead pairs. This is arrived at by raising (1 – Shorting probability for lead pair) to the (Total lead spaces) power.

Lastly, the net results of the whisker risk calculation for the single part defined on this sheet is presented:

- **RELIABILITY**. This is the probability that no lead pair on the part forms a whisker short, whether it be a lead whisker short, a solder whisker short, or a pad whisker short. It is the product of the lead whisker, solder whisker, and pad whisker Reliability for not shorting for part values.
- **TOTAL SHORTS**. The expected total number of whisker shorts for this part, calculated as the sum of the Shorts per part for lead, solder, and pad whiskers.

Lead, Solder, and Pad Whisker Sheets

The Lead Whisker, Solder Whisker, and Pad Whisker sheets are used to enter the respective whisker density and whisker length PDFs for the corresponding whisker types. This section describes the Lead Whisker sheet, but the Solder and Pad Whisker sheets are identical.

- **Lead Material/Finish**. This user-entered value is for reference purposes only. It is not used in the calculation.
- **Data Reference/Condition**. This user-entered value is for reference purposes only. It is not used in the calculation.
- **Distribution**. This user-entered integer (1, 2, 3, 4, or 5) is used to specify the whisker length PDF distribution type. As indicated in the adjacent cell, the meanings of the values are:
    - **1**: *Numerical*. An arbitrary cumulative distribution function (CDF) is used. The CDF must be entered in the Numerical Distribution section of the Lead Whisker sheet.
    - **2**: *Log-normal*. A log-normal whisker length PDF is used. The user-entered parameters of the log-normal distribution must be entered in the 3-Parameter Lognormal Distribution section of the Lead Whisker Sheet.
    - **3**: *Log-Cauchy*: A log-Cauchy whisker length PDF is used. The user-entered parameters of the log-Cauchy distribution must be entered in the 3-Parameter Log Cauchy Distribution section of the Lead Whisker Sheet.
    - **4:** *Cauchy*. A Cauchy whisker length PDF is used. The user-entered parameters of the Cauchy distribution must be entered in the Cauchy Distribution section of the Lead Whisker Sheet.
    - **5**: *Weibull*. A Weibull whisker length PDF is used. The user-entered parameters of the Weibull distribution must be entered in the 3-Parameter Weibull Distribution section of the Lead Whisker Sheet.

    Further information about the distribution types can be found in [1].

- **Whisker Density**. This user-entered value is the areal whisker density.
- **Whiskerable Area**. This value is reproduced from the Whiskerable Lead Area in the Part Data sheet's Calculated Areas section, for convenience.
- **Total Whiskers Generated**. This calculated value is the total number of tin whiskers generated on those areas of the lead that might produce a bridging whisker. This does not include the side of the lead opposite the adjacent lead in the lead pair under consideration, for example. It is calculated as $\text{Whiskerable Area} \times \text{Whisker Density}$.
- **Whisker Bridging Fraction**. (Equivalent to the whisker bridging probability.) The fraction of whiskers growing in a direction that points to a target area on the adjacent lead, solder, or pad that are sufficiently long to in fact make contact. It is calculated as a double numerical integral of the product of the whisker spacing distribution and the whisker length distribution. See [1, p. 11] for details.
- **Whisker View Factor**. This calculated value is the fraction of total whiskers generated that grow in a direction such that, if sufficiently long, they would bridge to the adjacent lead. This value is taken from the Whisker View Factors section of the Part Data sheet.
- **Coating Effectiveness**. The effective reduction in whiskers generated due to conformal coating. This value is taken from user-entered Overall Coating Effectiveness in the Part Data sheet's Manual Lead Dimensions section.
- **Total Whiskers Bridging**. The total number of whiskers that are expected to bridge between adjacent leads. It is calculated as $\text{Total Whiskers Generated} \times \text{Whisker Bridging Fraction} \times \text{Whisker View Factor}$. This is equivalent to equation (1).
- **Reliability for not bridging**. The probability that no whisker bridges form for the lead pair, calculated as $(1 - view\_factor \times bridging\_fraction)^{total\_whiskers}$, where *view_factor* is the Whisker View Factor, *bridging_fraction* is the Whisker Bridging Fraction, and *total_whiskers* is the Total Whiskers Generated.
- **Reliability for not shorting**. The probability that no whisker shorts form for the lead pair, calculated as $(1 - view\_factor \times bridging\_fraction \times shorting\_probability)^{total\_whiskers}$, where *view_factor* is the Whisker View Factor, *bridging_fraction* is the Whisker Bridging Fraction, *shorting_probability* is the Shorting Probability value in the Part Data sheet, and *total_whiskers* is the Total Whiskers Generated.

<Distribution Type> Distribution

The label for this section will depend on the type of whisker length distribution (1, 2, 3, 4, or 5) that has been entered as the Distribution value described in the previous section. For example, if '2' is entered for the Distribution type, then this section will be labeled "3-Parameter Lognormal Distribution".

This section should be used to enter the whisker length distribution PDF parameters for all but the numerical distribution type (see the next section for this case). Two methods of specifying the PDF parameters are available.

Implicit Distribution Parameters

With this method, the user enters two points on the CDF for the distribution, and, depending on the distribution, an optional minimum whisker length. Using these values and the distribution type, the spreadsheet calculates the distribution parameters. The values to be entered are

- **Fraction for Short Whisker**. The user-entered cumulative fraction for the short-whisker CDF point.
- **Fraction for Long Whisker**. The user-entered cumulative fraction for the long-whisker CDF point.
- **Minimum Length**. For distributions that support a minimum whisker length parameter (log-normal, log-Cauchy, and Weibull), this is the minimum whisker length.
- **<short-whisker-fraction> Length**. The length of the whisker that corresponds to the Fraction for Short Whisker value.
- **<long-whisker-fraction> Length**. The length of the whisker that corresponds to the Fraction for Long Whisker value.

An example is presented in the following figure:

15	Data can be entered as long/short whisker length/fraction or with specific distribution parameters	
16	**3-Parameter Weibull Distribution:**	
17	Fraction for Short Whisker =	7.000%
18	Fraction for Long Whisker =	80.00%
19	Minimum Length =	0
20	7.% length =	0.016
21	80.% length =	0.538
22	Whisker Minimum (0) =	
23	Whisker α (char. len., 0.3136) =	
24	Whisker β (shape,nondim, 0.8816) =	

Figure 1

These values indicate a Weibull distribution where there is no minimum whisker length, 7% of whiskers are 16 microns or shorter, and 80% of whiskers are 538 microns or shorter.

Observe that the calculated distribution parameters are displayed in parentheses in the labels for the last three cells. For example, in Figure 1, the characteristic length, α, is 0.3136.

Explicit Distribution Parameters

With this method, the values of the parameter are entered explicitly. The values to enter depend on the distribution type specified in the Distribution cell:

- Log-normal ('2'), Log-Cauchy('3'): Specify **Whisker Minimum**, **Whisker μ** (location parameter), and **Whisker σ** (scale parameter).
- Cauchy ('4'): Specify **Whisker x_0** (location parameter), and **Whisker γ** (scale parameter).
- Weibull ('5'): Specify **Whisker Minimum**, **Whisker α** (characteristic length parameter), and **Whisker β** (shape parameter).

Long Whisker Fraction and Length

The **Long Whisker Fraction** is a default value (in a blue cell) which specifies the length of the longest whisker length to be used in the numerical integration that the spreadsheet performs when calculating the bridging fraction. The length of this longest whisker is specified via the cumulative fraction (i.e. CDF value) that corresponds to the long whisker value. It is recommended that the default value, 95%, be used. The adjacent **length** cell displays the corresponding long whisker length.

Numerical Distribution

If the Distribution value '1' is entered, the user must specify the whisker length distribution as a cumulative distribution table in the green cells within the Numerical Distribution section. Up to 5000 points may be entered.

Usage Notes for Numerical Distribution

It is not recommended that cutting-and-pasting be used when modifying the table of values, as this can interfere with cell references used by the spreadsheet. Cell values can be modified by entering new values, or by highlighting cell ranges and clearing these values (with the Delete key, for example) before entering new values.

Two warning messages may be encountered when entering values for the numerical whisker length distribution table:

1. WARNING - Minimum Length Needs to be Less Than <value>. This messages indicates that the minimum whisker length value available from the numerical distribution table is larger than the minimum value needed for integrating with the whisker spacing distribution.
2. WARNING - Maximum Length of <value> Needs to be More Than <value>. This message indicates that the maximum whisker length value available from the numerical distribution table is smaller than the maximum value needed for integrating with the whisker spacing distribution.

These warnings conditions are artifacts of the way the values of the numerical distribution are interpolated from entered values. The first warning message can be addressed by adding a (0.0001%, 0 mm) point to the CDF table*. This minimum CDF value must be > 0%, however*. The second warning message can be addressed by adding a (100%, <max-length>) CDF point that is sufficiently large, and replacing the previous maximum length CDF point with a slightly smaller value for the percentage. For example, if the final CDF point is (100%, 4.0), it could be replaced with (99.9999%, 4.0), followed by a new (100%, 5.00) CDF point.

Also, be aware that because the numerical distribution length values are interpolated between adjacent table points, the reported maximum value from the numerical distribution will be the mean (either geometric or arithmetic) of the final two points.

Whisker Length PDF Plot

Regardless of the whisker length distribution type chosen, a graph of PDF value vs. Whisker Length is displayed in the upper-right section of the sheet.

Distribution Plots Sheet

This sheet consists of a single graph that collects nine curves:

- **Whisker Distribution PDFs**. There is one plot for each of the lead, solder, and pad whisker length distribution plots (three plots in all). These are displayed with dashed lines, and reproduce the plots displayed in the Lead Whisker, Solder Whisker, and Pad Whisker sheets. The legend indicates the type of distribution in parentheses (e.g. "Lead Whisker (3)" indicates that the length distribution of the lead whiskers is given as a log-Cauchy PDF).
- **Whisker Spacing Distribution PDFs**. There is one plot for each of the lead, solder, and pad whisker spacing distribution plots (three plots in all). See the Whisker Spacing Distributions section of this document for an explanation of whisker spacing. These plots are displayed with a solid line.
- **Bridge Interference PDFs**. There is one plot for each of the lead, solder, and pad whisker interference distributions. Integrating this PDF from A mm to B mm gives the probability that a bridging whisker would have grown between A and B mm longer than it needed to in order to form a bridge, had it not formed a bridge first.

Shorting Prob. Sheet

This sheet contains a table and graph showing the relation between applied voltage and shorting probability – that is, the probability that a bridging whisker will from an electrical short. See the Theory of Operation section for details. Although it is possible to modify the parameters of the lognormal distribution used by editing their values in the blue-colored cells, this is not recommended unless there is new data found to replace the results found in [2].

Revision Info. Sheet

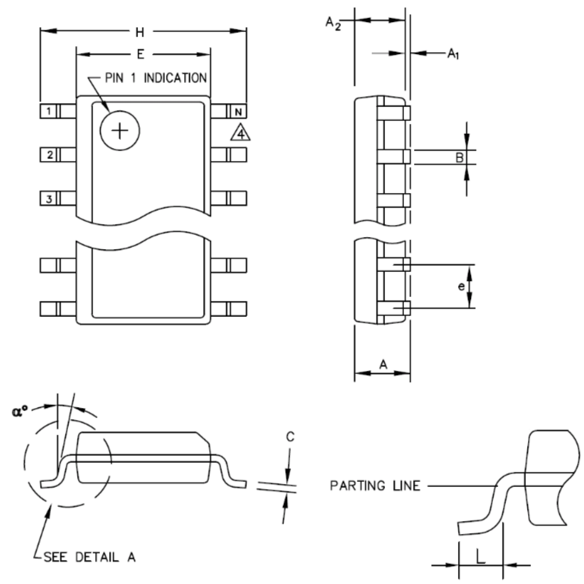
This sheet gives a revision history of this spreadsheet, indicating what changes were made in each version, and on which dates.

Reference Data Sheet

This table shows the parts that were analyzed in the Monte Carlo study underlying many of the formulas used in the spreadsheet. See [1] for further details.

Worked Example 1

You have been asked to determine the expected number of tin whisker shorts for a 14-lead SOIC part with the following geometry data:



Package Height (A_2)	= 1.75 mm
Package Seating Plane (A_1)	= 0.18 mm
Lead Span (H)	= 6.00 mm
Body Width (E)	= 3.90 mm
Lead Foot Length (L)	= 0.75 mm
Lead Thickness (c)	= 0.20 mm
Lead Width (B)	= 0.43 mm
Lead Pitch (e)	= 1.25 mm
Lead Angle from Vertical (α)	= 10 degrees
Number of Leads	= 14
Number of Sides with Leads	= 2

1. Open the spreadsheet and navigate to the **Part Data** sheet.

2. Enter the geometry data above as shown below in the green cells:

16	**Part Drawing Dimensions:**		
17	Part Description (optional):		
18	Package Height (A_2) =	1.75	
19	Package Seating Plane (A_1) =	0.18	
20	Lead Span (H) =	6	
21	Body Width (E) =	3.9	
22	Lead Foot Length (L) =	0.75	
23	Lead Thickness (c) =	0.2	
24	Lead Width (B) =	0.43	
25	Lead Pitch (e) =	1.25	
26	Lead Angle from Vertical (α, θ) =	10	deg
27	Number of Leads =	14	
28	Number of Sides with Leads =	2	

... | Roll Up | **Part Data** | Lead Whisker | Solder

3. In the **Lead Whisker, Solder Whisker, and Pad Whisker** sheets (once for each):
   a. Enter **400** for the Whisker Density.
   b. Enter **2** for the Distribution type, indicating a lognormal distribution.

c. Enter **0** for Minimum Length (the minimum whisker length parameter).

d. Enter **0.31** for Whisker µ (location) parameter.

e. Enter **0.88** for Whisker σ (scale) parameter.

Here is an example of this data as entered into the Lead Whisker sheet:

6	**Whisker Density =**	**400**	**whiskers/dim^2**
7	Whiskerable Area =	1.26790482	dim^2
8	Total Whiskers Generated =	507.161929	
9	Whisker Bridging Fraction =	59.72%	(fraction of whiskers that are long enough to hit)
10	Whisker View Factor =	0.0516089	(fraction of infinite whiskers that will hit)
11	Coating Effectiveness =	50%	
12	**Total Whiskers Bridging =**	**15.6308389**	
13	Reliability for not bridging =	0.00%	
14	Reliability for not shorting =	0.15%	
15	Data can be entered as long/short whisker length/fraction or with specific distribution parameters		
16	**3-Parameter Lognormal Distribution:**		
17	Fraction for Short Whisker =		
18	Fraction for Long Whisker =		
19	Minimum Length =		
20			
21			
22	Whisker Minimum (0) =	0	
23	Whisker µ (location,ln(dim))=	0.31	
24	Whisker σ (scale,nondim) =	0.88	
25			
26	Long Whisker Fraction =	95%	length = 5.797757
27	WARNING - Not used, using calculated distribution		
28	**Numerical Distribution:**		

User Notes | Roll Up | Part Data | **Lead Whisker** | Solder Whisker | Pad Whisker

4. Return to the **Part Data** sheet. Leave the default values for applied voltage (which is 5 V), PWB Pad Thickness (0.063 mm), and Overall Coating Effectiveness (50%).

5. The final result, 139 expected shorts, is displayed in the TOTAL SHORTS cell, and the reliability for the part not shorting (0.00%)is displayed in the RELIABILITY cell:

123	**WHISKER SHORTING RESULTS:**			
124	**Coating Effectiveness =**	50%		
125	Total lead spaces =	12		
126				
127	**Applied Voltage =**	**5**	**V**	
128	Shorting Probability =	41.4%		
129	**Whisker Type:**	**Lead**	**Solder**	**Pad**
130	Bridges per lead:	15.63084	9.245838	3.123422
131	Bridges per part:	187.5701	110.9501	37.48106
132	Shorts per part:	77.57465	45.88638	15.5013
133	Bridging probability for lead pair:	100.00%	99.99%	95.96%
134	Shorting probability for lead pair:	99.85%	97.85%	72.92%
135	Shorting probability for part:	100.00%	100.00%	100.00%
136	Reliability for not shorting for part:	0.00%	0.00%	0.00%
137				
138	**RELIABILITY (this part only) =**	**0.00%**		
139	**TOTAL SHORTS (this part only) =**	**139**		

Worked Example 2

In this example, we demonstrate the use of the **Roll Up** sheet to analyze an assembly with more than one part.

1. With the spreadsheet still open, blank out the values in the **Part Drawing Dimensions** section of the Part Data sheet:

16	**Part Drawing Dimensions:**		
17	Part Description (optional):		
18	Package Height (A_2) =		
19	Package Seating Plane (A_1) =		
20	Lead Span (H) =		
21	Body Width (E) =		
22	Lead Foot Length (L) =		
23	Lead Thickness (c) =		
24	Lead Width (B) =		
25	Lead Pitch (e) =		
26	Lead Angle from Vertical (α, 0) =		deg
27	Number of Leads =		
28	Number of Sides with Leads =		
29			
30	**Note: Blank out cells with red border to use rollup**		

2. Enter the data in the **Roll Up** sheet's green cells as shown in the following figure. If clearing cells before entering values, only the green cells should be cleared.

11		Coating Effectiveness = 50%									OVERALL SHORTING PROBABILITY = 100.00%							
12											OVERALL RELIABILITY = 0.00%							
13											OVERALL TOTAL SHORTS = 5,227							
14	Ref. Des.	Part Number (ref)	Number of Parts	Package Height (A_2)	Package Seating Plane (A_1)	Lead Span (H)	Body Width (E)	Lead Foot Length (L)	Lead Thick. (c)	Lead Width (B)	Lead Pitch (e)	Lead Angle From Vertical (α, deg)	Number of Leads	Number of Sides with Leads	Part Reliability for Not Shorting	Shorts per Part	Overall Reliability for Not Shorting	Total Shorts
16	U1		4	1.75	0.18	6	3.9	0.75	0.2	0.43	1.25	10	14	2	0.00%	138.9623	0.00%	555.8493074
17	U2		3	1.5	0.2	5.2	5	0.6	0.2	0.6	1.05	0	64	4	0.00%	1556.922	0.00%	4670.766479

User Notes | Roll Up | Part Data | Lead Whisker | Solder Whisker | Pad Whisker | Distribution Plots | Shorti ...

3. Press **Shift-F9** on your keyboard when ready. This calculates the OVERALL TOTAL SHORTS expected across all seven components. The value computed should be 5,227. The OVERALL SHORTING PROBABILITY (100%) and OVERALL RELIABILITY (for not shorting – 0%) are also displayed.

Acknowledgements

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References

[1] S. A. McKeown, S. J. Meschter, P. Snugosvsky and J. Kennedy, "SERDP Tin Whisker Testing and Modeling: Simplified Whisker Risk Model Development," in *ICSR (Soldering and Reliability) Conference Proceedings*, 2014.

[2] K. J. Courey, S. S. Asfour, A. Onar, J. A. Bayliss, L. L. Ludwig and M. C. Wright, "Tin Whisker Electrical Short Circuit Characteristics -- Part II," *IEEE Transactions on Electronics Packaging Manufacturing,* vol. 32, no. 1, pp. 41-48, 2009.