

# Basic Geometry Whisker Risk Model Spreadsheet

*User Guide*

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## Introduction

The Basic Geometry Whisker Risk Model Spreadsheet can be used to calculate the expected number of tin whisker shorts on one of several possible simple geometries (parallel plates, parallel round pins, and perpendicular plates), based on user-specified 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 length probability density function (PDFs), calculated whisker spacing PDF, and calculated bridge interference PDF 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 provided, 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 simple conductor-pair geometry, which may be one of the following four types:

- **Equal Parallel Plates** (Case 1). These are two parallel plates of equal area. The plates have identical lengths ( $L$ ) and widths ( $W$ ), and the two plates are separated by a specified distance ( $S$ ).
- **Equal Perpendicular Plates** (Case 2). These are two perpendicular plates of equal area. The plates have identical lengths ( $L$ ) and widths ( $W$ ), and a specified spacing between the center of the plates ( $S$ ). See Figure 1.
- **Parallel Round Pins** (Case 3). These are two parallel round pins of equal length ( $L$ ) and diameter ( $D$ ), and the two pins are separated by a specified pitch ( $P$ ) between their center lines.
- **Unequal Parallel Plates** (Case 4). These are two parallel plates of differing size. The larger plate has a specified length ( $L$ ) and width ( $W$ ), and the smaller plate has a specified length ( $l$ ) and width ( $w$ ). The spacing  $S$  between the plates is also specified.

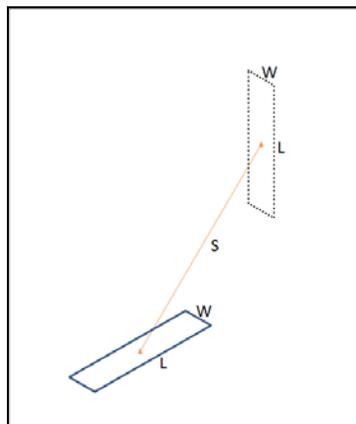


Figure 1

As an optional feature, the total number of expected shorts in a collection of multiple geometry cases can be calculated.

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

- **Geometry.** This includes the length and width of the plates, the length and diameter of the pins, and the spacing or pitch separating them.
- **Applied Voltage.** This is a single voltage applied to all conductor pairs. It is used to calculate the probability that a whisker that physically bridges a conductor pair will produce an electrical short.
- **Whisker Density.** This is the areal whisker density, i.e. the number of whiskers per mm<sup>2</sup>.
- **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 conductor pair 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).
- **Conformal Coating Effectiveness.** This is a percentage that characterizes the effective conformal coating coverage for the conductor pair, 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 conductors.

The whisker view factor (sometimes called the *whisker shape factor*) is the probability that a whisker growing from a conductor will grow in a direction such that it would, if sufficiently long, make contact with the adjacent conductor. Note that for geometry cases 1, 2, and 3, the probability value used in the spreadsheet has been pre-multiplied by two, so that the expected number of whiskers calculated are for a *conductor pair*, accounting for whiskers sourced on *either* conductor in the pair. Because the view factor has been pre-multiplied by two, its value may exceed 1.0. For case 4, the user can control whether whiskers grow from one or both plates.

The whisker bridging probability (sometimes called the *whisker bridging fraction*), 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 conductor will grow sufficiently long to in fact make contact.

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

$$\text{Total Whisker Bridging} = \rho_w \times A_w \times VF_w \times P_B \quad (1)$$

where

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

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 conductor pair value is multiplied by the shorting probability to determine the expected number of shorts per conductor pair.

In addition to calculating the expected number of shorts per conductor pair, the spreadsheet also calculates the reliability for not shorting, that is, the probability that no whisker shorts form on the conductor pair.

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

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

Then

$$\begin{aligned} P_{WS} &= \text{probability that a single whisker forms a short} = P_B \times VF_w \times P_{SHORT}, \\ R_{NS} &= \text{probability of no shorts forming for a conductor pair} = (1 - P_{WS})^N, \\ P_{CPS} &= \text{probability of at least one short forming for a conductor pair} = 1 - R_{NS} \quad (2) \\ &= 1 - (1 - P_{WS})^N \end{aligned}$$

By using the **Roll Up** sheet (which is described in the next section), one may optionally specify a set of one or more conductor-pair geometries – called *cases* – including an associated number of *instances* for each case. The expected number of shorts-per-instance is summed over all instances to arrive at an expected overall total shorts for the entire set of conductor-pair geometry instances.

## Spreadsheet Structure

The spreadsheet workbook is organized into eight 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 conductor pair, or if the Roll Up sheet is used, for the entire set of conductor pair instances) 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 a set of conductor pair geometries. It may be easier to understand the following description after studying the remaining sheets (especially the Model 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 main portion of this sheet is a table of conductor-pair geometry cases, with eight columns of data to be entered by the user, and five columns of calculated values: **Extrapolation Warning**, **Reliability per Instance**, **Shorts per Instance**, **Overall Reliability**, and **Total Shorts** (per conductor-pair geometry). Each row of the table defines a conductor-pair geometry, including a description and number of instances of that type in the set. The remaining columns of user-entered data are **Case (i.e. Case Code)**, **Length**, **Dia./Width**, **Pitch/Spacing**, **Smaller Length**, and **Smaller Width**. These are identical to the attributes entered in the **Model** 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 Model tab is instead performed once for each row of conductor-pair geometry data in the Roll up sheet. The calculation result is available in the Shorts per Instance column. This value is multiplied by the value in the **Number of Instances** cell for that row to produce the Total Shorts (i.e. the expectation value for the total number of shorts) for all instances of the conductor-pair geometry defined in that row.

Two reliability values for each conductor-pair geometry are also displayed in this sheet. The Reliability per Instance is the probability that a single instance of the conductor-pair geometry will have no shorting whiskers (even though the expected number of shorts may be non-zero). The Overall Reliability is the probability that none of the Number-of-Instances instances of this conductor-pair geometry will

have any shorting whiskers (and is therefore equal to the Reliability per Instance raised to the Number of Instances power).

The Total Shorts for each conductor-pair geometry 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 set of conductor-pair instances.

The **OVERALL RELIABILITY** is the probability that none of the conductor-pair instances in the Roll Up set will have a shorting whisker, calculated as the product of the Overall Reliability value in each row. The **OVERALL SHORTING PROBABILITY** is then  $1 - (\text{OVERALL RELIABILITY})$ , that is, the probability that there will be at least one shorting whisker in the set.

Note that although the data entered in each row of the Roll Up table replaces values that would normally be entered in the Model 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 conductor pair instance. This includes data values that must be entered in the Model sheet. Thus, when using the Roll Up sheet to evaluate an entire set of conductor pairs, 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 **Dimensions** section of the Model sheet. As described, the dimensions will then be taken from the table in the Roll Up sheet.

## Model Sheet

The Model sheet is used to enter data describing the conductor pair 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.

- **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.
- **Rounding Digits for Prompt Display.** This specifies the number of digits to be used for some attribute labels in the spreadsheet.

## Dimensions

These values are to be entered only if the Roll Up sheet is not being used to analyze a set of conductor pairs. The values are

- **Description.** An optional description of the case. This is not used in the calculation.
- **Case Code.** An integer indicating the conductor pair type: 1 – parallel plates equal size; 2 – perpendicular plates of equal size; 3 – parallel round pins of equal size; 4 – parallel plates of unequal size.
- **Length.** The length of the plate, or, in case 3 (round pins), the length of each pin.
- **Diameter/Width.** The diameter of the round pin for case 3, and the width of the plate otherwise.
- **Pitch/Spacing.** The distance (i.e. pitch) between the pin centerlines for case 3; the space between the two parallel plates in cases 1 and 4; and the distance between the centers of the perpendicular plates in case 2 (see dimension ‘S’ in Figure 1).
- **Smaller Length, Smaller Width.** In case 4, the length and width of the smaller plate in the conductor pair.
- **Case Code 4 Whisker from Both Surfaces?.** For case 4, parallel plates of unequal size, this parameter specifies whether whiskers grow from only one plate (FALSE) or from both plates (TRUE).

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

This section also contains the **Overall Coating Effectiveness**, which defaults to 0%. 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 conductor 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 conductor pair 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 Model sheet have been pre-multiplied by (1 – Overall Coating Effectiveness) to incorporate the effect of the conformal coating.

## Calculated Parameters

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

- **Spacing.** This is the space between the facing sides of adjacent conductors. In case 3 (round pins), it is Pitch - Diameter. In all other cases, it is equal to the Spacing value that has been entered in the Dimensions section.
- **Width/Spacing.** This is the conductor width (in the case of plates) or conductor diameter (in the case of round pins) divided by the Spacing value.

- **View Factor Metric.** This value is used to calculate the whisker view factors. The metric depends on geometric parameters and is used in a power law relation to determine the view factor. The details of the metric calculation and power law relations can be found in [1].

#### *Recommended Range for View Factor Metric*

A recommended minimum and maximum value for the view factor metric is displayed in this section of the Model sheet. These limits are derived from the Monte Carlo simulations described in [1]. If the calculated view factor metric has been extrapolated beyond the recommended range, a warning message is generated: **\*\*\*WARNING\*\*\* Results Extrapolated from Original Data**.

#### *Calculated Areas*

These areas are calculated from the conductor pair geometry. The **Whiskerable Area** is the area of the plate or, in case 3, half the area of the round pin (not including end caps). It is used to calculate the View Factor Metric, and to determine the Total Whiskers Generated in the Whisker sheet. The **Single Side Area** is the projected side area perpendicular to the surface (equal to the length times the width of a plate, or the length times twice the diameter for round pins). It is used to calculate the View Factor Metric.

#### *Whisker View Factors*

This View Factor is the calculated view factor for whiskers. It depends on the view factor metric in the Calculated Parameters section, and on the Overall Coating Effectiveness. 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 a conductor would have to grow in order to make contact with the adjacent conductor, as determined by the whisker spacing distributions described in the next section. They are calculated from simple formulas based on the conductor pair geometry. For details, see sections 3.2.1 and 3.2.2 of [1]. In addition, the 95% Length (the length such that 95% of the bridging whiskers have length less than or equal to this value) is calculated here, using a linear combination involving the conductor pair geometry and minimum and maximum whisker limits. See section 3.2.3.1 of [1] for details.

#### *Whisker Spacing Distributions*

To calculate the probability that a whisker will form a bridge to the adjacent conductor, *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 *whisker spacing distribution*. For a given conductor pair geometry, consider those whiskers which grow in a direction such that, if sufficiently long, they would eventually bridge to the adjacent conductor. 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 conductor. If we were to measure the lengths of these whiskers, we would arrive at a “spacing” distribution – a PDF describing the probability that a randomly selected bridging whisker would need to grow a given distance in order to traverse the space between the adjacent conductors.

Note that how long any given whisker must grow in order to bridge will depend upon where on its conductor 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 conductor pair geometry (length, width, and spacing, e.g.), and is entirely independent of the whisker length distribution.

With the exception of the large/small parallel plate geometry (case 4), the whisker spacing distribution used by the spreadsheet is based on three non-dimensional, normalized whisker spacing CDF curves (one curve each for the parallel plate, perpendicular plate, and parallel round pin geometries). These distributions were determined using previously executed Monte Carlo simulations. Using the minimum and maximum whisker spacing limits and the 95% whisker length, the non-dimensional curve is scaled to produce the whisker spacing CDFs used by the spreadsheet. For further details, see Table 5 and the preceding text in [1].

For the large/small parallel plate geometry case, the whisker spacing CDF curve is calculated using an approximation that is calculated with a closed-form equation. This equation, in turn, was derived from geometrical considerations and the explicit solution for the case of an infinitesimal source and a round plate, as confirmed by Monte Carlo simulations. See section 3.3 of [1] for a discussion of this formula.

This section of the Model sheet also contains the **Lead Material/Finish** and **Lead Data/Reference Condition** values. These values are displayed for convenience, and are taken from the user-entered values in the Whisker sheet. They are not used in the calculation.

### Whisker Shorting Results

This final section of the Model sheet contains the primary output values calculated by the sheet – the total expected shorts for this conductor pair, 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 Dimension section, and 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 conductor pairs in the Roll Up sheet when that sheet is used. See the Theory of Operation section for details.
- **Shorting Probability.** This is the probability that a whisker bridge between conductors forms an electrical short, based on the applied voltage. See the Theory of Operation section for details.
- **Bridges.** The expected number of whisker bridges formed, taken from the Total Whiskers Bridging cell in the Whisker sheet. For geometry case 4, if the Whisker from Both Surfaces? value is set to TRUE in the Dimensions section of the Model sheet, the value is first multiplied by a factor of two.
- **Shorts.** The expected number of whisker shorts, calculated as Bridges  $\times$  Shorting probability.
- **Bridging probability.** The probability that the conductor pair will form at least one whisker *bridge*. This is  $1 - (\text{Reliability for not bridging})$ , where the Reliability for not bridging is taken from the Whisker sheet.
- **Shorting probability.** The probability that the conductor pair will form at least one whisker *short*. This is  $1 - (\text{Reliability for not shorting})$ , where the Reliability for not shorting is taken from the Whisker sheet.

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

- **RELIABILITY.** This is the probability that the conductor pair does not form a whisker short. It is  $1 -$  (Shorting probability).
- **TOTAL SHORTS.** The expected total number of whisker shorts for the conductor pair, identical to the Shorts value described in this section.

## Whisker Sheet

This sheet is used to enter the whisker density and whisker length PDF.

- **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 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 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 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 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 Whisker Sheet.

Further information about the distribution types can be found in [2].

- **Whisker Density.** This user-entered value is the areal whisker density.
- **Whiskerable Area.** This value is reproduced from the Whiskerable Area in the Model sheet's Calculated Areas section, for convenience.
- **Total Whiskers Generated.** This calculated value is the total number of tin whiskers generated on the conductor. It is calculated as Whiskerable Area  $\times$  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 conductor 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 [2, 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 conductor. This value is taken from the Whisker View Factors section of the Model 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 Model sheet's Dimensions section.
- **Total Whiskers Bridging.** The total number of whiskers that are expected to bridge between the conductors. It is calculated as Total Whiskers Generated  $\times$  Whisker Bridging Fraction  $\times$  Whisker View Factor. This is equivalent to equation (1).
- **Reliability for not bridging.** The probability that no whisker bridges form for the conductor 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 conductor 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 Model 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 $\alpha$ (char. len., 0.3136) =	
24	Whisker $\beta$ (shape, nondim, 0.8816) =	

Figure 2

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,  $\alpha$ , 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  $\mu$**  (location parameter), and **Whisker  $\sigma$**  (scale parameter).
- Cauchy ('4'): Specify **Whisker  $x_0$**  (location parameter), and **Whisker  $\gamma$**  (scale parameter).
- Weibull ('5'): Specify **Whisker Minimum**, **Whisker  $\alpha$**  (characteristic length parameter), and **Whisker  $\beta$**  (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 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 message 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 three curves:

- **Whisker Length Distribution PDF.** This graph shows the whisker length probability distribution, displayed with a dashed line. It reproduces the plot displayed in the Whisker sheet. The legend indicates the type of distribution in parentheses (e.g. "Whisker (3)" indicates that the length distribution of the whiskers is given as a log-Cauchy PDF).
- **Spacing Distribution PDF.** This graph shows the spacing distribution probability density function. See the Whisker Spacing Distributions section of this document for an explanation of whisker spacing. This plot is displayed with a solid line.
- **Bridge Interference PDF.** This plot shows the whisker interference distribution probability density function. 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 form 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 [3].

#### [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 conductor pair geometries 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 two parallel plates of equal size, with no conformal coating, and with the following spacing and dimensions:

**Length** = 5 mm  
**Width** = 2 mm  
**Spacing** = 1 mm

Follow these steps:

1. Open the spreadsheet and navigate to the **Model** sheet.
2. Enter the geometry data above as shown below in the green cells in the Dimensions section:

Case Description: Equal Parallel Plates		
Description (optional, Case 4):		
Case Code (1) =	1	(1-parallel,2-
Length (9) =	5	
Width (7) =	2	
Spacing (0.5) =	1	

3. In the **Whisker** sheet
  - a. Enter **2** for the Distribution type, indicating a lognormal distribution.
  - b. Enter **400** for the Whisker Density.
  - c. Enter **0** for the Whisker Minimum (the minimum whisker length parameter).
  - d. Enter **0.31** for the Whisker  $\mu$  (location) parameter.
  - e. Enter **0.88** for the Weibull  $\sigma$  (scale) parameter.

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

6	<b>Whisker Density =</b> 400 whiskers/dim <sup>2</sup>
7	Whiskerable Area = 10 dim <sup>2</sup>
8	Total Whiskers Generated = 4000
9	Whisker Bridging Fraction = 51.01% (fraction of whiskers that are long enough to hit)
10	Whisker View Factor = 1.04521555 (fraction of infinite whiskers that will hit)
11	Coating Effectiveness = 0%
12	<b>Total Whiskers Bridging = 2132.60486</b>
13	Reliability for not bridging = 0.00%
14	Reliability for not shorting = 0.00%
15	Data can be entered as long/short whisker length/fraction or with specific distribution parameters
16	<b>3-Parameter Lognormal Distribution:</b>
17	Fraction for Short Whisker =
18	Fraction for Long Whisker =
19	Minimum Length =
20	
21	
22	Whisker Minimum (0) = 0
23	Whisker $\mu$ (location, ln(dim)) = 0.31
24	Whisker $\sigma$ (scale, nondim) = 0.88
25	
26	Long Whisker Fraction = 95% length = 5.797757

- Return to the **Model** sheet. Leave the default values for applied voltage (which is 5 V, and Overall Coating Effectiveness (0%).
- The final result, 882 expected shorts, is displayed in the TOTAL SHORTS cell, and the reliability for not shorting (0.00%) is displayed in the RELIABILITY cell:

67	<b>WHISKER SHORTING RESULTS:</b>
68	Coating Effectiveness = 0%
69	
70	Applied Voltage = 5
71	Shorting Probability = 41.4%
72	
73	Bridges: 2132.605
74	Shorts: 881.9961
75	Bridging probability: 100.00%
76	Shorting probability: 100.00%
77	
78	<b>RELIABILITY (this geometry only) = 0.00%</b>
79	<b>TOTAL SHORTS (this geometry only) = 882</b>

## Worked Example 2

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

1. With the spreadsheet still open, blank out the values in the Dimensions section of the Model sheet:

10	<b>Dimensions:</b>	
11		<b>Case Description:</b> Equal Parallel Plates
12		Description (optional, Case 4):
13		Case Code (1) =
14		Length (9) =
15		Width (7) =
16		Spacing (0.5) =
17		
18		
19		

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.

4	Lead Material/Finish: <a href="#">Lead material here</a>												<b>OVERALL SHORTING PROBABILITY = 100.00%</b> <b>OVERALL RELIABILITY = 0.00%</b> <b>OVERALL TOTAL SHORTS = 29</b>		
5	Lead Data/Reference Condition: <a href="#">Lead condition here</a>														
6															
7															
8	Description (must be unique)	Number of Instances	Case (1-parallel, 2-perpendicular, 3-round, 4-large/small)	Case Description (ref)	Length	Dia./Width	Pitch/Spacing	Smaller Length (case 4 only)	Smaller Width (case 4 only)	Extrapolation Warning	Reliability per Instance	Shorts per Instance	Overall Reliability	Total Shorts	
10	Case 1	4	1	Equal Parallel Plates	3	2	5			FALSE	0.11%	6.768906	0.00%	27.07562257	
11	Case 3	3	3	Parallel Round Leads	2	0.5	4			FALSE	50.03%	0.692161	12.52%	2.076482928	

This shows the OVERALL TOTAL SHORTS expected across all seven conductor pairs. The value computed should be 29. The OVERALL SHORTING PROBABILITY (100%) and OVERALL RELIABILITY (for not shorting – 0%) are also displayed.

## Acknowledgements

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## References

- [1] BAE Systems, "Simplified Whisker Risk Model Extensions," 2016.
- [2] 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.
- [3] 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.