Microsoft Excel Interface Option for Lossless Calculations in Si8000m/Si9000e

Si Excel User Guide

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Si Excel User Guide

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Personal Computer Requirements

Computer	IBM PC AT or compatible
Processor	Intel Pentium or compatible – 1GHz or better
Operating system	Microsoft™ Windows 10™ or later
System memory required	2GB recommended
Hard disk space required	100MB (min.)
Video standard	FHD (HD 1080) (1920 x 1080) minimum
Mouse	Microsoft compatible
Software key port	Parallel port/USB port
Spreadsheet	Microsoft™ Excel™ 2010 or later

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Si8000m/Si9000e Field Solver Excel Interface

Si8000m/Si9000e Field Solvers

The Polar Instruments Si8000m Multiple Dielectric Controlled Impedance Field Solver and the Si9000e Insertion Loss Field Solver use advanced field solving methods to calculate PCB trace impedance for most single-ended and differential circuit designs. Based on Boundary Element analysis, the Si8000m and Si9000e Field Solver are able to provide rapid lossless modelling to predict the finished impedance of multiple dielectric PCB builds for a wide range of microstrip, stripline and coplanar structures.

Lossless calculations

The Si8000m assumes negligible insertion loss in the transmission line and provides for lossless modelling; the Si9000e includes the lossless modelling of the Si8000m but also adds extensive insertion loss modelling capabilities. The Si8000m Field Solver provide for rapid calculation of single PCB trace impedance values against significant PCB parameters (e.g., trace height and thickness, dielectric constant, etc.) Given a target impedance the goal seeking functions of the Si8000m allows the user to calculate circuit parameter values to achieve the desired impedance.

Multiple dielectric builds

Advanced modelling allows the designer to predict the finished impedance of multiple dielectric PCB builds and also take into account the local variations in dielectric constant on close spaced differential structures (e.g., areas of high resin concentration between differential pairs).

Surface coating modelling

The resist thickness adjacent to, above and between surface traces is included in applicable models. This offers an elegant solution to modelling surface coating which can be tailored to the particular resist application method in use. Both field solvers also extract even, odd and common impedance. It is becoming increasingly necessary to control these characteristics on high-speed systems such as USB 2.0 and LVDS.

Microsoft Excel® for Windows interface

The Microsoft Excel® for Windows interface is offered as a purchasable option for lossless modelling in both the Si8000m and Si9000e using the associated calculation engines, providing easy graphing and data sharing. Using Excel's familiar user interface and powerful Autofill and Chart Wizard features, the field solving calculation engine can rapidly chart Z_0 against varying parameters, providing easy comparison and evaluation of the behaviour of most popular controlled impedance structures.

32-bit Si Excel / 64-bit Si Excel 64 Interface

The Si Excel Interface add-on to the Polar Si8000m and Si9000e is a comprehensive lossless controlled impedance design tool which provides modelling for a wide variety of structures as a set of functions through a Microsoft® Excel user interface. Si Excel x64 supports both Excel 32-bit and 64-bit environments.

The Si Excel Interface allows the operator to perform rapid calculations of PCB trace values against significant PCB parameters. The Si Excel Interface solves for impedance, propagation delay and inductance and capacitance per unit trace length along with effective dielectric constant and velocity of propagation.

Evaluating PCB structure behaviour

For situations with structure dimensional constraints, the field solvers allow the designer and board fabricator easily to accommodate variations in supplier material dimensions.

Support is provided for single or multiple dielectric builds in a comprehensive range of trace and dielectric configurations. The field solvers provide models for structures with dielectric layers above and below traces, soldermask modelling and includes compensation for resin rich areas between traces.

Structure spreadsheet functions

The field solvers incorporate the Quick Solver for single impedance and parameter calculations along with a comprehensive set of advanced field solving methods incorporated as user-defined functions in the popular Microsoft Excel spreadsheet format.

The structure functions included in Excel format enable advanced functions, for example, sensitivity analysis, i.e., graphing the effects of a range of parameter value changes. Single or multiple dielectric builds are supported in a comprehensive range of trace and dielectric configurations. Models are included for structures with dielectric layers above and below traces, soldermask configurations and compensation for resin rich areas between traces.

Introduction to Controlled Impedance PCBs

Controlled impedance

The increase in processor clock speed and component switching speed on modern PCBs means that the interconnecting paths between components (i.e. PCB tracks) can no longer be regarded as simple conductors.

At fast switching speeds or high frequencies (i.e. for digital edge speeds faster than 1ns or analog frequencies greater than 300MHz) PCB tracks must be treated as *transmission lines*.

That means that for for stable and predictable high speed operation the electrical characteristics of PCB traces and the dielectric of the PCB must be controlled.

One critical parameter is the *characteristic impedance* of the PCB track (the ratio of voltage to current of a wave moving down the signal transmission line); this will be a function of the physical dimensions of the track (e.g. track width and thickness) and the dielectric constant of the PCB substrate material and dielectric thickness.

The impedance of a PCB track will be determined by its inductive and capacitive reactance, resistance and conductance. PCB impedances will typically range from 25Ω to 120Ω.

In practice a PCB transmission line typically consists of a line conductor trace, one or more reference planes and a dielectric material. The transmission line, i.e. the trace and planes, form the *controlled impedance*.

The PCB will frequently be multi-layer in fabrication and the controlled impedance can be constructed in several ways. However, whichever method is used the value of the impedance will be determined by its physical construction and electrical characteristics of the dielectric material:

- The width and thickness of the signal trace
- The height of the core or prepreg material either side of the trace
- The configuration of trace and planes
- The dielectric constant of the core and prepreg material

Impedance matching

Components themselves exhibit characteristic impedance so the impedance of the PCB tracks must be chosen to match the characteristic impedance of the logic family in use.

If the impedance of the PCB tracks does not match the device characteristic impedance multiple reflections will occur on the line before the device can settle. This can result in increased switching times or random errors in high-speed digital systems. The value and tolerance of impedance will be specified by the circuit design engineer and the PCB designer, however, it will be left to the PCB manufacturer to conform to the designer's specification and verify the finished boards meet the specification.

Calculation methods

The Si8000m / Si9000e incorporate field solving for single-ended and differential impedance structures. The discrete numerical analysis in the field solvers uses the Boundary Element Method to evaluate the residual field. A piecewise linear approximation is used with a weighted sub-division of the perimeter of the trace cross-section to predict the surface charge distribution on the trace. Knowing the boundary voltage conditions and the charge distribution allows the Boundary Element Method to predict the capacitance of the structure. This in turn allows the impedance of the structure to be calculated.

Transmission Line Structures

Microstrip and Stripline Transmission Lines

Controlled impedance PCBs are usually produced using *microstrip and/or stripline transmission lines* in single-ended (unbalanced) or differential (balanced) configurations.

A micro strip line consists of controlled width conductive traces on a low-loss dielectric (in practice the dielectric may be constructed from a single dielectric or multiple dielectric layers) mounted on a conducting ground plane. The dielectric is usually made of glass-reinforced epoxy such as FR-4. For very high frequencies PTFE may be used. Other reinforcement/resin systems are also available.

For close spaced differences on woven glass reinforced dielectrics, refer to application note AP139 on the Polar Instruments web site, www.polarinstruments.com

There are several configurations of PCB transmission line:

Exposed, or surface, microstrip

Coated microstrip (coating usually solder mask)

Buried, or embedded, microstrip

Centred stripline

Dual (offset) stripline

Coplanar strips and waveguides

The structures above can be constructed with single or multiple dielectrics.

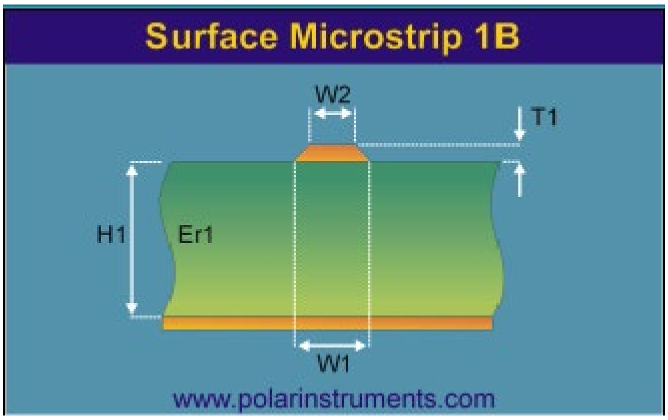
Single-ended Transmission Lines

Single-ended transmission lines are the commonest way to connect two devices (i.e. a single conductor connects the source of a device to the load of another device). The reference (ground) plane provides the return path.

Note that in the diagrams the trace is trapezoidal in profile and width, W, refers to the trace width nearest the upper surface, W_1 refers to the trace width nearest the lower surface.

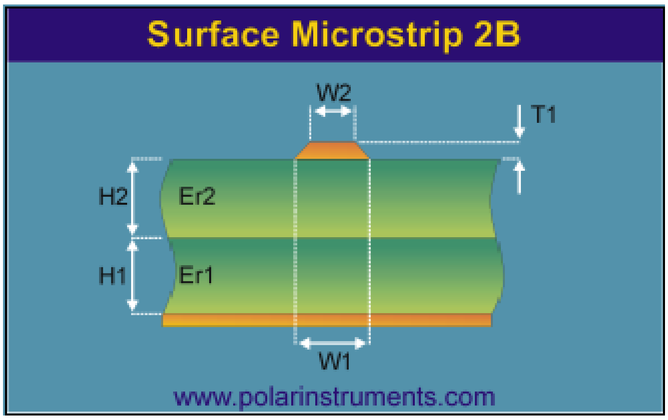
Surface Microstrip

In the diagram below (*surface*, or *exposed*, microstrip) the signal line is exposed (to air) and referenced to a power or ground plane. Structures are categorised according to the arrangement of the dielectric with respect to the trace (below or above the trace). The diagram below shows the surface microstrip structure using a single dielectric layer below the signal trace (designated 1B.)



Surface microstrip with single dielectric below the trace

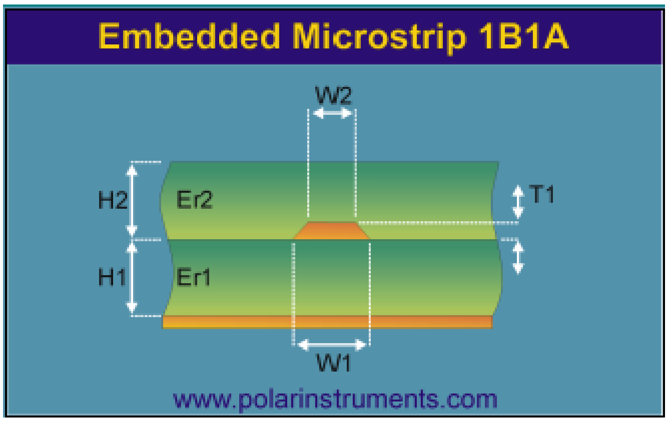
The diagram below shows the surface microstrip structure using two dielectric layers below the trace (designated 2B).



Surface microstrip with two dielectric layers below the trace

Embedded Microstrip

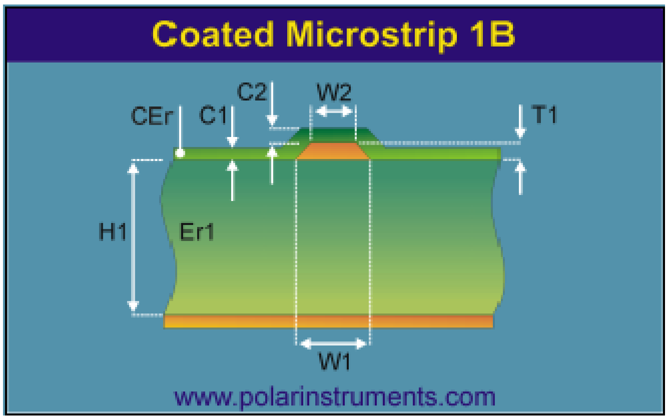
Embedded, or buried, microstrip is similar to the surface version, however the signal line is embedded between two dielectrics and located a known distance from the reference plane.



Embedded microstrip with two dielectric layers, one below and one above the trace

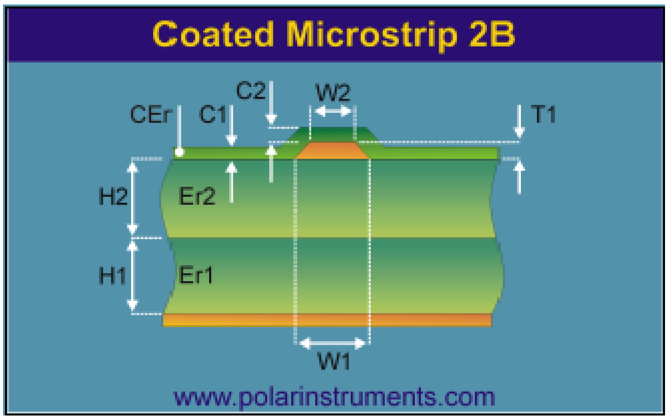
In this structure the two dielectrics are arranged one below and one above the trace (designated 1B1A). Embedding the signal line can lower the impedance by as much as 20% compared to an equivalent surface microstrip construction.

Coated Microstrip



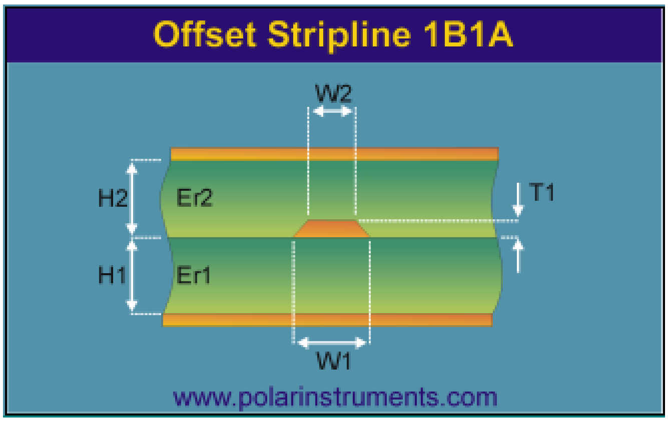
Coated microstrip with single dielectric below the trace

Coated microstrip is similar to the surface version, however the signal line is covered by a solder mask. This coating can lower the impedance by up to a few ohms depending on the type and thickness of the solder mask.



Coated microstrip with two dielectrics below the trace

Offset Stripline



In this configuration the signal trace is sandwiched between two planes and may or may not be equally spaced between the two planes. This construction is often referred to as Dual Stripline.

A second mirror trace will be positioned H_1 from the top ground plane. These two signal layers will be routed orthogonally (crossing at right angles so as to minimise the crossing area).

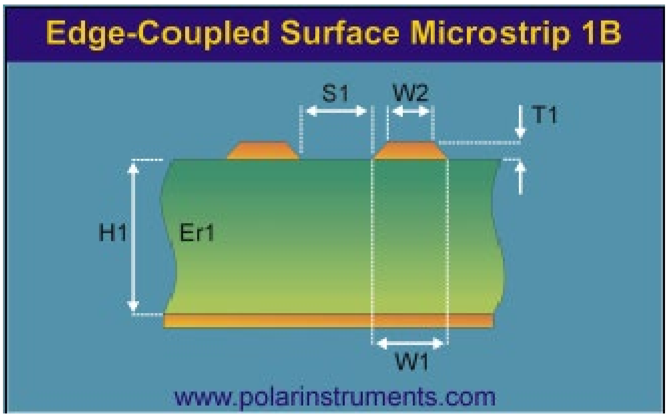
Differential Transmission Lines

The differential configuration (often referred to as a *balanced line*) is used when better noise immunity and improved timing are required. In differential mode the signal and its logical complement are applied to the load.

The balanced line thus has *two* signal conductors and an associated reference plane or planes as in the equivalent single-ended (unbalanced) case. Fields generated in the balanced line will tend to cancel each other, so EMI and RFI will be lower than with the unbalanced line. External noise will be "common-moded out" as it will be equally sensed by both signal lines.

Note that in the following diagrams (except the Broadside-coupled Stripline) the traces are trapezoidal in profile and width, W, refers to the trace width nearest the upper surface, W_1 refers to the trace width nearest the lower surface.

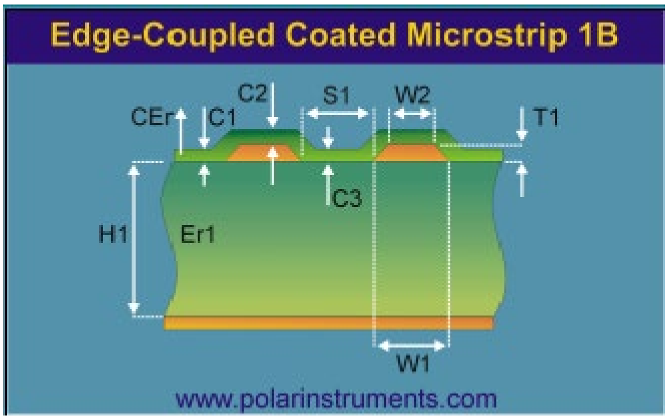
Edge-coupled Surface Microstrip



Edge-coupled surface microstrip with single dielectric below the trace

In this construction the gap between the traces, S1, defines the coupling factor and hence the differential impedance. The etch factor, plating density and undercut will make this construction simple to manufacture, but with a wider tolerance due to the extra processing required on external layers.

Edge-coupled Coated Microstrip

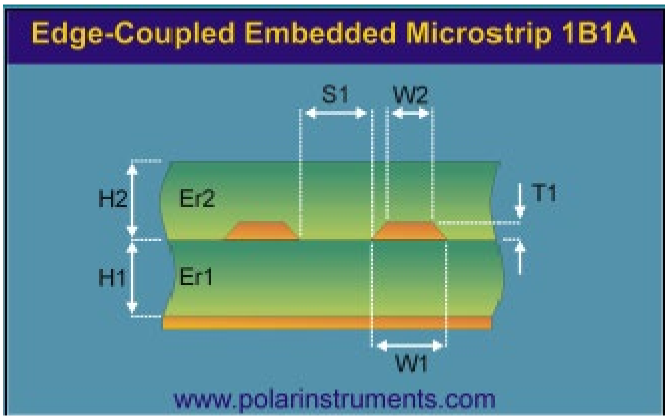


Edge-coupled coated microstrip with single dielectric below the trace

As in the case of the Surface Microstrip this construction is simple to fabricate, but the extra process of adding solder mask coating can cause impedance variations. The designer is ableS to specify the thickness of the coating outside, above and between the traces to allow for variations in the board fabricating process.

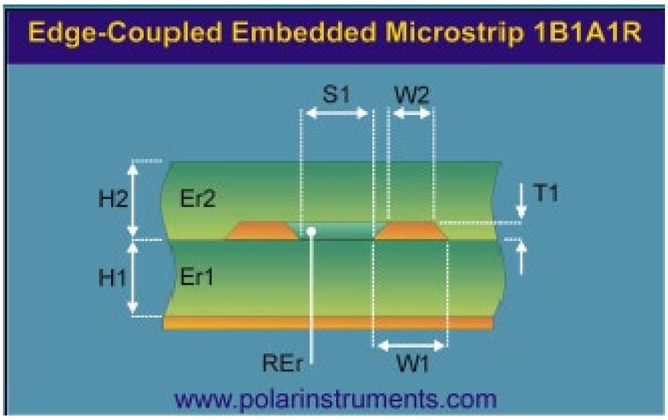
This construction is particularly sensitive to solder mask flooding with LPI (Liquid Photo Imagable) solder mask. This causes the dielectric constant in the edge coupling region to vary, depending on flood depth.

Edge-coupled Embedded Microstrip



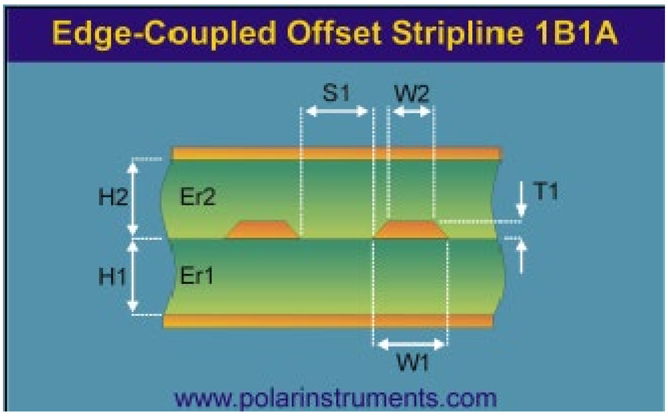
Edge-coupled embedded microstrip with one dielectric below and one above the traces

The reduced processing of internal layers makes the Edge-coupled Embedded Microstrip construction easy to fabricate with more consistent results than the equivalent surface trace structure. During the manufacturing process resin will be forced in between the traces resulting in a resin-rich region (shown as Rer in the 1B1A1R model below) between the two traces. This region will result in a dielectric with Er different from the rest of the structure.



Edge-coupled embedded microstrip with resin-rich region between traces

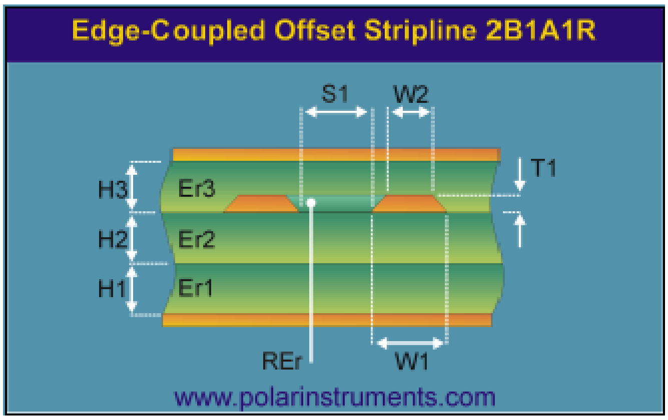
Edge-coupled Offset Stripline



Edge-coupled offset stripline – one dielectric below,one above the traces

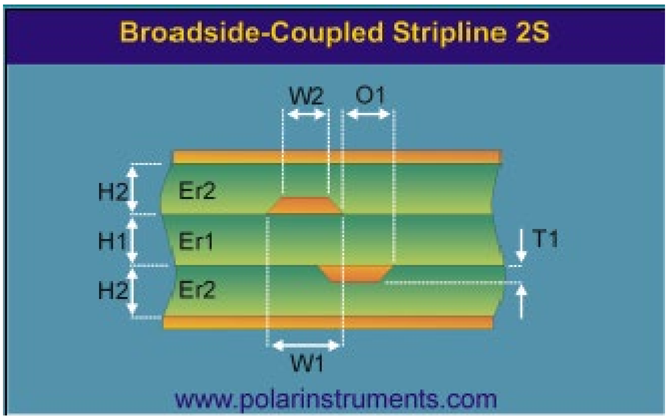
As in the case of the single-ended Offset Stripline construction this structure can be made up as a dual construction with a mirrored edge-coupled differential pair set a distance from the upper reference plane. The lower pair is routed orthogonal to the upper to minimise layer to layer coupling and cross-talk.

The model below shows a structure with two layers below the traces and one above and includes the resin rich region between the traces



Edge-coupled offset stripline structure modelling the resin-rich region between the traces

Broadside-coupled Stripline

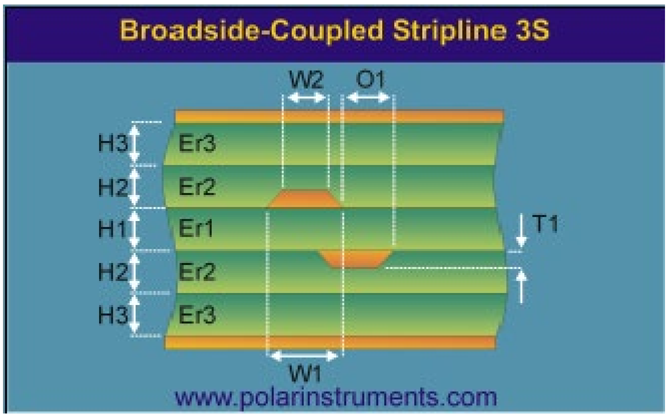


Broadside-coupled offset stripline with two substrate dielectrics, H1, H2

This apparently simple construction is actually one of the most difficult to fabricate to produce consistent impedance results.

Despite having internal layers with minimal processing, the most common structure is that with both traces overlaid for maximum coupling.

Inner-layer mis-registration and slight offsets and differences in etching combine to make this more difficult to achieve consistent results, particularly if the traces are fine-line.



Broadside-coupled offset stripline with three substrate dielectrics, H1, H2 and H3

The broadside-coupled model assumes symmetry of dielectric in the two H2 and H3 layers — the two layers will normally be fabricated from the same material, i.e. with the same dielectric constant.

Note that in the Broadside-coupled Stripline case the traces are trapezoidal in profile and width, W_2 *refers to the trace width nearest the surfaces,* W_1 *refers to the trace width nearest the center.*

Coplanar Lines

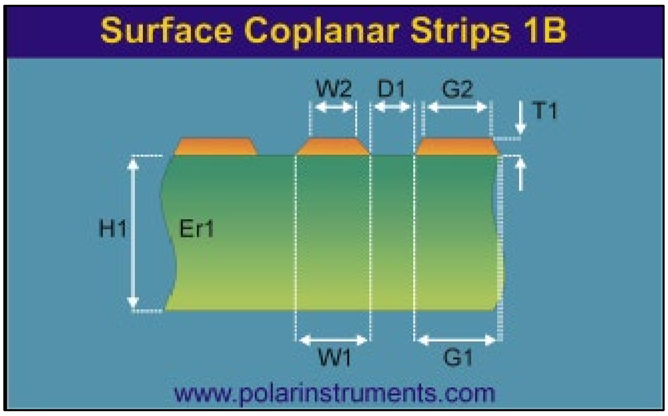
Most microstrip and stripline transmission line structures can be manufactured in a coplanar version.

Coplanar structures have the advantage of single-sided construction with the signal line and ground on the same plane. Components can be grounded on the same plane as the signal line; this means the coplanar configuration is ideally suited for surface mounted devices.

In addition, the coplanar configuration shows only minor dispersion effects compared to microstrip lines.

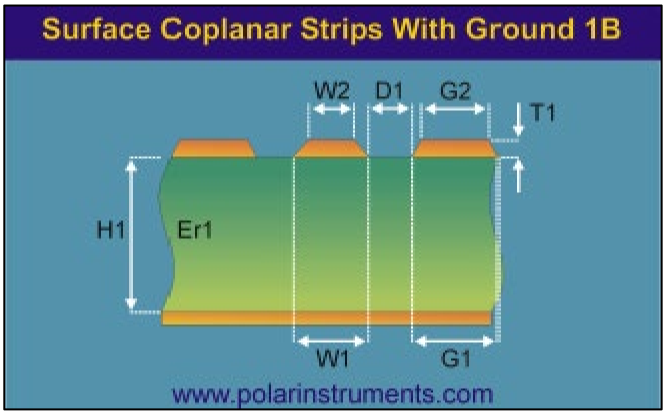
Coplanar lines incorporate ground conductors adjacent to the controlled impedance trace(s) in the same plane as the trace(s).

Surface Coplanar Strips



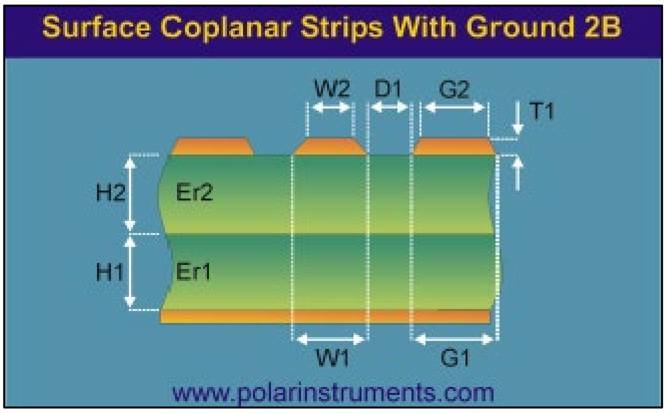
Surface Coplanar Strips with Ground

Coplanar lines may be constructed with or without a ground plane underneath the controlled impedance trace(s).



This structure is an example of a controlled impedance trace on a single sided board that will typically be used in consumer applications.

Differential Surface Coplanar Strips



The diagram above shows a differential surface coplanar structure with strips and a lower ground plane fabricated using two dielectric layers

Installing the Si Excel Interface

Activating the Si Excel Interface

Note: It will be necessary to activate the product license prior to performing calculations.

Licensing is based on FlexNet Publisher.

The Polar licensing system supports both floating licenses and licenses node-locked to a machine's ethernet address or to FLEXnet ID keys.

Floating (counted) licenses will require the server-side installer, available from the Polar web site support page.

If a hardware key (dongle) license has been purchased it will be necessary to download and install the key drivers (available from the Polar web site support page.)

Si Excel Interface is supplied for 32-bit versions of Microsoft Excel/Office.

Si Excel x64 Interface is supplied for 64-bit versions of Microsoft Excel/Office.

The Si Excel Interface / Si Excel x64 Interface is licensed for Si8000m or Si9000e.

Contact Polarcare at polarcare@polarinstruments.com or your local office for licensing information.

Starting the software

Si Excel delivers two Excel interfaces:

SiExcel / SiExcelx64.xlsm – workbooks containing sample worksheets of the most commonly used structures. Select a structure via the associated worksheet tab, vary the structure parameters and plot the impedance calculation results.

SiExcelExpert / SiExcelExpertx64.xlsm SiExcelxExpert64.xlsm – a workbook that provides a link to the impedance structure functions that can be accessed from your own Excel workbooks. Use your own worksheet data as structure input parameters and embed the calculated result back to your worksheet cell(s.)

Click the appropriate Si Excel Interface icon on the desktop to start the program.

Uninstalling the software

To uninstall the software, click the Windows Start button and choose Control Panel. Double-click Programs and Features and choose the appropriate interface from the list. Right click and choose Uninstall.

Si Excel Interface Lossless Controlled Impedance Design System

Dialog box graphics from different versions of Microsoft™ Excel™ may display slight differences from those shown here.

The Si Excel Interface Lossless Controlled Impedance Design System is a comprehensive controlled impedance design aid which provides modelling for a wide variety of structures as a set of functions through a Microsoft® Excel user interface.

A package of Microsoft™ Excel™ spreadsheets allows direct access to the field solver; you can graph any parameter you choose using the pre-prepared Microsoft™ Excel™ workbooks or build your own workbooks to model your process.

The Si Excel functions included in Excel format enable advanced decision making; adding to the features currently available from the Si8000m Sensitivity Analysis tab, the Si Excel Interface provides access to the lossless field solving functions from within Microsoft™ Excel™ offering an extremely flexible and powerful way to calculate and graph the effects of a range of a parameter value changes.

The Field Solver functions for the Polar SI8000m controlled impedance structures are built into the Microsoft™ Excel™ workbooks SiExcelx64.xls and SiExcelx64Expert.xls as user-defined functions.

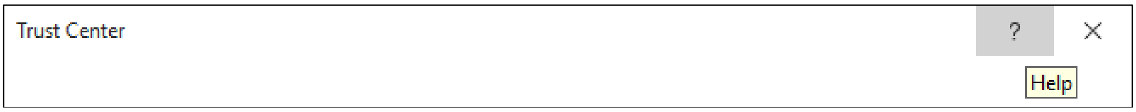
This allows rapid and convenient analysis of board trace characteristics such as impedance, propagation delay, inductance and capacitance against several varying board parameters.

In addition to the Field Solver functions, the SiExcelx64.xls workbook includes a selection of the most popular pre-built sample data worksheets incorporating tables of functions and their associated parameters. Structure models not included can be built as required as described later in this section.

Enabling the Si Excel functions

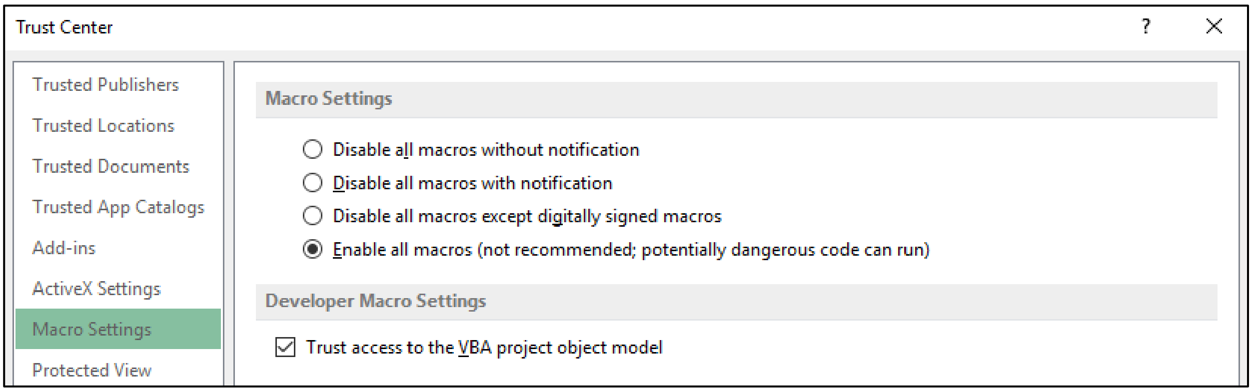
If the SiExcelx64.xls workbook opens with the warning that the workbook contains macros (Visual Basic code), click the Developer tab of the ribbon and then the Macro Security command in the Code section to display the Trust Center Macro Settings to allow the field solver to perform calculations.

Click Trust Center Help for a discussion on security levels in Microsoft™ Excel™.



Alternatively, click the Excel File menu and choose Options – from the Excel Options dialog, choose Trust Center.

Choose Trust Center Settings and from the dialog, Enable macros.



Note: The workbook opens by default as read-only; this allows the operator to perform calculations but not save changes to the workbook.

The SiExcelExpert / Si Excel Expert x64 workbooks include the controlled impedance functions but not the sample worksheets.

These are supplied so that users can construct their own customised structure models.

Double click the Si Excel or Si Excel 64 icon on the desktop; Microsoft Excel opens the SiExcel.xlsm or Si Excel 64 workbook at the index sheet.

Controlled impedance structure categories

The index sheet displays the structure categories;

Single ended structures

Differential structures

Differential without ground

Surface coplanar

Coated coplanar

Embedded coplanar

Offset coplanar

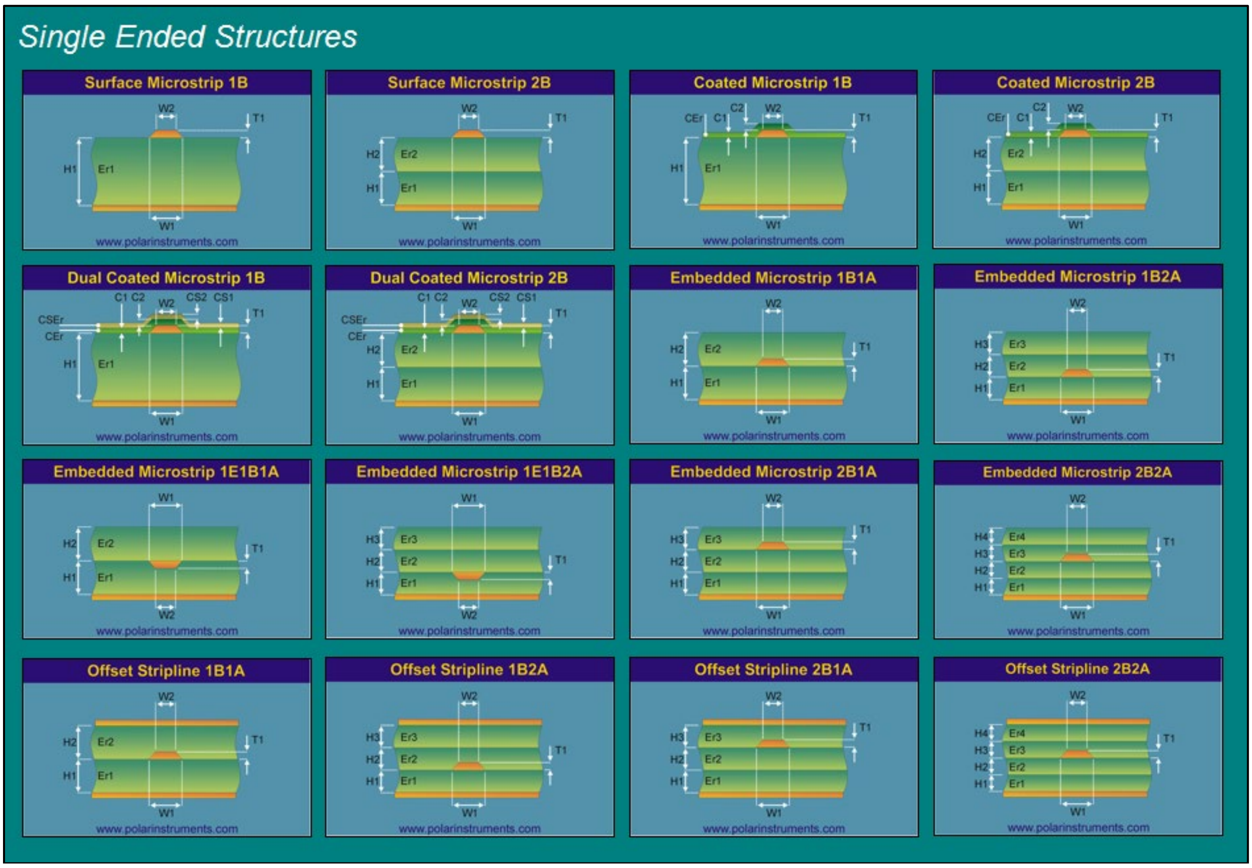
Differential surface coplanar

Differential coated coplanar

Differential embedded coplanar

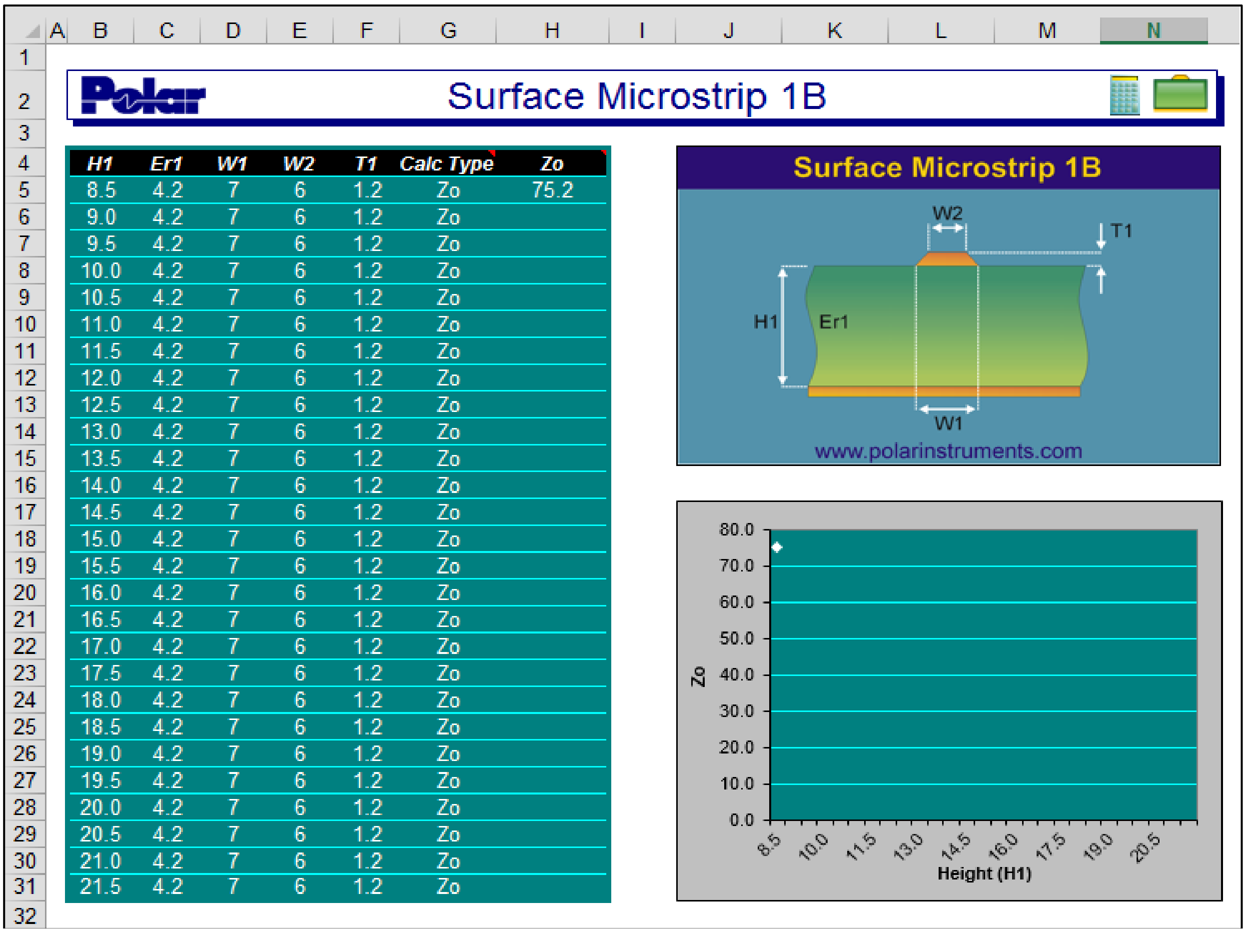
Differential offset coplanar

Each group of structures contains the associated models – the Single Ended structures are shown below.



Structure index sheet — Single ended structures

To select a structure, scroll to the category and click on its graphic, for example, Surface Microstrip 1B. Excel activates the associated worksheet.



H1	Er1	W1	W2	T1	Calc Type	Zo
8.5	4.2	7	6	1.2	Zo	75.2
9.0	4.2	7	6	1.2	Zo	
9.5	4.2	7	6	1.2	Zo	
10.0	4.2	7	6	1.2	Zo	
10.5	4.2	7	6	1.2	Zo	
11.0	4.2	7	6	1.2	Zo	
11.5	4.2	7	6	1.2	Zo	
12.0	4.2	7	6	1.2	Zo	
12.5	4.2	7	6	1.2	Zo	
13.0	4.2	7	6	1.2	Zo	
13.5	4.2	7	6	1.2	Zo	
14.0	4.2	7	6	1.2	Zo	
14.5	4.2	7	6	1.2	Zo	
15.0	4.2	7	6	1.2	Zo	
15.5	4.2	7	6	1.2	Zo	
16.0	4.2	7	6	1.2	Zo	
16.5	4.2	7	6	1.2	Zo	
17.0	4.2	7	6	1.2	Zo	
17.5	4.2	7	6	1.2	Zo	
18.0	4.2	7	6	1.2	Zo	
18.5	4.2	7	6	1.2	Zo	
19.0	4.2	7	6	1.2	Zo	
19.5	4.2	7	6	1.2	Zo	
20.0	4.2	7	6	1.2	Zo	
20.5	4.2	7	6	1.2	Zo	
21.0	4.2	7	6	1.2	Zo	
21.5	4.2	7	6	1.2	Zo	

Surface Microstrip sample worksheet

Each worksheet comprises the graphic associated with the chosen model, a table with predefined values and an embedded chart that uses selected columns from the table as its data source.

Structure models not included in the workbook can be built as required as described later.

Choosing table columns for display

The chart data source is set by default to chart impedance Z_0 against substrate height H_1. Right click the chart and use the Select Data… command to redefine the chart source data and show results for other columns.

Moving through the structure sheets

Structure sheets may also be selected via the Tab Scrolling Buttons,

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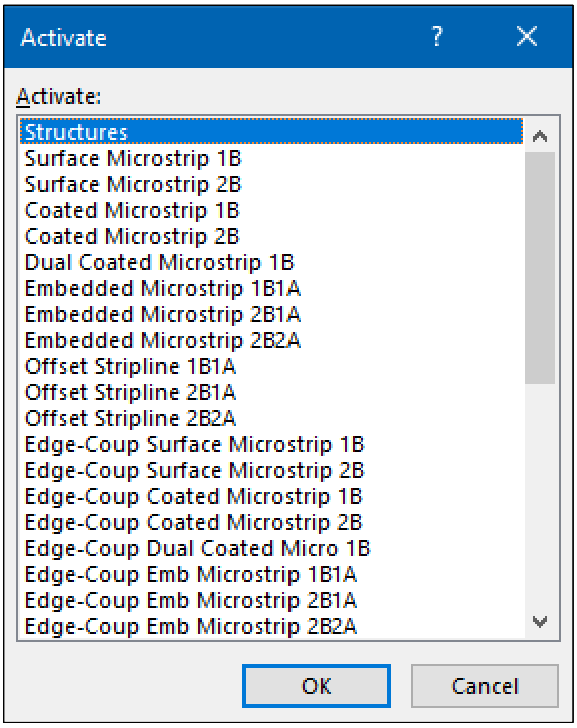
Click the buttons to select the first, previous, next or last structure sheets.

Alternatively, use the Ctrl + Page Up/Ctrl + Page Down keys to move to the previous/next sheet.

To move directly to a structure, right click the Tab Scrolling Buttons to display the list of structure sheets.



Select the structure to activate from the list and click OK. (Scroll through the list to display all supplied structures.)

Calculating trace characteristics

Each worksheet includes a pre-built sample application, incorporating a table of typical dimensions for use with the function associated with the structure and a chart displaying the change in impedance (Z_0), propagation delay (D), inductance (L), capacitance (C) or effective Er (EER) against structure dimensions (in the sample chart below Z_0 is shown against a varying Substrate Height (H1) with other parameters fixed).

H1	*Er1*	*W1*	*W2*	*T1*	*Calc Type*	*Zo*
8.5	4.2	7	6	1.2	Zo	75.2
9.0	4.2	7	6	1.2	Zo	
9.5	4.2	7	6	1.2	Zo	
10.0	4.2	7	6	1.2	Zo	
10.5	4.2	7	6	1.2	Zo	
11.0	4.2	7	6	1.2	Zo	
11.5	4.2	7	6	1.2	Zo	
12.0	4.2	7	6	1.2	Zo	
12.5	4.2	7	6	1.2	Zo	
13.0	4.2	7	6	1.2	Zo	
13.5	4.2	7	6	1.2	Zo	
14.0	4.2	7	6	1.2	Zo	

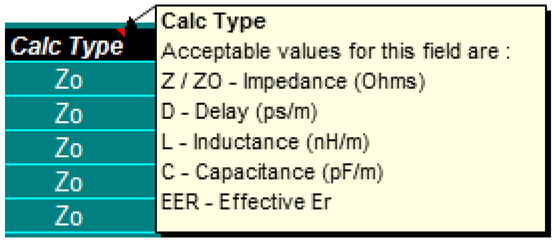
Sample table with increasing values of H

The sheet opens with the single value of Z_0 calculated for the structure dimensions shown in the first row. The field solving function is located in the cell labelled Z_0, the parameters for the function are contained in the associated cells labelled H1, Er1, W1, W2, T1, etc.

Choosing the calculation type

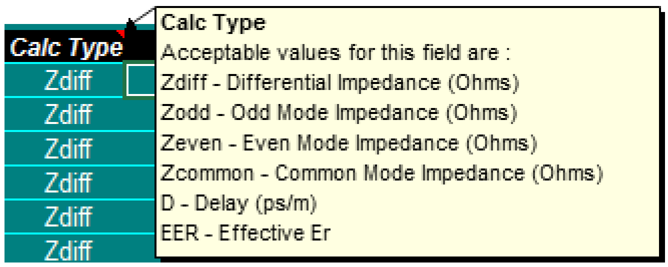
To calculate other characteristics for the selected parameters, enter the value D, L, C or EER in the associated cell in the Calculation Type column (labelled **Calc Type**), move to another cell and press the Calculate button. Re-label the results column if necessary.

To see which characteristics are available for a structure, move the mouse over the Calc Type label to display the Note text box.



Single ended calculation types

Differential structures include other characteristics, e.g. Zeven, Zodd, Zcommon.

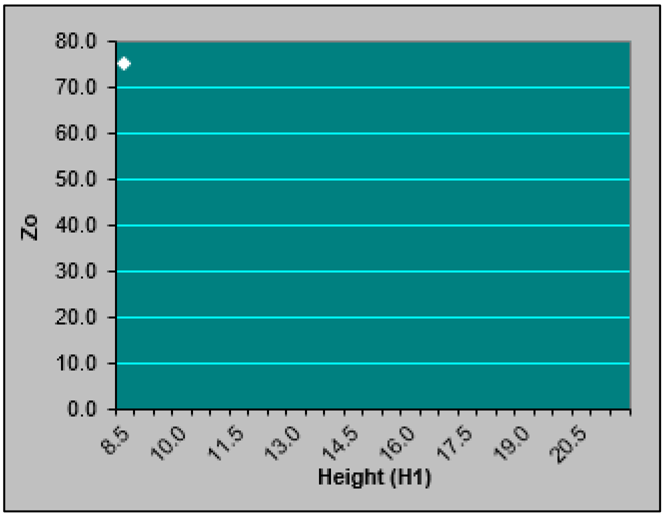


Differential calculation types

Enter the characteristic type in the Calc Type cells (Zeven, Zcommon, etc.) exactly as shown in the pop-up note above.

Charting against varying board parameters

The structure sheet opens with the value of Z_0 against H_1 for the structure dimensions shown in the first row and charted as shown below.



To chart the change in Z_0 (or D, L, C or EER) as the height, H1, changes over a range of values, use the Excel Fill Handle to copy the function formula down into the associated cells.

(To activate the Fill Handle, move the mouse to the lower right corner of the active cell. The mouse changes to a black plus sign. If the Fill Handle does not appear, select the File tab then Options | Advanced | Editing Options and tick the Enable fill handle and cell drag and drop check box.)

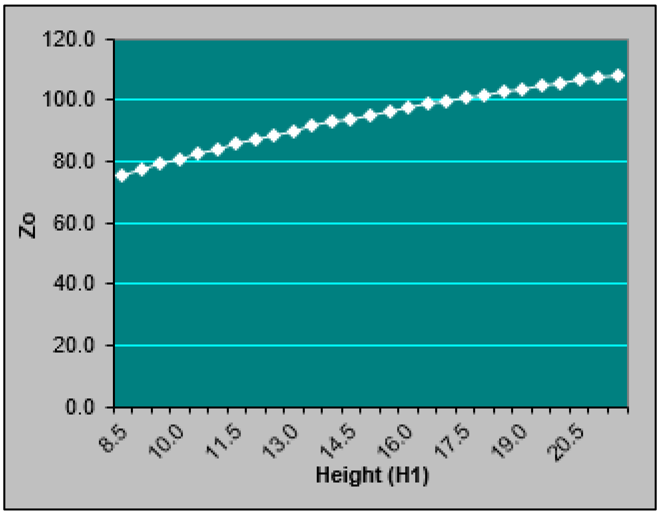
H1	Er1	W1	W2	T1	Calc Type	Zo
8.5	4.2	7	6	1.2	Zo	75.2
9.0	4.2	7	6	1.2	Zo	
9.5	4.2	7	6	1.2	Zo	
10.0	4.2	7	6	1.2	Zo	
10.5	4.2	7	6	1.2	Zo	
11.0	4.2	7	6	1.2	Zo	
11.5	4.2	7	6	1.2	Zo	
12.0	4.2	7	6	1.2	Zo	
12.5	4.2	7	6	1.2	Zo	
13.0	4.2	7	6	1.2	Zo	
13.5	4.2	7	6	1.2	Zo	
14.0	4.2	7	6	1.2	Zo	

Use Excel's Fill Handle to copy the formula down

Press the **Calculate** button to recalculate the worksheet. (The SiExcelx64.xls workbook sets Excel's Calculation mode to Manual; see the File tab, choose Options | Formulas | Calculation options.) Excel solves for the selected characteristic in all associated rows.

H1	Er1	W1	W2	T1	Calc Type	Zo
8.5	4.2	7	6	1.2	Zo	75.2
9.0	4.2	7	6	1.2	Zo	77.1
9.5	4.2	7	6	1.2	Zo	79.0
10.0	4.2	7	6	1.2	Zo	80.8
10.5	4.2	7	6	1.2	Zo	82.5
11.0	4.2	7	6	1.2	Zo	84.1
11.5	4.2	7	6	1.2	Zo	85.7
12.0	4.2	7	6	1.2	Zo	87.1
12.5	4.2	7	6	1.2	Zo	88.6
13.0	4.2	7	6	1.2	Zo	90.0
13.5	4.2	7	6	1.2	Zo	91.3
14.0	4.2	7	6	1.2	Zo	92.6
14.5	4.2	7	6	1.2	Zo	93.9
15.0	4.2	7	6	1.2	Zo	95.1

The embedded chart is refreshed with the results of the calculation.



Plot of Z_0 as Height (H1) varies

Choosing other parameters

Z_0, D, L, C and Er can be plotted against any of the function parameters.

For example, to display Z_0 as Er1 varies, in the example reset H1 to a single value, e.g. 8.5, and plot Z_0 against changes of Er1 between 3.8 and 4.35 in 0.05 increments.

Changing the parameters

Select the first value in the Height column and use the Fill Handle to fill down to row 16 with the value 8.

Change the first value in the E_r column to 3.8, change the second value to 3.85 then select *both* cells.

Use the Fill Handle to fill down to row 16; Excel detects the two cell values as an incrementing sequence and fills the column accordingly with values increasing at 0.05 intervals.

Click the **Calculate** icon to refresh the Z_0 column.

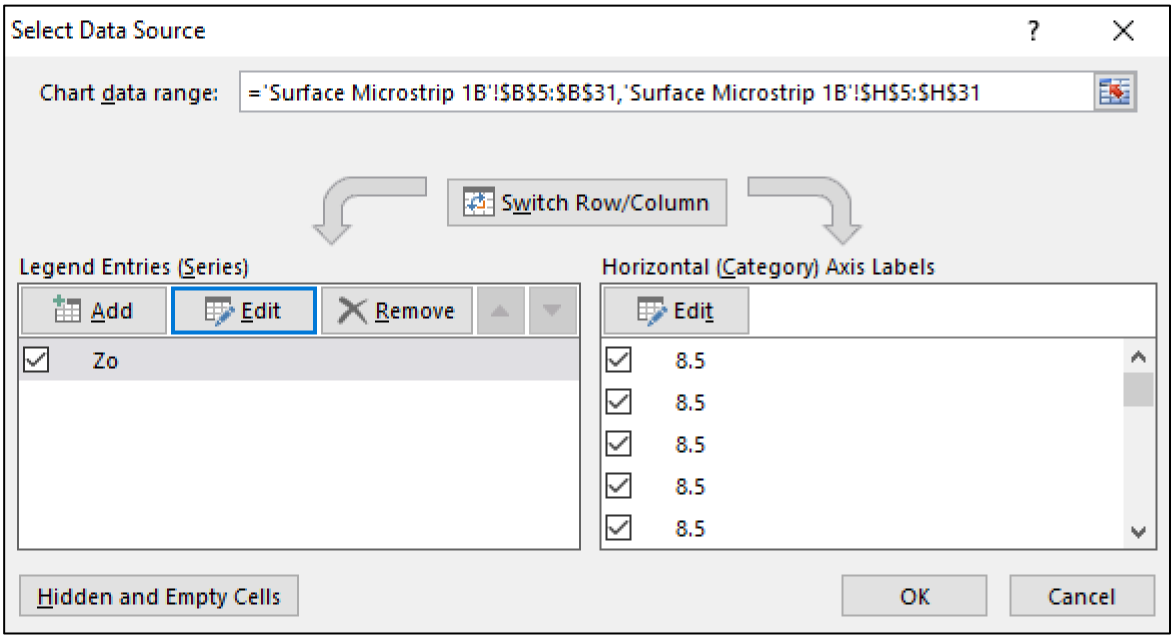
H1	Er1	W1	W2	T1	Calc Type	Zo
8.5	3.8	7	6	1.2	Zo	78.4
8.5	3.85	7	6	1.2	Zo	78.0
8.5	3.9	7	6	1.2	Zo	77.6
8.5	3.95	7	6	1.2	Zo	77.1
8.5	4	7	6	1.2	Zo	76.7
8.5	4.05	7	6	1.2	Zo	76.3
8.5	4.1	7	6	1.2	Zo	75.9
8.5	4.15	7	6	1.2	Zo	75.6
8.5	4.2	7	6	1.2	Zo	75.2
8.5	4.25	7	6	1.2	Zo	74.8
8.5	4.3	7	6	1.2	Zo	74.4
8.5	4.35	7	6	1.2	Zo	74.1

Z0 against Er1 with other parameters fixed

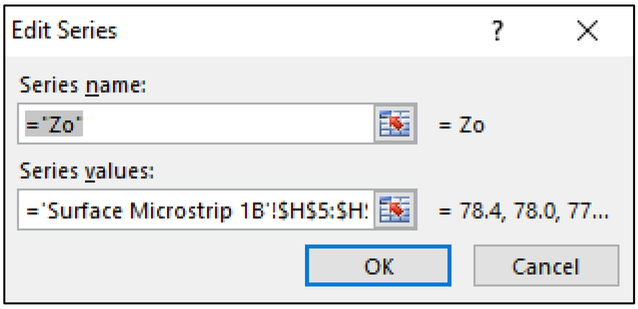
Modifying the chart

It will be necessary to modify the chart to reflect the new scales and Category axis.

Right click the chart area and choose Select Data…

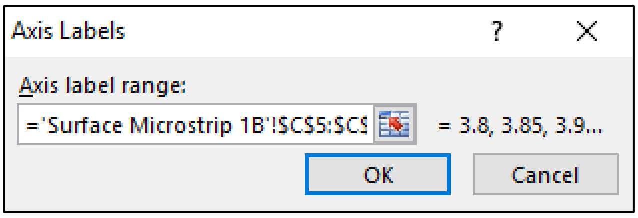


From the Select Data Source dialog box, click the Z_0 Series and choose Edit; the Series page shows the source data cell ranges for the chart.



Click the Collapse Dialog button,  , and select the new range of values of Z_0.

In the Horizontal (Category) Axis Labels pane click Edit and select the range of Er values charted.

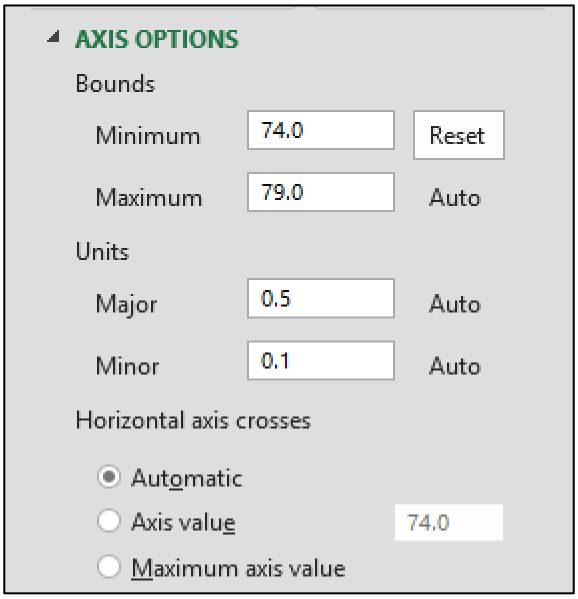


Click the button again to restore the dialog box and press **OK**.

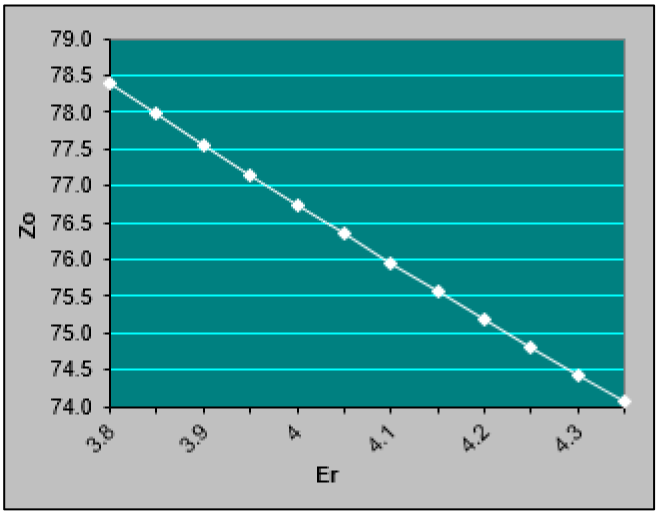
Click the Category Axis Title label and replace the H with Er. Right click the horizontal (Er) axis and format as required.

Right click the value (Z_0) axis and choose Format Axis…

Choose the Scale tab and change the values as necessary for Minimum and Maximum scale values.



The chart should appear as shown below.



Format the chart (color, scales, etc.) as required.

Repeat the procedure for other parameter values.

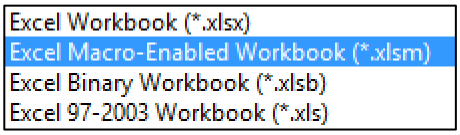
Using the controlled impedance functions in other workbooks

The controlled impedance functions supplied by the Si Excel workbooks, Si Excel.xlsm/SiExcelx64.xslm or SiExcelExpert/SiExcelExpertx64.xlsm, are available for use as user defined functions in other workbooks.

Prior to using any of the functions it will be necessary to ensure the SiExcel.xlsm / SiExcelx64 workbook or SiExcelExpert/SiExcelExpertx64.xlsm is open. In this discussion the worksheet is assumed to refer to the SiExcel.xlsm workbook.

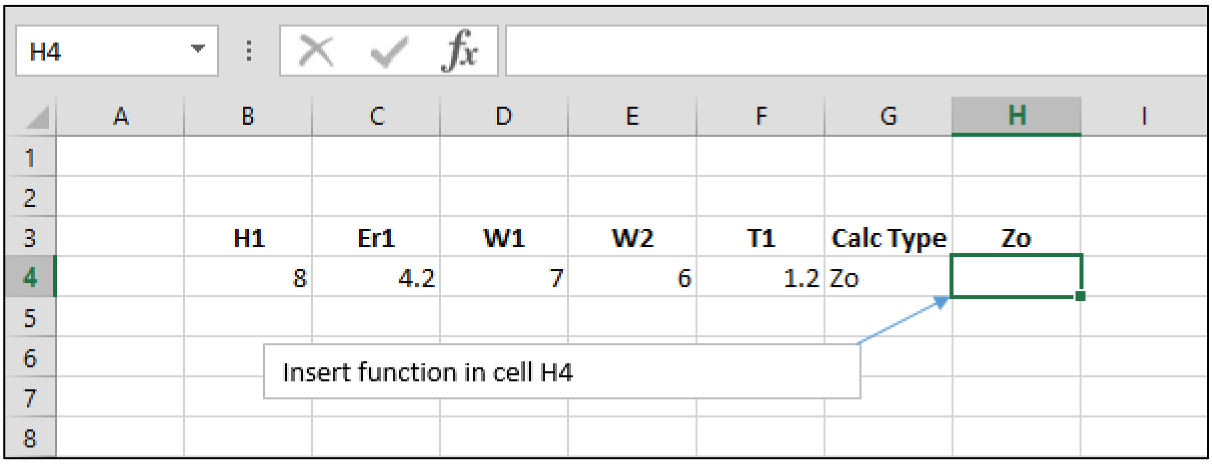
The functions use the board parameters, H1, W1, Er1, etc. as arguments. Parameter values can be derived from existing data in worksheet cells or inserted into the Function Arguments dialog directly.

Begin and save a new workbook. It will be necessary to save the workbook as a macro-enabled workbook.



It is recommended that worksheets are prepared with labels and parameter values (as shown below) *prior* to inserting controlled impedance functions.

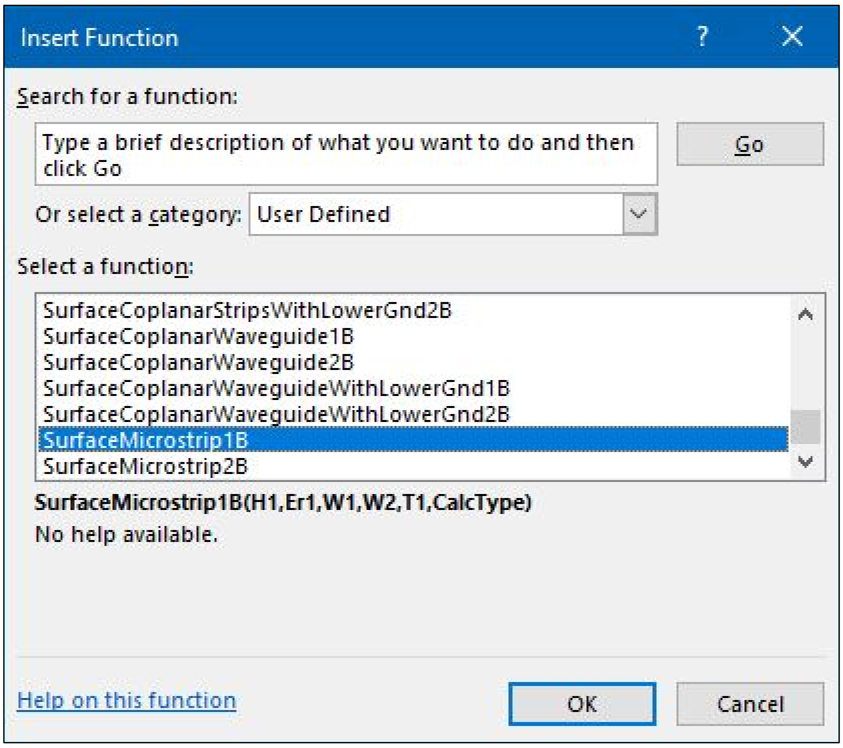
In the example below cells B3 – H3 contain the labels for a Surface Microstrip 1B structure. The parameter values for the Surface Microstrip structure are contained in cells B4 to G4. The Surface Microstrip 1B function will be inserted into cell H4 and reference cells B4 – G4.



Construct the model as show above and click the **Insert Function** button on the formula bar.

The Insert Function dialog box is displayed.

From the function category dropdown select the User Defined functions to display the structure functions.

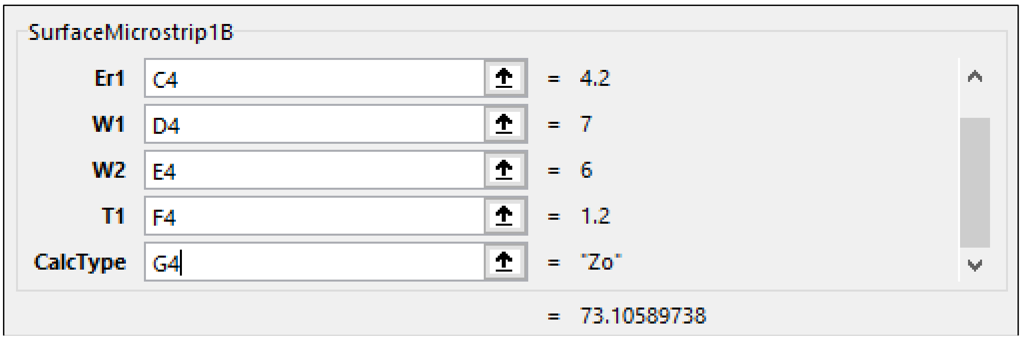


If necessary, scroll to the controlled impedance structure functions; click the function associated with the surface microstrip structure (SurfaceMicrostrip1B in this example) and click OK: the Function Arguments dialog is displayed.

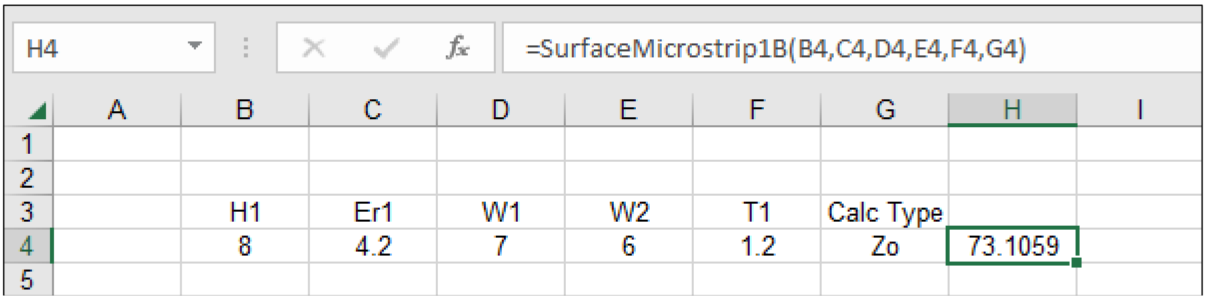
Using the Function Arguments dialog to enter formulas

Use the Excel Function Arguments dialog to enter function parameters. The Function Arguments dialog creates an edit box for each argument in the function.

Click into each edit box and then into the worksheet cell containing the associated argument in turn (or use the Collapse Dialog button ( ) in the **H1** edit box and select cell B4: click the button again. Tab through the other edit boxes and repeat the procedure for each value.) As the function is entered, the Function Arguments dialog displays the value of each of its arguments, the current result of the function, and the current result of the entire formula. When the last value is entered Excel calculates and displays the final result.



Press OK to close the Function Arguments dialog and complete the formula.



	A	B	C	D	E	F	G	H	I
1									
2									
3		H1	Er1	W1	W2	T1	Calc Type		
4		8	4.2	7	6	1.2	Zo	73.1059	
5									

Z_0 calculated for a single set of values

To calculate Z_0 over a range of parameter values, select the data and formula (cells B4 to H4) and use the Fill Handle to copy down as necessary.

Select each column of cells as appropriate and enter the new parameter values.

Hint: to fill a range of cells with a single value select the range, type the value and press Shift + Enter.

Press Shift + F9 to recalculate the sheet.

If necessary, use the Increase Decimal/Decrease Decimal buttons

to select the required number of decimal places.

Format as required.

H1	Er1	W1	W2	T1	Calc Type	Zo
8	3.80	7	6	1.2	Zo	76.24228
8	3.85	7	6	1.2	Zo	75.82773
8	3.90	7	6	1.2	Zo	75.41997
8	3.95	7	6	1.2	Zo	75.01880
8	4.00	7	6	1.2	Zo	74.62406
8	4.05	7	6	1.2	Zo	74.23555
8	4.10	7	6	1.2	Zo	73.85313
8	4.15	7	6	1.2	Zo	73.47663
8	4.20	7	6	1.2	Zo	73.10590
8	4.25	7	6	1.2	Zo	72.74079
8	4.30	7	6	1.2	Zo	72.38116
8	4.35	7	6	1.2	Zo	72.02687

Z_0 calculated for changing Er_r

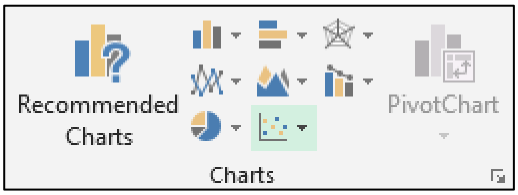
Charting results

Use the Excel Chart Wizard to chart the results.

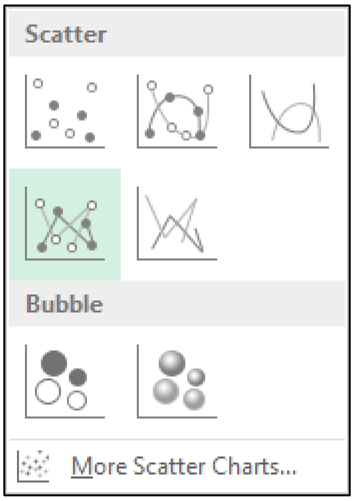
Select the area to be charted: in this example the Er1 and Z_0 ranges (to select non-adjacent ranges, press Ctrl while dragging the mouse over each range). If necessary, decrease decimal to the appropriate resolution.

H1	Er1	W1	W2	T1	Calc Type	Zo
8	3.80	7	6	1.2	Zo	76.24228
8	3.85	7	6	1.2	Zo	75.82773
8	3.90	7	6	1.2	Zo	75.41997
8	3.95	7	6	1.2	Zo	75.01880
8	4.00	7	6	1.2	Zo	74.62406
8	4.05	7	6	1.2	Zo	74.23555
8	4.10	7	6	1.2	Zo	73.85313
8	4.15	7	6	1.2	Zo	73.47663
8	4.20	7	6	1.2	Zo	73.10590
8	4.25	7	6	1.2	Zo	72.74079
8	4.30	7	6	1.2	Zo	72.38116
8	4.35	7	6	1.2	Zo	72.02687

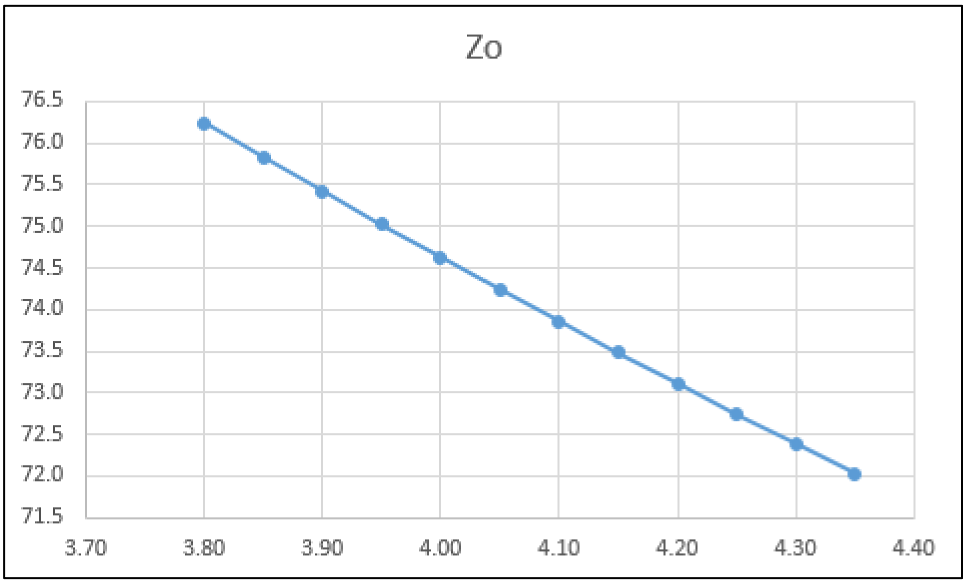
From the Insert tab on the ribbon Click the **Insert Scatter (X,Y)** button



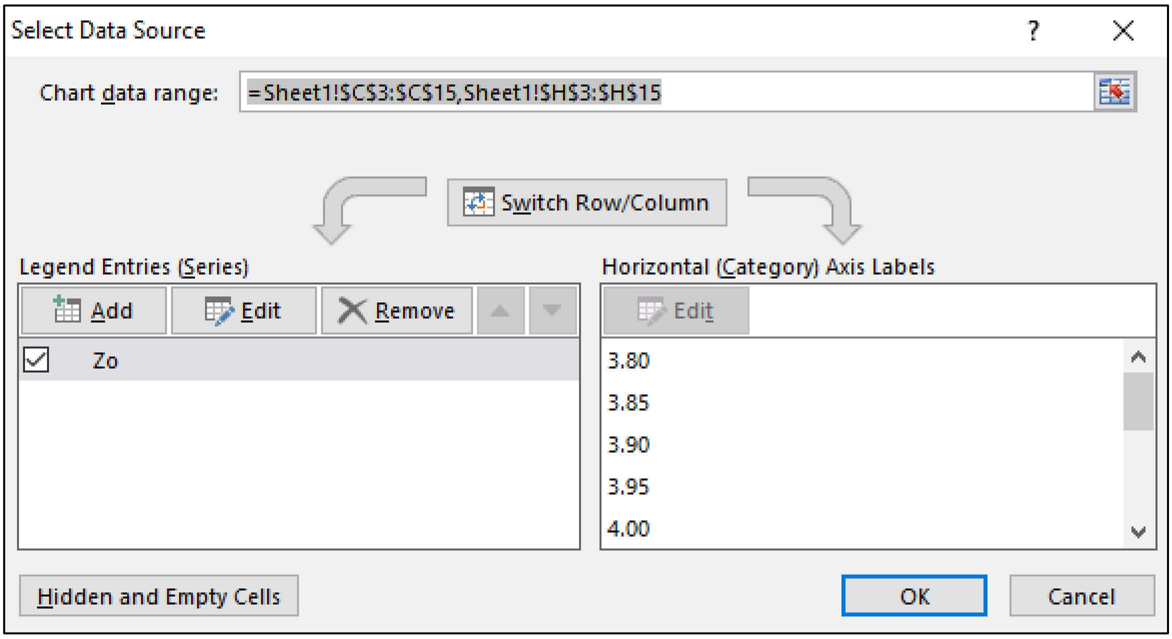
From the scatter type choose Scatter with Straight Lines and Markers



Excel charts the selected data.

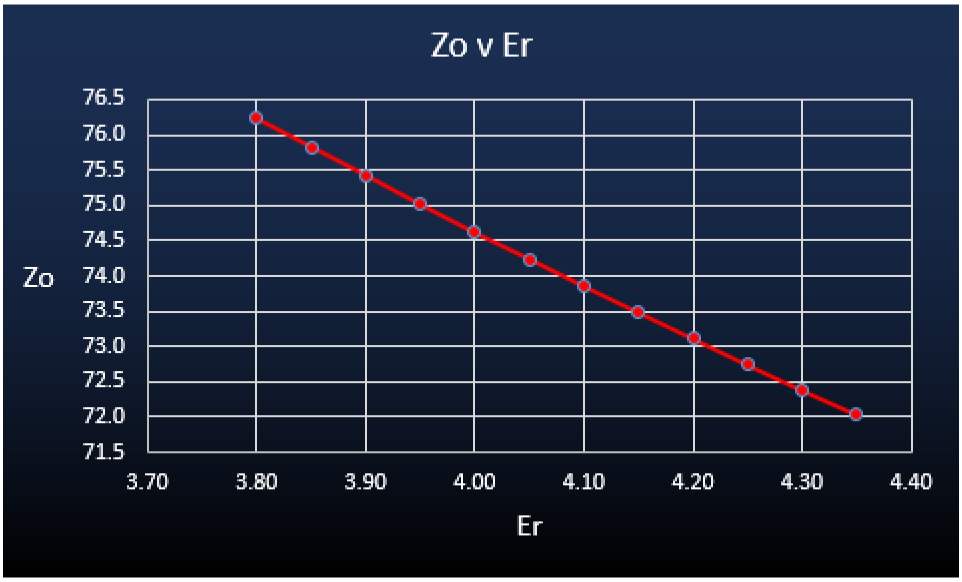


Right click the chart and choose Select Data and check the Data Source.

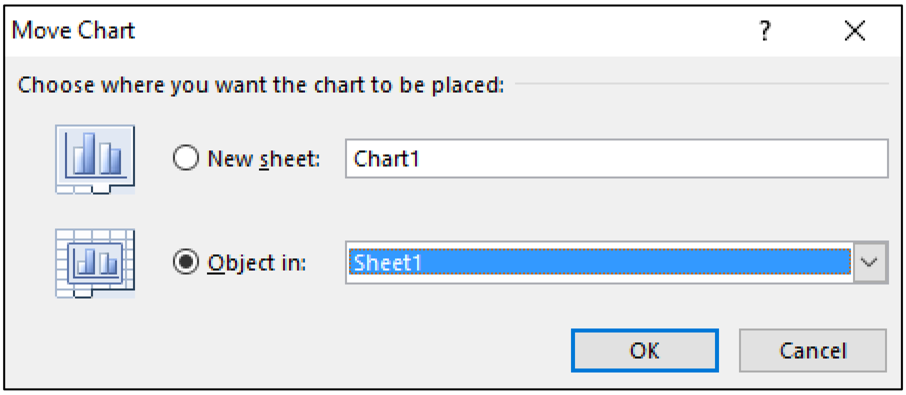


Check the Chart Data Range**:** in this case the cell references are correct.

From the Design tab of the ribbon, click add Chart element or use the standard chart formats, and add titles for the chart and its axes and (optionally) remove the legend. Format the chart as required.



If necessary, right click the chart and choose Move Chart.



Using Move Chart dialog box to choose where Excel relocates the chart.

To place the chart on a new chart sheet, click New sheet: and type a name for the new chart sheet.

To embed the chart on the worksheet, click Object in:, select a sheet name from the list box, and click OK.

Drag and size the embedded chart as required on the worksheet.

To modify the data series (e.g. line weight, marker style etc.) right click the chart line and choose Format Data Series…

Change the series format as required.

Plotting multiple data series

Plotting Z_0 for surface and coated microstrip

Inserting the first data series

Supply the data and plot the data series for Surface Microstrip as described earlier.

H1	Er1	W1	W2	T1	Calc Type	Zo
8	3.80	7	6	1.2	Zo	76.2
8	3.85	7	6	1.2	Zo	75.8
8	3.90	7	6	1.2	Zo	75.4
8	3.95	7	6	1.2	Zo	75.0
8	4.00	7	6	1.2	Zo	74.6
8	4.05	7	6	1.2	Zo	74.2
8	4.10	7	6	1.2	Zo	73.9
8	4.15	7	6	1.2	Zo	73.5
8	4.20	7	6	1.2	Zo	73.1
8	4.25	7	6	1.2	Zo	72.7
8	4.30	7	6	1.2	Zo	72.4
8	4.35	7	6	1.2	Zo	72.0
8	4.40	7	6	1.2	Zo	71.7

In this example, plot Z_0 against E_r.

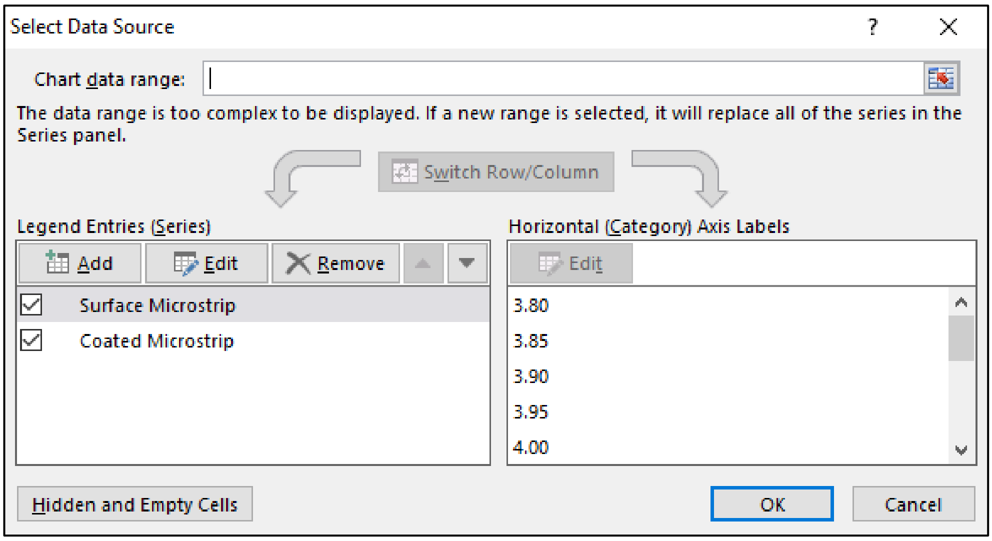
To format any chart item, right click the item and change its properties via the short cut menu.

Adding the second data series

Supply the data for the Coated Microstrip structure as shown below.

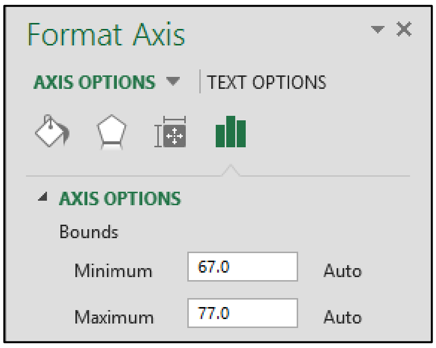
H1	Er1	W1	W2	T1	C1	C2	Cer	Calc Type	Zo
8	3.80	7	6	1.2	1	1	3.80	Zo	72.2
8	3.85	7	6	1.2	1	1	3.85	Zo	71.7
8	3.90	7	6	1.2	1	1	3.90	Zo	71.3
8	3.95	7	6	1.2	1	1	3.95	Zo	70.9
8	4.00	7	6	1.2	1	1	4.00	Zo	70.5
8	4.05	7	6	1.2	1	1	4.05	Zo	70.2
8	4.10	7	6	1.2	1	1	4.10	Zo	69.8
8	4.15	7	6	1.2	1	1	4.15	Zo	69.4
8	4.20	7	6	1.2	1	1	4.20	Zo	69.0
8	4.25	7	6	1.2	1	1	4.25	Zo	68.7
8	4.30	7	6	1.2	1	1	4.30	Zo	68.3
8	4.35	7	6	1.2	1	1	4.35	Zo	68.0
8	4.40	7	6	1.2	1	1	4.40	Zo	67.6

Right click the chart and choose **Select Data…** from the menu. Click the Add to add another data series. Highlight the Zo column of the Coated Microstrip and add the series to the chart. Click Edit to rename the series if a legend is required.

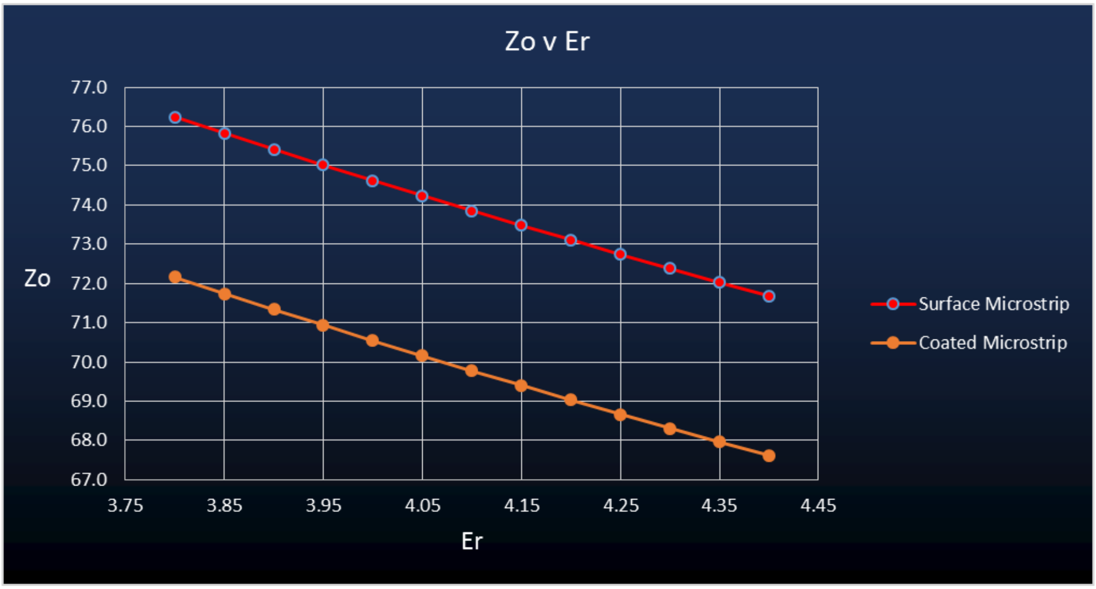


Add the name *Coated Microstrip* to the Name text box, click the Z_0 series from the Series list and add the name *Surface Microstrip*; press **OK**.

Right click the Y axis and choose **Format Axis…**, choose the Axis Options bounds and specify a suitable value (in this case 67) as the minimum value.



The chart should appear similar to that shown below.



Plotting Z_{even} and Z_{odd} v trace separation

In this example the Edge Coupled Offset Stripline structure is used to examine the effects of decreasing trace separation on even and odd impedance.

Choose the Edge Coupled Offset Stripline structure from the main index sheet.

Supply the values for H1 (copy the value 8 to all cells in the height column).

Supply the decreasing values for S (7.75 to 0.25 in 0.5 steps).

Change the Calc Type to Z_{odd}.

Change the Formula column heading to Zodd.

Fill down the formula column with the function.

Press the **Calculate** button to display the results.

Insert a column to the right of the formula column.

Select the formula cells, choose **Copy** and select the cell to the right of the Z_{odd} label.

Paste the Z_{odd} values into the column.

Change the Calc Type and the label of the formula column to Z_{even}.

Press the **Calculate** button. Partial results are shown below.

H1	Er1	H2	Er2	W1	W2	S1	T1	Calc Type	Zeven	Zodd
3.00	4.2	3.00	4.2	7	6	10	1.2	Zeven	21.4	21.3
3.00	4.2	3.00	4.2	7	6	9.75	1.2	Zeven	21.4	21.3
3.00	4.2	3.00	4.2	7	6	9.5	1.2	Zeven	21.4	21.3
3.00	4.2	3.00	4.2	7	6	9.25	1.2	Zeven	21.4	21.3
3.00	4.2	3.00	4.2	7	6	9	1.2	Zeven	21.4	21.3
3.00	4.2	3.00	4.2	7	6	8.75	1.2	Zeven	21.4	21.3
3.00	4.2	3.00	4.2	7	6	8.5	1.2	Zeven	21.4	21.3
3.00	4.2	3.00	4.2	7	6	8.25	1.2	Zeven	21.4	21.3
3.00	4.2	3.00	4.2	7	6	8	1.2	Zeven	21.4	21.3
3.00	4.2	3.00	4.2	7	6	7.75	1.2	Zeven	21.4	21.2
3.00	4.2	3.00	4.2	7	6	7.5	1.2	Zeven	21.4	21.2
3.00	4.2	3.00	4.2	7	6	7.25	1.2	Zeven	21.4	21.2

The associated chart should show the results for Z_{even}.

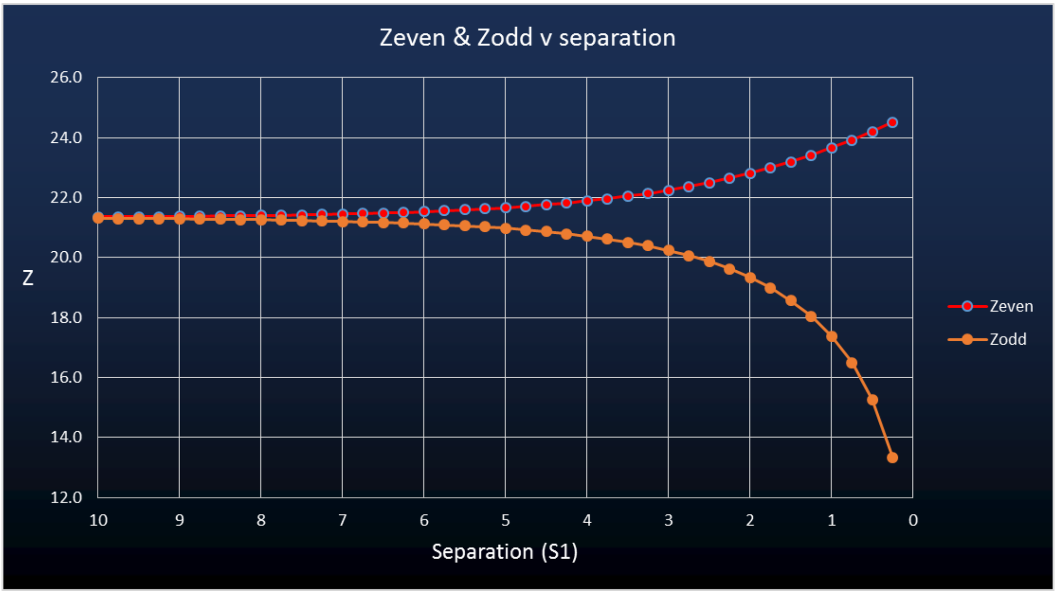
Drag the column of Z_{odd} values onto the chart.

Modify the chart so the Source Data Category (X) axis labels, and Series refer to the S1, Z_{even} and Z_{odd} cell ranges.

Choose a suitable minimum value for the Value (Y) axis.

Format the axes and add text labels as required.

The results are shown below.

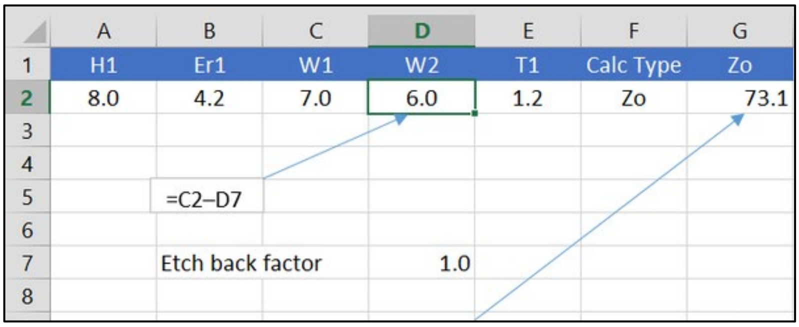


Using more complex models

Calculating the effect of etch back

In this example, the effect of PCB trace side-wall slope will be considered. The process includes charting the change in impedance due to variations in dielectric thickness and trace width. Choose the surface microstrip structure.

Begin by entering the parameter values for the surface microstrip structure in cells A2:F2.



The etch back factor will be a variable so assign W1 a value of **7.00**, locate the etch back factor in cell D7 and define W as C2–D7 (i.e. W1 minus etch back factor). Assign a value of **0.3** as etch back factor and insert the Surface Microstrip function into cell F6:

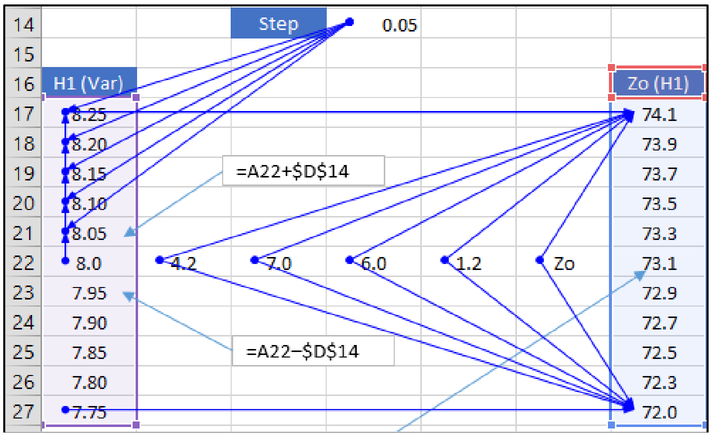
=SurfaceMicrostrip(A2,B2,C2,D2,E2,F2)

Press Shift-F9 to calculate.

Calculating the effect of variations in Height

Next, chart the effect of varying height H1 in 0.05 steps. Create references to cells A2–F7 in cells A22–F22, add the surface microstrip function to G22 and change references B22–F22 to mixed as shown below (click into the formula and use the F4 key to change each reference).

= !SurfaceMicrostrip1B(A22,B$22,C$22,D$22,E$22,F$22)



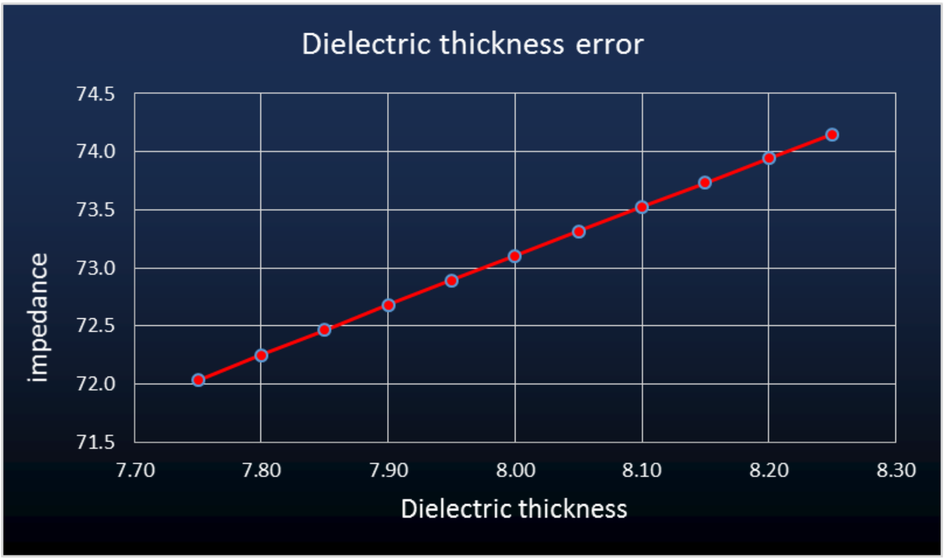
Copy the formula in G22 up to cell G17 and down to G27 as shown above

Create a step value of **0.05** in D14, enter the equation **=A22+$D$14** in cell A21 and fill it up to A17.

Enter the equation **=A22-$D$14** in cell A23 and fill it down to A27.

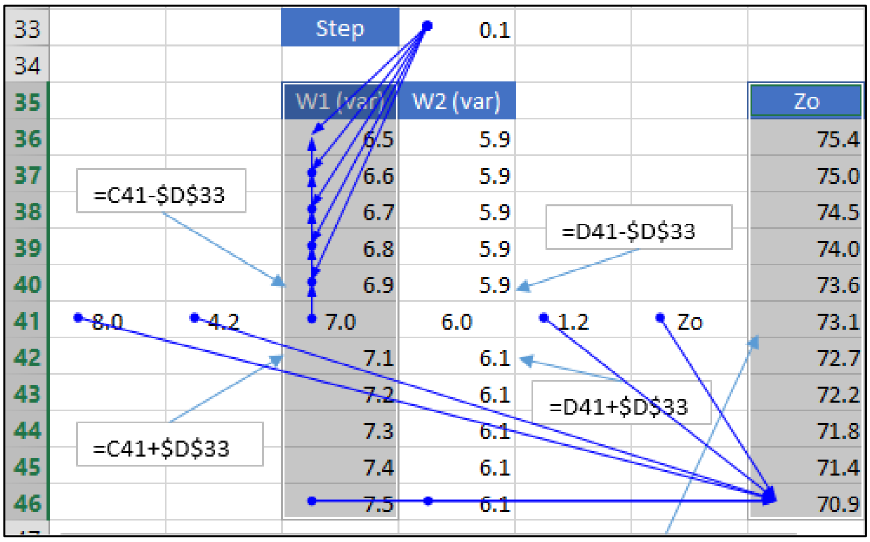
Use the Auditing Toolbar Trace Precedent and Dependent arrows to check references are as shown above. Press Shift-F9 to recalculate.

Select ranges H1(var) A17:A27 and Z_0(H1) G17:G27 and chart; the chart should appear as below.



Charting trace width error

Next, chart the effect of varying the trace width with a fixed trace side slope



33			Step	0.1			
34							
35			W1 (var)	W2 (var)			Zo
36			6.5	5.9			75.4
37			6.6	5.9			75.0
38			6.7	5.9			74.5
39			6.8	5.9			74.0
40			6.9	5.9			73.6
41	8.0	4.2	7.0	6.0	1.2	Zo	73.1
42			7.1	6.1			72.7
43			7.2	6.1			72.2
44			7.3	6.1			71.8
45			7.4	6.1			71.4
46			7.5	6.1			70.9

Create references to A2:F2 in cells A41:F41.

Enter the formula

=SurfaceMicrostrip1B(A$41,B$41,C41,D41,E$41,F$41) in cell G41 and copy it up to G36 and down to G46 as shown. (Note that C41 and D41 are left as relative references.)

Create a step value of **0.10** in cell D33.

Enter formula **=D41-$D$33** in cell C40 and fill up to C36.

Enter formula **=C40-$D$33** in cell D40 and fill up to D36.

Enter formula **=C42-$D$33**in cell D42 and fill down to D46.

Enter formula **=C41+$D$33** in cell C42 and fill down to C46.

Use the auditing arrows to check cell precedents and dependencies.

Recalculate.

Select ranges C36:C46 and G36:G46 and chart.

The trace width error chart should appear as shown below.

Charting etch back error

Finally, chart the effect of etch back error.

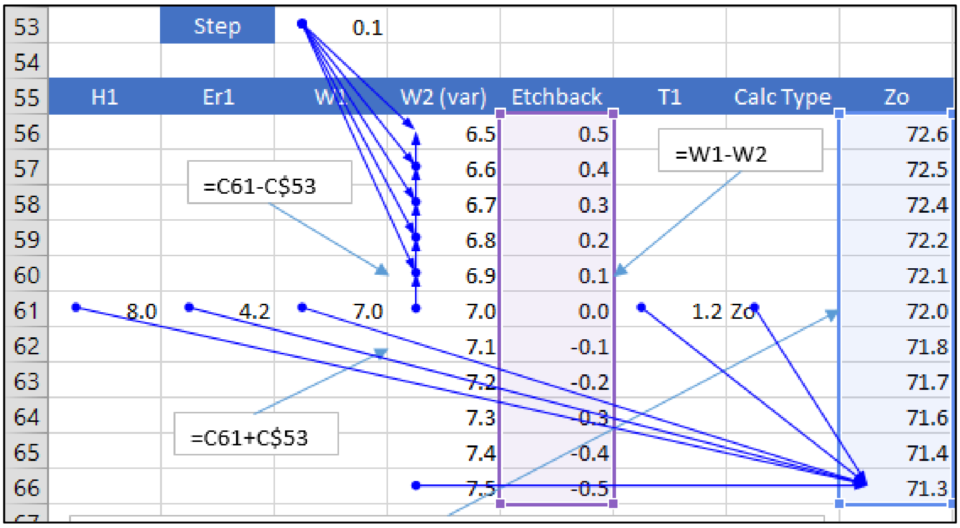
Create references to cells A2:F2 in cells A61:F61.

Enter the function

=SurfaceMicrostrip1B(A$61,B$61,C$61,D61,E$61,F$61)

in cell G61. (Note the relative reference to cell D61.) Fill up to G56 and down to G66.

Create a step value of 0.10 in cell C53



Enter the formula **=D61–C$53** in cell D60 and fill up to D56.

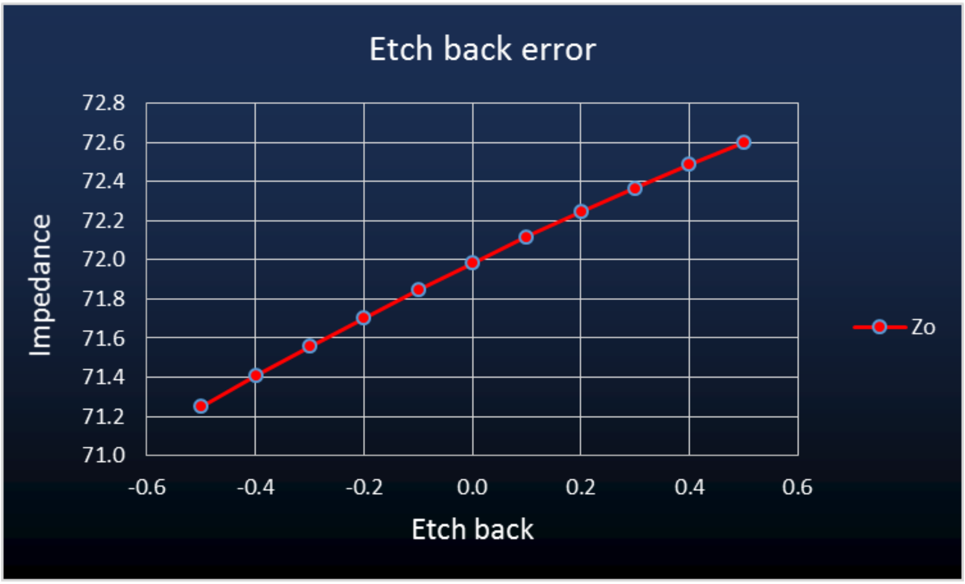
Enter the formula **=D61+C$53** in cell D62 and fill down to D56.

Insert cells E55:E66 and add label

Audit the precedents and dependencies.

Select cell ranges Etch back (E56:E66) and Z_0 (H56:G66) and chart.

The chart for an etch back error of 0.1 appears below.



Change the etch back factor cell value in cell C53 and recalculate to observe the change in impedance of a different trace side slope.

Terms used in this manual

AC	Alternating Current
CMOS	Complementary Metal Oxide Silicon
DC	Direct Current
ECL	Emitter Coupled Logic
EMI	Electromagnetic Interference
FR-4	Epoxy Glass Dielectric Material
TDR	Time domain Reflectometry
TTL	Transistor-Transistor Logic
Z_o	Characteristic Line Impedance
Z_o'	Characteristic Line Impedance (Loaded)
E_r	Relative Permittivity (homogeneous dielectric materials)
E'_r	Effective Relative Permittivity (non-homogeneous dielectric materials)

References

Wadell, Brian C – Transmission Line Design Handbook, Artech House 1991

IPC-2141 – Controlled Impedance Circuit Boards and High-Speed Logic Design, April 1996

Cohn, Seymour B. – Characteristic Impedance of the Shielded-Strip Transmission Line
IRE Trans MTT-2 July 1954 pp52–57

Abramowitz, Milton and Irene A Stegun – Handbook of Mathematical Functions, Dover, New York 1965

Hilberg, Wolfgang – From Approximations to Exact Relations for Characteristic Impedances.
IEE Trans MTT-17 No 5 May 1969 pp259–265

Hart, Bryan – Digital Signal Transmission, Pub: Chapman and Hall 1988

Harrington, Roger F – Field Computation by Moment Methods, Pub: MacMillan 1968

Sadiku, Matthew N O – Numerical Techniques in Electromagnetics, Pub: CRC Press 1992

Silvester P P – Microwave Properties of Microstrip Transmission Lines. IEE Proc vol 115 No 1 January 1969 pp43–48

Silvester P P & Ferrari R L – Finite Element for Electrical Engineers Pub, Cambridge University Press 1983

Brebbia, C A – The Boundary Element Method for Engineers, Pub: Pentech Press 1980

Paris, Federico and Canas, Jose – Boundary Element Method: Fundamentals and Applications
Pub: Oxford University Press 1997

Kobayashi, Masanor – Analysis of the Microstrip and the Electro-Optic Light Modulator
IEEE Trans MTT-26 No 2 February 1979 pp119–127

Bogatin, Eric; Justice, Mike; DeRego, Todd and Zimmer, Steve – Field Solvers and PCB Stack-up Analysis: Comparing Measurements and Modelling
IPC Printed Circuit Expo 1998 paper 505–3

Li, Keren and Fujii, Yoichi – Indirect Boundary Element Method Applied to Generalised Microstrip Analysis with Applications to Side-Proximity Effect in MMICs
IEE Trans MTT-40 No 2 February 1992 pp237–244