SONNET® USER'S GUIDE

RELEASE 11

SONNET®

Cover: James Clerk Maxwell (1831-1879). A professor at Cambridge University, England, Maxwell established the interdependence of electricity and magnetism. In his classic treatise of 1873, he published the first unified theory of electricity and magnetism and founded the science of electromagnetism.

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Release 11

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Chapter 1 Introduction

The Sonnet User's Guide is intended to provide in depth discussions of features of Sonnet's software. There is a short exposition of the theory behind Sonnet's analysis engine, ***em***, followed by discussions of geometry elements and features available in Sonnet. This manual also contains tutorials demonstrating how to use some features in Sonnet. The tutorials follow chapters discussing that topic. Please refer to the ***Table of Contents*** to see what tutorials are available.

For installation instructions and the basics of using Sonnet, please refer to the **Getting Started** manual. To learn about new features in this release, please refer to **Chapter 2, "What's New in Release 11"** on page 23.

The Sonnet Design Suite

The suite of Sonnet analysis tools is shown on page 18. Using these tools, Sonnet provides an open environment to many other design and layout programs. The following is a brief description of all of the Sonnet tools. Check with your system administrator to find out if you are licensed for these products:

Project Editor

The project editor is a user-friendly graphical interface that enables you to input your circuit geometry or circuit netlist for subsequent ***em*** analysis. If you have purchased the DXF and/or the GDSII translator, the translator interface is found in the project editor. You also set up analysis controls for your project in the project editor.

Program module: ***xgeom***

Analysis Engine

Em is the electromagnetic analysis engine. It uses a modified method of moments analysis based on Maxwell's equations to perform a true three dimensional current analysis of predominantly planar structures. ***Em*** computes S, Y, or Z-parameters, transmission line parameters (Z_0, Eeff, VSWR, GMax, Zin, and the Loss Factor), and SPICE equivalent lumped element networks. Additionally, it creates files for further processing by the current density viewer and the far field viewer. ***Em***’s circuit netlist capability cascades the results of electromagnetic analyses with lumped elements, ideal transmission line elements and external S-parameter data.

Program module: ***em***

Analysis Monitor

The analysis monitor allows you to observe the on-going status of analyses being run by ***em*** as well as creating and editing batch files to provide a queue for ***em*** jobs.

Program module: ***emstatus***

Response Viewer

The response viewer is the plotting tool. This program allows you to plot your response data from ***em,*** as well as other simulation tools, as a Cartesian graph or a Smith chart. You may also plot the results of an equation. In addition, the response viewer may generate Spice lumped models.

Program module: ***emgraph***

Current Density Viewer

The current density viewer is a visualization tool which acts as a post-processor to ***em*** providing you with an immediate qualitative view of the electromagnetic interactions occurring within your circuit. The currents may also be displayed in 3D.

Program module: ***emvu***

Far Field Viewer

The far field viewer is the radiation pattern computation and display program. It computes the far-field radiation pattern of radiating structures (such as patch antennas) using the current density information from ***em*** and displays the far-field radiation patterns in one of three formats: Cartesian plot, polar plot or surface plot.

Program module: ***patvu***

GDSII Translator

The GDSII translator provides bidirectional translation of GDSII layout files to/ from the Sonnet project editor geometry format.

Program module: ***gds***

DXF Translator

The DXF translator provides bidirectional translation of DXF layout files (such as from AutoCAD) to/from the Sonnet project editor geometry format.

Program module: ***dxfgeo***

Agilent Interface

The Agilent Interface provides a seamless translation capability between Sonnet and Agilent Series IV and Agilent ADS. From within the Series IV or ADS Layout package you can directly create Sonnet geometry files. ***Em*** simulations can be invoked and the results incorporated into your design without leaving the Series IV or ADS environment.

Program module: ***ebridge***

Microwave Office Interface

The Microwave Office Interface provides a seamless incorporation of Sonnet's world class EM simulation engine, *em*, into the Microwave Office environment using Microwave Office's EM Socket. You can take advantage of Sonnet's accuracy without having to learn the Sonnet interface. Although, for advanced users who wish to take advantage of powerful advanced features not presently supported in the integrated environment, the partnership of AWR and Sonnet has simplified the process of moving EM projects between Microwave Office and Sonnet.

Program Module: ***sonntawr***

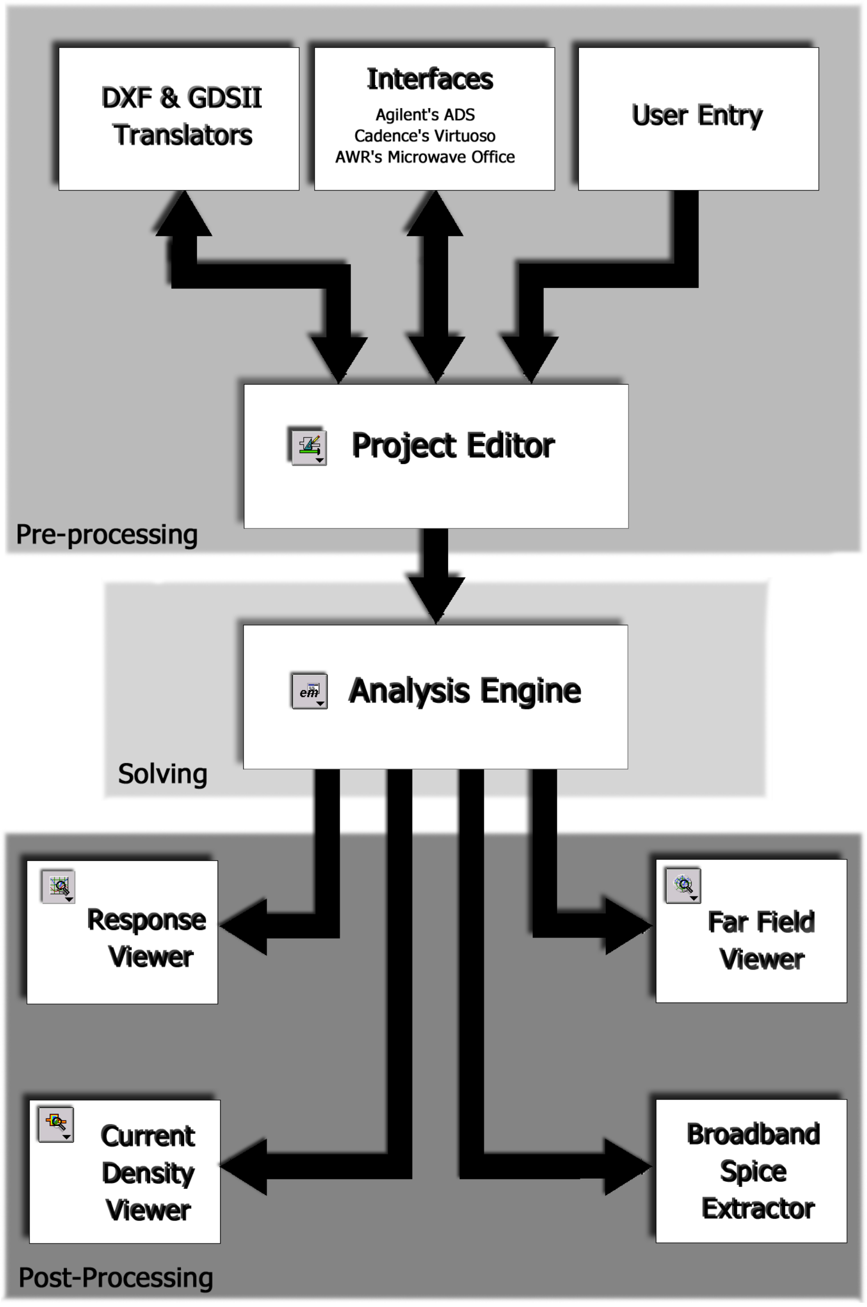
Cadence Virtuoso Interface

This Sonnet plug-in for the Cadence Virtuoso suite enables the RFIC designer to configure and run the EM analysis from a layout cell, extract accurate electrical models, and create a schematic symbol for Analog Artist and RFDE simulation.

Program Module: ***sonntcds***

Broadband Spice Extractor

A new Broadband Spice extraction module is available that provides high-order Spice models. In order to create a Spice model which is valid across a broad band, the Sonnet broadband SPICE Extractor feature finds a rational polynomial which "fits" the S-Parameter data. This polynomial is used to generate the equivalent lumped element circuits which may be used as an input to either PSpice or Spectre. Since the S-Parameters are fitted over a wide frequency band, the generated models can be used in circuit simulators for AC sweeps and transient simulations.


DXF & GDSII Translators
Interfaces
Agilent's ADS
Cadence's Virtuoso
AWR's Microwave Office
User Entry
Project Editor
Pre-processing
Analysis Engine
Solving
Response Viewer
Far Field Viewer
Current Density Viewer
Broadband Spice Extractor
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Em performs electromagnetic analysis [85, 86, 88] for arbitrary 3-D planar [60] (e.g., microstrip, coplanar, stripline, etc.) geometries, maintaining full accuracy at all frequencies. ***Em*** is a “full-wave” analysis in that it takes into account all possible coupling mechanisms. The analysis inherently includes dispersion, stray coupling, discontinuities, surface waves, moding, metalization loss, dielectric loss and radiation loss. In short, it is a complete electromagnetic analysis. Since ***em*** uses a surface meshing technique, i.e. it meshes only the surface of the circuit metalization, ***em*** can analyze predominately planar circuits much faster than volume meshing techniques.

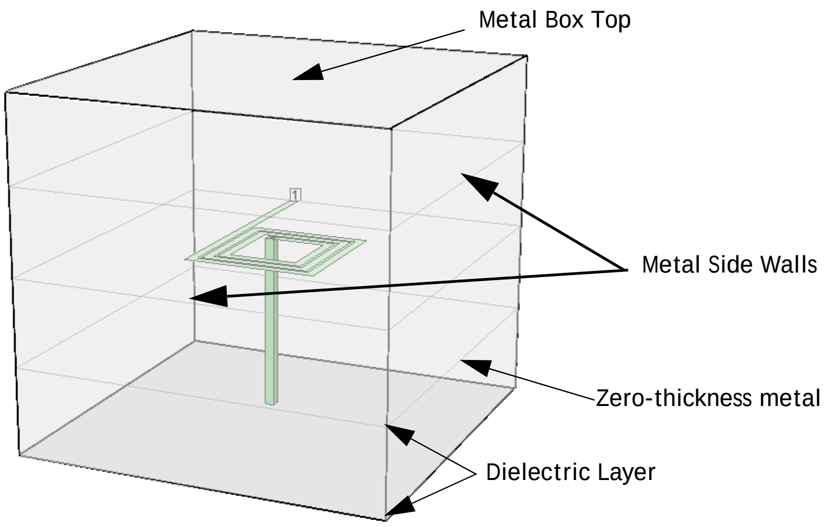
The Analysis Engine, *em*

Em analyzes 3-D structures embedded in planar multilayered dielectric on an underlying fixed grid. For this class of circuits, ***em*** can use the FFT (Fast Fourier Transform) analysis technique to efficiently calculate the electromagnetic coupling on and between each dielectric surface. This provides ***em*** with its several orders of magnitude of speed increase over volume meshing and other non-FFT based surface meshing techniques.

Em is a complete electromagnetic analysis; all electromagnetic effects, such as dispersion, loss, stray coupling, etc., are included. There are only two approximations used by ***em.*** First, the finite numerical precision inherent in digital computers. Second, ***em*** subdivides the metalization into small subsections made up of cells.

A Simple Outline of the Theory

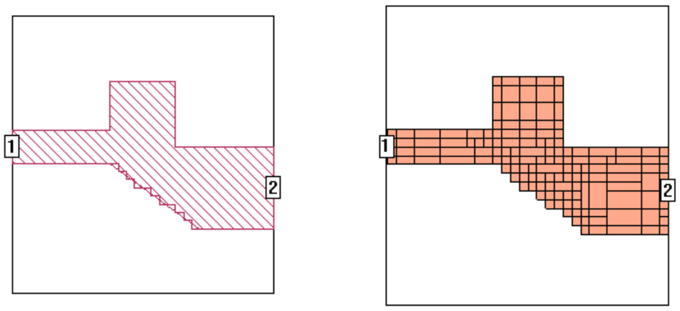
Em performs an electromagnetic analysis of a microstrip, stripline, coplanar waveguide, or any other 3-D planar circuit by solving for the current distribution on the circuit metalization using the Method of Moments. The metalization is modeled as zero-thickness metal between dielectric layers.



Em analyzes planar structures inside a shielding box.
Port connections are usually made at the box sidewalls.

Subsectioning the Circuit

Em evaluates the electric field everywhere due to the current in a single subsection. ***Em*** then repeats the calculation for every subsection in the circuit, one at a time. In so doing, ***em*** effectively calculates the "coupling" between each possible pair of subsections in the circuit.



The picture on the left shows the circuit as viewed in the project editor. On the right is shown the subsectioning used in analyzing the circuit.

Zero Voltage Across a Conductor

Each subsection generates an electric field everywhere on the surface of the substrate, but we know that the total tangential electric field must be zero on the surface of any lossless conductor. This is the boundary condition: no voltage is allowed across a perfect conductor.

The problem is solved by assuming current on all subsections simultaneously. ***Em*** adjusts these currents so that the total tangential electric field, which is the sum of all the individual electric fields just calculated, goes to zero everywhere that there is a conductor. The currents that do this form the current distribution on the metalization. Once we have the currents, the S-parameters (or Y- or Z-) follow immediately.

If there is metalization loss, we modify the boundary condition. Rather than zero tangential electric field (zero voltage), we make the tangential electric field (the voltage on each subsection) proportional to the current in the subsection. Following Ohm’s Law, the constant of proportionality is the metalization surface resistivity (in Ohms/square).

Sonnet is designed to work with your existing CAE software. Since the output data is in Touchstone or Compact format (at your discretion), ***em*** provides a seamless interface to your CAE tool.

Em Origins

The technique used in ***em*** was developed at Syracuse University in 1986 by Rautio and Harrington [85, 86, 88]. It was originally developed as an extension of an analysis of planar waveguide probes [90]. The technique expresses the fields inside the box as a sum of waveguide modes and is thus closely related to the spectral domain approach.

The complete theory has been published in detail in peer reviewed journals. A full list of relevant papers is presented in Appendix II "Sonnet References" on page 361.

Chapter 2 What’s New in Release 11

This chapter summarizes new capabilities and changes in release 11 of Sonnet. If you are not yet familiar with ***em***, you may want to just skim this chapter, skipping any terms that are unfamiliar. If you are an experienced user, this chapter merits detailed reading.

Sonnet User’s Manuals are only updated with each full release. However, our on-line help is also available at our web site and will periodically be updated with new material. To access this help, go to www.sonnetsoftware.com/support and click on the “Knowledge Base” link for the most recent updates.

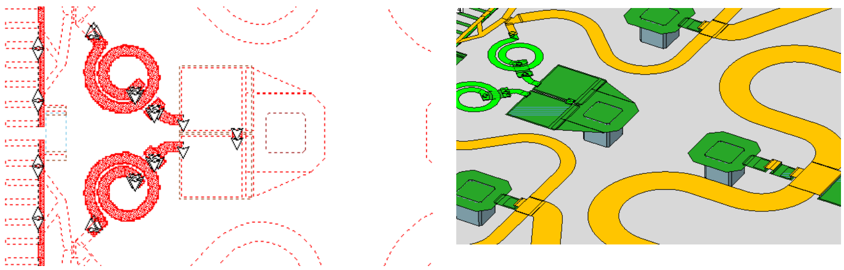
Sonnet Lite

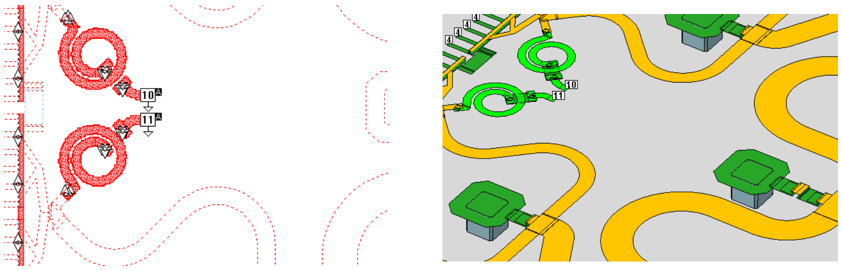
If you are looking for what’s new and changed in the Sonnet Lite release, please refer to the What’s New topic in online help in either the Sonnet task bar or the project editor. For what’s new in the full release, see the sections below.

New Features

Below is a summation of the major new features in release 11 of Sonnet. See below for more details. For changes from release 10, refer to “Changes,” page 28. Entries preceded by a * were added in release 10.53.

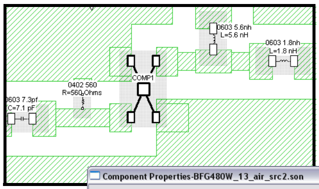
Co-calibrated Internal Ports & Calibration Groups: Co-Calibrated Internal Ports introduce perfectly calibrated connections on the interior of circuitry so that models may be connected in your favorite frequency or time domain circuit simulator. For instance, Co-Calibrated Ports might be used for calibrated internal connections for later attachment of a sophisticated non-linear transistor model in an electrical circuit simulation. The co-calibrated ports are associated with a calibration group. All of the ports in a calibration group share a common ground and are de-embedded simultaneously during the analysis to remove all cross-coupling them—even if they are very closely spaced. There is no limitation on how many ports may be in a calibration group. For a detailed discussion of co-calibrated internal ports, see “Co-calibrated Internal Ports,” page 71.

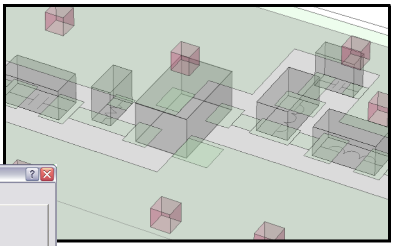

MMIC circuit with MIM capacitor termination which can be removed for simulation.

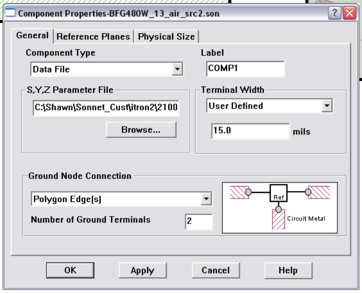


MIM capacitor termination is removed and replaced with Co-Calibrated Ports. MIM capacitor model may be accurately attached later using circuit theory simulation.

Components: The “Component,” a new object in Sonnet, is introduced in this release. A Component is used to include an electrical or circuit theory model into your electromagnetic simulation. The electrical model may be an ideal component (such as an ideal capacitor), or a data model component (such as a vendor S-parameter model for a surface mount transistor or amplifier). The EM analysis engine, em, uses circuit theory to attach the specified component to your geometry for the simulation, or creates ports which may be connected in a circuit simulation tool. Components are based on a new de-embedding technology used for co-calibrated ports.For a detailed discussion of components, please see Chapter 6 "Components" on page 81.






Component Properties-BFG480W_13_air_src2.son

General | Reference Planes | Physical Size

Component Type: Data File

Label: COMP1

S,Y,Z Parameter File: C:\Shawn\Sonnet_Cust\itron2\2100

Terminal Width: User Defined, 15.0 mils

Ground Node Connection: Polygon Edge(s)

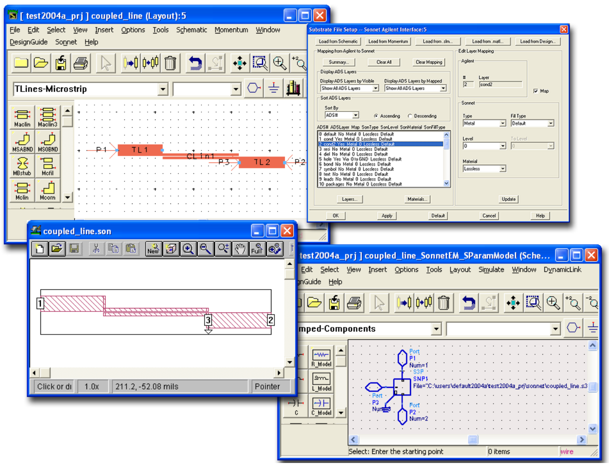
Number of Ground Terminals: 2

Top Left: Surface mount technology (SMT) power amplifier using a vendor data model Component for the transistor. Surface mount passive Components are also shown.

Bottom: Sonnet Component definition window for the Data File component that represents the transistor.

64 Bit Processing: Version 11 of Sonnet introduces the new 64-bit processing analysis engine. The 64-bit processing analysis engine is automatically installed when you install Sonnet. Using the 64-bit processing requires that you have a 64-bit operating system. The 64-bit analysis engine will only be used if the project you are analyzing requires more than 3.2 Gbytes of memory. Below that threshold, the 32-bit processing analysis engine will be used. The switch is made automatically by the software. Projects which require below 3.2 Gbytes of memory are analyzed more quickly using the 32-bit engine; however, the 64-bit engine can analyze problems too big for the 32-bit engine to handle.

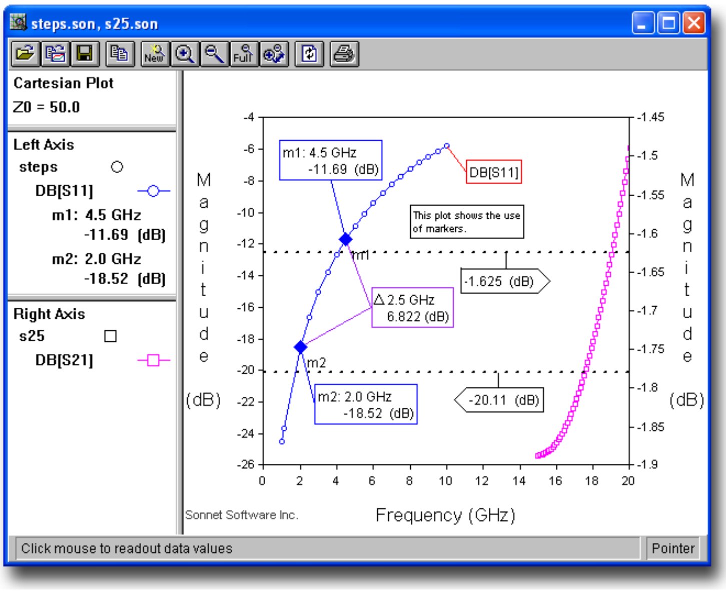
New Agilent Interface: In this release we introduce a new Agilent ADS Interface which is significantly more integrated than in previous Sonnet releases. The new interface enables you to setup and run your simulations all without leaving the ADS environment, and provides and intuitive, easy-to-use GUI interface. Existing layout projects in ADS can be used to instantly create accompanying Sonnet projects, including Momentum project information. Sonnet extraction models created during EM simulation are automatically imported into ADS, along with a schematic “layout look-alike” symbol and accompanying model layout. Sonnet models may also incorporate the new Co-Calibrated Ports or Components features. For all the details on the new interface, see Chapter 1, "Agilent Interface," of the **Translators** manual.



emCluster* using Platform LSF:** Release 10.53 introduced a new Sonnet product, ***emCluster using Platform LSF (LSF Cluster), which allows your Sonnet ***em*** analysis to interface with Platform Computing's Load Sharing Facility (LSF) cluster computing software to improve the efficiency and processing time of your Sonnet analyses. Sonnet's LSF Cluster feature provides you with the ability to split your analysis project into multiple jobs which may then be processed in parallel on a computer cluster to greatly reduce your processing time. You may also take advantage of Sonnet ***emCluster***'s ability to choose a server host computer based on analysis size, licensing considerations, loading, time of day, etc. For example, smaller jobs may be sent to a computing host reserved just for them to avoid waiting behind a larger job which requires substantially more processing time. For detailed instructions on setting up ***emCluster***, please refer to the **Setting Up emCluster** document available in PDF format on the Administration and Installation page of the Manual interface. You may access this interface by selecting *Help* ⇒ *Manuals* from any Sonnet application or by clicking on the Manuals button on the Sonnet task bar. For a detailed discussion on using LSF Cluster, please refer to Chapter 16, "***emCluster*** using LSF (LSF Cluster)" on page 229 of this manual.

emCluster* using Sonnet networking:** This release introduces a new module in ***emCluster, ***emCluster*** using Sonnet networking (Sonnet Cluster). Sonnet Cluster allows you distribute your processing across a cluster of computers but without the need for LSF software. Documentation for this feature was not available at the time of this printing; please contact your Sonnet representative about receiving documentation on this feature.

Markers in the Response Viewer: This release introduces Markers, a new feature in the response viewer. Markers allow you to annotate a plot in the response viewer to help you more easily interpret your data and more clearly present your data to others. Markers are available under the Graph Menu in the response viewer main menu. There are six types of markers: Data, Curve, Vertical Line, Horizontal Line, Delta and Note. For details, see Help by selecting *Help* ⇒ *Contents* or by clicking on the Help button in any dialog box.



***New Cadence Virtuoso Utilities Available:** There are two new utilities available for the Sonnet Virtuoso Interface. The first utility, the Symbol Model Utility may be used to create a symbol view from a Sonnet Broadband Spice model file in the Spectre format (.scs). This utility program is independent of the Sonnet Virtuoso interface and may be run separately. The second utility, Substrate Conversion, is for converting an Agilent Substrate file (.tch) into a Sonnet Substrate File (.matl) which may be used in the Sonnet Virtuoso interface. For more details, please see Chapter 2, “Cadence Virtuoso Interface” in the Translators manual.

Export to DXF New Features: Changes have been made to the export to DXF command in the project editor. The following features are now supported:

- Trace and Via information exported to separate DXF layers
- Sonnet Vias may be converted to Circular Vias in DXF
- Different Materials on the same Sonnet level can be exported to separate DXF layers

For more details, please see online help for the *File* ⇒ *Export* ⇒ *DXF* command in the project editor.

Changes

Below is a summation of the major changes in release 11 of Sonnet. See below for more details. Entries preceded by a * were added in release 10.53. For new features in release 11, refer to “New Features,” page 24.

***Cadence Virtuoso Interface Menu Change:** In release 10.52, when you opened a layout view in Cadence’s Virtuoso, the Sonnet-Virtuoso menu automatically appeared in the main menu. Since release 10.53, you must first select *Tools* ⇒ *Sonnet* from the layout view’s main menu in order for the Sonnet-Virtuoso menu to be loaded in the layout view. For more details, please refer to “Creating a SonnetEM View,” page 79 in the **Translators** manual.

New FLEXnet Licensing Manager: This release of Sonnet Software uses FLEXnet Licensing 10.8 in place of FLEXlm, the former license manager. In previous releases, it was possible to install a new version of Sonnet Software while retaining the old installation and have both versions of the software use the same license server simultaneously. This is not possible with the new license manager since the format of Sonnet’s licensing files has changed. You can continue to use your old license with FLEXlm as your license manager, but the two types of licensing managers cannot run simultaneously on the same license server. For more details on licensing, see the appropriate installation manual.

***Thick Metal Modeling:** In release 10.52, if you used more than two sheets of metal to model your thick metal, then the interior sheets were modeled using only a ring of metal on the edge of the polygon. This was changed for this release so that all sheets in the thick metal model are now modeled as full sheets. This was done to improve the accuracy of the loss at low frequency. Also, the subsectioning for thick metal has been made more efficient. In some cases, these changes may increase or decrease the total number of subsections; therefore, the memory requirement of your circuit may change from release 10.52.

***HSpice Compatibility:** PSpice files (“.lib”) which are generated by Sonnet when creating Broadband Spice model (see *Analysis* ⇒ *Output Files* in the project editor or *Output* ⇒ *Broadband Model File* in the response viewer) are now compatible with HSpice.

The Spice Model created now only uses positive elements except for one condition. If the model contains a very small resistor then a positive and a negative resistor are connected in series such that the sum of the two resistors is the equivalent of the small resistor needed in the model. In this case, HSpice will issue a warning about the negative resistance but the model will be valid.

Multi-Frequency Caching: The multi-frequency caching run option is no longer available in this release.

***Turning Object Snap Off:** When you open an existing geometry project or create a new geometry project, the Object Snap option in the Snap Setup dialog box (*Tools ⇒ Snap Setup*) is "on" by default. If you do not wish to have Object Snap "on" by default when you open a geometry project, you may do the following:

1 **Open the Sonnet Initialization file in a text editor.**

The Sonnet Initialization file is found at

<Sonnet Directory>/data/sonnet.ini

where <Sonnet Directory> is the location where your Sonnet software is installed. If you are using a Windows OS, the default location would be C:\Program Files\sonnet.11.52\data\sonnet.ini.

2 **In the [xgeom] section of the sonnet.ini file, add the following line:**

ObjectSnap=off

3 **Save the Sonnet.ini file.**

More Accurate Memory Estimate: The algorithm for determining a memory estimate (*Analysis ⇒ Estimate Memory*) for a project has been improved and is now more accurate than in previous releases. Therefore, when comparing the same project file in release 10 and release 11, you may find the memory estimate in release 11 is higher than that in release 10, even when the number of subsections is identical. This is simply because release 11 now includes more terms in its memory estimate calculation. The projects will typically require the same amount of memory.

Symmetric Matrix Solver: In this release, the analysis engine, ***em***, will use the symmetric matrix solver in both Sonnet Level2 and Level3 suites which effectively increases the size of the project which can be analyzed by about 40%.

Chapter 3 Subsectioning

The Sonnet subsectioning is based on a uniform mesh indicated by the small dots in the project editor screen. The small dots are placed at the corners of a “cell”. One or more cells are automatically combined together to create subsections. Cells may be square or rectangular (any aspect ratio), but must be the same over your entire circuit. The cell size is specified in the project editor in the Box Settings dialog box which is opened by selecting *Circuit ⇒ Box*. The analysis solves for the current on each subsection. Since multiple cells are combined together into a single subsection, the number of subsections is usually considerably smaller than the number of cells. This is important because the analysis solves an N x N matrix where N is the number of subsections. A small reduction in the value of N results in a large reduction in analysis time and memory.

Care must be taken in combining the cells into subsections so that accuracy is not sacrificed. ***Em*** automatically places small subsections in critical areas where current density is changing rapidly, but allows larger subsections in less critical areas, where current density is smooth or changing slowly.

However, in some cases you may wish to modify the automatic algorithm because you want a faster, less accurate solution, or a slower, more accurate solution, than is provided by the automatic algorithm. Also, in some cases, you may have knowledge about your circuit that the software does not. For example, you may know that there is very little current on a certain area of your metal. Or you may have chosen a small cell size because you have a small dimension in your circuit, but do not need the accuracy of a small cell size in larger structures within your circuit. In these cases, you can change the method by which ***em*** combines cells into subsections.

This chapter explains how ***em*** combines cells into subsections and how you can control this process to obtain an analysis time or the level of accuracy you require. There is also a discussion of selecting the cell size and how that may affect the ***em*** analysis.

Conformal Mesh is a special case of subsectioning used to model polygons with long diagonal or curved edges. For more information on subsectioning when using conformal mesh, see "Conformal Mesh Subsectioning," page 46.

Tips for Selecting A Good Cell Size

As you know, ***em*** subdivides the circuit into subsections which are made up of "cells," the building block in the project editor. The following discussion describes how to select a cell size. You may also use the Sonnet Cell Size Calculator which allows you to enter important dimensions to calculate the most efficient cell size which provides the required accuracy. To access the Cell Size calculator, click on the Cell Size Calculator button in the Box Settings dialog box, which is invoked when you select *Circuit* ⇒ *Box* from the project editor menu.

TIP

Select a cell size that is smaller than 1/20 of a wavelength.

Before calculating a cell size, it is important to calculate the wavelength at your highest frequency of analysis. An exact number is not important. If you know the approximate effective dielectric constant of your circuit, use this in the wavelength calculation; otherwise, use the highest dielectric constant in your structure.

Most circuits require that your cell size be smaller than 1/20 of a wavelength. Larger cell sizes usually result in unacceptable errors due to incorrect modeling of the distributed effects across the cell. Cell sizes smaller than $\lambda/20$ may increase the accuracy slightly but usually increases the total number of subsections, which increases the analysis time and memory requirements.

TIP

When possible, round off dimensions of your circuit so that they have a larger common multiple.

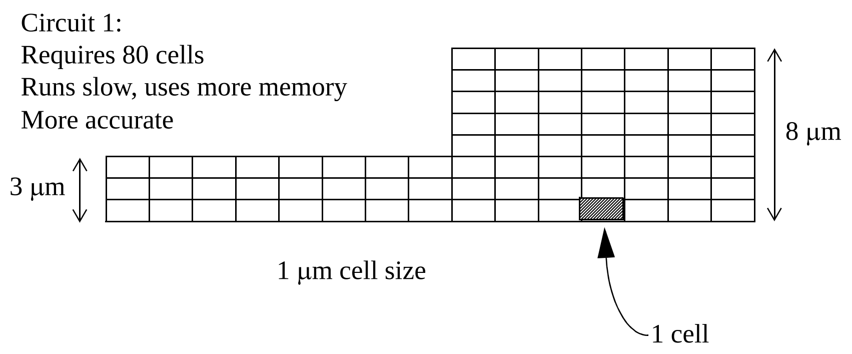
Since your circuit geometry is snapped to the nearest cell, you must find a cell size such that all of the dimensions of the circuit are a multiple of this cell size. For example, if your circuit has dimensions of 30 microns, 40 microns and 60 microns, possible cell sizes are 10 microns, 5 microns, 2.5 microns, 2 microns, etc. Large cell sizes result in more efficient analyses, so choosing 10 microns is probably best.

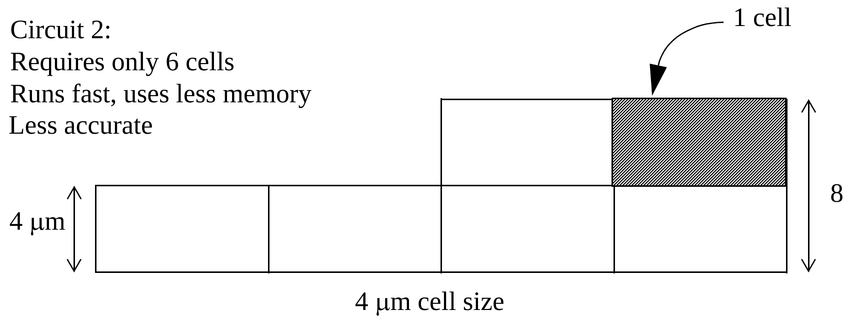
TIP

Calculate the X cell size and the Y cell size independently.

The X cell size and Y cell size do not have to be the same number. Calculate the X cell size based on just your dimensions in the X direction, and your Y cell size based on just your dimensions in the Y direction.

For example, if you have a spiral inductor with widths of 3 microns and spacings of 8 microns, modify the 3 microns to 4 microns. You may now use 2 cells instead of 8, speeding up the analysis by several orders of magnitude with little impact on circuit performance. This concept is illustrated below.





Circuit 1 takes more time and memory to analyze than circuit 2 even though they have approximately the same amount of metal. This is because the dimensions in circuit 2 are divisible by 4, so a 4 µm cell size may be used. Circuit 1 requires a 1 µm cell size. Think about the sensitivity of your circuit to these dimensions and your fabrication tolerances. If your circuit is not sensitive to a 1 micron change or can be made with only a +/- 1 micron tolerance, you can easily round off the 3 micron dimension in circuit 1 to the 4 micron dimension in circuit 2.

Cell Size Calculator

Sonnet also provides a cell size calculator which you may use to calculate the optimal cell size based on your critical circuit parameters. You access the Cell Size Calculator in the Box Settings dialog box (*Circuit* ⇒ *Box*). Using the Cell Size Calculator is detailed in Chapter 6, “Determining Cell Size” of the **Getting Started** manual. A detailed discussion of all the entries in the cell size calculator may be found in online help.

Viewing the Subsections

You can see the subsections used by Sonnet by following the instructions below. Be aware that your dielectric layers must be defined and at least one port must be added to your circuit before you may use the Estimate Memory command.

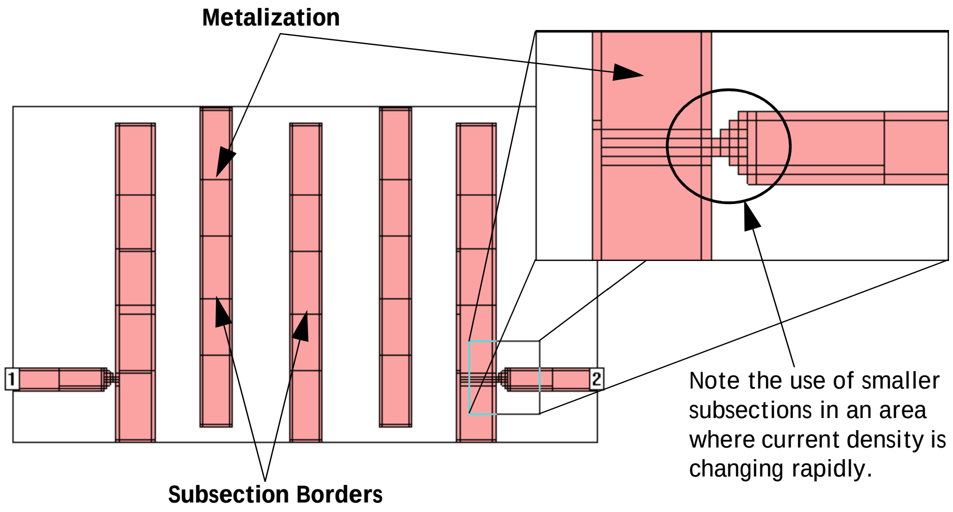
To view the subsectioning, do the following:

1 **From the project editor, select Analysis => Estimate Memory.**

This calculates the amount of memory required for your analysis.

2 **Click the View Subsections button.**

A picture of your circuit will appear. The metal will show up as red, and the subsection borders will show up as black lines as shown in the illustration below:


Metalization
1
2
Subsection Borders
Note the use of smaller subsections in an area where current density is changing rapidly.

Subsectioning and Simulation Error

As discussed above, Sonnet uses a fixed resolution grid and discretely meshes a given metallization pattern based on that underlying grid. The edges of metal patterns in a design do not necessarily have to be aligned to the grid, even though Sonnet only simulates metal fill which is on the grid. Off grid metalization may be over or under filled depending on the degree of misalignment between grid and metal pattern. While misalignment gives the user visual feedback of one potential error source in a Sonnet simulation, it is important to keep in mind that every planar Method of Moments (MoM) simulation contains multiple sources of error.

Unlike Sonnet, most EM software vendors speak very little about error sources (see “Accuracy Benchmarking,” page 343). The fact that Sonnet shows misalignment between the desired metal pattern and simulation grid does not necessarily imply that Sonnet simulations will be any less accurate than competitive simulators that mesh using infinite resolution. With all simulation packages the user should investigate every potential error source (which will vary depending on the MoM technique used) and ensure a good converged data set is achieved.

Changing the Subsectioning of a Polygon

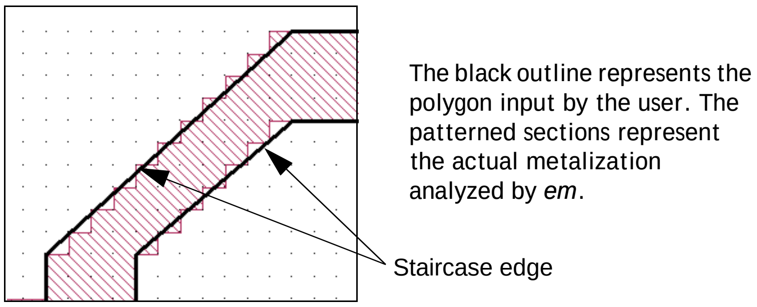
Sonnet allows you to control how cells are combined into subsections for each polygon. This is done using the parameters “X Min”, “Y Min”, “X Max” and “Y Max”. These parameters may be changed for each polygon, allowing you to have coarser resolution for some polygons and finer resolution for others. See “Modify - Metal Properties” in the project editor’s online help for information on how to change these parameters.

Before discussing how to make use of these parameters, we need to first understand ***em***’s automatic subsectioning for a polygon when the parameters are set to their default settings.

Default Subsectioning of a Polygon

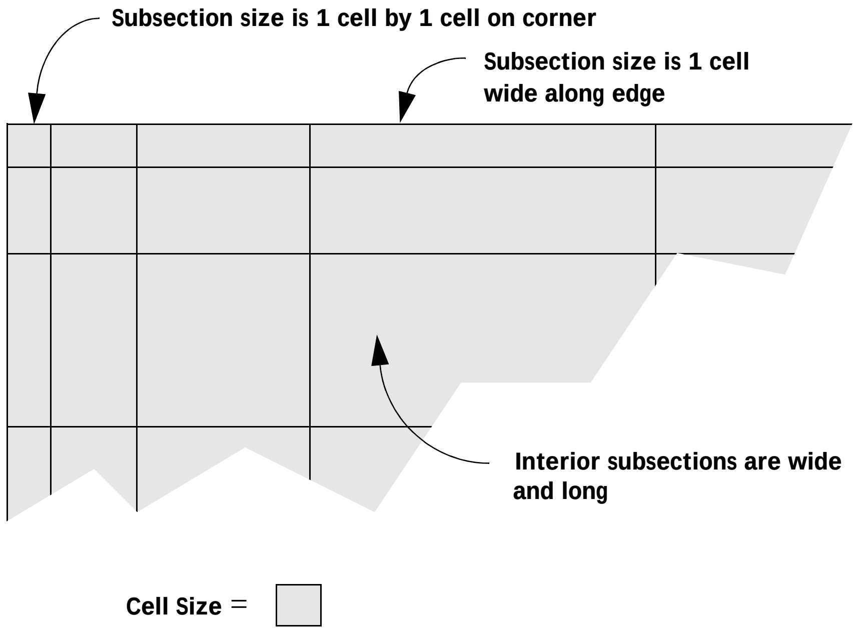
By default, Sonnet fills a polygon with “staircase” subsections. Other, more advanced fill types (diagonal and conformal) are covered in other chapters of this manual. For diagonal subsections, see **Chapter 17, “Vias and 3-D Structures”** on page 243. For conformal mesh, see **Chapter 12, “Conformal Mesh”** on page 173. This chapter deals exclusively with staircase subsections.

This fill type is referred to as staircase because when using small rectangular subsections to approximate a diagonal edge, the actual metalization takes on the appearance of a staircase, as in the example shown below.


The black outline represents the polygon input by the user. The patterned sections represent the actual metalization analyzed by *em*.
Staircase edge

The default values for the subsectioning parameters are X Min = 1, Y Min = 1, X Max = 100 and Y Max = 100. These numbers specify the smallest and largest allowed dimensions of the subsections in a polygon. With X Min = 1, the smallest subsection in the X dimension is one cell. With X Max = 100, subsections are not allowed to go over 100 cells in length.

The illustration below shows how these default subsectioning parameters are used. Notice in the corner, the subsection size is just one cell. The current density changes most rapidly here, thus, the smallest possible subsection size is used.


Subsection size is 1 cell by 1 cell on corner
Subsection size is 1 cell wide along edge
Interior subsections are wide and long
Cell Size =

A portion of circuit metal showing how *em* combines cells into subsections. In this case the subsectioning parameters are set to their default values: X Min = 1, Y Min = 1, X Max = 100 and Y Max = 100.

As we go away from the corner, along the edge, the subsections become longer. For example, the next subsection is two cells long, the next one is four cells long, etc. If the edge is long enough, the subsection length increases until it reaches X Max (100) cells, or the maximum subsection size parameter, whichever comes first, and then remains at that length until it gets close to another corner, discontinuity, etc.

Notice, however, that no matter how long the edge subsection is, it is always one cell wide. This is because the current density changes very rapidly as we move from the edge toward the interior of the metal (this is called the edge singularity).

In order to allow an accurate representation of the very high edge current, the edge subsections are allowed to be only one cell wide. However, the current density becomes smooth as we approach the interior of the metal. Thus, wider subsections are allowed there. As before, the width goes from one cell to two cells, then four, etc.

TIP

If two polygons butt up against each other or have a small overlap, the modeling of the edge singularity will require a larger number of subsections at the boundary between the two polygons. Using the Merge command (*Edit ⇒ Merge Polygons*) to join the two polygons into one will reduce the number of required subsections and speed up your analysis.

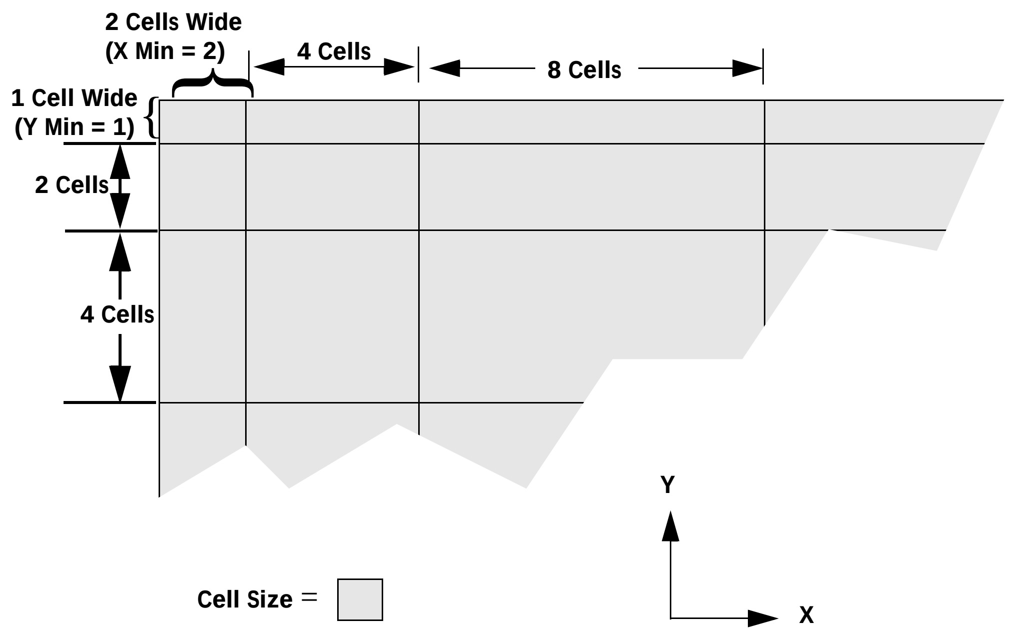
Conversely, if you have an area of your circuit at which you desire greater accuracy, using the Divide (*Edit ⇒ Divide Polygons*) command at the point of interest to create two polygons, forces the analysis to use smaller subsections in order to model the edge singularities.

X Min and Y Min with Edge Mesh Off

Having the edge mesh option “on” is the default state for Sonnet projects; however, examining the case where edge mesh is “off” first makes understanding the concept easier. This part of the discussion only applies to Manhattan polygons, which is a polygon that has no diagonal edges. Turning edge mesh off for non-manhattan polygons has no effect.

On occasion, you may wish to change the default subsectioning for a given polygon. You can do this using the subsectioning parameters X Min, Y Min, X Max and Y Max.

For Manhattan polygons with edge mesh off, X Min and Y Min set the size of the edge subsections. By default, X Min and Y Min are 1. This means the edge subsections are 1 cell wide. When X Min is set to 2, the subsections along vertical edges are now 2 cells wide in the X direction (see the figure on page 40). This reduces the number of subsections and reduces the matrix size for a faster analysis. However, accuracy may also be reduced due to the coarser modeling of the current density near the structure edge or a discontinuity.



A portion of circuit metal showing how *em* combines cells into subsections for Manhattan polygons when X Min = 2 and Y Min = 1.

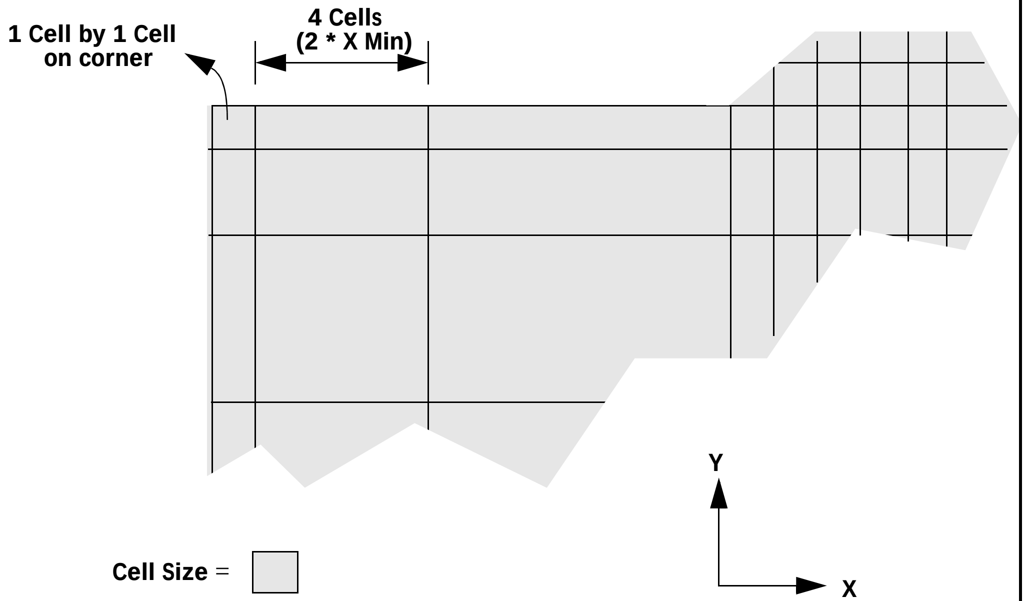
If X min or Y min are greater than your polygon size, ***em*** uses subsections as large as possible to fill the polygon.

NOTE: **The subsection parameters, X Min, Y Min, X Max and Y Max are specified in *cells* (not mils, mm, microns, etc.). For example, X Min = 5 means that the minimum subsection size is 5 cells.**

Although the X Min and Y Min parameters are very useful options, it is not a substitute for using a larger cell size. For example, a circuit with a cell size of 10 microns by 10 microns with X Min = 1 and Y Min =1 runs faster than the same circuit with a cell size of 5 microns by 5 microns with X Min = 2 and Y Min = 2. Even though the total number of subsections for each circuit may be the same, ***em*** must spend extra time calculating the value for each subsection for the circuit with the smaller cell size.

X Min and Y Min with Edge Mesh On

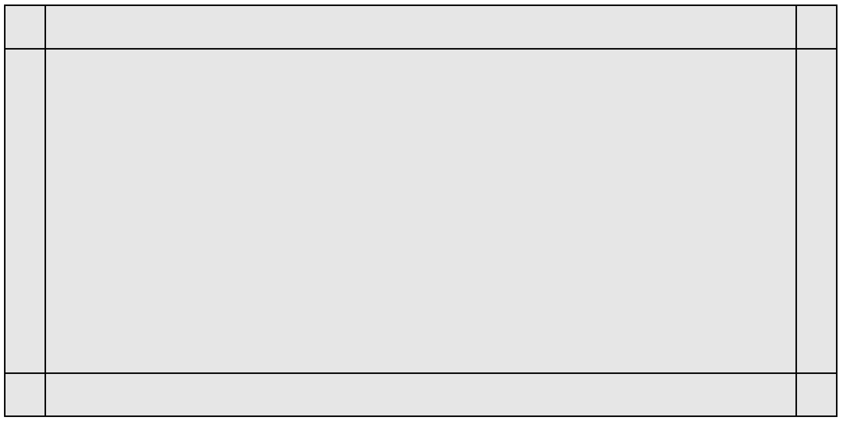
Having the edge mesh option “on” is the default state for Sonnet projects because it provides a more accurate analysis. Having edge mesh “on” for a polygon changes how the subsections on the very edge are handled. Starting from the left side of the previous example with edge mesh off, the subsections were 2 cells, 4 cells and 8 cells wide. With edge mesh on, the subsections for the same polygon would be 1 cell, 4 cells, and 8 cells as shown in the illustration below. Notice only the outermost edge is affected.



A portion of circuit metal showing how *em* combines cells into subsections for polygons with edge mesh on, with X Min = 2 and Y Min = 1. Edge mesh polygons always have 1 cell wide edge subsections.

As mentioned in the previous section, the edge mesh setting only affects Manhattan polygons (i.e. those with no diagonal or curved edges). Edge mesh is always “on” for non-Manhattan polygons, regardless of the edge-mesh setting for that polygon.

When used in conjunction with large X Min or Y Min values, the edge mesh option can be very useful in reducing the number of subsections but still maintaining the edge singularity, as shown in a simple example below. This is very often a good compromise between accuracy and speed.



In the case pictured above, X Min and Y Min are set to be very large, and the frequency is low enough so that the Max. Subsection size parameter corresponds to a subsection size that is larger than the polygon.

Using X Max and Y Max for an Individual Polygon

You may control the maximum subsection size of individual polygons by using the X Max and Y Max parameters. For example, if X Max and Y Max are decreased to 1, then all subsections will be one cell. This results in a much larger number of subsections and a very large matrix which are the cause of increased analysis time. Thus, this should be done only on small circuits where extremely high accuracy is required or you need a really smooth current density plot.

NOTE: **If the maximum subsection size specified by X Max or Y Max is larger than the size calculated by the Max. Subsection Size parameter, the Max. Subsection Size parameter takes priority. The Max. Subsection Size is discussed in "Setting the Maximum Subsection Size Parameter," page 45.**

Using the Speed/Memory Control

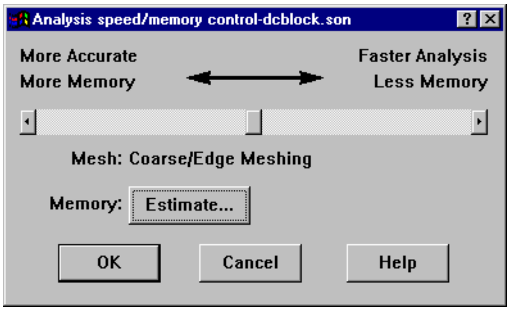
The Speed/Memory Control allows you to control the memory usage for an analysis by controlling the subsectioning of your circuit. The high memory settings produce a more accurate answer and usually increase processing time. Conversely, low memory settings run faster but do not yield as accurate an answer.

To access the Speed/Memory Control, follow the instructions below.

1 **Select *Analysis* ⇒ *Setup* from the project editor main menu.**

2 **In the Analysis Setup dialog box which appears, click on the Speed/Memory button.**

3 **In the Analysis Speed/Memory Control dialog box which appears, select the desired setting.**


Analysis speed/memory control-dcblock.son

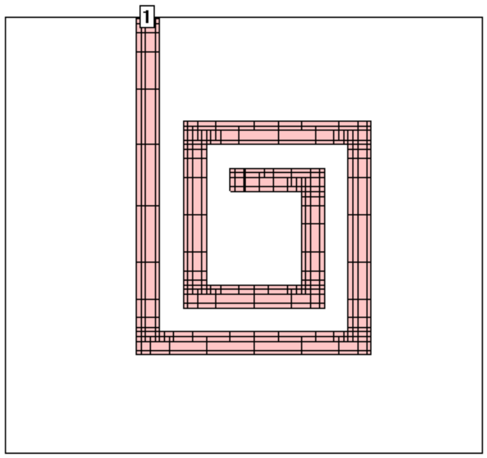
More Accurate
More Memory

Faster Analysis
Less Memory

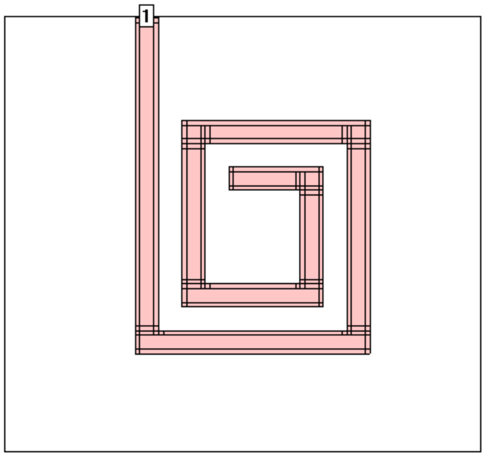
Mesh: Coarse/Edge Meshing

Memory: Estimate...

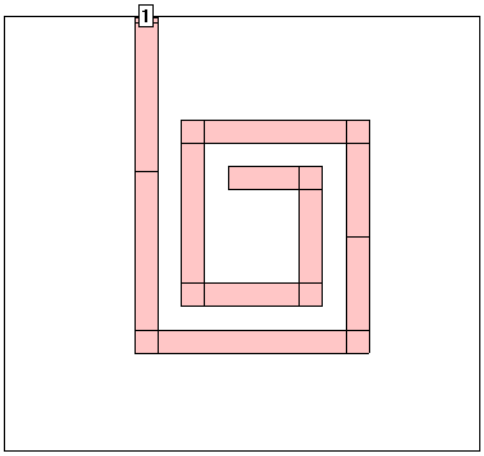
There are three settings for the Speed/Memory Control: Fine/Edge Meshing, Coarse/Edge Mesh, Coarse/No Edge Meshing. Fine/Edge Meshing is the default setting and is described in "Default Subsectioning of a Polygon," page 36. An example is shown below. Again, note that this setting provides the most accurate answer but demands the highest memory and processing time.



The second option is Coarse/Edge Mesh. This setting is often a good compromise between speed and accuracy. When this setting is used, the Xmin and Ymin of all polygons are set to a large number - typically, the value of 50 is used - and edge mesh is on. Shown below is a typical circuit with this setting. Notice the edges of the polygons have small subsections, but the inner portions of the polygons have very large subsections because of the large Xmin and Ymin.



The last option is Coarse/No Edge Meshing. For this setting, all polygons are set to a large Xmin/Ymin and edge mesh is set to “off.” This yields the fastest analysis, but is also the least accurate. Shown below is the subsectioning of a typical circuit using this option.



Setting the Maximum Subsection Size Parameter

The parameter Max. Subsection Size allows the specification of a maximum subsection size, in terms of subsections per wavelength, where the wavelength is approximated at the beginning of the analysis. The highest analysis frequency is used in the calculation of the wavelength. This value is a global setting and is applied to the subsectioning of all polygons in your circuit.

The default of 20 subsections/λ is fine for most work. This means that the maximum size of a subsection is 18 degrees at the highest frequency of analysis. Increasing this number decreases the maximum subsection size until the limit of 1 subsection = 1 cell is reached.

You might want to increase this parameter for a more accurate solution. For example, changing it from 20 to 40 decreases the size of the largest subsections by a factor of 2, resulting in a more accurate (but slower) solution. Keep in mind that using smaller subsections in non-critical areas may have very little effect on the accuracy of the analysis while increasing analysis time.

Another reason for using this parameter is when you require extremely smooth current distributions using for the current density viewer. With the default value of 20, large interior subsections may make the current distribution look “choppy.”

Setting this value to a large number forces all subsections to be only 1 cell wide, providing smooth current distribution. Again, analysis time is impacted significantly.

The Max. Subsection Size parameter is specified in the Advanced Subsectioning Controls which are opened by selecting *Analysis ⇒ Advanced Subsectioning* from the project editor main menu.

Defining the Subsectioning Frequency

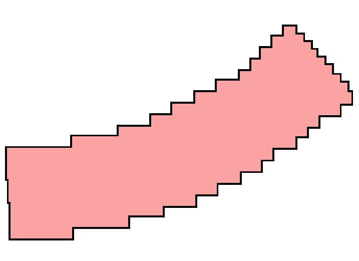
The subsectioning parameter, Max. Subsection Size, applies to the subsectioning of all polygons in your circuit, and is defined as subsections per wavelength. Normally, the highest analysis frequency is used to determine the wavelength. However, this may be changed by using the Subsectioning Frequency options in the Advanced Subsectioning Control dialog box in the project editor. This dialog box is opened by selecting *Analysis ⇒ Advanced Subsectioning* from the project editor main window. For details on what options are available to define the subsectioning frequency, click on the Help button in the Advanced Subsectioning Control dialog box.

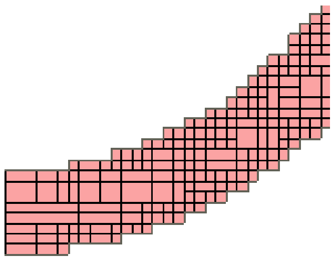
The frequency defined by the selected option is now used to determine the maximum subsection size instead of the highest frequency of analysis. Thus, the same subsectioning can be used for several analyses which differ in the highest frequency being analyzed.

Conformal Mesh Subsectioning

Conformal meshing is a technique which can dramatically reduce the memory and time required for analysis of a circuit with diagonal or curved polygon edges. For a detailed discussion of conformal mesh and its rules of use, please refer to "Conformal Mesh," page 173. Only the effect of conformal mesh on subsectioning is discussed in this chapter.

This technique groups together strings of cells following diagonal and curved metal contours to form long subsections along those contours. Whereas staircase fill results in numerous small X- and Y-directed subsections, conformal mesh results in a few long conformal subsections. The illustration below shows the actual metalization of a conformal section in close up alongside the same section using staircase fill.

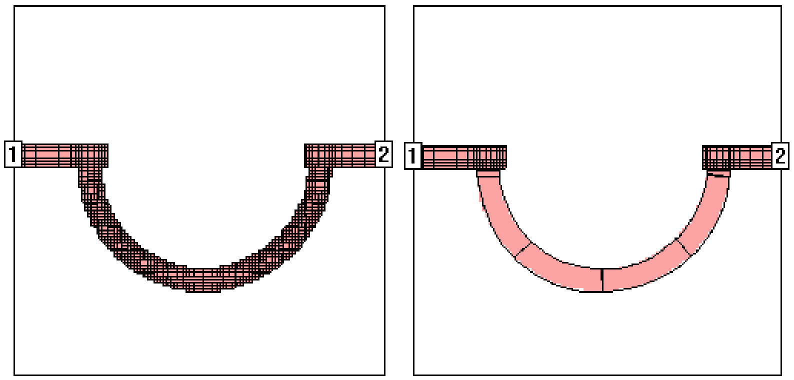

Conformal section


Staircase Fill

Conformal sections, like standard subsections, are comprised of cells, so that the actual metalization still shows a "jagged" edge when the polygon has a smooth edge. However, the sections can be much larger due to conformal meshing. These larger sections yield faster processing times with lower memory requirements for your analysis.

Standard subsectioning requires a lot of subsections to model the correct current distribution across the width of the line. Conformal subsections have this distribution built into the subsection. Sonnet conformal meshing automatically includes the high edge current in each conformal section. This patented Sonnet capability is unique. (U.S. Patent No. 6,163,762 issued December 19, 2000.)

An example of a circuit using both standard subsectioning and conformal mesh is shown below. The circuit shown at the left is displayed using standard subsectioning (staircase fill). Conformal meshing for the curved part of the circuit is shown on the right. Note that for the curved part of the geometry, conformal mesh uses substantially fewer subsections than the number used in the standard subsectioning.



Conformal Mesh Subsectioning Control

When you apply conformal mesh to a polygon, it is possible to limit the maximum length of a conformal section in order to provide a more accurate simulation. The default length of a conformal section is 1/20 of the wavelength at the subsectioning frequency. For more information on the subsectioning frequency, see "Defining the Subsectioning Frequency," page 46.

To set the maximum length for a conformal section, do the following:

1 **Select the desired polygon(s).**

The selected polygons are highlighted.

2 **Select *Modify* ⇒ *Metal Properties***

This opens the Metalization Properties dialog box.

3 **Click on the Maximum Length checkbox in the Conformal Mesh Subsectioning Controls section of the dialog box.**

This will enable the Length text entry box to the right. Note that this checkbox is only enabled when Conformal is chosen as the Fill Type.

4 **Enter the desired Maximum Length in the text entry box.**

Click on the OK button to close the dialog box and apply the changes.

For a more detailed discussion of Conformal Mesh, please refer to **Chapter 12, "Conformal Mesh"** on page 173. There is also an App note on conformal mesh available in online help.

Chapter 4 Metalization and Dielectric Layer Loss

This chapter is composed of two parts: metalization loss and dielectric layer loss. For information on dielectric brick loss, see **Chapter 19, "Dielectric Bricks"** on page 265. Both the theoretical aspect of how Sonnet models loss and the practical how to's of assigning loss in your circuit are covered, including the use of metal and dielectric material libraries. The discussion of metalization loss begins below. For the discussion of dielectric loss, see "Dielectric Layer Loss," page 59.

There is also a paper available by the president and founder of Sonnet Software, Dr. James Rautio which contains a detailed discussion of metal losses. You may find this paper at www.sonnetsoftware.com/support/publications.asp.

Metalization Loss

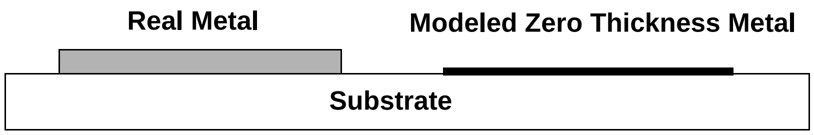
Metalization loss is specified in the project editor in the Metal Types dialog box which is opened by selecting *Circuit* ⇒ *Metal Types*. Losses may be assigned to circuit metal, top cover and ground plane. Sidewalls are always assumed to be perfect conductors.

A common misconception is that only one type of metalization is allowed on any given level. In fact, different metalizations (i.e., different losses) can be mixed together on any and all levels. For example, it is possible to have a thin film resistor next to a gold trace on the same level.

Sonnet allows you to use pre-defined metals, such as gold and copper, using the global library. The global library allows you to define your own metal types as well. There is also a local metal library which can be created for an individual or to share between users.

Sonnet's Loss Model

The Sonnet model of metal loss uses the concept of surface impedance, measured in Ohms/sq. This concept allows planar EM Simulators, such as Sonnet ***em***, to model real 3-dimensional metal in two dimensions.



If you are unfamiliar with this concept, please refer to any classic textbook such as **Fields and Waves in Communication Electronics** by Simon Ramo, John R. Whinnery and Theodore Van Duzer, John Wiley & Sons, New York, 1965.

It is important to note that this technique models the loss of the true 3-dimensional metal fairly accurately, but does not model any change in field distribution due to the metal thickness. This approximation is valid if the metal thickness is small with respect to the width of the line, the separation between lines, and the thickness of the dielectric. If the true 3-dimensional affect of the metal is important, then you should consider using the Thick Metal Model metal type as discussed in **Chapter 18, "Thick Metal"** on page 255.

Some electromagnetic analyses use a "perturbational" approach for loss. This means that they assume the current flowing everywhere is the same as the lossless case. This approximation works for low loss metals (good conductors). However for thin film resistors (high loss), the lossless current is not the same as the lossy current and a perturbational approach fails. ***Em's*** loss analysis is not perturbational. It works just as well for a 100 Ohms/square resistor as it does for a 0.004 Ohms/square good conductor. The Sonnet loss analysis also properly models the transition between electrically thin (low frequency) and electrically thick (high frequency) conductors. See reference [24] in reference Appendix II listed on page 361 for a detailed description of the theory used by Sonnet. See reference [91] listed on page 369 for the equations actually used in the Sonnet model.

Another aspect of loss is that the surface impedance of a good conductor has an imaginary part which is equal to the real part. This reactive surface impedance is physically due to the increased surface inductance caused by the current being confined closer to the surface of the conductor. This surface reactance is included in the Sonnet loss model. The effect is small, but potentially significant in certain cases.

Keep in mind that a circuit running with lossless metal and dielectrics requires about one-half the amount of memory and runs about twice as fast. Therefore, the simplest approximation is to run a lossless simulation. This can be quite useful in the initial design phase.

Problems In Determining Metal Loss

Sonnet's loss model is very accurate if accurate values are used. In practice, however, there are many aspects of metal loss that cannot easily be accounted for. For example, surface roughness, metal purity, metal porosity, etc. cannot easily be measured and included in an all-encompassing loss model. In addition, most software programs, Sonnet included, do not allow you to enter all of the parameters that determine metal loss. Many users like to use the ideal values as a starting point and add a little of their own “real-world” loss. But how much should be added to the ideal models? This question is not easily answered, but is addressed in the next section.

An additional loss problem exists with planar EM analysis tools such as Sonnet. The problem stems from the fact that planar EM tools treat the metal conductor as zero thickness. This means that there is no difference between the top of the conductor and the bottom of the conductor. In some circuits, stripline for example, the current is symmetrical with half of the current flowing on the top of the conductor and half flowing on the bottom of the conductor. The zero thickness model works well in these cases.

In other circuits, such as microstrip, the current can be unequally distributed, resulting in higher loss than the equivalent stripline circuit. If you know the ratio between the top and the bottom currents, you can obtain a better loss model. All planar solvers must either estimate this value in order to calculate metal loss, or the information must be input by the user. For this class of circuits, it is difficult for the user to know an exact value of the current ratio without obtaining measured data on the circuit. For these cases, assuming all the current flows on one side of the conductor gives a "worst case" loss result. This tends to compensate for the "best case" loss caused by ignoring the other aspects of loss (metal porosity, etc.) mentioned earlier.

Determining Good Input Values

The best method to determine proper loss values is to build and measure a simple structure of the desired metalization. The structure should be sensitive enough to loss so that measurement errors do not significantly affect the results. Then analyze the same structure on Sonnet and adjust the loss values until the calculated loss matches the measured loss. This may take several iterations before success, but then you can use these values for similar circuits. You are now effectively using measured values for the loss parameters.

Creating Metal Types

To assign loss to a polygon in Sonnet, you first define a metal type by inputting its loss parameters and then assign that metal type to the polygon drawn in your circuit. The previous section(s) described how to determine values for the Sonnet loss model. This section provides instructions for creating a metal type and discusses the loss models used in the Metal Editor dialog box.

The Metal Editor dialog box allows you to enter a loss definition for the metal type. There are five different methods for entering loss: Normal, Resistor, Rd./Ref, General and Sense. The different loss models are discussed below followed with a procedure for entering new metal types. The discussions assume simple, single conductor microstrip and stripline geometries where mentioned.

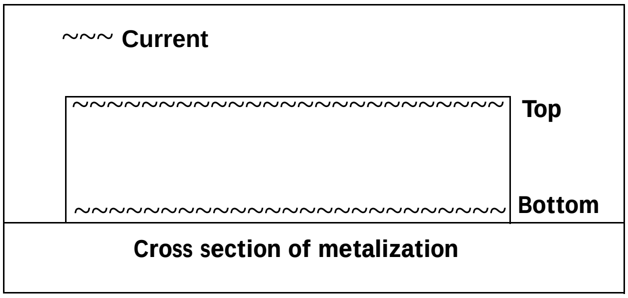
You do not need to read the details of each loss model. Instead, you should make yourself familiar with the loss models you are likely to use. Most users only need concern themselves with "Normal." All the methods use the same loss model in Sonnet; which model you choose depends on the parameters you know about your real metal type.

Normal

For the Normal metal type, you determine the loss using the bulk conductivity, the metal thickness and the current ratio.

NOTE: Metal thickness is used only in calculating loss; it does not change the physical thickness of metalization in your circuit. The metalization in your circuit is still modeled as zero-thickness.

Sonnet models your circuit using zero thickness metal, but your real circuit possesses a metal thickness. At higher frequencies current flows in a thin skin around the edge of the metal, as pictured below. The current ratio is the ratio of the current flowing on the top of the metal to the current flowing on the bottom of the metal.



There are no sides in a zero thickness model; therefore when translating from these parameters, the current which flows on the sides is ignored. In some circuits, stripline for example, the current is symmetrical with half of the current flowing on the top of the metal and half flowing on the bottom of the metal. In this instance, the current ratio is 1. If you had twice as much current flowing on the top as on the bottom, the current ratio is 2. This could occur for some microstrip circuits, for example. It is difficult to know an exact value of the current ratio without obtaining measured data on your circuit. All planar solvers must estimate this value in order to calculate metal loss; this particular model in Sonnet allows you to enter the value. Note that reciprocal values have the same effect; i.e., 0.5 results in the same loss as 2.0.

Resistor

To define a metal which you wish to use as a resistor, enter the DC resistance in ohms/sq in the Rdc text entry box which appears when you select this metal type. To use this loss model, the resistivity should be constant over the frequency range of interest.

Rdc/Rrf

This method allows you to enter two values: R_{DC} and R_{RF}. The first parameter, R_{DC}, determines loss at low frequency (where the conductor is much thinner than the skin depth). Surprisingly, other electromagnetic analyses often predict zero loss at low frequency because they assume R_{DC} is zero.

The second parameter is the skin effect coefficient, R_{RF}. ***Em*** multiplies this number by the square root of the frequency (in Hertz) to yield the Ohms/square value at high frequency.

The equations for R_{DC} and R_{RF} are:

$$R_{DC} = 1/(\sigma t)$$

$$R_{RF} = \textbf{Skin effect coefficient} = \sqrt{(\pi\mu)/\sigma}$$

where σ is the bulk conductivity in mhos/meter, t is the metalization thickness in meters, and $\mu = 4\pi \times 10^{-7}$ H/m. Typical values for R_{DC} and R_{RF} are 0.004 and 3e-7. If you start getting very strange loss results, check $R_{RF,}$ paying special attention to the exponent.

Em also properly models the transition between electrically thin (low frequency) and electrically thick (high frequency) conductors. The transition frequency from R_{DC} to R_{RF} is the square of R_{DC}/R_{RF}. At this frequency, and a relatively narrow band around it, both coefficients are important. If the skin effect coefficient (R_{RF}) is set to 0.0, then the value of R_{DC} is used over all frequencies. This is the usual case for resistors.

The above equation for R_{RF} assumes that all of the current travels on just one side of the conductor. This is a good approximation for some microstrip circuits. However, if the current really travels on both sides, this gives a pessimistic value for the loss. The equation should be modified for other structures. Stripline, for example, has current of equal amplitude on both the top and bottom of the conductor. In this case, you should divide the R_{RF} value by two, while maintaining R_{DC}.

As an example, the conductivity (σ) for copper is 5.8E+7 Mhos/m, giving R_{DC} = 0.006 Ohms/square (t = 3 um) and a microstrip R_{RF} = 2.6E-7**.** In reality, the bulk conductivity of copper, or any other given metal, may not equal the laboratory value, so the figures as calculated above are likely to be lower than actual results. The table below provides calculated results of commonly used metals using the equations above.

.

Properties of Commonly Used Metals

Metal	σ (S/M)	RDC (Ω/sq) t = 1 μM	RDC (Ω/sq) t = 1 mil	RRF ($\Omega Hz^{-1/2}$/sq) "Skin Effect" (microstrip)
Aluminum	3.72e7	0.027	1.1e-3	3.3e-7
Brass	1.57e7	0.070	2.5e-3	5.0e-7
Copper	5.80e7	0.017	6.8e-4	2.6e-7
Gold	4.09e7	0.024	9.6e-4	3.1e-7
Nichrome	1.00e6	1.000	3.9e-2	2.0e-6
Silver	6.17e7	0.016	6.4e-4	2.5e-7
Tantalum	6.45e6	0.155	6.1e-3	7.8e-7
Tin	8.70e6	0.115	4.5e-3	6.7e-7

General

This loss model includes the metalization resistivity described above in Rdc/Rrf. The General loss definition also includes the metalization reactance, composed of the surface reactance, X_{dc} and the kinetic inductance, L_s.

Surface reactance, X_{dc}, is specified, in Ohms/square. ***Em*** uses the same reactance at all frequencies.

Until recently, the only surface resistivities of practical interest were pure real, i.e., pure loss. With the growing application of superconductors in high frequency work, surface reactance reaches significant levels. A superconductive effect known as "kinetic inductance" slows the velocity of the electrons with no loss of energy. This can be modeled as a surface inductance.

The effect of surface inductance is to make ε_{eff} larger, or the velocity of propagation slower. For normal conductors, ε_{eff} can never be larger than ε_{rel}. In a superconductor, this is no longer true. This unusual effect becomes significant for very thin substrates.

Surface inductance, L_s, is specified in the project editor in the Metal Types dialog box accessed by selecting *Circuits* $\Rightarrow$ *Metal Types*. This parameter takes into account the surface reactance at higher frequencies.

There are three recommended approaches to obtaining a value for Ls. A first order approximation is to assume the metal is a perfect conductor.

$$R_{DC} = 0 \qquad R_{rf} = 0 \qquad L_s = 0$$

This model works well for moderate frequencies (less then 150 GHz) and moderate circuit dimensions which are much greater than the London depth of penetration.

The second approach is a model which is still valid at moderate frequencies, but includes effects due to kinetic inductance. The kinetic inductance is a function of temperature and can be approximated in the following manner:

$$R_{DC} = 0 \qquad R_{rf} = 0 \qquad L_s = \mu_0\lambda_L(T)$$

where

$\mu_0 = 4\pi(10^{-7})$ H/m

$\lambda_L(T) = \lambda_0/(\sqrt{1-(T/T_c)^4})$ London depth of penetration at temp.

λ_0 = London depth at T = 0 meters

T_c = Critical (Transition) Temperature in degrees Kelvin

The third model should be used to account for high frequency effects or effects due to small circuit dimensions. In these cases, the surface resistances proportionality to ω^2 begins to dominate and the following model is suggested. The resistivity is a function of frequency-squared, and Sonnet presently does not have a method to do this. Therefore, if you are analyzing over a broad band, you need to have a separate project for each frequency, using the following equations.[1]

$$R_{rf} = 0$$
$$R_{DC} = \frac{1}{2}\omega^2\mu_0^2(\lambda_L(T))^3\sigma_N(\eta_n/(\eta_n+\eta_s))$$
$$L_s = \mu_0\lambda_L(T)$$

1. Shen, Z. Y., "High-Temperature Superconducting Microwave Circuits," Boston, 1994, Artech House.

where

$\omega = 2\pi f$ radians/sec

σ_N = Conductivity of the superconductor in its normal state (Mhos/m^3)

η_n = Normal state carrier density (1/m^3)

η_s = Superconducting state carrier density (1/m^3)

μ_0 and $\lambda_L(T)$ are as defined above

The Surface Impedance, Z_s, for superconductors is modeled in Sonnet using the following equation:

$$Z_s = R_{DC} + j \cdot (\omega L_s + X_{DC}) \qquad \text{for } |L_s| > 0.0$$

Sense

Em solves for the current distribution; however, on occasion, you may want to view the fields, not the current. You do this with what is called a “sense metal”. The sense metal is a rectangular patch of conductor placed where you want to see the tangential electric field. (You cannot view the normal direction of the field with Sonnet.)

For further discussion of sense metal, see Chapter 24, “Viewing Tangential Electric Fields,” on page 339.

Thick Metal

For thick metal, you input two parameters: the bulk conductivity and the metal thickness. The loss is calculated in the same manner as for the Normal metal type, except that the thickness in this case represents a physical thickness which eliminates the need to enter the current ratio.

For a detailed discussion of thick metal, see Chapter 18, “Thick Metal” on page 262.

How to Create a Metal Type

For detailed instructions on creating a metal type, please refer to “metal types:adding” in the Index of Help. You may access help by selecting *Help* $\Rightarrow$ *Contents* from the main menu of any Sonnet application or by clicking on the Help button in any dialog box.

Metal Libraries

There are two types of metal libraries available in Sonnet: global and local. The metal libraries contain standard definitions for metal types which may be used in your projects. There is no real difference between the global and local library. The names refer to how they are used. The global library would usually be used as a group wide library of standard metals for a group of designers.

There is a default global library supplied by Sonnet which contains definitions for some common metals. The default location for the global library is in <Sonnet Directory>/data/library where <Sonnet Directory> is the directory in which your Sonnet software is installed. You may choose to use this location or can save this library in another location.

The local library would usually be used as the user's own library of metal definitions. This library may be stored in a location of the user's choice. You use the Metal Editor dialog box to add, edit and delete entries to these libraries.

For instructions on adding metals to a metal library, editing metals in a metal library or using metals defined in a metal library, please refer to Sonnet Help available from the Help menu in any Sonnet application.

Via Loss

The loss of a via is accomplished in much the same way as a metal polygon. The only difference is that a via is a 3D object and a polygon is only two-dimensional. Therefore, the Sonnet via loss model is only an approximation. In general, edge-vias use the loss of the polygon they are attached to, and via-polygons have their own loss properties. To assign loss to a via polygon, select the via-polygon, and choose *Modify ⇒ Via Properties*. In the Via Properties dialog box, select a metal type in the Via Loss drop list for the via polygon. For extremely precise loss analysis of vias, you should use the same measurement approach as discussed earlier for polygon loss.

Setting Losses for the Box Top and Bottom (Ground Plane)

You set the loss for the box top or bottom by assigning a metal type to the box top or bottom. The box top and bottom use the same metal types which are used for the metalization in your circuit, i.e., the polygons and via polygons. In addition, there are two special metal types available in Sonnet for the Top and Bottom metals: Free Space and Waveguide Load. See Chapter 20, “Antennas and Radiation” for a discussion of how and why you would use these types.

To assign a metal type to the Box Top or Bottom metal, select *Circuit ⇒ Box Settings* from the project editor main menu. In the Box Settings dialog box which appears on your display, select the desired metal type for the top metal from the Top Metal drop list and the desired metal type for the bottom metal from the Bottom Metal drop list.

Dielectric Layer Loss

The dielectric layer loss calculations in Sonnet are virtually exact, given the substrate really has a frequency independent conductivity, and/or loss tangent. Our web site has a lossy conductivity benchmark you can perform on any electromagnetic solver (or measurement system). See Benchmarking on the Products section of our web site, www.sonnetsoftware.com.

The dielectric loss is calculated in Sonnet at the beginning stages of the analysis. The method Sonnet uses starts with the calculation of a sum of waveguide modes. The exact solution requires an infinite sum of modes, but Sonnet truncates this sum to some reasonable value (the truncation has never been a source of error). So, for each mode, if there is a lossy dielectric, the calculation involves complex numbers instead of just real numbers. This is NOT a discretized function - it is a continuous function. Therefore, the dielectric loss calculation can be thought of as exact (only limited to the precision of the machine).

A more reasonable source of error is in the assumption that the conductivity is constant with frequency. All real dielectrics have frequency-dependant loss (some smaller than others). Sonnet supplies you with two parameters (Loss Tan and Diel Cond) to control this frequency dependency. The equation Sonnet uses to calculate the TOTAL loss is given in “Dielectric Layer Loss,” page 61. There are some dielectrics with more complicated frequency dependencies, but this equation works for most dielectrics. Of course, this requires that you know the frequency dependency of your dielectric. If you have a method of measuring the loss as a function of frequency (or published data which you can trust), and if it is constant over your range of frequencies, then dielectric loss is probably not a source of error. Be careful, however, of published loss data. Verify that the data is valid over your frequency range.

Dielectric Layer Parameters

You can set the dielectric constant and loss of a dielectric layer by changing the following parameters in the project editor by selecting *Circuits ⇒ Dielectric Layers,* then clicking on the Above, Below or Edit button in the Dielectric Layers dialog box. This opens the Dielectric Editor dialog box which allows you to edit the parameters below.

- **Erel:** The relative dielectric constant (ε_r). The ratio ($\varepsilon/\varepsilon_o$), where ε is the real part of the permittivity of the dielectric layer material, and ε_o is the permittivity of free space. The ratio is dimensionless.

- **Dielectric Loss Tan:** The dielectric loss tangent. The ratio ($\varepsilon''/\varepsilon'$), where $\varepsilon = \varepsilon' - j\varepsilon''$, and ε is the complex permittivity of the dielectric layer material. The ratio is dimensionless.

- **Diel. Cond:** The dielectric conductivity, σ, where σ is the bulk conductivity in siemens per meter.

- **Mrel:** The relative magnetic permeability (μ_r) of the dielectric layer material.

- **Magnetic Loss Tan:** The magnetic loss tangent of the dielectric layer material.

One last parameter that may be specified for a dielectric layer is the Z Partitioning. This value may be changed in the Z Partitions dialog box which is opened when you click on the Z Parts button in the Dielectric Layers dialog box.

- **Z-Partitions:** The z-partitioning parameter is the setting which controls the number of partitions which the dielectric layer is divided into in the z direction. for the dielectric layer. While this parameter is specified in the dielectric layer window, it only has an effect on the dielectric bricks on that layer. Changing this value for a particular layer will have absolutely no affect on the analysis if there are no bricks on the layer. If there are multiple bricks on the layer, the Z subsectioning for all of those bricks will be identical.

  The more partitions (better resolution) used in the Z-dimension, the more accurate the analysis; however, analysis time and memory requirements also increase dramatically.

Dielectric Layer Loss

Em uses the above parameters to calculate the total effective tanδ for the dielectric material as follows:

$$\tan\delta \;=\; (\mathbf{Loss\ Tan}) + \frac{(\mathbf{Diel\ Cond})}{\omega(\mathbf{Erel})\varepsilon_o}$$

where, ω is the radian frequency (ω = 2πf, where f is frequency in hertz). Note that tanδ has both a frequency-dependent term and a frequency-independent term.

The above equation for tanδ can also be expressed in terms of conductivity as follows:

$$\mathbf{Total\ Effective\ Cond} \;=\; (\mathbf{Loss\ Tan})\omega(\mathbf{Erel})\varepsilon_o + (\mathbf{Diel\ Cond})$$

Both equations are equivalent. Each describes how ***em*** uses the input dielectric parameters to compute loss in the dielectric material.

See “Circuit ⇒ Dielectric Layers” in the project editor’s online help for information on setting these parameters.

How to Create a New Dielectric Layer

For detailed instructions on creating a new dielectric layer, please refer to “dielectric layers:adding” in the Index of Help. You may access help by selecting *Help ⇒ Contents* from the main menu of any Sonnet application or by clicking on the Help button in any dialog box.

Dielectric Libraries

The dielectric libraries contain standard definitions of dielectric materials which may be used for your dielectric layers. There are two types of dielectric libraries available in Sonnet: global and local. There is no real difference between the two libraries. The names refer to the way in which they are used.

NOTE: **The Dielectric Libraries materials may not be used for dielectric bricks but only for dielectric layers.**

The global library would usually be used as a group wide library of standard dielectrics for a group of designers.There is a default global library supplied by Sonnet which contains definitions for dielectric materials.   The default location for the global library is in <Sonnet Directory>/data/library where <Sonnet Directory> is the directory in which your Sonnet software is installed. You may choose to use this location or can save this library in another location.

The local library would usually be used as the user's own library of dielectric material definitions. This library may be stored in a location of the user's choice. You use the Dielectric Editor dialog box to add, edit and delete entries to these libraries.

Chapter 5 Ports

This chapter describes the five different types of ports used in Sonnet, how they are modeled and how to place or delete them in your circuit.

The five types of ports used in Sonnet are the standard box-wall port, the co-calibrated internal port, the via port, the auto-grounded port and the ungrounded internal port. The co-calibrated port is a new feature introduced in Release 11.

Port Type Overview

As mentioned above, the five types of ports available in Sonnet are the standard box wall, co-calibrated internal port, via port, autogrounded port and internal ungrounded port. All ports in Sonnet are two-terminal devices. The box wall and co-calibrated port types are those used the majority of the time. Each type of port is described below.

Box wall:

- Most common type of port.
- Positive terminal is attached to a metal polygon and the negative terminal is attached to the box wall (ground).
- De-embedding is the most accurate for this type.
- Used for connections to the periphery of your geometry.

- Reference planes may be used.

For more information on box wall ports, see "Standard Box Wall Port," page 70.

Co-calibrated internal port:

- Used in the interior of a circuit.
- Identified as part of a calibration group with a common ground node connection. The ground node connection can be defined as floating or the Sonnet box.
- When ***em*** performs the electromagnetic analysis, the co-calibrated ports within a group are simultaneously de-embedded.
- Highly accurate de-embedding.
- Often used by a circuit simulation tool to connect some type of element into your geometry at a later time outside the Sonnet environment.
- Reference planes may be used.

For more information on co-calibrated internal ports, see "Co-calibrated Internal Ports," page 71.

Via port:

- Used in the interior of a circuit.
- Negative terminal is connected to a polygon on a given level and the positive terminal is connected to a second polygon on another level above.
- Cannot be de-embedded.
- Most commonly used to attach a port between two adjacent levels in your circuit or when you want a port to go up to the box cover rather than down to ground.
- Reference planes cannot be used.

For more information on via ports, see "Via Ports," page 76.

Auto-grounded port:

- Used in the interior of a circuit.
- The positive terminal is attached to the edge of a metal polygon and the negative terminal is attached to the ground plane through all intervening dielectric layers.
- Used in place of a co-calibrated port to reduce the de-embedding processing time at the cost of less accuracy.
- Reference planes may be used.

NOTE: When using auto-grounded ports, be aware than any coupling between auto-grounded ports is not accounted for when performing the de-embedding.

For more information on auto-grounded ports, see “Automatic-Grounded Ports,” page 77.

Ungrounded Internal Ports:

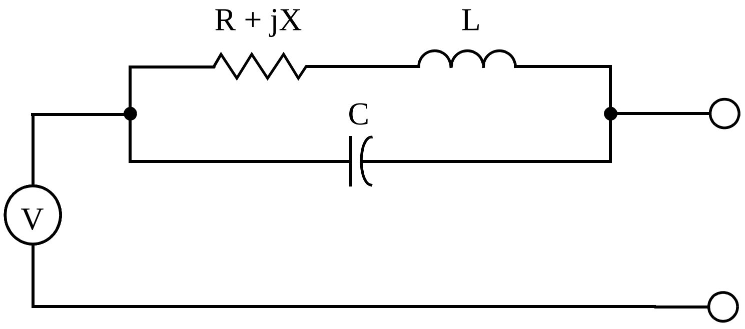
- Used in the interior of a circuit.
- Each terminal is attached to one of two adjacent polygons.
- Used in place of a co-calibrated port when you do not want any space between the two polygons.
- Will have a different ground reference from the other ports in the circuit.
- Commonly used to add a series element in post ***em*** processing.
- Reference planes cannot be used.

For more information on ungrounded internal ports, see “Ungrounded Internal Ports,” page 79.

Port Normalizing Impedances

The default normalizing impedance for a port is 50 ohms. This is done since 50 ohms is an industry standard; some analysis tools only accept the value of 50 ohms as the normalizing impedance.

In rare cases, you may wish to have S-parameters normalized to some other impedance. The normalizing impedance in Sonnet is represented by four numbers as shown in the diagram below. First is the real part in ohms. Next comes the reactive part in ohms. Third is the inductive part in nanohenries (nH). The last number is the capacitive part in picofarads (pF). The inductive and capacitive parts modify only the reactive portion of the load, they are included so you do not have to manually re-calculate the reactive part at each frequency.



Equivalent circuit of an *em* port.

NOTE: **The normalizing impedances are ignored if Y- or Z-parameters are specified for output. Y- and Z-parameters are always normalized to one ohm.**

This capability should be used only by the most advanced user. This feature should never be applied to data which is to be used in a standard circuit theory program other than Sonnet's. Many programs assume S-parameters normalized to exactly 50 ohms; S-parameters normalized to another value would introduce error into the analysis.

Changing Port Impedance

There are two methods for changing the impedance of a port. If you wish to change the impedance of a given port, and do not need to see the impedance values of other ports, take the following steps using the project editor:

1 Select the desired port(s). This will enable the *Modify* menu option.

2 Select *Modify* ⇒ *Port Properties* to open the Port Properties dialog box.

3 The impedance values can be changed by typing the desired values in the *Resistance*, *Reactance*, *Inductance* and *Capacitance* text boxes in the dialog box. This changes the parameters on all ports selected and all ports with the same number as the ports selected.

If you wish to change the impedance of a given port, and wish to see the impedance values of other ports while doing so, proceed as follows:

1 Select *Circuit* ⇒ *Ports* from the main menu to open the Port Impedance dialog box.

2 The impedance values for any port can be changed by typing the desired values in the *Resistance*, *Reactance*, *Inductance* and *Capacitance* fields in the row labeled with the desired port number.

TIP

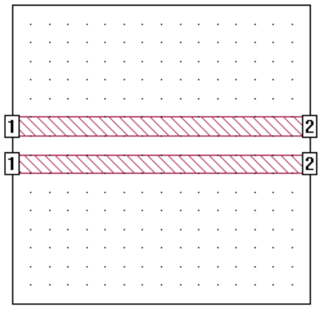
Note that the impedance of multiple ports may be changed at the same time through the first method by selecting multiple ports before selecting *Modify* ⇒ *Port Properties*, and by the second method, by modifying all the desired port values while the Port Impedance dialog box is open.

Special Port Numbering

All ports are assigned a number at the time they are created in the project editor. There is no limit on the number of ports and the number of ports has a minimal impact on the analysis time needed for de-embedding. By default, the ports are numbered by the order in which they are created (i.e. first port created is assigned the number 1, second port created is assigned the number 2, etc.). With this default method, all ports are positive and unique. However, there are some applications that require the ports to have duplicate, or even negative, numbers.

Ports with Duplicate Numbers

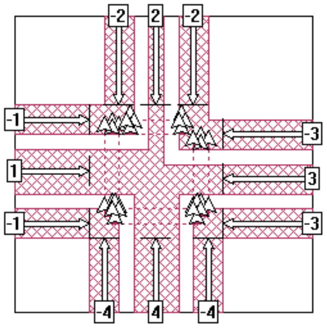
All ports with the same number, as pictured below, are electrically connected together. As many physical ports as desired may be given the same numeric label. Such ports are sometimes called “even-mode” or “push-push” ports and have many uses, including simulating the even-mode response of a circuit. See "Modeling an Arbitrary Cross-Section," page 262, for an example of using "push-push" ports.



Ports with identical port numbers are electrically connected together.

Ports with Negative Numbers

Ports may also have negative numbers as shown in the figure below. This feature can be used to redefine ground. Strictly speaking, ***em*** sums the total current going into all the positive ports with the same port number and sets that equal to the total current going out of all the ports with that same negative port number. For example, for a circuit with a +1 port and a -1 port, ***em*** sets current flowing into port +1 to be equal to the current flowing out of port -1. Thus, they are sometimes called "balanced", "push-pull" or "odd-mode" ports. Coplanar lines can be represented with balanced ports. See below for an example of push-pull ports.



An example of a coplanar waveguide cross junction.

Ports are required to be in sequential order with no numbers missing. If the ports are not in sequential order, you will receive an error message when you attempt an analysis. The port order for the S, Y, or Z-parameters will be listed in increasing numeric order. For the example of a two-port , the output would be S11, S21, S12, and S22. For a four-port, it would be S11, S12, S13, S14, S21, S22, etc.

For a discussion of using ports to model coplanar waveguides (CPW), please see "Modeling Co-Planar Waveguide (CPW) in Sonnet" under Tips and App Notes in online help. You can find this topic by selecting "CPW" in the help Index.

NOTE: **When you are referred to Sonnet's Help, you may access Help by selecting** *Help ⇒ Contents* **from the menu of any Sonnet application or by clicking on the Help button in any dialog box.**

Changing Port Numbering

You can change the port number of any port after it has been added to your circuit. Any nonzero integer, negative or positive, is valid. To change the number on a port or ports, do the following:

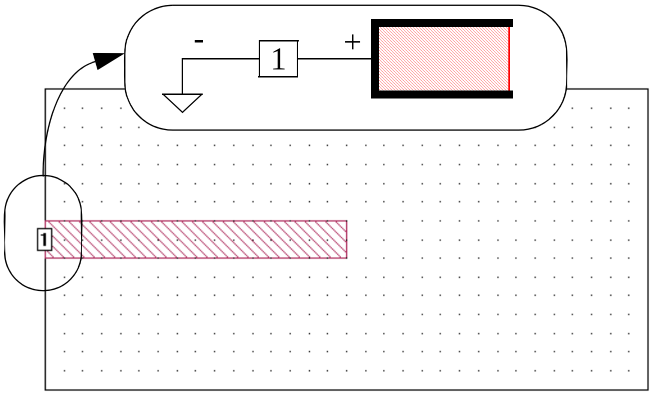
1 Select the port(s) whose number you wish to change.

2 Select *Modify ⇒ Port Properties* from the main menu to open the Port Properties dialog box.

3 The number for the selected port(s) can be changed by typing the desired port number in the dialog box. Note that if multiple ports are selected, all are set to the number input in the dialog box.

Standard Box Wall Port

A standard box wall port is a grounded port, with the positive terminal attached to a polygon edge coincident with a box wall and the negative terminal attached to ground. An example of a standard box-wall port is shown below. Standard box-wall ports can be de-embedded and can also have reference planes. This type of port is the most commonly used.



Adding Box wall Ports

You add a standard box wall port to your circuit by selecting the command *Tools* ⇒ *Add Ports* and clicking on the polygon edge on the box wall where you wish to place the port. Ports are numbered automatically, in the order in which they are added to your circuit, starting at the number one. You may change the properties of a port after it has been added to the circuit by selecting the port and using the *Modify* ⇒ *Port Properties* command. For detailed instructions for these tasks, please click on the Help button in the Modify Port Properties dialog box which appears when you select the command.

Ref. Planes and Cal. Lengths for Box Wall Ports

Reference planes and calibration lengths are both used during the de-embedding process in which the analysis engine removes the port discontinuity and a desired length of transmission line. For details of how these values are used during the de-embedding process, please refer to **Chapter 7, “De-embedding”** on page 97.

For a box wall port, you may set either a reference plane or a calibration length; both values cannot be set at the same time for box wall ports. All ports on any given box wall use the same reference length. To set either of these values for box wall ports, use the *Circuit ⇒ Ref. Planes/Cal. Length* command. For details, please click on the Help button in the Reference Planes/Calibration Lengths dialog box which appears when you select the command.

Co-calibrated Internal Ports

Co-calibrated ports, new in release 11, are used in the interior of a circuit. These ports are often used by a circuit simulation tool to connect some type of element into your geometry at a later time outside the Sonnet environment. Co-calibrated internal ports are identified as part of a calibration group with a common ground node connection. When ***em*** performs the electromagnetic analysis, the co-calibrated ports within a group are simultaneously de-embedded using a high accuracy de-embedding technique[1]; thus, coupling between all the ports within a calibration group is removed during de-embedding. This type of port is the most commonly used internal port.

Ground Node Connection

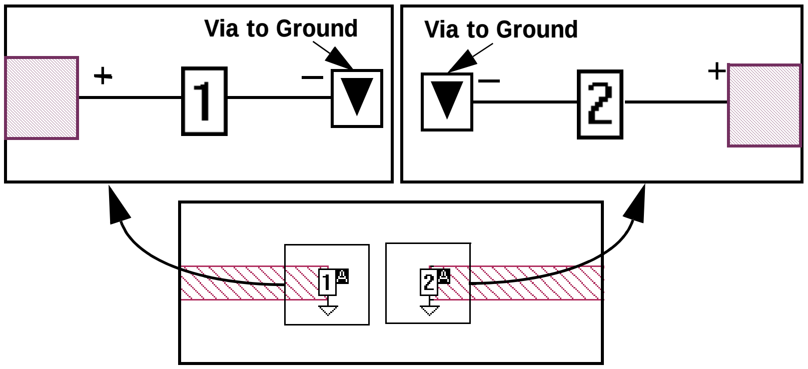
You must define how the common ground of your calibration group is connected to your circuit. There are two types of ground node connection: Sonnet Box and Floating.

Sonnet Box: When the ground node connection is defined as the Sonnet box, all co-calibrated ports in the group are globally grounded to the Sonnet box. To do this, a via is automatically created which connects to the top or bottom of the Sonnet box. You should choose this option if the element model or measured data to be connected to these ports includes shunt elements. Examples are:

- S-parameter data that includes pads or other coupling to ground.
- Transistor data that includes a via in the model/measurement.

1 ”Deembedding the Effect of a Local Ground Plane in Electromagnetic Analysis,” by James C. Rautio, president and founder of Sonnet Software, Inc. The article is available in PDF format in the Support section of our web site.

This type of co-calibrated port is illustrated below. The positive terminal is attached to a polygon edge of a feedline and the negative terminal is attached to a via to ground which is removed during de-embedding.



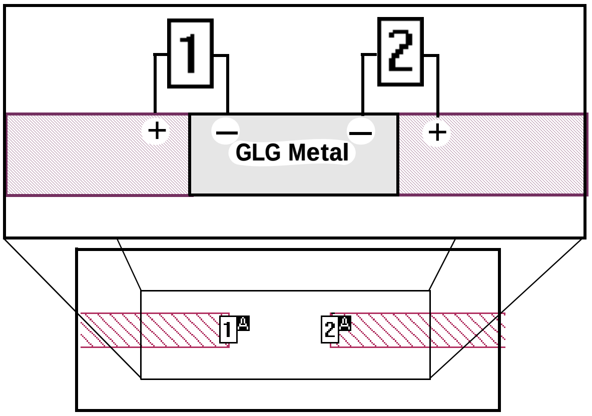
When the Sonnet box is selected as the ground node connection, the analysis engine automatically determines the most efficient direction the ground via extends taking into consideration both the distance and the loss of the box top or bottom. When using this type of ground, you must make sure that there is a clear path with no metal on other levels interfering with the path to the box top and bottom.

In addition, either the box top or bottom must have loss less than 50 ohms/sq. For example, you should not use “Free Space” for both your box top and bottom definition. If the loss is too high on both the box top and bottom for a ground via from the Component to be attached, the analysis engine will issue an error message.

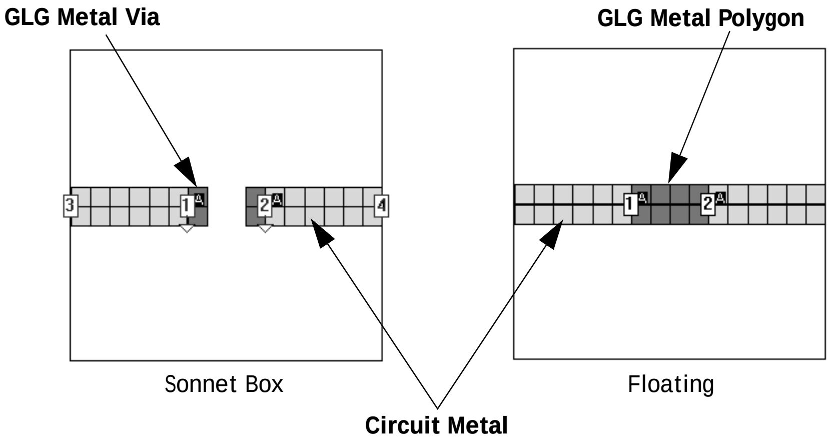
Floating: When the ground node connection is defined as Floating, all co-calibrated ports in the group are connected to a common ground but not to the Sonnet box. Instead, the ground node is left unconnected to the rest of your circuit. You should choose this option if the element model or measurement data that will be connected to these ports does not have a ground reference, or does not have shunt elements. Examples of this are:

- A series RL equivalent circuit
- S-Parameter data that was measured without any pads

This type of co-calibrated port is illustrated below. Sonnet automatically adds extra metal which connects the co-calibrated ports in a calibration group. This extra metal is defined as Generalized Local Ground (GLG) metal since it acts as a local ground for the ports in the calibration group. This metal is removed during the de-embedding process. The positive terminal of a co-calibrated port is attached to a polygon edge of a feedline and the negative terminal is attached to GLG metal.



To observe the GLG metal for either type of ground node connection, you may select the *View ⇒ View Subsections* command in the project editor. When the Subsection Viewer appears, select *View ⇒ GLG Metal* from the subsection viewer's main menu. Views of two calibration groups, as viewed in the subsection viewer with the GLG metal displayed, are shown below. A calibration group which is grounded to the Sonnet box is shown on the left and one with a floating ground is shown on the right.

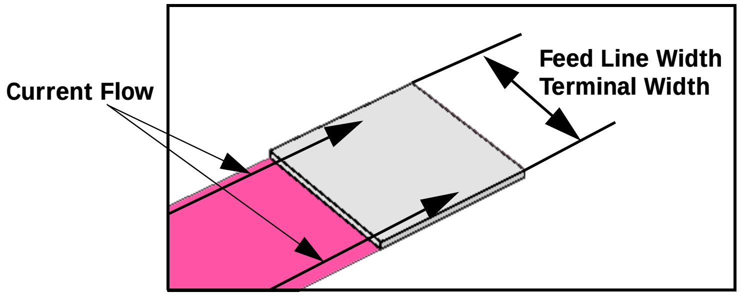


Note that in the case of the Sonnet box ground node connection, the GLG metal does not connect the two ports. Instead, there is a via composed of GLG metal which extends to ground.

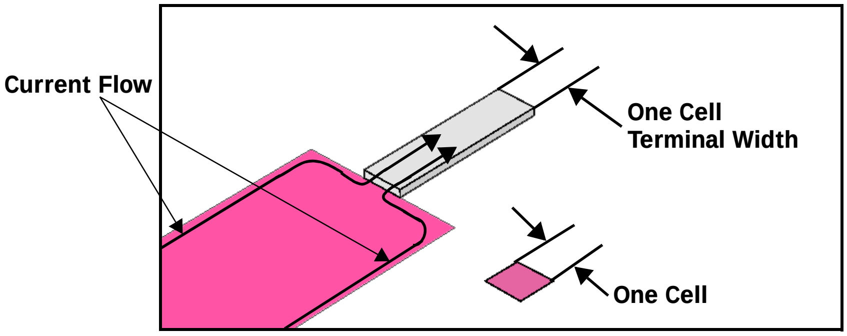
Terminal Width

You must also determine how you will define the terminal width for your calibration group. Terminal width is the electrical contact width of the component which is to be attached. This allows the current flow from the circuit geometry into the component to be accurately modeled. There are three settings for terminal width: Feed Line Width, One Cell, and User Defined. Please note that the terminal width is not shown in the project editor.

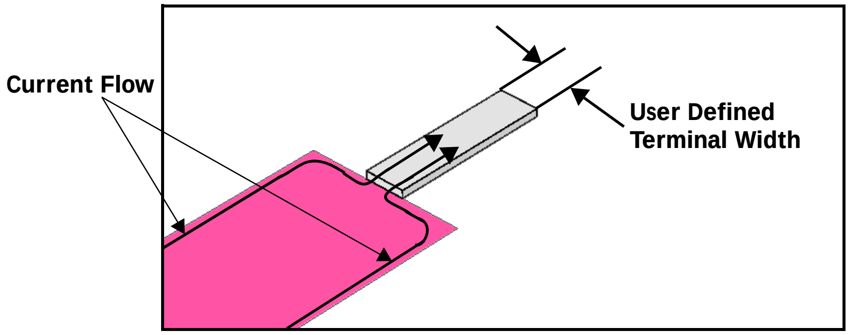
Feed Line Width: This defines the terminal width as equal to the feed line to which the co-calibrated port is attached. This is illustrated below.



One Cell: This defines the terminal width to the smallest possible size as pictured below.



User Defined: This allows you to enter any value desired for the terminal width. This type of Terminal Width is shown below.



Adding Co-calibrated Ports

You add co-calibrated ports to your circuit by selecting the command *Tools ⇒ Add Ports* and clicking on an open polygon edge where you wish to place the port. Once the ports have been added to the circuit, you select the ports, then use the *Modify ⇒ Port Properties* command which allows you to select the co-calibrated port type and assign each port to a calibration group. For detailed instructions on this process, please refer to “co-calibrated internal port” in online Help’s index.

Ref. Planes and Cal. Lengths for Co-calibrated Ports

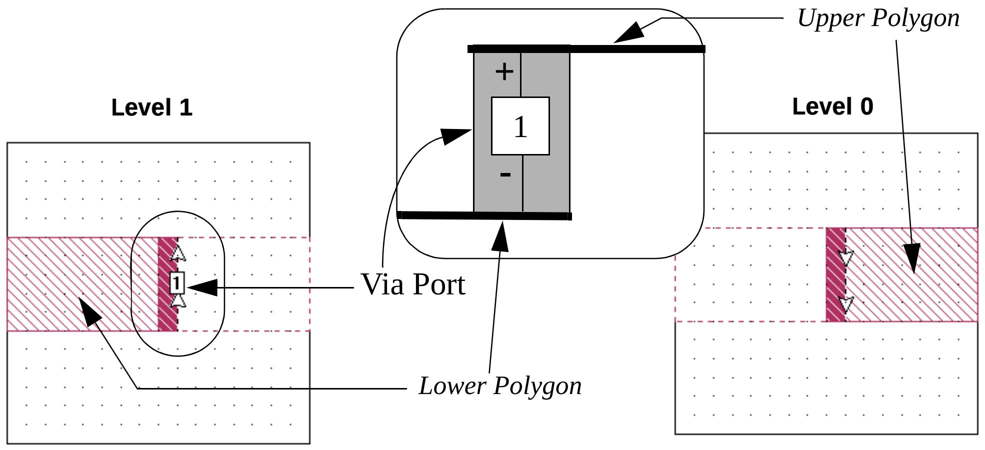
You may specify both a reference plane and a calibration length for co-calibrated ports. For a detailed discussion of how reference lengths and calibration lengths are used during the de-embedding process, please refer to Chapter 7 "De-embedding" on page 97 and Chapter 8 "De-embedding Guidelines" on page 107. For directions on how to set a reference plane and/or calibration length for a co-calibrated port, please refer to “calibration group” online Help’s index.

Use in Components

Co-calibrated ports are used to implement the Component feature. Many of the considerations which apply to the property setup of a Component also apply to the property setup for a calibration group. To gain a deeper understanding of the co-calibrated ports implemenation and uses, we highly recommend that you also read Chapter 6 "Components" on page 81.

Via Ports

A via port has the negative terminal connected to a polygon on a given circuit level and the positive terminal connected to a second polygon on another circuit level. A via port can also have the negative terminal connected to the top or bottom of the box. An example of this port type on an edge via is shown below.



An example of a circuit with a standard via port. A side view of the enclosed area on the circuit is shown in the middle.

Unlike co-calibrated ports, ***em*** cannot de-embed via ports. However, in a circuit which contains a combination of via ports and other port types, the other port types can still be de-embedded. ***Em*** will automatically identify all of the other ports present in the circuit and de-embed them, but leave the via ports un-de-embedded.

The example file Dual_patch has an example of a via port used in a patch antenna. This example file can be found in the Sonnet example files.

In most cases where you need grounded ports, your first choice would be to use co-calibrated ports (as discussed earlier), especially since it is possible to accurately de-embed co-calibrated ports. The most common case where a via port would be used is when you wish to attach a port between two adjacent levels in your circuit. Another application is when you wish to connect a port to the interior of a polygon, which is not allowed for co-calibrated ports which must be added to an open polygon edge.

You can not apply reference planes to via ports, since it is not possible for ***em*** to de-embed them.

Adding Via Ports

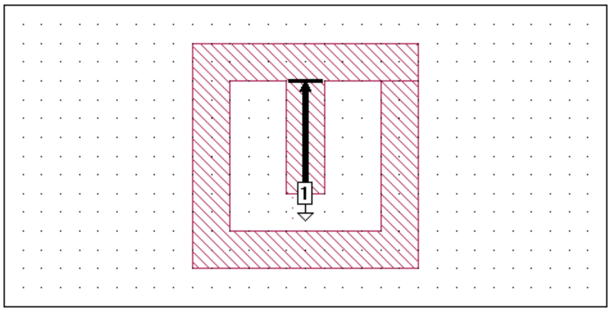
To add a via port, you must first create a via. The via can be an edge-via or a via polygon. For more details on how to create vias, see “vias” in online Help’s index.

Once the via is in place, click on the Add a Port button in the tool box and click on the via to add a port.

NOTE: **The via port only appears in the project editor on the bottom level of the via; if you are adding the port to any other level of the via, the port is not displayed in the project editor. To see the port, go to the metal level on which the bottom of the via is placed.**

Automatic-Grounded Ports

An automatic-grounded port is a special type of port used in the interior of a circuit similar to a co-calibrated internal port. This port type has the positive terminal attached to the edge of a metal polygon located inside the box and the negative terminal attached to the ground plane through all intervening dielectric layers. An auto-grounded port with a reference plane is shown below. Auto-grounded ports can be de-embedded by the analysis engine.



In most circuits, the addition of co-calibrated ports has little influence on the total analysis time of the ***em*** job. However, for some circuits, co-calibrated ports may require more time in the de-embedding phase of the analysis. In these cases, you may wish to use auto-grounded ports, which are more efficient but less accurate than co-calibrated ports, since the de-embedding for auto-grounded ports does not take into account the coupling between the auto-grounded ports.

Special Considerations for Auto-Grounded Ports

Metal Under Auto-Grounded Ports

Similiar to co-calibrated ports which use the Sonnet box as the ground node connection, you cannot have metal directly beneath an auto-grounded port in a multilayer circuit. Auto-grounded ports are two-terminal devices with the positive terminal connected to an edge of a metal polygon and the negative terminal connected to the ground plane. When ***em*** detects the presence of an auto-grounded port, it automatically connects the two terminals in this manner. This includes circuits which have multiple dielectric layers between the polygon and the ground plane. However, in order for ***em*** to accomplish this, there must be a direct path from the edge of the metal polygon to the ground plane. When an auto-grounded port is used in a circuit where there is more than one dielectric layer between the port and the ground plane, ***em*** checks to make sure that there is no metal directly beneath the auto-grounded port. If metal is found, ***em*** prints an error message and stops.

Edge of Metal Polygon is Lossless

Auto-grounded ports can attach to the edge of any metal polygon in the interior of a circuit. There are no restrictions on the loss parameters of the metal used in the polygon. However, along the edge of the metal polygon where the port is attached,

em does force the cells to be lossless. For most circuits, this should have little or no effect on the results. If, however, the port is attached to a highly lossy metal polygon, such as a thin-film resistor, the edge cell(s) of that polygon will be made lossless, and the output results may be affected.

Adding Auto-grounded Ports

You add an auto-grounded port to your circuit by selecting the command *Tools ⇒ Add Ports* and clicking on the open polygon edge where you wish to place the port. Once the port has been added to the circuit, you select the port, then *Modify ⇒ Port Properties*. In the Port Properties dialog box which appears, you select the auto-grounded type. For detailed instructions on this process, please refer to “auto-grounded ports” in online Help’s index.

Ref. Plane and Cal. Length for Autogrounded Ports

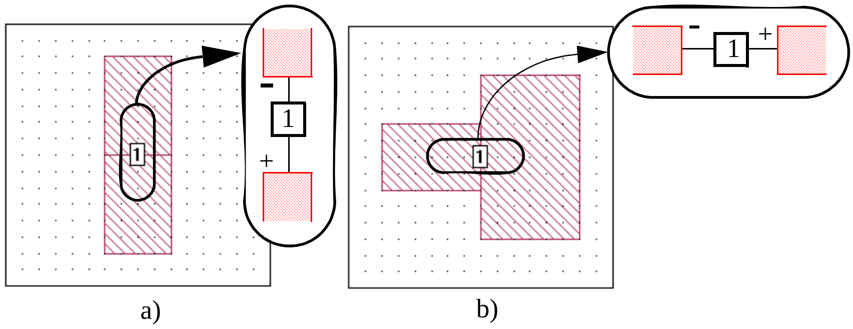
To set a reference plane or calibration length for an auto-grounded port, use the *Modify ⇒ Port Properties* command. You enter the desired Reference Plane and/ or Calibration Length in the appropriate field. For detailed instructions please refer to online help. Note that if you enter a reference plane, it applies only to the selected port(s). For details on how reference planes and calibration lengths are used in the de-embedding process, please refer to Chapter 7 "De-embedding" on page 97 and Chapter 8 "De-embedding Guidelines" on page 107.

TIP

Changing a port to an autoground type and setting up a reference plane or calibration length for the port can be accomplished at the same time in the Port Properties dialog box. It is also possible to set calibration lengths for multiple ports by selecting the desired ports, selecting *Modify ⇒ Port Properties* and inputting a value in the calibration length text entry box in the Port Attributes dialog box.

Ungrounded Internal Ports

An ungrounded internal port is located in the interior of a circuit and has its two terminals connected between abutted metal polygons. An ungrounded internal port is illustrated below. Note that internal ports have their negative terminals on the left or top side of the port depending on how the port is oriented. Ungrounded internal ports can be de-embedded by ***em***, however, you may not set a reference plane or calibration length**.** Ungrounded internal ports are not as accurately de-embedded as co-calibrated internal ports, but they do not require any space between the two polygons as is required for a co-calibrated port.



Unground internal ports are not allowed on the edge of a single polygon because this would leave one terminal of the port unattached. Also, care should be taken in interpreting the results for circuits which use these ports since the ports do not all access a common ground.

You add an ungrounded-internal port in the same manner that you add a standard box wall port; for details, see "Adding Box wall Ports," page 70.

Chapter 6 Components

Introduction

Release 11 introduces a new Components feature. The Component feature is built upon the high accuracy de-embedding technique[1] used for Sonnet co-calibrated internal ports technology. Using this technique, the user can insert an ideal element, measurement of a physical component, or even results from another Sonnet project. In addition, using the Component feature in conjunction with the Agilent Interface, Microwave Office Interface, or the Cadence Virtuoso Interface provides a powerful tool to model complex circuits.

The Components features allows for a high level of flexibility by using three different Component types:

- **Data File type:** If you would like to insert an S-parameter data file of your component into your Sonnet model.
- **Ideal type:** If you would like to insert an ideal component (R, L, or C) into your Sonnet model.
- **Ports Only type:** If you would like to use a separate circuit simulation tool for the final, combined simulation, you may insert only ports within the Sonnet model.

1”Deembedding the Effect of a Local Ground Plane in Electromagnetic Analysis,” by James C. Rautio, president and founder of Sonnet Software, Inc. The article is available in PDF format in the Support section of our web site.

In cases where the data file or ideal component types are used, the Sonnet solver uses a circuit simulation technique to produce the combined results. Since this is a post EM analysis step, the user can change the ideal component value, or associated S-parameter data file, without requiring a new EM analysis; only the circuit simulation part of the analysis is performed by the analysis engine.

Please note that the coupling from the inside of the component to the rest of the circuit is not considered in the Sonnet analysis. Only the coupling from the component's terminals is considered.

When connecting external parts to your EM structure, we highly recommend that you use either the co-calibrated ports or the Component feature. This novel approach provides greatly enhanced accuracy for this application by perfectly de-embedding the ports, thus completely removing all coupling between them. Autoground Ports have the limitation of not removing any port to port coupling.

Before proceeding to use the Component feature, it would be helpful to become familiar with the related co-calibrated internal ports discussed in "Co-calibrated Internal Ports," page 71 in the Ports chapter.

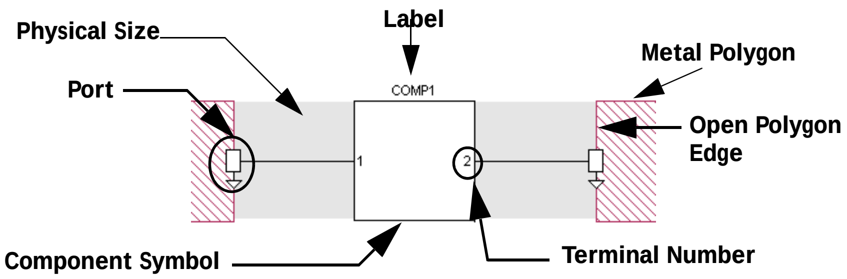
Component Assistant

When you select any of the Add Component commands in the project editor, the Component Assistant appears on your display. Whenever you select a control in the Component Properties dialog box, the assistant provides a description of the field, and often, an illustration of the principle, so that you may select the correct setting and model your Component more accurately.

If the Component Assistant does not appear, you should select the "Use Component/Calibration Group Assistant" checkbox on the Hints tab of the Preferences dialog box in the project editor (*File ⇒ Preferences*).

Anatomy of a Component

The Component is represented in your circuit by a component symbol. The label of the Component appears above the component symbol and the terminal numbers are identified there. Ports, indicating where the terminals of the Component are connected to the metal in your circuit, are represented by a small rectangle. Component ports are only numbered when the Component model type is Ports Only. An example of a Component as it appears in the project editor is shown below.



Component Symbol This is the symbol which represents your Component in your project.

Port The Component port defines the point at which the Component is connected to the circuit metal and must be attached to an open polygon edge. This point also serves as a reference plane for de-embedding the Component unless a reference plane is added for the port. There is one Component port for each terminal on the Component. Component ports are modeled using co-calibrated internal ports. For more information on co-calibrated ports, please see “Co-calibrated Internal Ports,” page 71.

Terminal Numbers Terminal numbers identify the physical pin on your Component connected to the corresponding Component port.

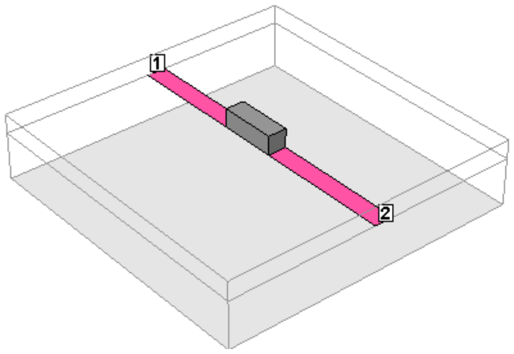
Components may have an unlimited number of terminals, with the exception of those Components which use the Ideal Component model, since the available ideal components are limited to two terminals. Terminals and/or ports are numbered in the order in which they are added to your circuit and may be modified after the Component is added to your circuit.

Label The label is user-defined text which identifies the Component in your circuit. Each Component label in a project must be unique.

Open Polygon Edge Component ports may be placed only on open polygon edges. You may use a reference plane to control how much, if any, of your circuit metal is also de-embedded in addition to the Component. For more information, see “Reference Planes,” page 91.

Physical Size

You may also optionally enter a physical package size for your Component. These measurements (height, width, and length) are not used in the ***em*** simulation but are there to provide a graphic in both the 2D and 3D view which represent the actual size of the Component. This is especially useful for design presentations and reviews. Shown below is a 3D view of the example Component pictured above:



Component Types

There are three types of Component model: Data File, Ideal, and Ports Only. All three models are described below.

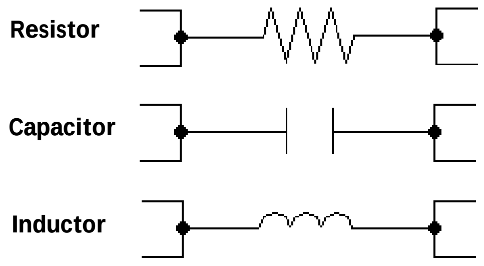
Data File

The Data File Component allows you to add a Component to your geometry that is modeled with a user specified S, Y, or Z-Parameter file (Touchstone format). The data file used for your Component can be the result of another simulation or measured data from an actual component. There is no limit to the number of ports you may use for a data file Component.

You add a data file type Component by selecting the command *Tools ⇒ Add Component ⇒ Data File.* This command opens the Components Properties dialog box as well as the Component Assistant.

Ideal Component

The Ideal component allows you to add a single 2-port ideal component. There are three types of ideal components available: resistor, capacitor, or inductor. All ideal components use a series element with two ports as shown below:



You add an Ideal component by selecting the command *Tools ⇒ Add Component ⇒ Ideal.* This command opens the Components Properties dialog box as well as the Component Assistant.

Ports Only

The Ports Only Component allows you to insert internal ports in your circuit which may be used later in a circuit design program. All of the ports associated with this Component have a common ground and are simultaneously de-embedded during the electromagnetic analysis. There is no limit to the number of ports your Component may have. This Component type is functionally equivalent to using co-calibrated internal ports. For a detailed discussion of co-calibrated ports, see “Co-calibrated Internal Ports,” page 71.

You add a Ports Only type Component by selecting the command *Tools ⇒ Add Component ⇒ Ports Only.* This command opens the Components Properties dialog box as well as the Component Assistant.

Component Properties

An important part of modeling a Component in Sonnet is to consider the conditions under which the measured data or model for your Component was obtained. These conditions should be used to determine:

- The type of ground node connection
- The terminal width
- If reference planes are used for the Component ports and if so, of what length

The ***em*** environment should be set up to use the Component in the same manner that the component was measured. The correct setting of the Component properties is discussed in detail below.

Ground Node Connection

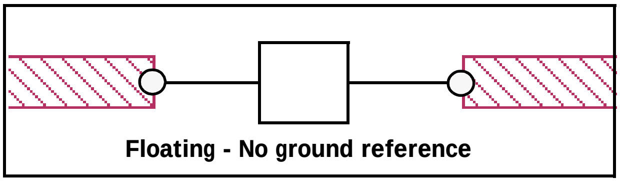
The ground node connection defines how the ground of your Component is connected to your circuit. There are three types of ground node connections: Sonnet Box, Floating, and Polygon Edge(s).

NOTE: The Ideal Component does not use a ground node connection by definition. The ground node connection needs to be specified for the Data File and Ports Only Component types.

Sonnet uses a common ground for all the Component ports associated with a given Component. This common ground should model as closely as possible how your component was measured or modeled. Vendors who supply components often have measured S-parameters or a model which may be used to create S-parameters. In either case, information about how these values were obtained should also be available. Use this information to guide your choice of ground node connection. The three types of ground node connection are discussed below.

Floating

When your ground node connection is set to Floating, all the Component ports reference a common local ground as pictured below. This option should be used if your Component does not have a ground reference, or if there are no shunt elements in your component model or measured data. Any shunt admittance is removed by ***em***.

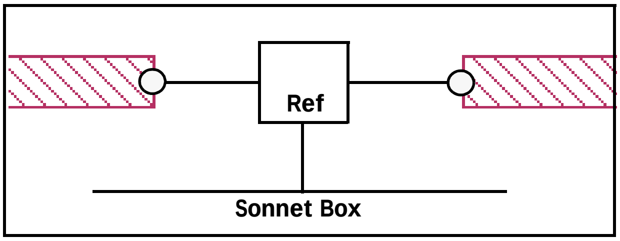


Examples of this are:

- A series RL equivalent circuit
- S-Parameter data that was measured without pads

Sonnet Box

When your ground node connection is set to Sonnet box, all the Component ports are globally grounded to the Sonnet box. To accomplish this, a via is automatically created which connects to the top or bottom of the Sonnet box. This option should be used if your component model, or measured data, includes shunt elements and you want the Component's ground reference to be connected to the Sonnet box.



Examples of this are:

- S-Parameter data that includes pads or other coupling to ground
- Transistor data that includes a via to ground in the model/measurement

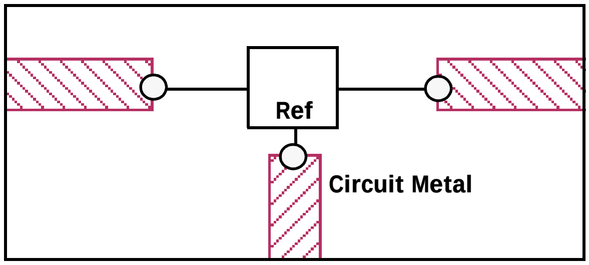
The analysis engine determines the most efficient direction the ground via extends taking into consideration both the distance and the loss of the box top or bottom. When using this type of ground, you must make sure that there is a clear path with no metal on other levels interfering with the path to either the box top or bottom.

If you are using a Component whose ground node connection is to the Sonnet box, either the box top or bottom must have loss less than 50 ohms/sq. For example, you should not use "Free Space" as your box top and bottom definition. If the loss is too high on both the box top and bottom for a ground via from the Component to be attached, the analysis engine will issue an error message.

[1]"Deembedding the Effect of a Local Ground Plane in Electromagnetic Analysis," by James C. Rautio, president and founder of Sonnet Software, Inc. The article is available in PDF format in the Support section of our web site.

Polygon Edge(s)

When your ground node connection is set to Polygon Edge(s), the ground reference of your Component is connected to a polygon edge(s) selected by you when adding the Component. You may specify as many ground terminals as you need.



Examples of this are:

- Transistor data without parasitics to ground, but with a ground path included in the Sonnet structure
- A multi-pin module with one or more ground pins

NOTE: **The Polygon Edge(s) ground node connection is only available for Data File type Components.**

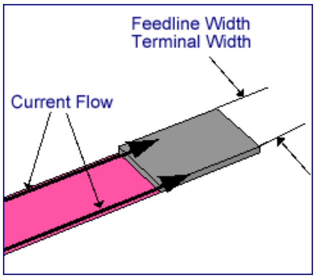
Terminal Width

The terminal width is the electrical contact width of the Component. Entering a terminal width allows you to accurately model the current flow from the circuit geometry into the Component.

There are three types of terminal width: feedline, one cell and user defined. Each type of terminal width is illustrated and explained below.

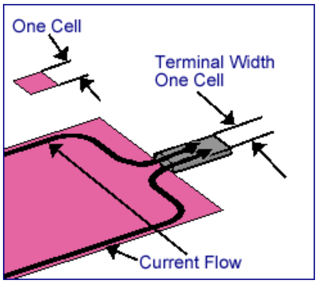
Feedline Width

Choosing Feedline Width sets your terminal width to match the length of the polygon edge to which the Component is attached. This option should be used when the polygon edge is about the same size as the width of the Component. An example is pictured below.



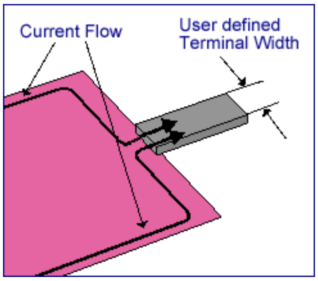
One Cell

One Cell sets your terminal width to the smallest possible size of one cell wide as pictured below.



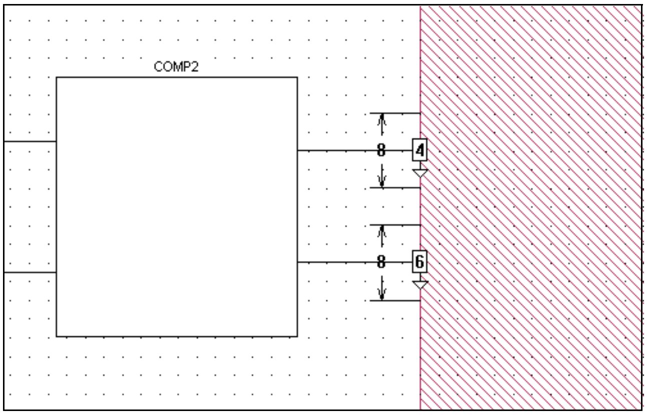
User Defined

This option allows you to enter a known electrical contact width. An illustration of a Component with User Defined terminal widths is shown below.

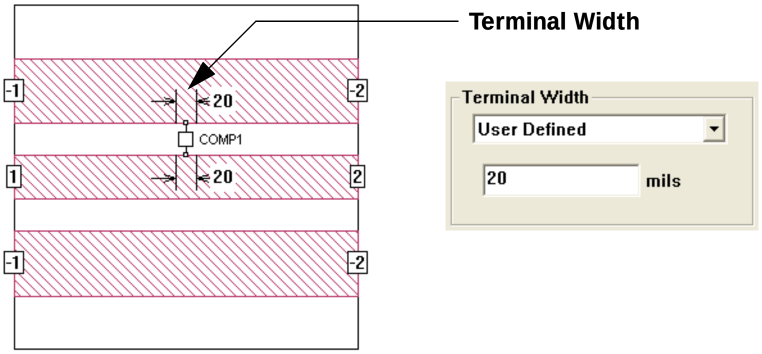


When you select user defined, your terminal width is defined based on the location of the Component port. The point at which the port is placed on the polygon edge becomes the center of the terminal width extending an equal distance on either side.

This ability to limit the terminal width size is important in cases where more than one Component port needs to connect to the same polygon edge or the polygon edge is extremely large. The next two images demonstrate these concepts.



The component has two terminals connected to a single polygon edge. The cell size is 2 mils and the user-defined terminal width is 8 mils as shown.

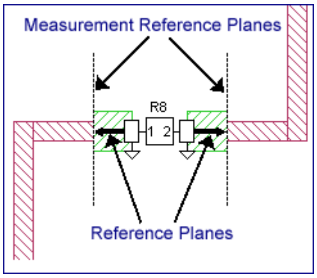


Terminal Width
User Defined
20 mils

A coplanar waveguide that uses a two port component. To the right is shown the entry in the Component Properties dialog box.

Reference Planes

Components require their ports to be on open polygon edges. Reference Planes can be used to effectively move your port position away from the polygon edge. To accomplish this, ***em*** uses circuit theory to cascade a negative length of the line with the analysis results. If no reference plane is specified, then de-embedding the Component removes none of the feedline metal but the port(s) are still de-embedded. The use of reference planes is illustrated below.



NOTE: **Reference planes may only be used when the ground node connection is defined as the Sonnet box.**

All the Component ports on a side of a Component use the same reference plane. For a detailed discussion of reference planes and de-embedding, please see **Chapter 7, “De-embedding”** on page 97.

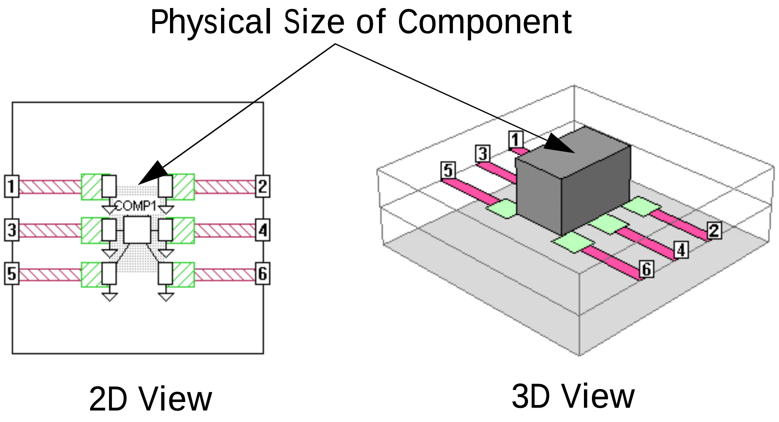
As with all Sonnet reference planes, the Component reference planes are snapped to the grid. It is important that you are working with a fine enough cell size to ensure the accurate placement of your reference planes. If the length is set to less than one half the cell size, then the reference plane will not be displayed in the project editor window.

Calibration Lengths

The analysis engine will automatically determine appropriate lengths for the calibration standards used in the de-embedding algorithm. Normally, the Auto setting (default) produces efficient and highly accurate simulation results. In rare cases, you may wish to manually override the automatic lengths. Before manually overriding these settings, please be sure to read **Chapter 8, “De-embedding Guidelines”** on page 107.

Physical Size

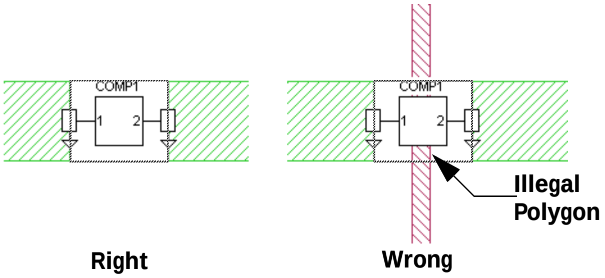
You may enter a physical size for your Component for display purposes. The physical dimensions length, width, and height, are not used in the simulation but do affect how your Component is displayed in the project editor. You may enter the precise dimensions or choose Auto to have the software choose approximate dimensions based on your Component's port placements. An example is shown below.



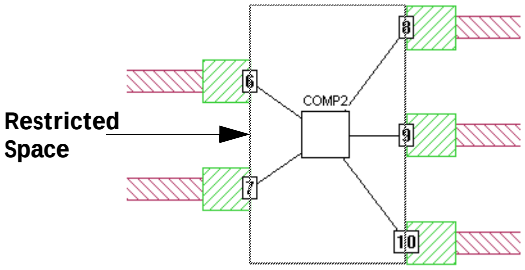
Rules for Using Components

The following restrictions apply to the placement of Components in your circuit:

1. **No objects may be placed within the "restricted space" in the interior of the Component:** Metal polygons, vias, or dielecric bricks may be present in the rectangular area defined by the port locations and the terminal width, as illlustrated below. The bottom circuit shows the restricted area in a multiport Component.



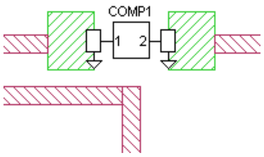
The dashed boxes identify the "restricted space" for each Component. On the circuit labeled "Wrong" a metal polygon passes through the middle of the restricted space.



2. **Components whose ground node connections are defined as the Sonnet box require direct access to the Sonnet top or bottom cover.** The analysis engine determines the most efficient direction the ground via extends taking into consideration both the distance and the loss of the box top or bottom. When using this type of ground, you must make sure that there is a clear path with no metal on other levels interfering with the path to either the box top or box bottom.

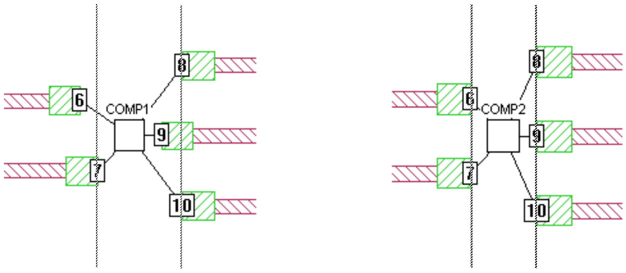
   In addition, the box top or bottom should not have loss greater than 50 ohms/sq. If the loss is too high on both the box top or bottom for a ground via from the Component to be attached, the analysis engine issues an error message.

3. **Nearby objects should be placed so that coupling between the Component and the object does not occur:** Metal polygons, vias, or dielectric bricks which couple to the Component ports may decrease the accuracy of the analysis as shown below.



4. **All ports must be on a single metal level:** Sonnet does not support multi-level Components.

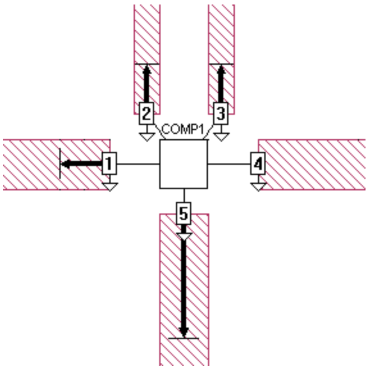
5. **Multiple ports on the same side of a Component should be aligned:** In the illustration below, the ports on Comp1 are placed incorrectly and will produce an error during an analysis. The ports on comp2 are placed correctly.



Wrong Correct

The dashed lines represent the alignment plane.

6. **Reference planes must be the same length for each side of a Component:** However, reference planes can be set independently for each side of the “port rectangle” as shown below.



Analysis of a Component

Data File Frequencies

When using a data file Component type, frequencies in your data file do not need to precisely match the Sonnet analysis frequencies. The analysis engine will interpolate between data file frequencies if necessary, but it will not extrapolate outside the frequency range of the data file.

Rerunning an Analysis

When the analysis engine analyzes your circuit with a Component, it first performs an electromagnetic analysis of the geometry, then uses circuit theory to connect the Component to the geometry. If you change the data file used for a Component or the value and/or type of an ideal component, in subsequent analyses ***em*** only needs to perform the circuit theory part of the analysis, significantly reducing processing time. Please note that any graphs of the response are not automatically updated. Instead, you need to select *Graph ⇒ Freshen Files* to update your graph in the response viewer.

Chapter 7 De-embedding

Each port in a circuit analyzed by ***em*** introduces a discontinuity into the analysis results. In addition, any transmission lines that might be present introduce phase shift, and possibly, impedance mismatch and loss. Depending upon the nature of your analysis, this may or may not be desirable. De-embedding is the process by which the port discontinuity and transmission line effects are removed from the analysis results.

The figure on page 98 illustrates the general layout of a circuit to be analyzed with ***em***. The device under test (DUT), shown as a box in the figure, is the circuitry for which we wish to obtain analysis results. The DUT is located inside the metal box and is connected to one or more ports. The ports may be located on box walls, as in the figure, or in the interior of the metal box (see Chapter 5 for a description of port types available in ***em***). Typically, transmission lines are necessary to connect the ports to the DUT.

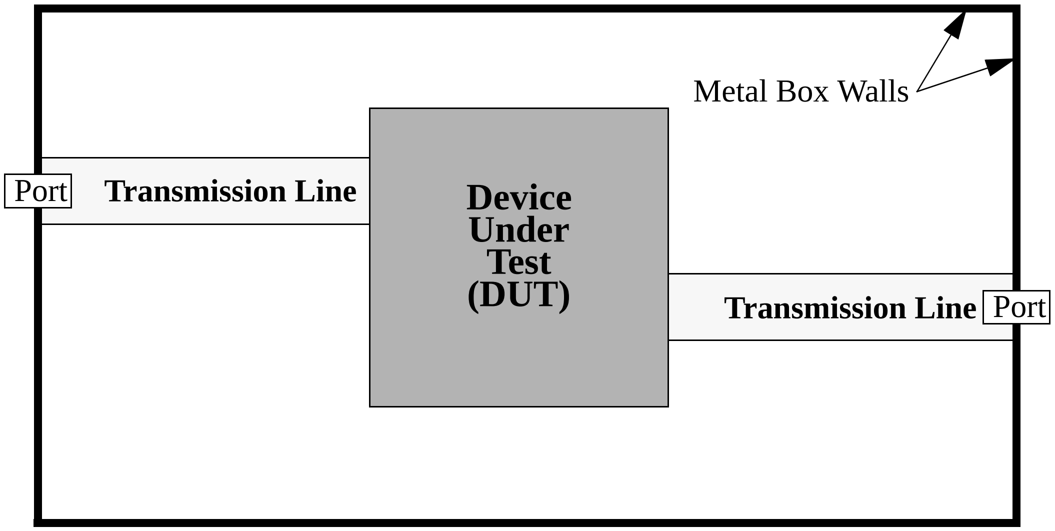
When de-embedding is enabled, ***em*** performs the following sequence of steps:

1 Calculates port discontinuities.

2 Removes effects of port discontinuities from analysis results.

3 Optionally shifts reference planes (removes effects of feed transmission lines from analysis results).

4 Calculates transmission line parameters E_{eff}, and Z_0.



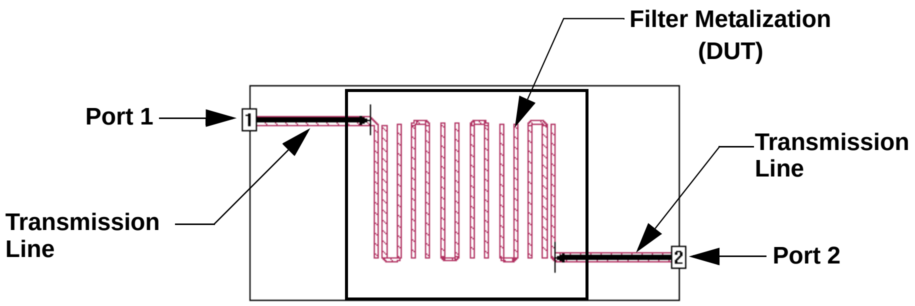
General layout of a circuit to be analyzed with *em*.

Upon completion of the de-embedding process, ***em*** outputs de-embedded S-parameter results, transmission line parameters and the calculated port discontinuities.

An abbreviated summary of the de-embedding algorithm used is presented in reference [76] and the complete theory is presented in reference [77] in **Appendix II, “Sonnet References”** on page 361. For a discussion of the de-embedding technique used for co-calibrated ports see ”Deembedding the Effect of a Local Ground Plane in Electromagnetic Analysis,” by James C. Rautio The article is available in PDF format in the Support section of our web site.

Enabling the De-embedding Algorithm

To demonstrate de-embedding with ***em***, we will analyze the filter shown below. This is an example of a hairpin filter with a passband of approximately 4.0 to 4.15 GHz. This circuit consists of eight sections making up the filter metalization, two ports and two transmission lines connecting the ports to the filter metalization. Reference planes have been defined for port 1 and port 2 at the left and right edges of the filter metalization, respectively. These reference planes instruct ***em*** to remove the effects of the transmission lines up to the filter metalization when de-embedding is enabled.



Port discontinuities and transmission lines at the upper left and lower right are removed from the *em* analysis results by enabling de-embedding.

NOTE: **Adding reference planes to a circuit in the project editor does not automatically enable de-embedding in *em*. However, the De-embed run option is set by default.**

You select the de-embed option in the Advanced Options dialog box in the project editor. This run option is set by default. To open the Advanced Options dialog box, select *Analysis* ⇒ *Setup* from the project editor main menu. Then click on the Advanced button in the Analysis Setup dialog box which appears.

An analysis was performed on the filter starting at 3.95 GHz to 4.2 GHz in 0.002 GHz steps with the de-embedding option on.

As ***em*** performs the analysis, messages are output to the status section of the analysis monitor detailing the various tasks in the process. The actual response data is shown in the output window when the Response Data button is pressed. Below is the output response data for the filter as it appeared in the analysis monitor**.**

```
Run 1:  Sat Apr 07 15:18:18 2001.  Frequency Sweep.

Frequency:  3.95 GHz
De-embedded 50-Ohm S-Params. Mag/Ang. Touchstone Format. (S11 S21 S12 S22).
3.95000000 0.999998 149.22 0.001765 -113.1 0.001765 -113.1 0.999998 164.55
!< P1 F=3.95 Eeff=(2.93154529 0.0) Z0=(52.0732019 0.0) R=0.0 C=0.0748436
!< P2 F=3.95 Eeff=(2.93105773 0.0) Z0=(52.0687952 0.0) R=0.0 C=0.07484847
```

De-embedded S-parameter, transmission parameter, and port discontinuity results

The analysis monitor displays the de-embedded S-parameter results along with the feed transmission line parameters (E_{eff} and Z_0) and calculated discontinuity (R and C) for each de-embedded port. "P1" and "P2" stand for "port 1" and "port 2", respectively. A detailed discussion concerning the port discontinuities (R and C) is presented in the next section.

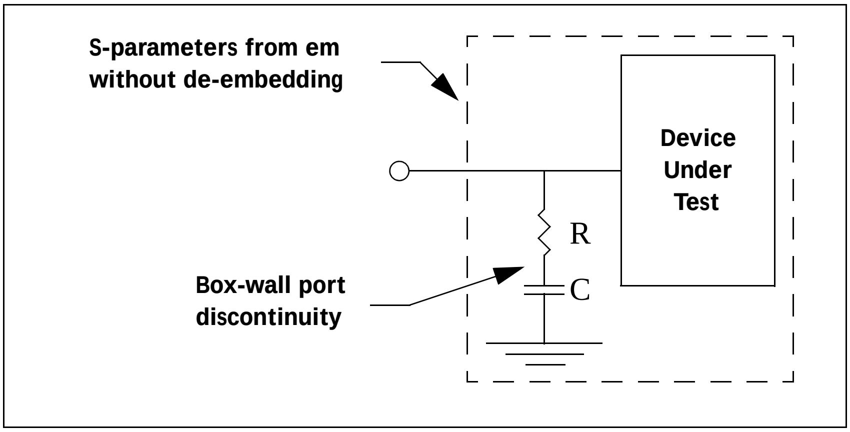
De-embedding Port Discontinuities

All ports in ***em*** introduce a discontinuity into the analysis results. Sometimes, this is desirable. For example, when analyzing a circuit fabricated with box walls, the effects introduced by a box-wall port discontinuity are real. Under this circumstance, the discontinuity should not be removed. However, in analyses where only the behavior of the DUT is of interest, all port discontinuities should be removed by de-embedding.

When enabled, ***em***'s de-embedding algorithm automatically removes the discontinuities for box-wall, co-calibrated, auto-grounded and ungrounded-internal ports (see "Port Type Overview," page 63 for a description of port types available in ***em***). A via port is the only type of port that cannot be de-embedded by ***em***. The port discontinuity for box wall ports is described in the section that follows. The discontinuity for the other types of ports is similar in nature.

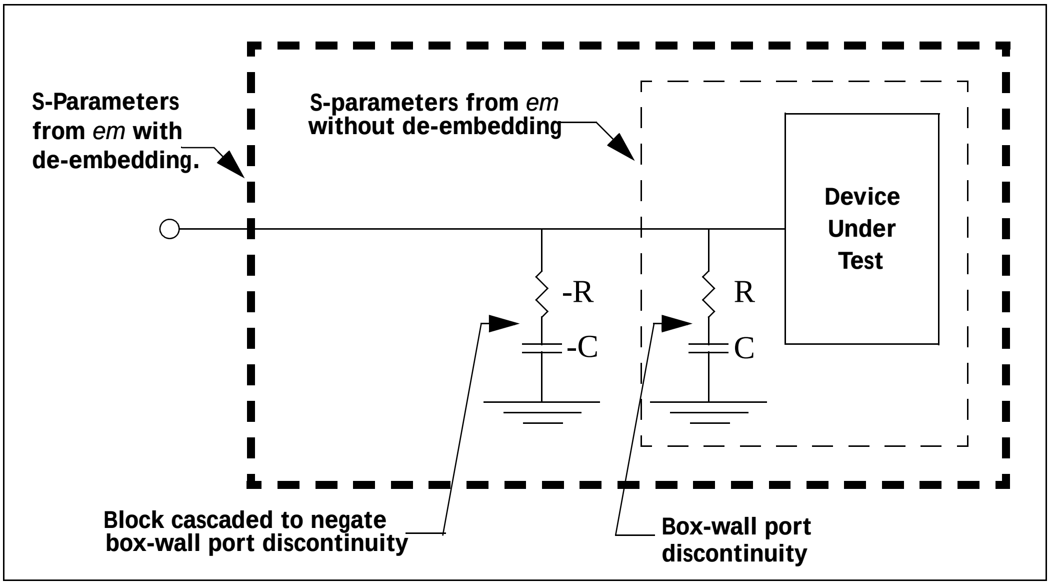
Box-Wall Ports

Box-wall ports have one port terminal connected to a polygon inside the metal box, and the second port terminal connected to ground (see the figure on page 70). The port discontinuity is modeled as a series resistor, R, and capacitor, C, shunted to ground as shown below. If the circuit being analyzed is completely lossless, the resistor value, R, is zero. Even with loss in the circuit, the capacitive reactance is normally very large compared to the resistance.



Port discontinuity associated with a box-wall port.

When enabled, ***em***'s de-embedding feature automatically calculates the values of R and C for each box-wall port present in the circuit. The port discontinuities are then removed by cascading a negative R and C as illustrated above.


S-Parameters from *em* with de-embedding.
S-parameters from *em* without de-embedding
Device Under Test
-R
-C
R
C
Block cascaded to negate box-wall port discontinuity
Box-wall port discontinuity

De-embedding automatically cancels the discontinuity associated with a box-wall port.

Shifting Reference Planes

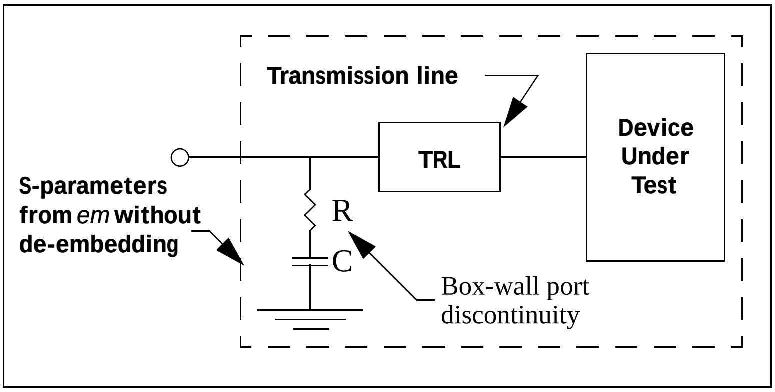
Transmission lines are required in many circuits to connect ports to the device under test (DUT). If the length of a transmission line is more than a few degrees relative to a wavelength, unwanted phase (and possibly loss) will be added to the S-parameter results. If the impedance of the transmission line differs from the normalizing impedance of the S-parameters (usually 50 ohms), an additional error in the S-parameters results. Thus, if we are only interested in the behavior of the DUT, any "long" transmission lines connecting the ports to the DUT should be removed during de-embedding. The process of removing lengths of transmission line during de-embedding is known as "shifting reference planes".

Reference planes may be specified in the project editor for box-wall, co-calibrated, and auto-grounded ports, but not ungrounded-internal and via ports. When ***em*** detects a reference plane, and de-embedding is enabled, it automatically builds and analyzes the calibration standards necessary to de-embed the port and shift the reference plane by the specified length.

NOTE: **Reference planes are not necessary for de-embedding. If you do not specify a reference plane in the project editor for a box-wall or auto-grounded port, the reference plane length defaults to zero. This means that *em* will not shift the reference plane for that port when de-embedding is enabled. However, *em* will remove the discontinuity for that port.**

Single Feed Line

The figure below shows a circuit with a length of transmission line, TRL, inserted between a box-wall port and the device under test.


Transmission line
TRL
Device Under Test
S-parameters from *em* without de-embedding
R
C
Box-wall port discontinuity

Port discontinuity and transmission line associated with a box-wall port.

When de-embedding is enabled, ***em*** removes the transmission line in a manner similar to that used to remove the port discontinuity. ***Em*** calculates S-parameters for the TRL alone, and then cascades a "negative" TRL along with negative R and C as illustrated in the next figure.

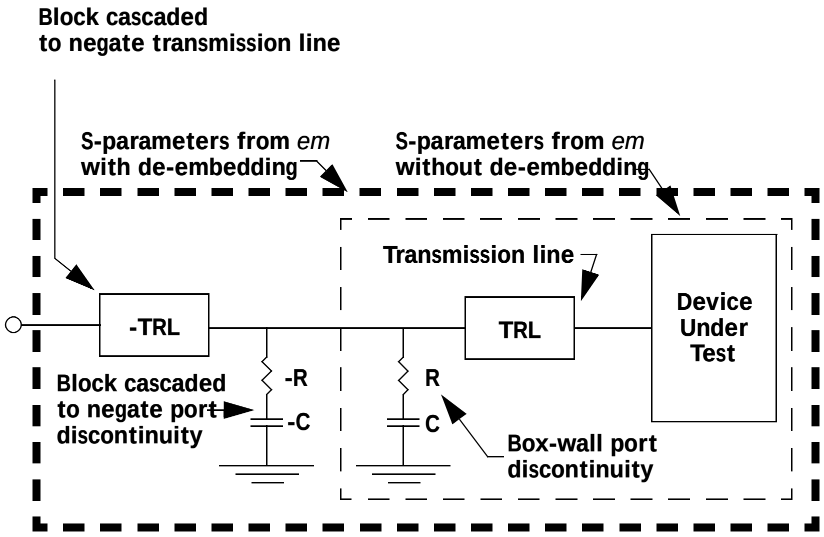


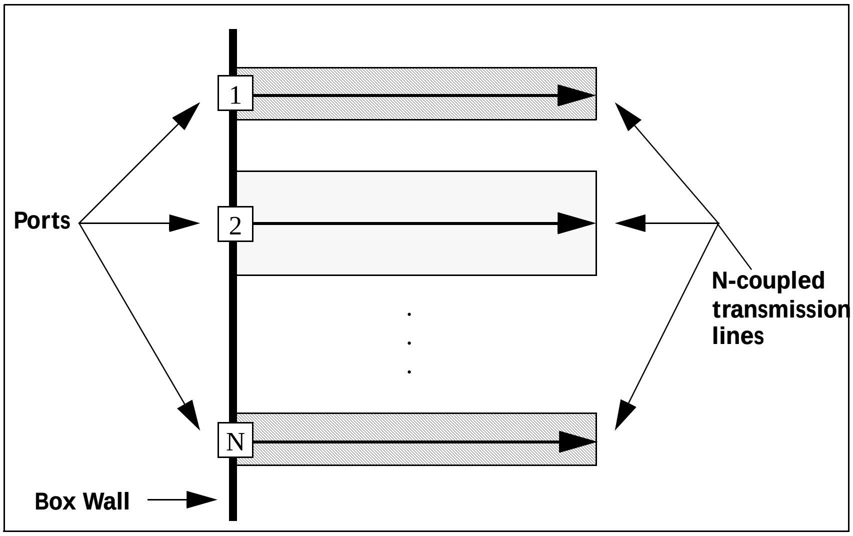
Illustration of how de-embedding removes the port discontinuity and transmission line associated with a box-wall port.

Coupled Transmission Lines

The two previous figures illustrated how the reference plane for a single transmission line attached to a box-wall port is shifted during de-embedding. In general, there may be multiple transmission lines on a given box wall on one or more circuit levels. This is illustrated in the next figure. In this situation, ***em*** shifts the reference plane an equal distance for all transmission lines on the given box wall. All coupling between the transmission lines is accounted for and removed.

NOTE: **When shifting a reference plane for coupled lines, *em* assumes the following:**

a) all coupled lines are either horizontal or vertical
b) the width of each coupled line is constant
c) the spacing between coupled lines is constant.



De-embedding shifts the reference plane an equal distance for all N-coupled transmission lines on a given box wall. The coupling between transmission lines is removed by the de-embedding process.

De-embedding Results

The listing below shows the de-embedded results obtained earlier in the chapter from the analysis of the example filter circuit (see page 99). This example illustrates the format of the de-embedded data is output in the analysis monitor and saved as part of your project. If you wish to also have a separate file containing your response data, you may specify that one be output from an analysis using the *Analysis* ⇒ *Output Files* command in the project editor. See “Analysis - Output Files” in the project editor’s online help for details on specifying a file.

```
Run 1:  Wed Oct 11 18:38:10 2000.  Frequency Sweep.

Frequency:  10 GHz
De-embedded 50-Ohm S-Params. Mag/Ang. Touchstone Format. (S11 S21 S12 S22).
10.0000000 1.000000 -72.59 6.414e-4 17.050 6.414e-4 17.050 1.000000 -73.31
!< P1 F=10.0 Eeff=(6.45562325 0.0) Z0=(51.7880826 0.0) R=0.0 C=0.04163932
!< P2 F=10.0 Eeff=(6.47619184 0.0) Z0=(51.8822385 0.0) R=0.0 C=0.04165009

Analysis successfully completed.
```

Example showing format of results obtained when de-embedding is enabled in *em*.

You should notice the following about the results in above:

- The line which starts with “De-embedded” is a comment line which describes the analysis results on the line below. In this example, the results are de-embedded 50 ohm S-parameters in Touchstone magnitude/angle format.
- The second line gives the analysis results.
- The remaining two lines give de-embedding information for each port in the circuit. The various fields are defined as follows:

P#:	Port number.
F:	Frequency in units defined earlier in the results file.
Eeff:	Effective dielectric constant of the transmission line connected to the port.
Z0:	TEM equivalent characteristic impedance of the transmission line, in ohms.
R:	Equivalent series resistance of port discontinuity, in ohms.
C:	Equivalent series capacitance of port discontinuity, in pF.

De-embedding Error Codes

Please see “De-embedding Error Codes” in online help for explanations of the error code messages. To access online help, select *Help* ⇒ *Contents* from any Sonnet application.

Chapter 8 De-embedding Guidelines

The previous chapter describes the basics of de-embedding: what it is, how it is enabled, and what it does when enabled. This chapter presents guidelines for obtaining good de-embedded results.

Calibration Standards

In order to determine the port discontinuity as described on page 100, Sonnet must electromagnetically analyze several calibration standards which include the same port discontinuity as the primary circuit. For a single box-wall port, the calibration standards are two through lines which have the same geometry (width, dielectrics, distance to box wall, etc.) as the polygon which has the port attached to it. Sonnet then builds and analyzes two through lines based on this geometry. If there is more than one port on a box wall, then the calibration standard is a multiple-coupled line.

The lengths of these two through lines can determine the accuracy of the de-embedding (see below for a discussion of the problems which can occur with improper lengths). By default, Sonnet chooses calibration lengths for you. If the port contains a reference plane, then the first calibration length is the same length as the reference plane and the second length is double the first. If no reference plane exists, Sonnet chooses one for you.

If you are having trouble with de-embedding, you may want to change this calibration length using the following sections as a guide. If you are using reference planes, you can simply change your reference plane length, and the calibration lengths will change accordingly. If you are not using reference planes, then you can set the calibration length using *Circuit ⇒ Ref. Plane/ Cal Length*. This allows you to set the first calibration length. The second is always twice as long as the first.

Defining Reference Planes

Sonnet places very few restrictions on the reference planes which may be defined for a given circuit. This is done intentionally so as to provide maximum flexibility for all users.

However, there are some basic guidelines concerning reference planes that should almost always be followed. These guidelines are discussed below.

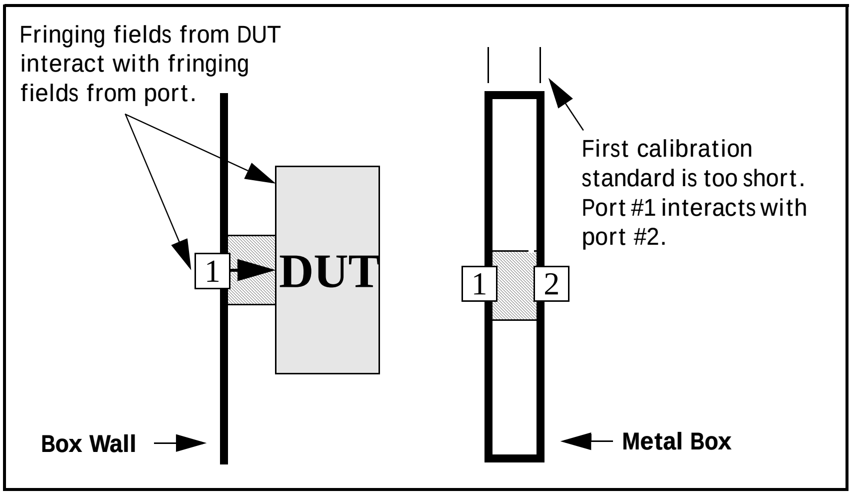
De-embedding Without Reference Planes

De-embedding does not require reference planes. Reference planes are optional for all box-wall, co-calibrated, and auto-grounded ports. If you do not specify a reference plane for a particular port in the project editor, ***em*** will assume a zero-length reference plane for that port. This means that de-embedding will remove the discontinuity associated with that particular port, but will not shift the reference plane for it.

As discussed in the next section, ***em*** may generate bad de-embedded results if you attempt to remove a very short (but greater than zero) reference plane. However, if you de-embed without a reference plane, ***em*** will not attempt to remove any length of transmission line at all. As a result, de-embedding without a reference plane does not lead to any error. Therefore, we recommend that you de-embed without reference planes rather than specify very short, non-zero, reference plane lengths.

Reference Plane Length Minimums

If the reference plane or calibration standard is very short relative to the substrate thickness or the width of the transmission line, ***em*** may generate poor de-embedded results. This is due to one or both of the following reasons which are illustrated below:


Fringing fields from DUT interact with fringing fields from port.
1
DUT
1
2
First calibration standard is too short. Port #1 interacts with port #2.
Box Wall
Metal Box

Poor de-embedding results may be obtained when very short (but non-zero) reference plane lengths are used.

- **The port is too close to the device under test (DUT).** There are fringing fields associated with the port and separate fringing fields associated with the DUT. If the port and DUT are too close, the fringing fields interact. The de-embedding algorithm (which is virtually identical to algorithms used in de-embedding measured data) is based on circuit theory and cannot handle fringing field interaction. See reference [66] in Appendix II, “Sonnet References,” for a detailed description of the problem.

- **The first calibration standard is too short.** In this situation, the discontinuity associated with port #1 interacts with the discontinuity associated with port #2. As a result, the first calibration standard does not “behave” like a transmission line and its S-parameters are invalid.

There is no precise rule as to how long a reference plane or calibration standard must be made in order to prevent the above effects from corrupting the de-embedded results. The required reference plane or calibration standard length is dependent upon the circuit geometry and the nature of the analysis. However, we recommend that you use reference plane or calibration standard lengths equal to or greater than one substrate thickness. This is sufficient for most types of analysis.

Reference Plane Lengths at Multiples of a Half-Wavelength

E_{eff} and Z_0 cannot be calculated when the length of the reference plane or calibration standard is an integral multiple of a half wavelength. For example, at an extremely low frequency the electrical length of the reference plane or calibration standard may be a fraction of a degree (i.e., zero half-wavelengths). In this case, the analysis is unable to accurately evaluate the electrical length and, especially, the characteristic impedance.

At some point as the length of the reference plane or calibration standard approaches a multiple of a half-wavelength, ***em*** is able to determine that the calculated values of E_{eff} and Z_0 are becoming corrupt. When this occurs, ***em*** outputs the error message "undefined: nl" in place of the E_{eff} and Z_0 values (see "De-embedding Error Codes" in online help). Note, however, that while ***em*** is unable to determine E_{eff} and Z_0, the de-embedded S-parameter results are still perfectly valid.

Reference Plane Lengths Greater than One Wavelength

If the length of the reference plane or calibration standard is more than one wavelength, incorrect E_{eff} results might be seen. However, the S-parameters are still completely valid.

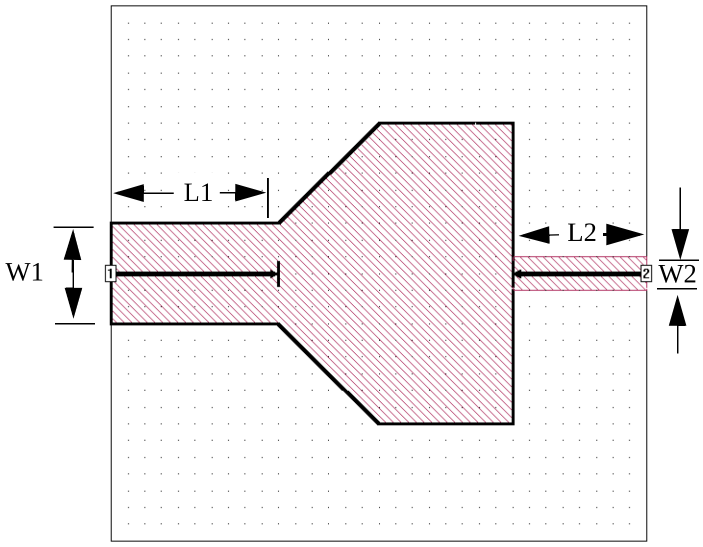
Em's calculation of E_{eff} is based on phase length. If the reference plane or calibration standard is, say, 365 degrees long, ***em*** first calculates E_{eff} based on a phase length of 5 degrees. However, ***em*** has some "smarts" built in. If a non-physical result is seen, ***em*** increases the calculated phase length by 360 degrees at a time until physical (i.e., $E_{eff} \geq 1.0$) results are obtained. This usually corrects the problem.

Thus, it takes a particularly long reference plane or calibration standard before the E_{eff} calculation fails. When it does fail, it suddenly jumps down to a value just above 1.0. Z_0 and the de-embedded S-parameter data still have full validity. This failure mode is rarely seen.

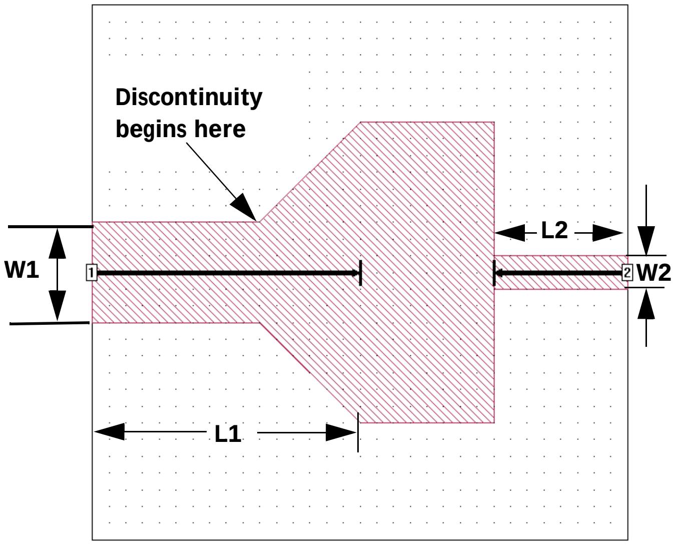
Non-Physical S-Parameters

Generally, reference planes should not be set in the project editor such that they extend beyond a discontinuity in the circuit. Doing so may result in non-physical S-parameters.

To illustrate this problem, consider the circuit shown below. In this circuit, the reference planes do not extend beyond any discontinuities. When de-embedding is enabled, the port #1 discontinuity is removed along with a transmission line of width W1 and length L1. Similarly, the port #2 discontinuity is removed along with a transmission line of width W2 and length L2. The de-embedded result is a set of 2-port S-parameters for the block in the middle of the circuit.



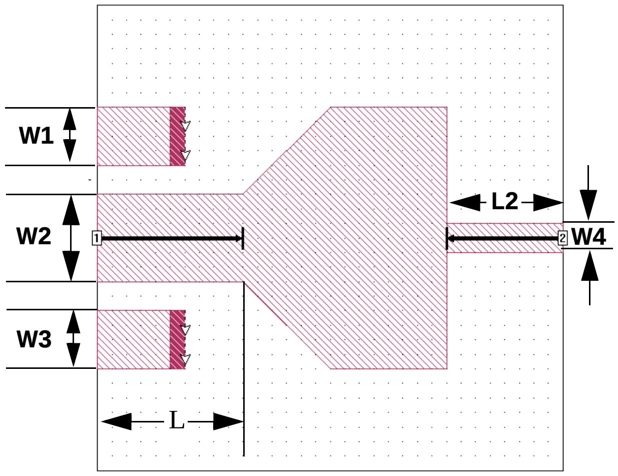
Now, consider the figure on page 112. This circuit is identical to the circuit shown above except that the length of the reference plane originating on the left box wall has been increased. If ***em*** is run with de-embedding enabled on this circuit, it "removes” a length of transmission line equal to the specified reference plane length. This occurs even though the actual port transmission line is shorter than the reference plane length. As a result, the de-embedded S-parameters are non-physical.



Example circuit for which non-physical S-parameters will be obtained when *em* is run with de-embedding enabled.

A second de-embedding example leading to non-physical S-parameter results is shown in the next figure. In this example, the circuit has two via pads on each side of the port transmission line. The via pads are grounded to the box wall.

When ***em*** is run with de-embedding enabled on this circuit, it “removes” three coupled transmission lines with a length equal to the reference plane length. Since the reference plane extends from the box wall beyond the vias, the de-embedded S-parameters are again non-physical.



Box Resonances

Because ***em***’s de-embedding algorithm is based on circuit theory, it is unable to de-embed a structure contained inside a resonant cavity; a limit it shares with all de-embedding algorithms. Thus, whenever you wish to de-embed a circuit with box resonances, you must take the necessary steps to remove those box resonances. (See Chapter 23 for a detailed description on identifying and removing box resonances.) Note that if you do de-embed a circuit with box resonances, ***em*** may generate a “bd” de-embedding error code: see section “De-embedding error codes” in online help. This error code indicates that ***em*** has detected bad values for E_{eff} and Z_0.

Higher Order Transmission Line Modes

De-embedding removes the port discontinuity and the connecting length of transmission line. The de-embedding assumes that there is only one mode propagating on the connecting transmission line, usually the fundamental quasi-TEM mode. If higher order modes are propagating, the de-embedded results are not valid. (The same is true for actual, physical, measurements.) If this is the case, we strongly recommend using a thinner substrate, unless, for some reason, multi-mode operation is desired.

Even when higher order microstrip modes are evanescent, there can still be problems. If the port is so close to the discontinuity of interest that their fringing (evanescent) fields interact, the de-embedding looses validity. Again, this is a problem which also arises in an actual physical measurement if the device to be de-embedded is too close to the fixture connector.

Chapter 9 Adaptive Band Synthesis (ABS)

The Adaptive Band Synthesis (ABS) technique provides a fine resolution response for a frequency band requiring only a small number of analysis points. ***Em*** performs a full analysis at a few points and uses the resulting internal, or cache, data to synthesize a fine resolution band.

TIP

This technique, in most cases, provides a considerable reduction in processing time.

Using the input frequency band, ***em*** first performs a full analysis of the circuit at the beginning and end frequencies. ***Em*** continues solving at discrete points, storing the full analysis data for each point. This process continues until enough internal, or cache, data is generated to synthesize a fine resolution response.

Once the frequency band response is synthesized, ***em*** outputs approximately 300 data points for the frequency band. These data points are a combination of the discrete analysis points and synthesized points. This combined data is referred to as adaptive data.

Em dedicates the bulk of the analysis time for an ABS analysis in calculating the response data at the discrete data points. Once the adaptive band synthesis is complete, calculating the adaptive data for the entire band uses a relatively small percentage of the processing time.

ABS Resolution

The ABS resolution is the value in frequency units between adaptive data points in your response output from an adaptive sweep. Normally, the resolution in an adaptive sweep is provided by ***em*** such that around 300 data points are output for a frequency band. It is possible for you to override this setting and use a coarser or finer resolution for your frequency band.

Entering a manual value to be used for ABS is done in the Advanced Options dialog box which is opened when you click on the Advanced button in the Analysis Setup dialog box. The Analysis Setup dialog box is opened when you select *Analysis ⇒ Setup* from the project editor menu. You enter the resolution by clicking on the Manual radio button in the ABS Resolution section of the Advanced Options dialog box and entering the desired resolution in the adjacent text entry box. For details on these dialog boxes, please refer to online help for the project editor.

There are several things to be aware of when using the manual setting for the ABS resolution. Coarse resolution does not speed things up. Once a rational polynomial is found to "fit" the solution, calculating the adaptive data uses very little processing time. A really coarse resolution could produce bad results by not allowing the ABS algorithm to analyze at the needed discrete frequencies. Fine resolution does not slow down the analysis unless the number of frequency points in the band is above approximately 1000 - 3000 points. A step size resulting in at least 50 points and less than 2000 points is recommended.

Q-Factor Accuracy

There is a Q-Factor analysis run option available in the Advanced Options dialog box in the project editor (Select *Analysis ⇒ Setup*, then click on the Advanced button in the Analysis Setup dialog box). Selecting this option forces a higher accuracy for ABS convergence by including the Q-factor of your analysis as a criterion for convergence. This is done to insure high accuracy in the Q-Factor result when ABS is used. The Q-Factor is defined as follows:

$$\left|(\mathrm{imag}\,Y_{nn})/(\mathrm{real}\,Y_{nn})\right|$$

The result is higher accuracy from the ABS sweep, but. this accuracy comes at the cost of requiring more discrete frequencies to be analyzed before conversion is reached.

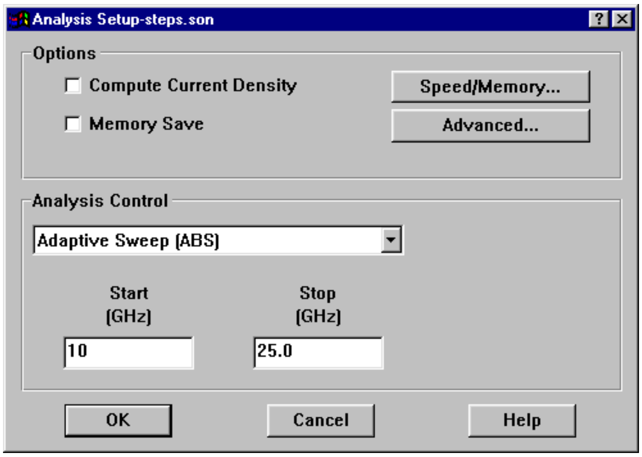
Running an Adaptive Sweep

To run an analysis using the Adaptive Band Synthesis technique, you do the following:

1 **Open your project in the project editor.**

2 **Select Analysis ⇒ Setup from the main menu of the project editor.**

The Analysis Setup dialog box appears on your display with an adaptive sweep already selected since Adaptive Sweep is the default for analysis control.



Analysis Setup-steps.son

Options
- ☐ Compute Current Density
- ☐ Memory Save

Analysis Control: Adaptive Sweep (ABS)

Start (GHz): 10
Stop (GHz): 25.0

3 **Select Adaptive Sweep (ABS) from the Analysis Control drop list if necessary.**

This selects the ABS technique for the analysis.

4 **Enter the desired frequency band in the Start and Stop text entry boxes.**

This defines the frequency band on which you wish to perform the ABS analysis. The step size is automatically set by ***em*** during the analysis. See page 116 for a description of how the ABS resolution is determined.

5 **Click on the OK button to close the dialog box and apply the changes.**

6 **Save the project by selecting *File ⇒ Save* from the menu or by clicking on the Save button on the tool bar.**

You need to save the file before analyzing it.

7 **Select *Project ⇒ Analyze* from the menu or click on the Analyze button on the tool bar.**

Em performs an adaptive sweep on your project. The analysis monitor appears on your display, and indicates the progress of the adaptive sweep.

The Adaptive Sweep is also available within the Frequency Sweep Combinations analysis controls. This allows you to mix adaptive sweeps with other types of sweeps. For more details, see the "Frequency Sweep Combinations" topic in on-line help in the project editor.

ABS Caching Level

There are three levels of ABS caching available: None, Stop/Restart, and Multi-Sweep plus Stop/Restart. The options for ABS caching level are found in the Advanced Options dialog box. To access the Advanced Options dialog box, select *Analysis ⇒ Setup* from the project editor main menu, then click on the Advanced button in the Analysis Setup dialog box which appears. The default is Stop/Restart.

Stop/Restart retains the cache data while the analysis is proceeding. Once the adaptive data has been calculated, the cache data is deleted from the project. This setting provides for the circumstance in which the analysis is stopped or interrupted before the adaptive data is synthesized; you will not lose the internal data produced so far.

Multi-Sweep with Stop/Restart retains all calculated cache data in your project for every analysis job run. In addition, cache data is calculated and saved for even non-ABS types of sweeps. This option can reduce processing time on subsequent ABS analyses of your project but increases project size on non-ABS sweeps. In order for the cache data to remain useful there are also subsectioning issues of which you must be aware. For a detailed discussion of the Multi-Sweep cache option, please refer to “Multiple ABS Sweeps and Subsectioning,” page 119.

The third setting for ABS caching level is None. In this setting cache data is not retained. This option should only be selected if you have constraints on disk space.

WARNING

If you select None for the ABS caching level, and an ABS sweep is stopped before the adaptive data has been calculated, you will have to start the analysis over from the beginning. Any processing time invested in the analysis is lost.

Multiple ABS Sweeps and Subsectioning

If you will need to run multiple ABS sweeps on a project, it is important to set your ABS caching to Multi-sweep to avoid having to re-calculate your caching data each time you analyze your circuit. But be aware that in order to maintain the validity of the caching data, the subsectioning of the circuit must remain the same. To control the subsectioning you must use the Advanced Subsectioning Controls which you open by selecting *Analysis ⇒ Advanced Subsectioning* from the main menu of the project editor.

TIP

The most efficient way to obtain response data for your circuit is to run a single ABS sweep over the entire desired frequency band.

The analysis engine, ***em***, uses the subsectioning frequency to calculate the wavelength which is used in setting the Maximum subsection size. The default setting used to determine the subsectioning frequency is to use the highest frequency from the present analysis job. If you perform multiple sweeps over different frequency bands then the cache data from one run will be invalid for the next, since the subsectioning frequency would be different. In order to avoid this you should select the **Previous Analysis Only** option which will use the highest frequency from all previous analysis jobs run on the project. In this case, you should analyze the frequency band with the highest upper limit first and take care to ensure that the subsectioning frequency being used provides accurate subsectioning for your circuit. For details on subsectioning, see Chapter 3 "Subsectioning" on page 31.

Another way to keep the subsectioning frequency consistent is to select the Use Fixed Frequency option for the subsectioning frequency and enter the desired frequency. This ensures that all analysis runs on the project will use the same subsectioning frequency. Again, care should be taken that the subsectioning frequency entered provides the desired accuracy.

Multi-Sweep Caching Scenarios

The analysis engine always attempts to use any existing data in the project which is consistent with the present analysis. Described below are some common scenarios describing ABS analyses when the ABS caching level is set to Multi-Sweep with Stop/Restart and how data consistency is maintained.

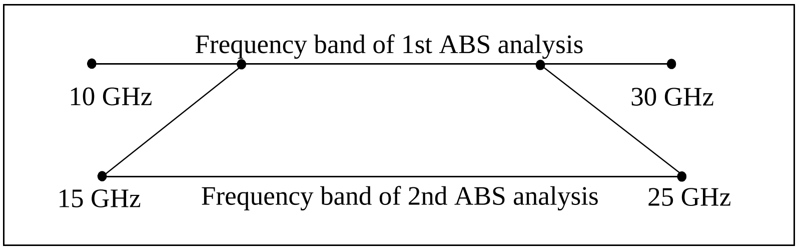
Higher or Lower Resolution over the Same Frequency Band: You are running an ABS analysis over the same band as a previous ABS analysis but with higher or lower resolution; an example is shown below. In order for the caching data to be valid for the second analysis, your Advanced Subsectioning controls must be set such that the subsectioning frequency is the same for both runs. If the subsectioning frequency remains the same, the second analysis will usually not require any re-analysis and the results should be provided very quickly. The only exception would be if the difference between the resolutions is unusually high.

Frequency Band 10 - 40 GHz

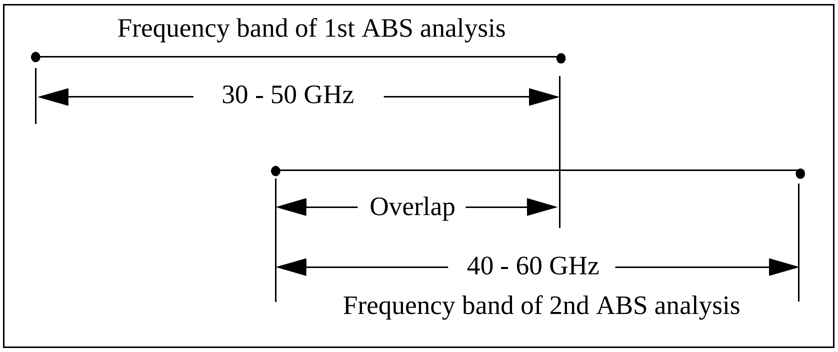
1st ABS analysis: 10, 10.1, 10.2, 10. 3 ... 39.8, 39.9, 40

2nd ABS analysis: 10, 10.05, 10.1, 10.15, 10.2 ... 39.85, 39.9, 39.95, 40

Zoom In: You are running an ABS analysis over a narrower band than the previous ABS analysis of the project, as shown in the diagram below. This provides higher resolution over the narrower band since the ABS analysis defaults to approximately 300 data points. In order for the caching data to be valid for the second analysis, your Advanced Subsectioning controls must be set such that the subsectioning frequency is the same for both runs. If the subsectioning frequency remains the same, the second analysis will not require any re-analysis and the results should be provided very quickly.


Frequency band of 1st ABS analysis
10 GHz
30 GHz
15 GHz
Frequency band of 2nd ABS analysis
25 GHz

Extending the Band: You are running an ABS analysis which overlaps a previous ABS analysis of the project, pictured in the diagram below. The caching data for the overlap between the two analyses will be reused although some calculation may need to be done in the extension of the frequency band where it does not overlap with a previous analysis. In order for the caching data to be valid for the second analysis, your Advanced Subsectioning controls must be set such that the subsectioning frequency is the same for both runs.


Frequency band of 1st ABS analysis
30 - 50 GHz
Overlap
40 - 60 GHz
Frequency band of 2nd ABS analysis

Accuracy Assurance: If you wish to check a particular data point in an ABS analysis and wish to ensure that a full calculation is done at a particular frequency point, you should select a Linear Sweep. This analysis will calculate caching data if Multi-sweep is selected for ABS caching data, but will not use the caching data in producing analysis results.

Find Minimum and Find Maximum

Find Minimum determines the frequency where the circuit response reaches a minimum. Find Maximum determines the frequency where the circuit response reaches a maximum. You enter a starting and ending frequency in the Start and Stop text entry boxes, respectively and select the parameter for which you wish to determine the minimum or maximum value. ***Em*** performs an ABS analysis for the frequency band, then uses the adaptive data to determine the frequency where the response reaches a minimum or a maximum.

The Find Minimum and Find Maximum commands are both available in the Frequency Sweep Combinations analysis controls. For more details, see the “Frequency Sweep Combinations” topic in online help in the project editor.

Parameter Sweep

You may choose either a linear sweep or an adaptive sweep for a parameter sweep. Selecting an adaptive sweep for a parameter sweep is done in the Parameter Sweep Entry dialog box. For more information about parameter sweeps, please see “Parameter Sweep,” page 136.

The following example assumes that you have already defined the parameter “Width” in your circuit. For more information on inputting a parameter, please refer to “Parameters,” page 130.

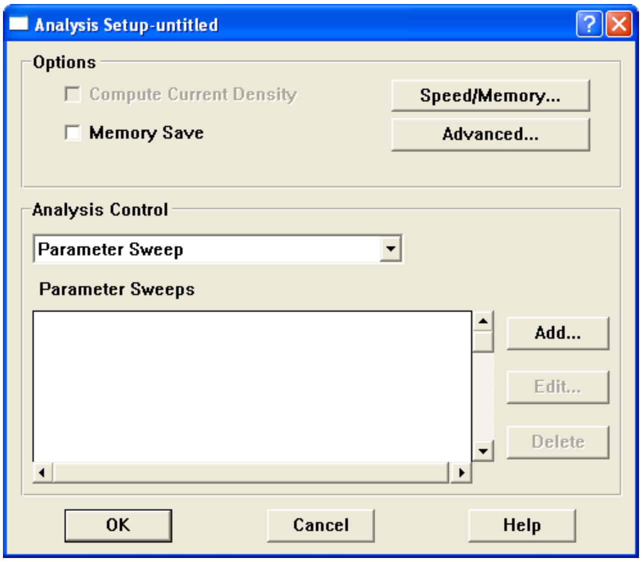
To select ABS for a parameter sweep, do the following:

1 **Select Analysis ⇒ Setup from the project editor main menu.**

The Analysis Setup dialog box appears on your display.

2 **Select Parameter Sweep from the Analysis Control drop list.**

The dialog box is updated to allow you to specify the parameter sweep.



Analysis Setup-untitled

Options

Compute Current Density

Memory Save

Speed/Memory...

Advanced...

Analysis Control

Parameter Sweep

Parameter Sweeps

Add...

Edit...

Delete

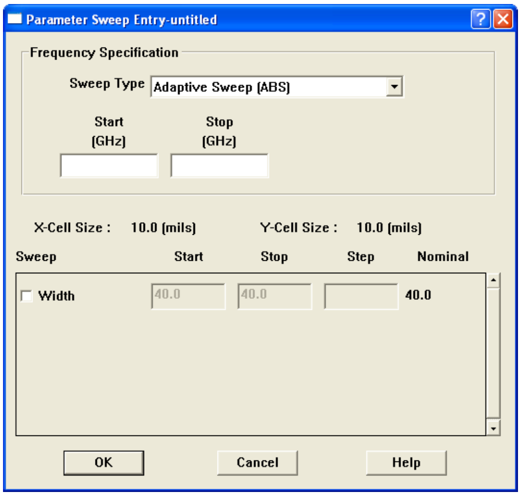
OK

Cancel

Help

3 **Click on the Add button to the right of the Parameter Sweep list box.**

The Parameter Sweep Entry dialog box appears on your display. The default frequency specification is a linear sweep.



Parameter Sweep Entry-untitled

Frequency Specification

Sweep Type Adaptive Sweep (ABS)

Start (GHz)

Stop (GHz)

X-Cell Size : 10.0 (mils) Y-Cell Size : 10.0 (mils)

Sweep	Start	Stop	Step	Nominal
Width	40.0	40.0		40.0

OK

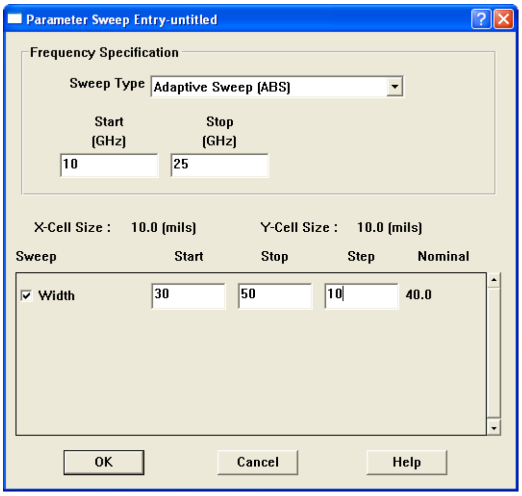
Cancel

Help

4 **Select Adaptive Sweep (ABS) from the Sweep Type droplist to select an adaptive frequency sweep.**

The dialog box changes so that there are only Start and Stop text entry boxes.

5 **Enter the frequency band for the ABS in the Start and Stop text entry boxes.**


Parameter Sweep Entry-untitled

Frequency Specification

Sweep Type: Adaptive Sweep (ABS)

Start (GHz): 10   Stop (GHz): 25

X-Cell Size : 10.0 (mils)   Y-Cell Size : 10.0 (mils)

Sweep	Start	Stop	Step	Nominal
☑ Width	30	50	10	40.0

This completes setting up an ABS frequency sweep for the parameter sweep. You would also need to select the parameters which you want to use in the parameter sweep and enter their data ranges before closing this dialog box.

Analysis Issues

There are several issues you should be aware of before using the ABS technique; these are covered below.

Multiple Box Resonances

You should be aware that circuits with multiple box resonances make it difficult for an ABS analysis to converge. The frequency band for an adaptive sweep should not contain multiple box resonances. If multiple box resonances are present the number of discrete full analysis points goes up dramatically and synthesis of the data becomes very difficult. If you do not know how to identify box resonances, see Chapter 23, "Package Resonances" for a detailed discussion of box resonances.

De-embedding

Adaptive data, resulting from an ABS analysis, is either de-embedded or non-de-embedded. With other analysis types, when the de-embedding option is enabled (default), then both de-embedded and non-de-embedded response data is calculated and available for display and output. This is not true for an adaptive sweep.

In an adaptive sweep, if you run with de-embedding enabled, de-embedded data is available for the whole band. Non-de-embedded data is available only for the discrete data points at which full analyses were performed while synthesizing the response.

If you wish to have non-de-embedded data for the whole frequency band, you must perform an adaptive sweep with the de-embed option disabled. Select *Analysis ⇒ Setup* from the main menu to open the Analysis Setup dialog box, then click on the Advanced button to open the Advanced Options dialog box. Click on the De-embed checkbox to disable de-embedding. For details on these dialog boxes, please refer to online help for the project editor.

For more information about de-embedding, see Chapter 7 "De-embedding" on page 97 and Chapter 8 "De-embedding Guidelines" on page 107.

Transmission Line Parameters

As part of the de-embedding process, ***em*** also calculates the transmission line parameters, Z_0 and E_{eff}. You should be aware that when running an ABS analysis these parameters are only calculated for the discrete data points at which a full analysis is run. If you need the transmission line parameters at more data points, analyze the circuit using a non-ABS analysis.

Current Density Data

Current density data is calculated for your circuit when the Compute Current Density option is enabled in the Analysis Setup dialog box. For non-ABS sweeps, current density data is calculated for all the response data. For an adaptive sweep, the current density data is only calculated for the discrete data points, therefore, your plot in the current density viewer shows a coarse resolution of your frequency band.

If you wish to calculate the current density data at more points in your band, run a non-ABS sweep for the points in question with the Compute Current Density option enabled.

For more information about the Compute Current Density option, see the help topic "Analysis ⇒ Setup" in online help for the project editor.

Ripple in ABS S-Parameters

Please note that when the value of the S-parameters is close to 1 (0 dB) over the entire band you may have small ripples or oscillations in the S-parameter values. This is due to the rational fitting model having too many degrees of freedom when trying to fit a straight line. If this is a problem, it is recommended that you analyze the frequency band in which this occurs with another type of sweep.

Output Files

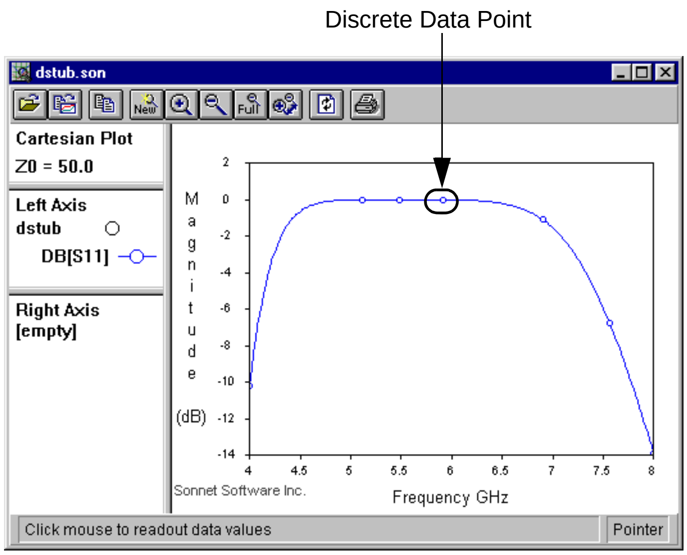
You specify additional output files in the Output Files dialog box which appears on your display when you select *Analysis ⇒ Output Files* from the project editor menu. You click on the appropriate button to open the corresponding file entry dialog box. Each entry dialog box has an option pertinent to ABS.

Response File

When you specify an optional output file for your project, you may select which type of data to output from an adaptive sweep. The data selection is controlled by the Include Adaptive Data checkbox in the File Entry dialog box. If this checkbox is selected, which is the default, then all the adaptive data from an ABS analysis is included in the output file. If this checkbox is cleared, then only the data for the discrete data points is included in the output file. We recommend leaving this box checked.

Viewing the Adaptive Response

When viewing an adaptive response (ABS) in the response viewer there are several things of which you need to be aware. The adaptive data is plotted as a line. A symbol indicating a data point only appears at the discrete frequencies at which a full analysis was executed as shown in the picture below.



When exporting data, you may choose to output only the discrete frequencies or the complete response data for the ABS analysis. To output only the discrete frequency data, unselect the Include Adaptive Data checkbox in the Export Data dialog box in the response viewer. For details, see online help in the response viewer.

Chapter 10 Parameterization and Optimization of a Geometry Project

It is often necessary to perform several iterations of a circuit design in order to meet specifications. Part of those iterations involves changing the dimensions or attributes of some part of your circuit. Parameterization and optimization can be used to make this task more efficient. Rather than create multiple circuits each with different lengths of key components, you may select dimensions of your circuit and define them as a parameter. In the analysis, you automatically vary the value of the parameter rather than setting up a separate circuit file for each value. Parameterizing your circuit also provides you with a way to quickly and easily change dimensions in the project editor.

For a tutorial which details how to add parameters to your circuit and perform an optimization, please refer to **Chapter 11, “Parameter Sweep and Optimization Tutorial”** on page 143.

The analysis engine, ***em***, adjusts the value of a parameter in one of two ways. The first is a parameter sweep in which ***em*** sweeps the parameter values through a user defined range. The second method is optimization in which the analysis engine controls the parameter value, within a user defined range, in an attempt to reach a user defined goal. Both parameterization and optimization of a geometry may be performed over a range of analysis frequencies.

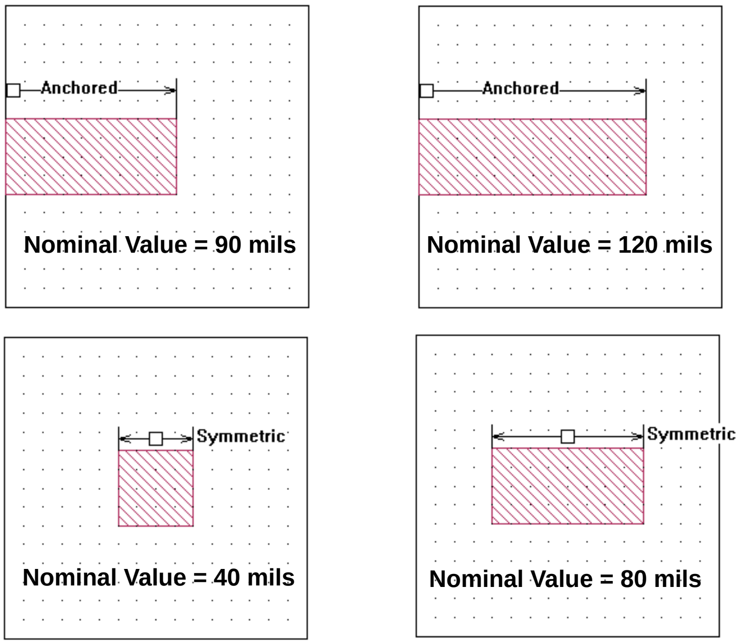
The first step in performing a parameter sweep or optimization is defining the parameters in the project editor.

Parameters

Parameters are user defined circuit attributes that allow the analysis engine to modify the circuit in order to perform parameter sweeps and optimization. Parameters also provide a quick way for the user to change dimensions in the project editor. For example, the length of a transmission line can be assigned the parameter "L." To change the length of the transmission line, you edit the value for "L."

In order to set up parameters, you must first input your circuit in the project editor. You select dimensions and define them as parameters, which allows you to vary those dimensions within an analysis. The initial value of the parameter is the length that appears in your circuit. This is the nominal value of the parameter. If you change the nominal value then the circuit is redrawn with that length.

There are two types of parameters: anchored and symmetric. An anchored parameter allows you to fix one end of a parameter then vary its length extending from that point. A symmetric parameter allows you to fix the center point of a parameter and vary the distance it extends on each side. The two parameter types are described in detail in the following sections.



Anchored Parameters

An anchored parameter is one which extends from a fixed point, the anchor, to a adjustable point set. It is comprised of three things: the anchor, the reference point and the adjustable point set. When defining your parameter, you perform the following steps:

- You select the anchor first. This is the fixed starting point for the parameter.
- You select the reference point. The reference is the first point in the adjustable point set. The distance from the anchor point to the reference point is the value of the parameter. When the value of the parameter is changed, the anchor retains the same position, but the reference point moves to a new position.
- Third, you select any additional points in your circuit you wish to move when the reference point moves. As the value of the parameter is varied,

the reference point, as well as the rest of the adjustable point set, is moved accordingly.

Note that the parameter is always defined as the distance between the anchor and the reference point in either the X direction or the Y direction, never as a diagonal distance between them.

Two examples of anchored parameters, each at two different nominal values, are illustrated below.

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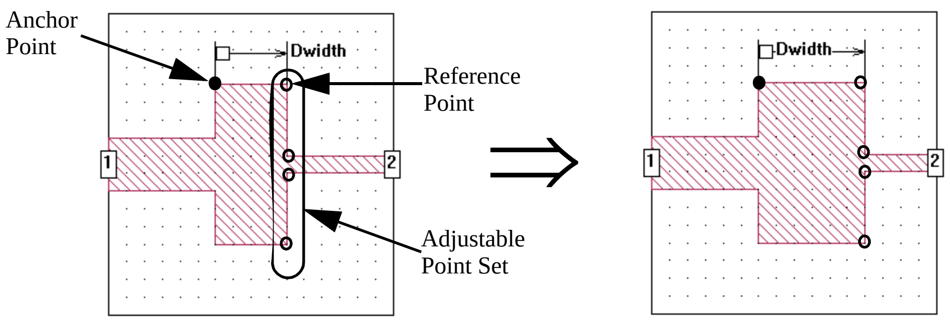
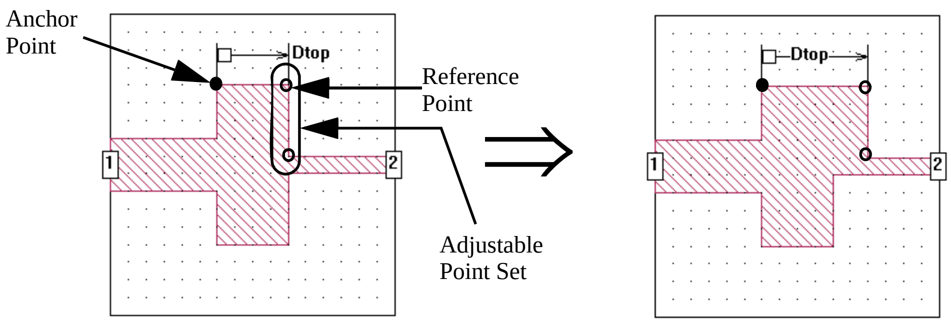


Dwidth, nominal value = 40 mils **Dwidth, nominal value = 60 mils**

Notice that although the top and bottom examples have identical anchor and reference points and starting and ending nominal values, that the resulting polygon on the top differs from that on the bottom due to a different adjustable point set (the point set is highlighted by the oval).



Dtop, nominal value = 40 mils **Dtop, nominal value = 60 mils**

Symmetrical Parameters

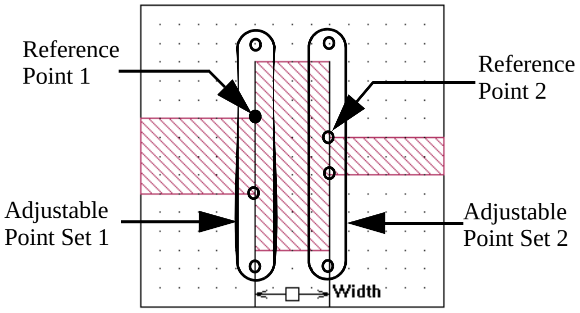
A symmetric parameter is one which extends from a fixed middle point to two reference points and their respective adjustable point sets. It is comprised of four things: the first reference point, the first reference point's adjustable point set, the second reference point and the second reference point's adjustable point set. The fixed middle point is defined as the midpoint between the two reference points when the parameter is defined; the user does not define an anchor point for a symmetric parameter. When defining your parameter, you perform the following steps:

- Select the first reference point.
- Select the adjustable point set that moves with the first reference point.
- Select the second reference point. The value of the parameter is the distance between the two reference points.
- Select the adjustable point set that moves with the second reference point.

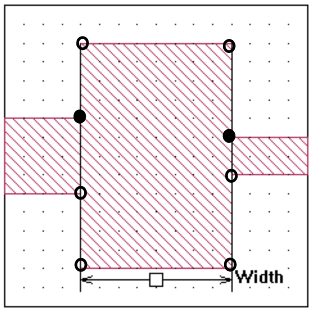
When the value is changed, each point set moves one half the distance of the difference between the present value and the previous value out from the middle point.

Note that the parameter is always defined as the distance between the reference points in either the X direction or the Y direction, never as a diagonal distance between them.

Two examples of symmetric parameters, each at two different nominal values, are illustrated below.

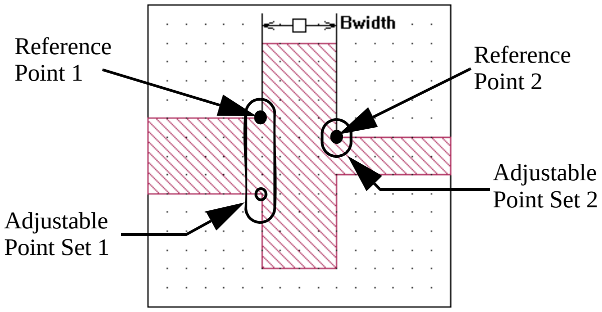


Width, nominal value = 40 mils

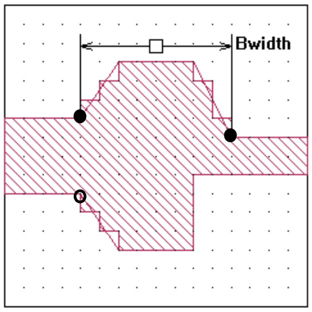


Width, nominal value = 80 mils

Notice that although the top and bottom examples have identical reference points and starting and ending nominal values, that the resulting polygon on the top differs from that on the bottom due to a different adjustable point set (the point set is highlighted by the oval).



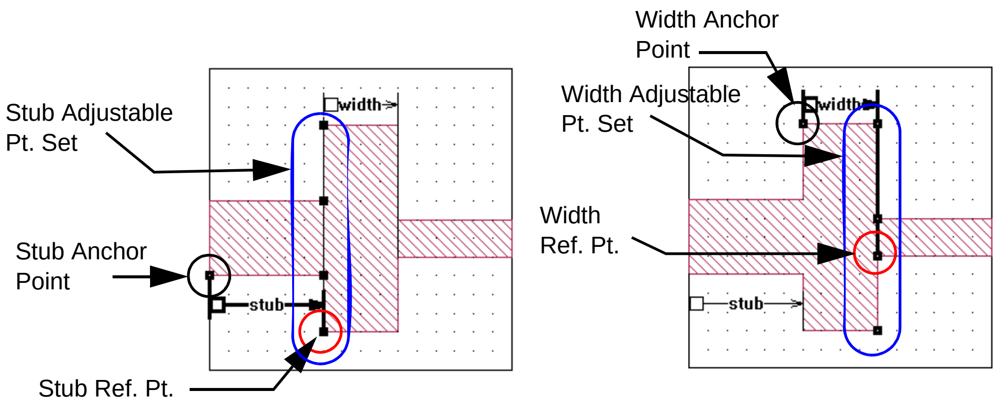
Bwidth, nominal value = 40 mils



Bwidth, nominal value = 80 mils

Dependent Parameters

One parameter is dependent upon another if the anchor point and/or the reference point(s) for the second parameter are part of an adjustable point set for the first parameter. You need to be aware of dependent parameters so that you can take into consideration the complete impact on your circuit when the value of the primary parameter is changed. When the primary parameter is changed, a dependent parameter is adjusted, i.e., the anchor point or reference point is moved, along with the primary parameter on which they depend. A picture of a dependent parameter is shown below with the Anchor and Reference points highlighted as well as the point sets.



The parameter "width" is dependent on the parameter "stub". Note that the anchor point for the parameter "width", shown on the right, is part of the adjustable point set for the parameter "stub," shown on the left.

You may use the Select Dependents command in the project editor to determine if there are any dependent parameters. With the project open in the project editor, do the following:

1 **Right-click on a parameter in your circuit.**

The parameter name and its point set is highlighted and a pop-up menu appears on your display.

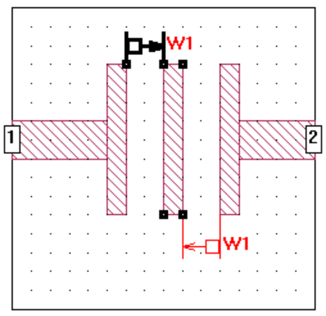
2 **Select "Select Dependents" from the pop-up menu.**

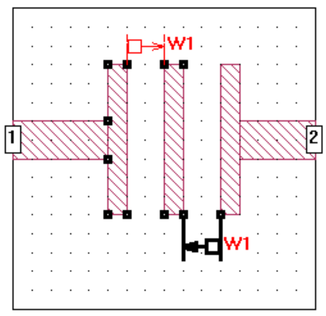
If any dependent parameters are present in your geometry, the dependent parameter is highlighted.

Circular Dependencies

Care should be taken when adding parameters to your circuit that they do not form a circular dependency. A circular dependency is formed when two parameters are dependent on each other. This can happen for two parameters or multiple parameters. In the case of multiple parameters, the dependency extends from the first parameter through all the parameters until the first parameter is dependent upon the last.

If the project editor detects a circular dependency, all the involved parameters are shown in red and their nominal values are fixed. An example of two parameters in a circular dependency is shown below.





A circular dependency is an error condition and must be corrected before you can analyze your circuit. As long as the circular dependency exists, you are not able to use a value for the parameter other than the nominal value which makes the parameter useless. You need to redefine one of the parameters such that it is no longer dependent on the other.

Reference Planes

Special care should be taken with reference planes when parameterizing your circuit. If a reference plane is linked to a point on your circuit and that point is selected as part of an adjustable point set, the reference plane changes length in response to changes in the parameter length.

Parameter Sweep

Once you have parameterized your circuit, you may use the parameters to perform a parameter sweep. A parameter sweep allows you to run through a set of analyses, with different parameter values, all in one step. This allows you to see how changes in your circuit affect the response of your circuit.

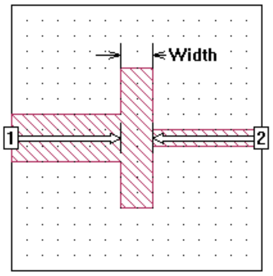
Setting up a parameter sweep consists of three parts: specifying analysis frequencies, choosing which parameters to vary and specifying data ranges for the chosen parameters.

The analysis frequencies for a parameter sweep are defined as a linear sweep consisting of a starting frequency, an ending frequency and the interval between analysis frequencies. This frequency set is used for each parameter value.

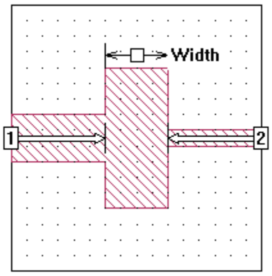
You may select one or multiple parameters when running a parameter sweep. For each parameter that you select you must specify a starting value, an ending value and the interval between parameter values.

You set up the parameter sweep in the Analysis Setup dialog box in the project editor. To access this dialog box, select *Analysis* ⇒ *Setup* from the main menu of the project editor. For details on using this dialog box, please refer to online help.

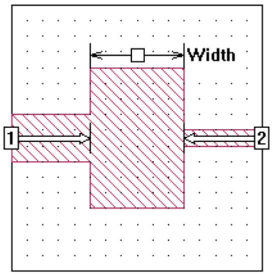
For example, the graphics below illustrate a parameter sweep of the circuit “steps” with a single parameter “Width” defined. The parameter sweep starts with a value of 20 mils for width and increases in steps of 20 until the parameter’s value is 60. ***Em*** automatically performs an analysis at each specified frequency for each circuit shown below when the parameter sweep is executed.



Width = 20 mils

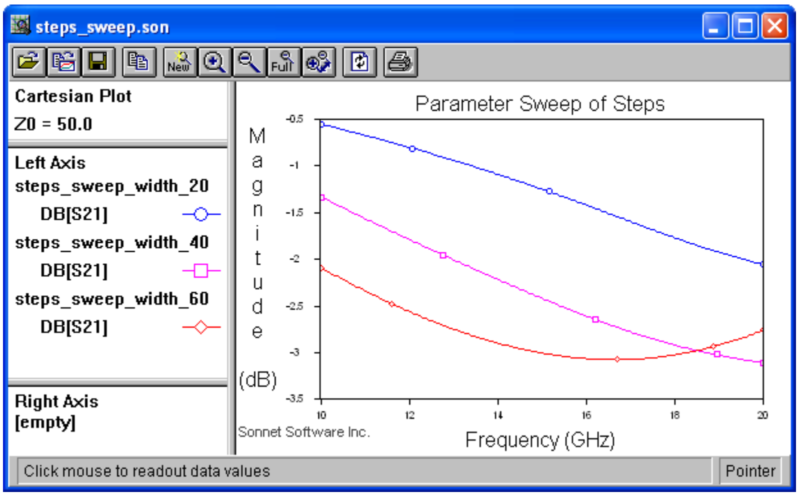


Width = 40 mils



Width = 60 mils

In the case of this sweep, an ABS analysis from 10 - 20 GHz was performed. The response data for the parameterization is shown in the graph below.



Since an analysis of the circuit at each combination of parameter values is executed for each specified analysis frequency, care should be taken when choosing data ranges. The higher the number of analysis frequencies and parameter values, the higher the number of analyses that must be computed by ***em***. The number of combinations specified is displayed in the project editor.

Optimization

You may also use parameters to perform an optimization on your circuit. An optimization allows you to specify goals - the desired response of your circuit - and the data range for the parameter(s) over which you seek the response. The software, using a conjugate gradient method, iterates through multiple parameter values, searching for the best set which meets your desired goals.

The conjugate gradient optimizer begins by analyzing the circuit at the nominal parameter values. It then perturbs each parameter individually, while holding the others fixed at their nominal values, to determine the gradient of the error function for that parameter. Once it has perturbed each parameter, it then performs a line search in the direction of decreasing error function for all parameters. After some iterations on the line search, the optimizer again calculates the gradients for all parameters by perturbing them from their present "best" values. Following this, a new line search is performed. This continues until one of three conditions are met:

1) the error goes to zero 2) the error after the present line search is no better than the error from the previous line search 3) the maximum number of iterations is reached. When one of these three conditions is met, the optimizer halts.

The equations used to determine the optimization goal error are as follows:

$$EqualOperatorError = \frac{\sum(Simulation(f) - Target(f))}{N}$$

where:
Target(f): Target value of measurement at frequency f.
Simulation(f): Simulated value of measurement at frequency f.
N: Number of frequencies in optimization goal.

$$GreaterThanOperatorError = \frac{\sum(Target(f)) - (MIN[Simulation(f), Target(f)])}{N}$$

where:
Target(f): Target value of measurement at frequency f.
Simulation(f): Simulated value of measurement at frequency f.
MIN[]: Determines minimum value of the specified arguments.
N: Number of frequencies in optimization goal.

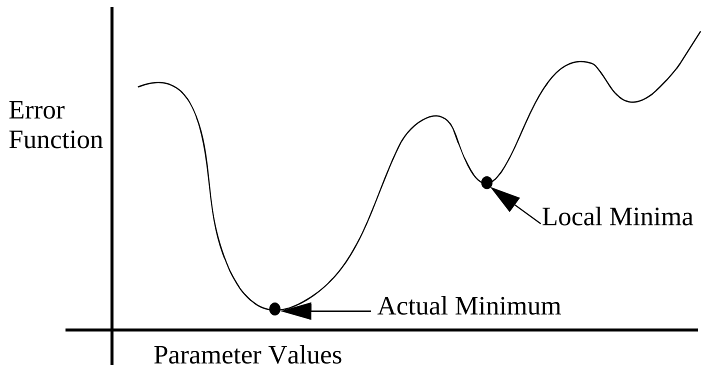
$$LessThanOperatorError = \frac{\sum(Simulation(f)) - (MIN[Simulation(f), Target(f)])}{N}$$

where:
Target(f): Target value of measurement at frequency f.
Simulation(f): Simulated value of measurement at frequency f.
MIN[]: Determines minimum value of the specified arguments.
N: Number of frequencies in optimization goal.

Setting up an optimization consists of five parts:

- Specifying optimization frequencies
- Specifying your goals
- Choosing which parameters to vary
- Specifying data ranges for the chosen parameters
- Specifying the maximum number of iterations

Care should be taken when setting the nominal values for the parameters to be optimized. The optimizer starts at the nominal values and converges to the minima which is closest to those nominal values. Thus, it is highly recommended that you perform some pre-analysis prior to doing the optimization to ensure that the nominal values are in the right value range when the optimizer is started. Otherwise, the optimizer may converge to a local minima for which the error is not the minimum achievable value, as pictured below.



You specify a goal by identifying a particular measurement and what value you desire it to be. For example $S_{11} < -20$ dB. Keep in mind that the goals you specify may not be possible to satisfy. ***Em*** finds the solution with the least error.

You may also specify a goal by equating a measurement in one network to a measurement in another network or file. For example, you may set S_{11} for network "Model" equal to S_{11} for network "Measured." Likewise, you may equate S_{11} for network "Model" to S_{11} for data file "meas.s2p."

You may select one or multiple parameters to optimize. For each parameter that you select you must specify minimum and maximum bounds. The analysis limits the parameters to values within the specified bounds.

You specify the number of iterations. For each iteration, ***em*** selects a value for each of the parameters included in the optimization, then analyzes the circuit at each frequency specified in the goals. Depending on the complexity of the circuit, the number of analysis frequencies and the number of parameter combinations, an optimization may take a significant amount of processing time. The number of iterations provides a measure of control over the process. Note that the number of iterations is a maximum. An optimization can stop after fewer iterations if the optimization goal is achieved or it finds a minima (finds no improvement in the error in further iterations).

Once the optimization is complete, the user has a choice of accepting the optimal values for the parameters resulting from the ***em*** analysis. Note that if the results of the optimization are accepted- used as the nominal values for the parameters- the actual metalization in the project editor is the closest approximation which fits the present grid settings. As a matter of fact, ***em*** analyzes “snapped” circuits and interpolates to produce responses for circuits which do not exactly fit the grid. For more information about the grid, see Chapter 3 "Subsectioning" on page 31.

Chapter 11 Parameter Sweep and Optimization Tutorial

This tutorial shows you how to set up parameters in a circuit, set up and execute a parameter sweep, set up and execute an optimization and view the results of both a parameter sweep and an optimization. For a detailed discussion of parameterization and optimization, please refer to Chapter 10.

This tutorial presumes that you are familiar with Sonnet Software, especially the project editor and the analysis monitor. If you are new to Sonnet, please review the tutorials in Chapter 4 and Chapter 5 of the **Getting Started** manual before performing this tutorial.

This examples uses the Sonnet example Par_dstub. If you do not know how to obtain a Sonnet example, select *Help ⇒ Examples* from any program menu, then click on the **Instructions** button.

TIP

If you are using the PDF manuals to read this section, click on the blue link above to take you to the Par_dstub example.

This is an example of a microstrip interdigital bandstop filter. This circuit is used to perform a parameter sweep and optimization. Most parameter sweeps and optimizations will present more of a challenge, but we have deliberately chosen a simple example to more clearly demonstrate Sonnet's methodology.

Our goal is to design the bandstop filter such that a stopband exists from 5 - 6 GHz and the passbands are from 1 - 4 GHZ and 7-10 GHz.

1 **Open Par_dstub in the project editor.**

2 **Select *File* ⇒ *Save As* from the project editor main menu.**

Since this file is a Sonnet example, it is a read only project. In order to be able to edit the circuit and save those changes, you must save a copy to your working directory.

Use the Save As browse window to save a copy of par_dstub.son to your working directory.

Setting Up Parameters

Before executing either a parameter sweep or optimization, it is first necessary to parameterize your circuit. Parameterization should be done to those dimensions you deem critical to the circuit's response and which are therefore more likely to change as the design progresses.

For this example, you will enter three parameters: two anchored parameters which are linked and one symmetric parameter.

An anchored parameter is one in which one end of the parameter is a fixed point with a point set which moves in reference to that fixed, or anchored point. A symmetric parameter is one with two reference points and two point sets which move relative to the center point between the reference points.

Parameters which appear in more than one place in a circuit but are of the same length and name are linked. Changing the value of one also changes the value of the other.

For a detailed discussion of parameters and their definitions, please refer to "Parameters" on page 130.

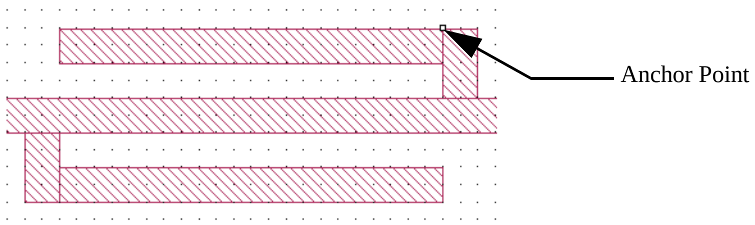
Anchored Parameters

The linked anchored parameters are input first, followed by the symmetric.

3 **Select *Tools* ⇒ *Add Parameter* ⇒ *Add Anchored* from the project editor's main menu.**

This places the project editor in Add an Anchored Parameter mode indicated by the change in cursor. Note that the message "Click Mouse to Specify the Anchor Point" appears in the status bar at the bottom of the project editor window. As you add a parameter, directions for each step appear in the status bar.

4 **To specify the Anchor point for the parameter, click the mouse on the corner of the upper stub, as shown in the picture below.**

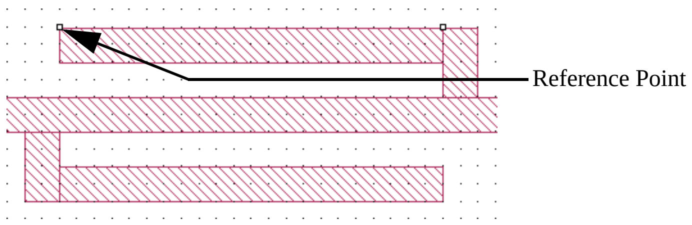


The anchor point is indicated by a small square which appears at the point you clicked. The next step is to select the reference point.

TIP

If you select the wrong point for either the anchor or reference point, press the Escape key to exit without adding a parameter. You may then start over.

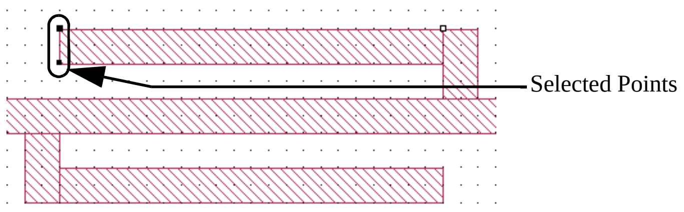
5 **Click on the top left end of the top stub to add the reference point.**



The reference point is indicated by a small square which appears at the point you clicked.

In the next step, you select the rest of the adjustable point set. Points may be selected by clicking on individual points or by lassoing a set of points with your mouse. You do not need to select the reference point since it is automatically included in the adjustable point set.

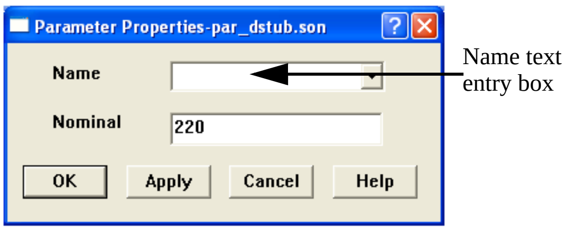
6 **Drag the mouse until both points on the end of the stub are selected.**



These points will be added to the adjustable point set. When the reference point moves in response to a change in the parameter value, these points move relative to the reference point.

7 **Once all the desired points are selected, press Enter.**

This completes the parameter creation. The Parameter Properties dialog box appears on your display.

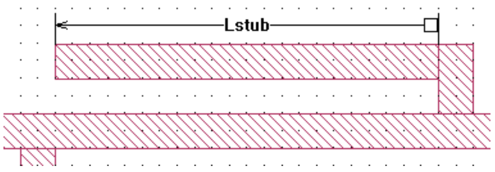


8 **Enter the name "Lstub" in the Name text entry box in the Parameter Properties dialog box and click on the OK button.**

This names the parameter. When you click on the OK button an arrow indicating the length and the name appear on your display.

9 **Move the mouse until the name is positioned above the stub. When the name is in the desired position, click on the mouse.**

The parameter should now appear as shown below.

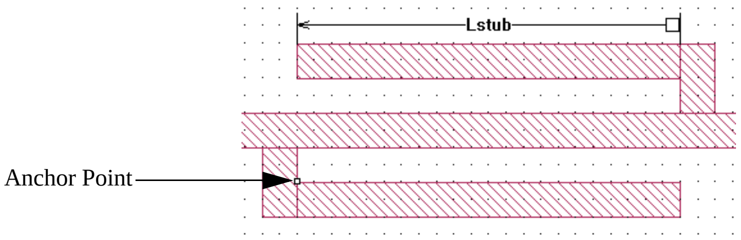


You will now enter the linked parameter. A linked parameter is another parameter identified in the circuit that has the same nominal value and name.

10 **Select *Tools* ⇒ *Add Parameter* ⇒ *Add Anchored* from the project editor's main menu.**

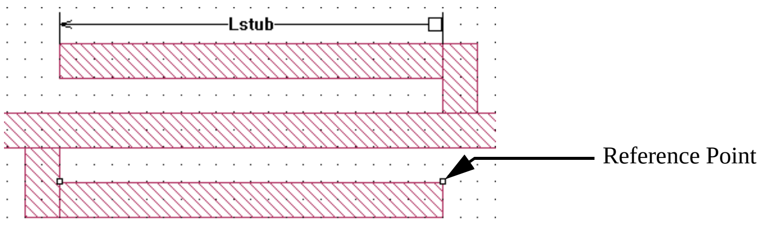
This places the project editor in Add an Anchored Parameter mode indicated by the change in cursor.

11 To specify the Anchor point for the parameter, click the mouse on the corner of the lower stub, as shown in the picture below.



The anchor point is indicated by a small square which appears at the point you clicked. The next step is to select the reference point.

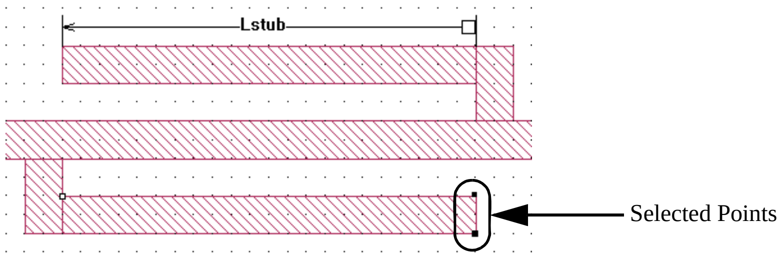
12 Click on the top right end of the bottom stub to add the reference point.



The reference point is indicated by a small square which appears at the point you clicked.

In the next step, you select the rest of the adjustable point set. Points may be selected using the any of the edit commands available in the project editor.

13 Drag the mouse until both points on the end of the stub are selected.



These points will be added to the adjustable point set. When the reference point moves, these points move relative to the reference point.

14 Once all the desired points are selected, press Enter.

This completes the parameter creation. The Parameter Properties dialog box appears on your display.

15 **Enter the name "Lstub" in the Name text entry box in the Properties dialog box and click on the OK button.**

This names the parameter. When you click on the OK button an arrow indicating the length and the name appear on your display. Use your mouse to move the label to the desired location, then click.

Since this parameter's nominal value is the same as the first parameter you defined, the project editor allows you to use the same name. These parameters are now linked. A change in value of one of the parameters changes both. If the parameters had been of a different length, you would have received an error message when you attempted to use the same name.

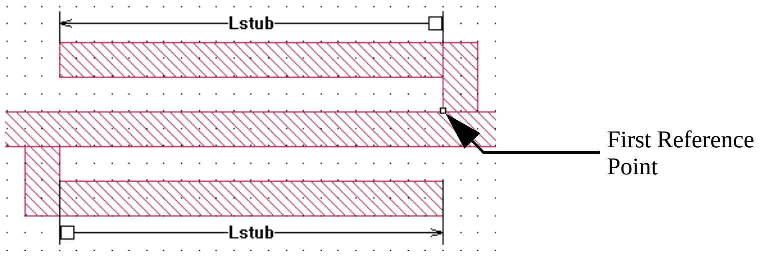
Next, you define the last parameter which is symmetric.

Symmetric Parameters

16 **Select *Tools* ⇒ *Add Parameter* ⇒ *Add Symmetric* from the project editor's main menu.**

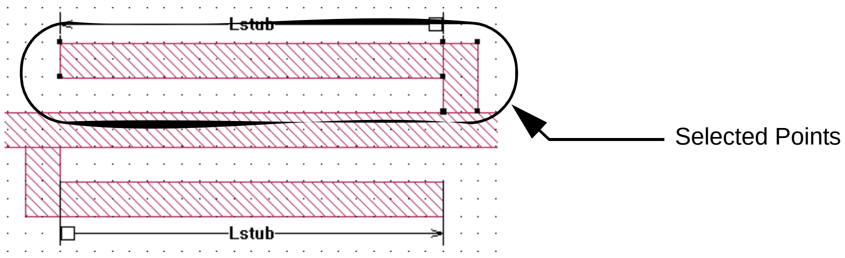
This places the project editor in Add a Symmetric Parameter mode indicated by the change in cursor. Note that the message "Click mouse to specify first reference point" appears in the status bar at the bottom of the project editor window. As you add a parameter, directions for each step appear in the status bar.

17 **To specify the first reference point for the parameter, click the mouse on the intersection of the inside of the top stub to the transmission line, as shown in the picture below.**



The first reference point is indicated by a small square which appears at the point you clicked. The next step is to select the point set you want attached to the first reference point.

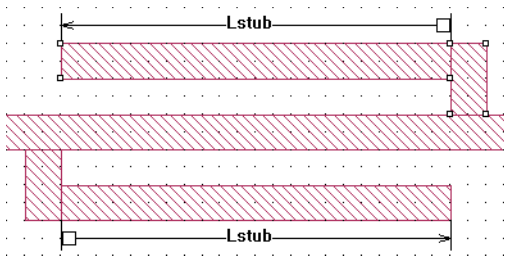
18 Drag the mouse until all points on the upper stub are selected.



These points will be added to the first adjustable point set. When the first reference point moves, these points move in the same direction and distance as the reference point.

19 Once all the desired points are selected, press Enter.

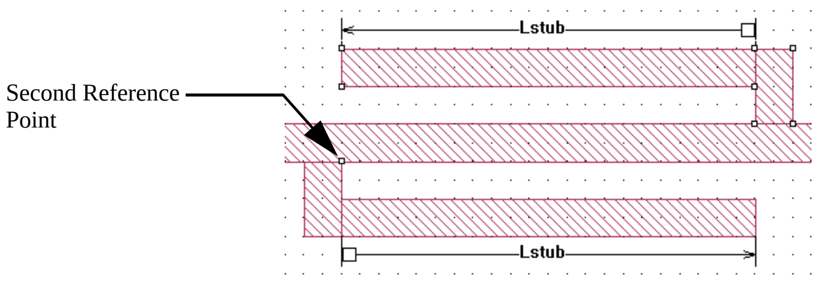
This completes the first point set. Your circuit should look similar to this:



The first point set is indicated by small open squares on all the points in the set.

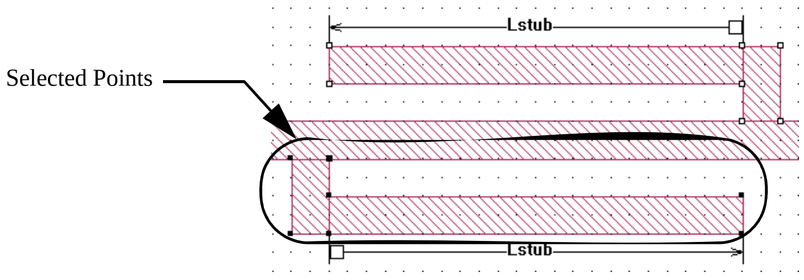
The message "Click Mouse to Specify Second Reference Point" appears in the status bar at the bottom of the project editor window. Next, you will specify the second reference point and its point set.

20 **To specify the second reference point for the parameter, click the mouse on the intersection of the inside of the bottom stub to the transmission line, as shown in the picture below.**



The second reference point is indicated by a small square which appears at the point you clicked. Note that the first point set continues to be identified by small squares on all its points. The next step is to select the point set you want attached to the second reference point.

21 **Drag the mouse until all points on the lower stub are selected.**



These points will be added to the second adjustable point set. When the second reference point moves, these points move in the same direction and distance as the reference point.

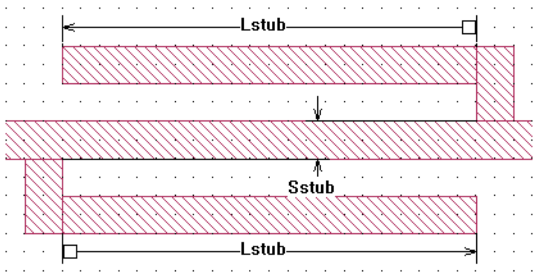
22 **Once all the desired points are selected, press Enter.**

This completes the second point set and the symmetrical parameter. The Parameter Properties dialog box appears on your display.

23 **Enter the name “Sstub” in the Name text entry box in the Parameter Properties dialog box and click on the OK button.**

This names the parameter. When you click on the OK button an arrow indicating the length and the name appear on your display. Note that since there is a difference between the reference points in both the x (horizontal) and y (vertical) direction, you may move the parameter name so that the parameter is defined in either the x or y direction.

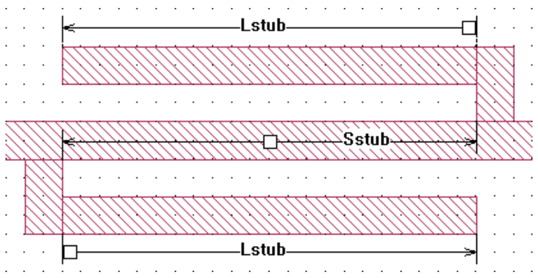
If you were to choose the y direction, moving the mouse to the left or right of both reference points to define your parameter, it would appear like this:



However, for this example, you define the parameter in the x direction, moving your mouse up or down, above or below both reference points.

24 Move the mouse until the name is positioned in the middle of the thru line. When the name is in the desired position, click on the mouse.

This sets the parameter in the x direction. The parameter should now appear as shown below.



This completes entering the parameters. Note that Lstub is affected by Sstub. As Sstub increases, although it does not directly affect the value of Lstub, the two stubs do get further apart. Lstub is dependent on Sstub.

25 Select *File* ⇒ *Save* for the project editor main menu.

This saves the changes you have made to the circuit so that you can analyze it.

The next section of the tutorial teaches you how to setup and run a parameter sweep on the circuit.

Parameter Sweep

The parameter sweep uses only the Lstub variable. You analyze the circuit at two different lengths for Lstub over a frequency band of 2.0 GHz to 10.0 GHz. When the sweep is complete, you view the response curves in the response viewer.

For a detailed discussion of a parameter sweep, please refer to "Parameter Sweep," page 136.

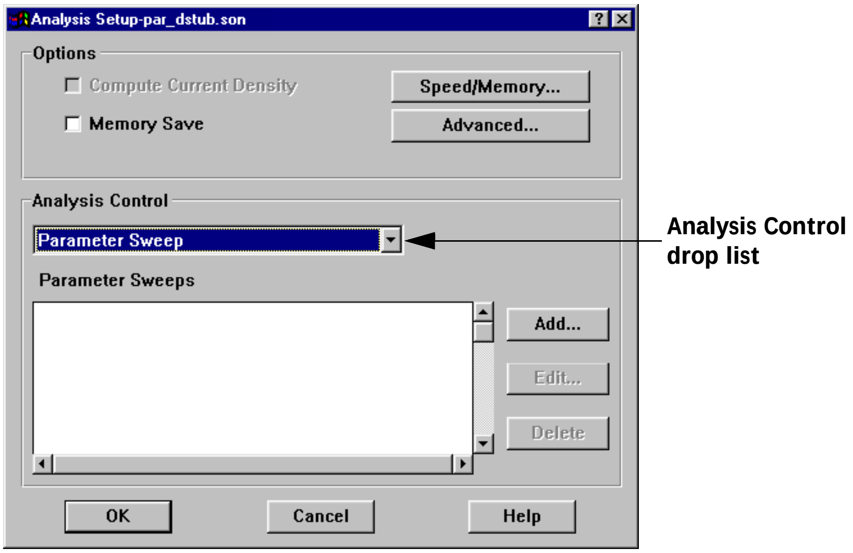
Setting Up a Parameter Sweep

1 **Select *Analysis* ⇒ *Setup* from the project editor's main menu.**

The Analysis Setup dialog box appears on your display.

2 **Select Parameter Sweep from the Analysis Control drop list.**

This selects a parameter sweep as the type of analysis. The dialog box's appearance changes to accommodate the input needed for a parameter sweep. Notice that the Compute Current Density run option is disabled for a parameter sweep.



3 **Click on the Add Button in the Analysis Control section of the dialog box.**

The Parameter Sweep Entry dialog box appears. This dialog box allows you to add a parameter sweep.

The first step is to specify the analysis frequencies you wish to use for the parameter sweep. For this example, you wish to perform an ABS sweep from 2.0 GHZ to 10.0 GHz. Since Adaptive Sweep (ABS) is the default sweep type, you do not need to take any action to select it.

4 **Enter 2.0 in the Start text entry box in the Frequency Specification section of the Parameter Sweep Entry dialog box.**

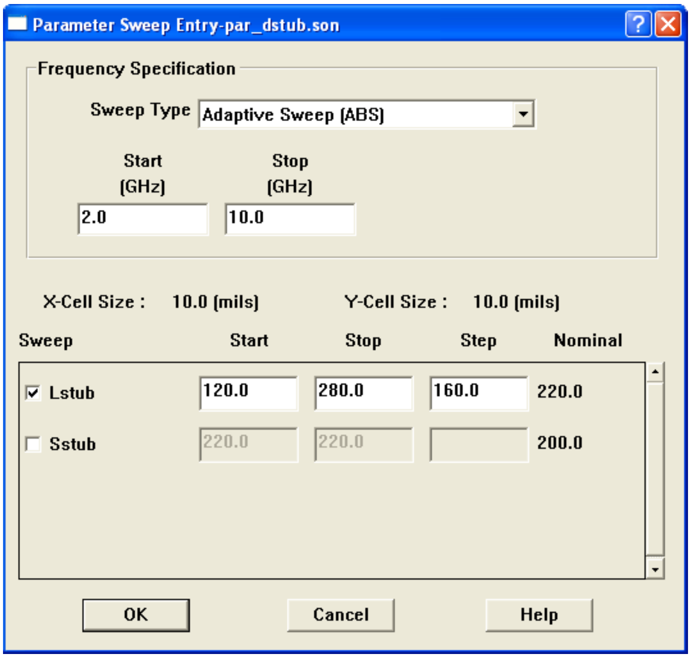
This is the starting frequency.

5 **Enter 10.0 in the Stop text entry box.**

This is the highest frequency. This defines a band of 2 GHz to 10 GHz for the adaptive sweep.

Next, you will select the parameters you wish to sweep.

6 **Click on the checkbox in the Sweep column of the entry for the Lstub parameter.**


Parameter Sweep Entry-par_dstub.son

Frequency Specification

Sweep Type: Adaptive Sweep (ABS)

Start (GHz)	Stop (GHz)
2.0	10.0

X-Cell Size : 10.0 (mils)   Y-Cell Size : 10.0 (mils)

Sweep	Start	Stop	Step	Nominal
☑ Lstub	120.0	280.0	160.0	220.0
☐ Sstub	220.0	220.0		200.0

It is possible to select multiple parameters for a parameter sweep; however, for this example, only one parameter is used. If you wished to deselect the parameter, you would simply click on the checkbox again. Unchecked parameters are simulated at their nominal value, so Sstub is a constant, fixed at 220 mils for the parameter sweep.

The nominal value, that is the present value of the parameter in the circuit, appears in the Nominal column of the parameter entry. In this case, the nominal value of Lstub is 220 mils, so the project editor shows the length as 220 mils, even though the start value for the parameter is different.

7 **Enter 120 in the Start text entry box in the Lstub row.**

This sets 120 mils as the first parameter value used for Lstub.

8 **Enter 280 in the Stop text entry box in the Lstub row.**

This sets 280 mils as the last parameter value used for Lstub.

9 **Enter 160 in Step text entry box in the Lstub row.**

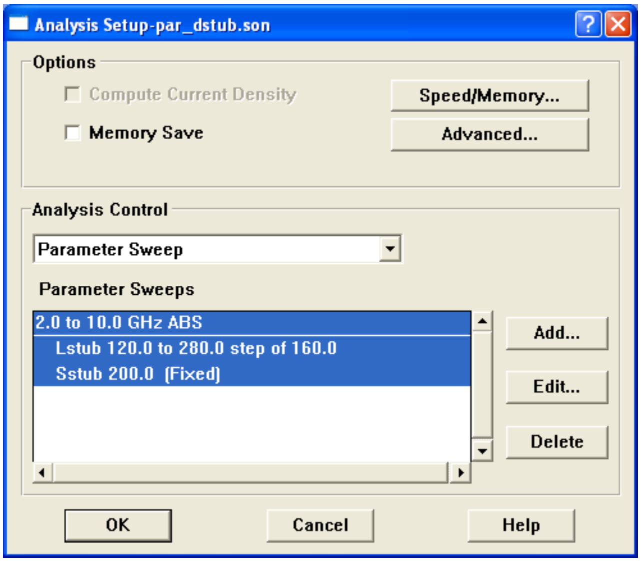
The interval between parameters is 160 mils; therefore, this parameter sweep analyzes at two parameter values, 120 and 280 mils. It is important to note that all three fields: start, stop, and step are required.

This completes the setup for the parameter sweep entry.

10 **Click on the OK button to close the dialog box.**

When the dialog box is closed, the Analysis Setup dialog box is updated with an entry for the parameter sweep that you just defined. In this case, since there are two values for a single parameter, there are two parameter combinations. Each combination is analyzed at each analysis frequency.

If you had a case in which there were two parameters, seven values for the first parameter and eleven values for the second parameter, there would be 77 parameter combinations for the analysis.



Parameter Sweep

Parameter Sweeps

2.0 to 10.0 GHz ABS
Lstub 120.0 to 280.0 step of 160.0
Sstub 200.0 (Fixed)

11 Click on the OK button of the Analysis Setup dialog box.

This completes the entry of the parameter sweep.

Next, you run the analysis and use the analysis monitor to observe the progress.

Executing the Parameter Sweep

12 Select *Project* ⇒ *Analyze* from the project editor’s main menu to invoke the analysis engine, *em*, and start the analysis.

If you are prompted, save the file. The output window of the analysis monitor appears on your display.

13 Click on the Response Data button in the analysis monitor output window.

This allows you to observe the analysis as it progresses. There is a progress bar at the top of the window which shows what percentage of the total analysis is complete with the number of frequencies analyzed appearing above it. The response data is output in the bottom of the window.

The analysis could take a few minutes to run depending on your computer.

Once the analysis is complete, you open the response viewer to look at your results.

Observing the Parameter Sweep Data

You want to see the data for the S_{21} response at Lstub = 120 mils and Lstub = 280 mils.

14 Select *Project ⇒ View Response ⇒ New Graph* from the main menu of the analysis monitor output window.

The response viewer window appears on your display with S_{11} displayed.

15 Right click on par_dstub in the Curve Group legend.

A pop-up menu appears on your display.

16 Select Edit Curve Group from the pop-up menu.

The Edit Curve Group dialog box appears on your display.

17 Double click on DB[S11] in the Selected list.

This moves the S_{11} response to the Unselected list. It will no longer appear in your plot.

18 Double click on DB[S21] in the Unselected list.

This moves the S_{21} response to the Selected list so that it appears in your plot.

19 Click on the Select Combinations button in the Edit Curve Group dialog box.

The Select Parameters dialog box appears on your display.

20 Click on the Select All button above the Selected Parameters list.

There should be only one entry in this list; the Select All button was used to demonstrate its function. This selects all the parameters in the Selected List.

21 Click on the Up Arrow button to move all the parameter combinations to the Unselected list.

22 **Double-click on Sstub = 220 mils, Lstub = 120 mils in the Unselected List.**

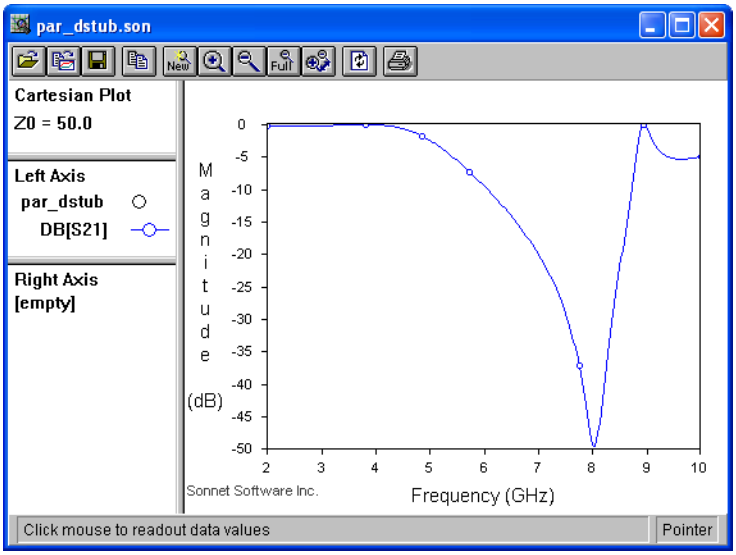
This moves this parameter combination to the selected list so that the data for this combination appears in your plot.

23 **Click on the OK button in the Select Parameters dialog box to apply the changes and close the dialog box.**

The entry “Lstub = 120.0 Sstub = 220.0” appears in the Parameter Combinations section of the Edit Curve Group dialog box.

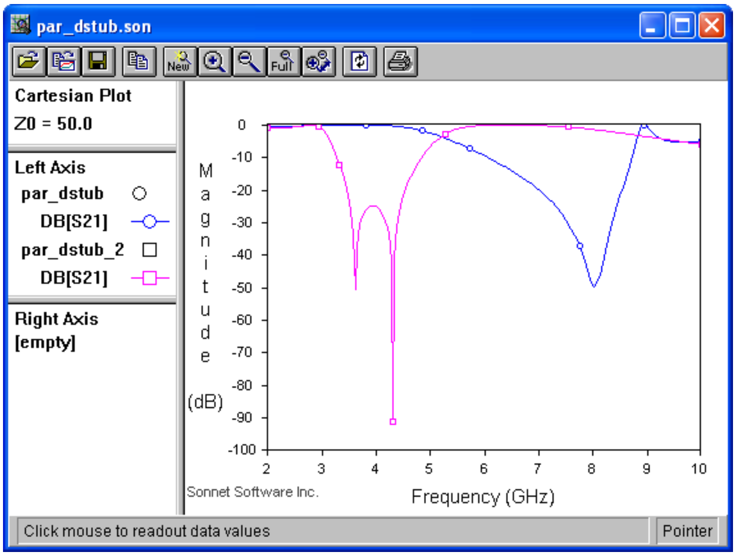
24 **Click on the OK button in the Edit Curve Group dialog box to apply the changes and close the dialog box.**

The plot is updated with the S21 response for Sstub = 220 mils, Lstub = 120 mils. The entry for the curve group, par_dstub appears in the Curve Group Legend. The graph should be similar to the one shown below.

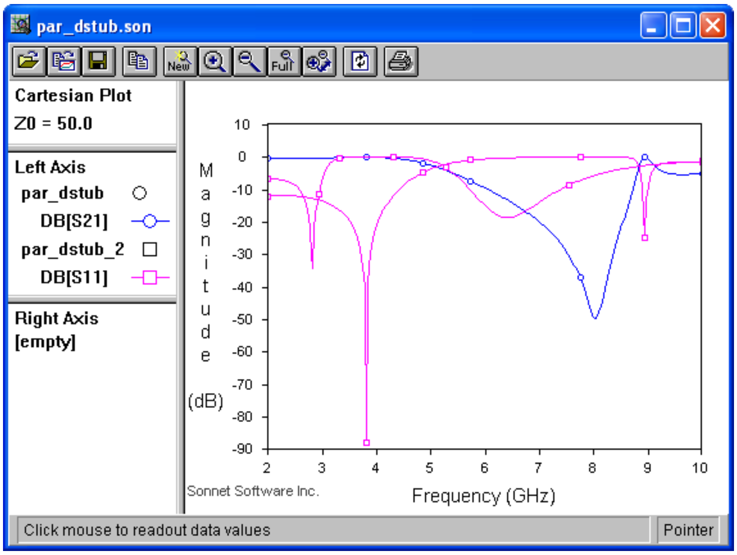


25 To add the response at Lstub = 280 mils, select *Curve ⇒ Add Curve Group* from the response viewer main menu.

The Add Curve Group dialog box appears. This curve group uses the default name of par_dstub_2. Following the same steps you used for par_dstub above, set up this curve group to display the S_{21} response for Lstub = 280 mils, Sstub = 220 mils. Your plot should now look like the one below.



You could also have right-clicked the curve group par_dstub in the Left Axis pane of the legend and selected "Edit Curve Group" from the pop-up menu. Using the Edit Curve group dialog box, you could have added this parameter combination to this curve group. This would result in one curve group with one symbol representing both parameter combinations. This is useful if you want multiple measurements (S_{21} and S_{11} for example). Each measurement would use a different symbol, but each parameter combination with a measurement would use the same symbol. An example is pictured below.



In the beginning, the goal of the filter design was stated as a stopband between 5.0 and 6.0 GHz. By looking at the graph of Lstub=120 as compared to Lstub=280, you can see that a filter with the required stopband would fall approximately in the middle of the two curves. So a value of 220 mils is chosen for the nominal value for Lstub for the optimization. A nominal value of 220 mils is chosen for Sstub.

Optimization

This next section of the tutorial shows how to set up and execute an optimization.

For a detailed discussion of optimization, please refer to "Optimization" on page 138.

If par_dstub.son is not still open in the project editor, open the file in the project editor.

Entering New Nominal Values

Usually for this type of circuit, you would optimize using both the defined parameters, Lstub and Sstub, but for the sake of processing time, the optimization only uses one parameter, Lstub.

The nominal value used for Sstub will be 200 mils. This was arrived at by actually executing the optimization using both parameters and using the closest value on the grid of the optimized parameter.

26 Double-click on the parameter Sstub in the circuit.

The Parameter Properties dialog box for Sstub appears on your display.

27 Change the nominal value in the Nominal text entry box to 200.

28 Click on the OK button to close the dialog box and apply the new nominal value.

The circuit is redrawn using the new nominal value for Sstub.

WARNING

It is recommended that you change the nominal value of parameters by using the properties dialog box, since changing your nominal value this way does not affect any previous response data in your project file. If you change the nominal value of the parameter by changing the circuit through editing commands, such as a reshape, all previous response data is deleted from the project file when you save.

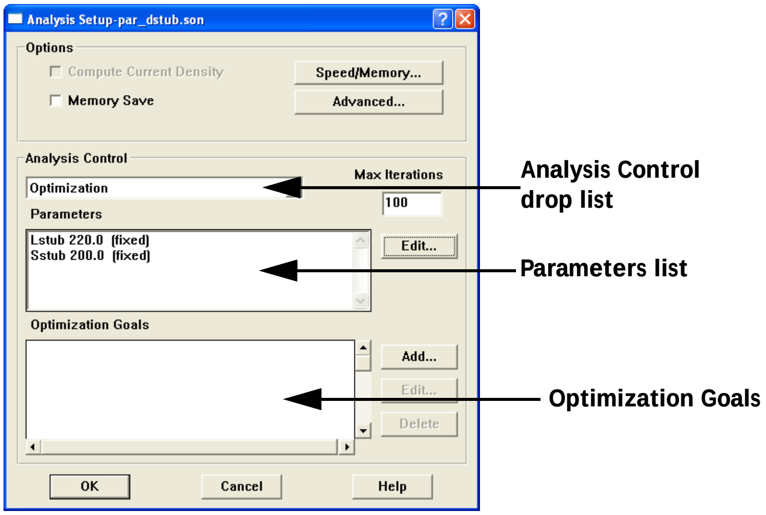
Setting Up an Optimization

29 Select *Analysis* ⇒ *Setup* from the main menu of the project editor.

The Analysis Setup dialog box appears on your display.

30 Select Optimization from the Analysis Control drop list.

This selects a optimization as the type of analysis. The dialog box's appearance changes to accommodate the input needed for an optimization. Note that initially the nominal values are listed for the parameters, since no range has yet been specified.



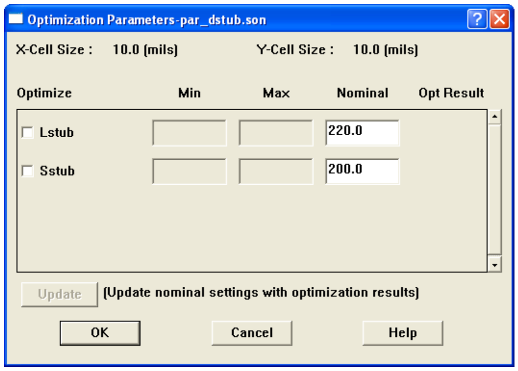
Optimization

100

Lstub 220.0 (fixed)
Sstub 200.0 (fixed)

31 Click on the Edit button on the right side of the Parameters list.

The Optimization Parameters dialog box appears on your display.


Optimization Parameters-par_dstub.son
Update
(Update nominal settings with optimization results)
OK
Cancel
Help

X-Cell Size : 10.0 (mils)   Y-Cell Size : 10.0 (mils)

Optimize	Min	Max	Nominal	Opt Result
Lstub			220.0	
Sstub			200.0	

Only one parameter, Lstub, is used for this optimization. The range for Lstub is 100 mils to 300 mils.

32 Click on the Optimize check button next to Lstub.

This selects the Lstub parameter to be used in the optimization. Note that the nominal value appears in the Nominal text entry box. If you wish to change the nominal value, you may do so by entering a new value. The circuit will be redrawn using the new nominal value. Since this is the first optimization run on this project file the Min and Max entries are blank. If a previous optimization had been run, the last entered values would remain.

WARNING

Editing parameter settings or optimization goals causes any pre-existing optimization iterations to be deleted from the project file.

33 Enter 100 in the Min text entry box in the Lstub row.

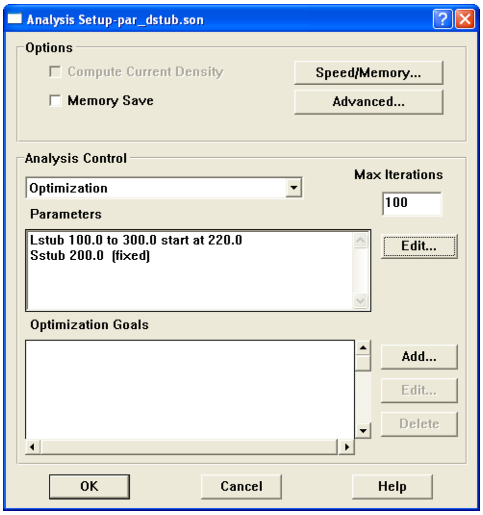
This sets the minimum value for the Lstub parameter to 100 mils for the optimization.

34 Enter 300 in the Max text entry box in the Lstub row.

This sets the maximum value for Lstub to 300 mils for the optimization.

35 Click on the OK button to apply the changes and close the dialog box.

When the dialog box is closed, the Analysis Setup dialog box is updated with an entry for the optimization parameters that you just defined.



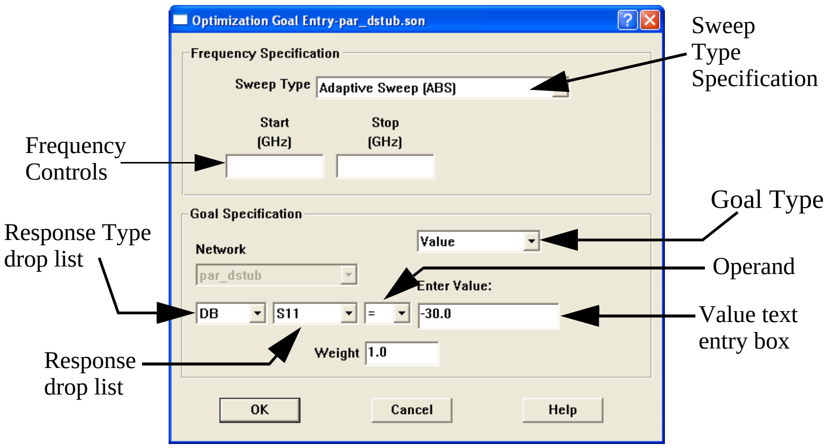
Lstub 100.0 to 300.0 start at 220.0
Sstub 200.0 (fixed)

Now that you have identified which parameter to vary and its range, you must specify the optimization goals. Since this is the first optimization for this project, there are no previously defined optimization goals and the list is empty. Having no goals present disables the Edit and Delete buttons. The Edit button allows you to modify an existing goal, and the delete button removes the goal from the list.

As mentioned earlier in the example, our goal for the filter is to have passbands at 1-4 GHz and 7-10 GHz with a stopband at 5-6 GHz. The optimization goals are set up accordingly. Since all three goals in this case are equally important, each uses the default Weight of 1.0. In cases where one goal is more essential, assigning it a higher weight than other goals tells ***em*** to concentrate more on reaching that particular goal.

36 Click on the Add button to the right of the Optimization Goals list.

The Optimization Goal Entry dialog box appears on your display.



The first goal corresponds to the first passband; therefore, you need to set the ABS frequency range to 1.0 GHz to 4.0 GHz. There are several different types of frequency sweeps available; you will use the default ABS sweep for this optimization.

37 Enter 1.0 in the Start text entry box in the Frequency Specification section of the dialog box.

This sets the beginning of the frequency band for this optimization goal at 1.0 GHz.

38 Enter 4.0 in the Stop text entry box in the Frequency Specification section of the dialog box.

This sets the end of the frequency band for this optimization goal at 4.0 GHz. This completes the specification of the frequency sweep for this optimization goal.

Since this is the first passband, your goal is to have DB[S21] be greater than -1.0 dB.

39 Select DB from the Response Type drop list on the left side of the equation.

This is the default, so DB may already be selected.

40 Select S21 from the Response drop list.

41 Select ">" from the Operand drop list.

42 Select Value from the Goal Type drop list.

This choice allows you to put in a specific value. This is the default; you may also specify another project file or another network in your project (if the project is a Network project). In those cases, you may select a response for that circuit to which you wish to match your selected response.

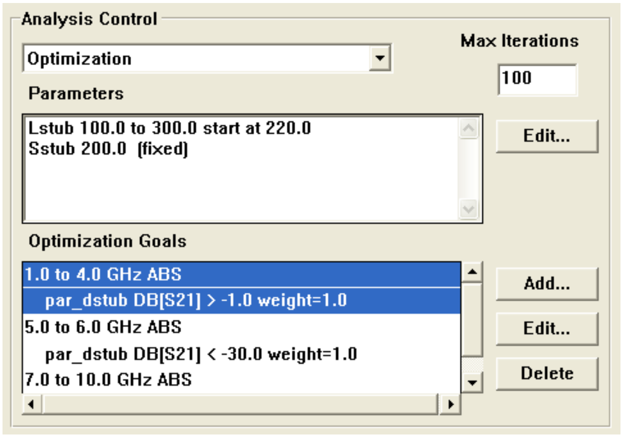
43 Enter -1.0 in the Value text entry box.

This sets your goal of DB[S21] > -1.0 dB.

44 Click on OK to apply the changes and close the dialog box.

The Analysis Setup dialog box is updated. An entry for this optimization goal now appears in the Optimization Goals list.

The other two goals should be entered in a similar manner. The second goal is a adaptive sweep from 5.0 GHz to 6.0 GHz with a desired response of DB[S21] < -30.0 dB. This is the stopband. The third goal is an adaptive sweep from 7.0 GHz to 10.0 GHz with a desired response of DB[S21] > -1.0. When you have completed entering these goals, the Optimization Goals list should appear as shown below.


Analysis Control

Optimization

Max Iterations: 100

Parameters

Lstub 100.0 to 300.0 start at 220.0
Sstub 200.0 (fixed)

Optimization Goals

1.0 to 4.0 GHz ABS
par_dstub DB[S21] > -1.0 weight=1.0
5.0 to 6.0 GHz ABS
par_dstub DB[S21] < -30.0 weight=1.0
7.0 to 10.0 GHz ABS

This completes the setup for the optimization.

Running an Optimization

This optimization took approximately 6.5 minutes on a 2 GHz Pentium 4.

45 Select *Project* ⇒ *Analyze* from the main menu of the project editor.

The output window of the analysis monitor appears on your display.

TIP

You can also click on the Analyze button on the project editor tool bar.

46 Click on the Response Data button in the analysis monitor output window if it is not already displaying the response data.

This allows you to observe the optimization as it progresses. The error for the first, present and best iteration are displayed and updated as the optimization progresses. The response data is output in the bottom of the window.

You may notice that some iterations complete more quickly than others. This is because ***em*** can reuse portions of the response data calculated for previous iterations.

Once the analysis is complete, you open the response viewer to look at your results. Be aware that since this optimization took a number of iterations to conclude, there may be small delays in opening the response viewer and the Edit Curve Group dialog box.

TIP

You may use the response viewer to observe data produced by the optimization while it is still running. The response viewer can chart any data which has been generated. This allows you to stop the optimization and start it over using new parameter ranges or new goals, if the results are not desirable. If you wish to continue viewing data as the optimization runs, use the Freshen Files command in the Response Viewer.

Observing your Optimization Data

Plotting the best iteration will allow you to judge whether or not to use the optimized values of the parameters.

47 Select *Project* ⇒ *View Response* ⇒ *New Graph* from the main menu of the analysis monitor.

The response viewer menu appears on your display with the DB[S11] response for the nominal values parameter combination displayed. There may be some delay while the project loads into the response viewer due to the amount of response data now included.

48 Click on the DB[S11] curve group in the legend to select it and select *Curve* ⇒ *Edit Curve Group* from the main menu of the response viewer.

The Edit Curve Group dialog box appears on your display.

49 Select Optimized from the Data Collection drop list in the Edit Curve Group dialog box.

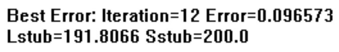
Notice that this drop list is now enabled since the project file now contains both parameter sweep data and optimized data.

50 Move DB[S11] to the Unselected list by double-clicking on the entry.

51 Move DB[S21] to the Selected list by double-clicking on the entry.

Since your optimization goals were set in reference to the DB[S21] response, you want to plot this response.

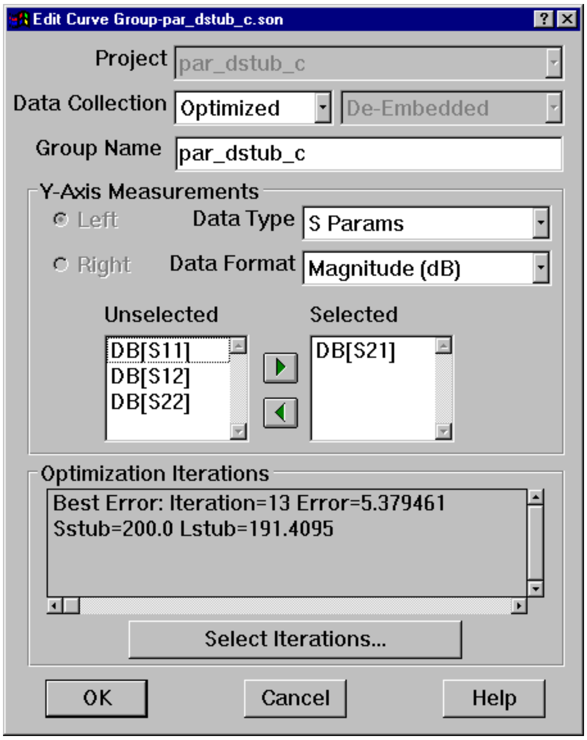
Notice that when you selected Optimized data that the parameter combination was updated to read:



Best Error: Iteration=12 Error=0.096573
Lstub=191.8066 Sstub=200.0

The best iteration is plotted by default when you select optimized data. If the optimization was still running, this is a useful way of always plotting the best iteration calculated so far. Pressing the Freshen Files button on the tool bar of the response viewer will always show the best iteration.

If you were to click on the Select Iterations button, the dialog box would appear with all the parameter values used in all 25 iterations available to plot. Since you wish to see the response at the best iteration, you do not need to change the parameter value for this curve group.


Edit Curve Group-par_dstub_c.son

Project: par_dstub_c

Data Collection: Optimized | De-Embedded

Group Name: par_dstub_c

Y-Axis Measurements

[✓ Left] Right

Data Type: S Params

Data Format: Magnitude (dB)

Unselected: DB[S11], DB[S12], DB[S22]

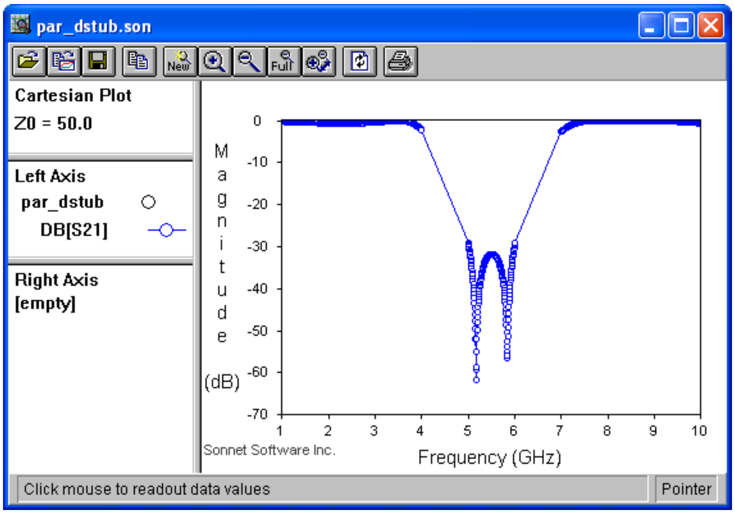
Selected: DB[S21]

Optimization Iterations

```
Best Error: Iteration=13 Error=5.379461
Sstub=200.0 Lstub=191.4095
```

52 Click on the OK button to close the dialog box and apply the changes.

The plot is updated showing DB[S21] for the best iteration. It should appear similar to the plot pictured below.



As you can see, the optimized circuit is producing the desired response of a stop-band from 5 - 6 GHz and the passbands from 1 - 4 GHZ and 7-10 GHz.

Accepting the Optimized Values

Since the desired responses have been achieved by the optimization, you return to the project editor to update the nominal value of your parameters with the optimized values.

If the project par_dstub is still open in the project editor, continue at step 55.

53 Click on the curve group, par_dstub in the Curve Group legend in the response viewer.

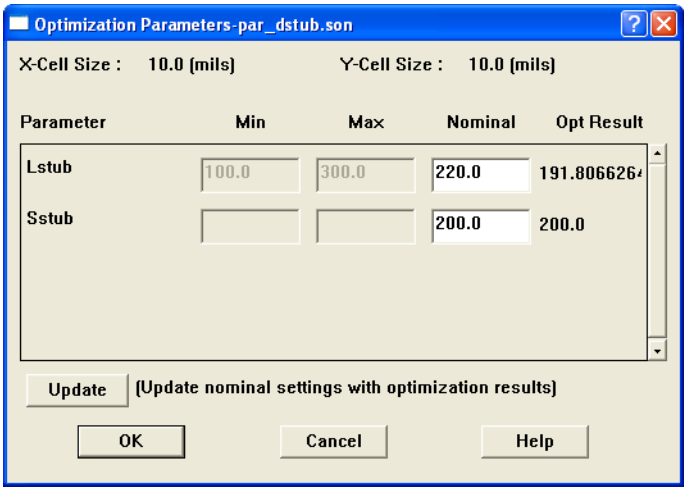
This selects a project file and thereby enables the project menu.

54 Select *Project* ⇒ *Edit* from the main menu of the response viewer.

The project editor appears on your display with par_dstub open.

55 Select *Analysis* ⇒ *Optimization Results* from project editor main menu.

The Optimization Parameters dialog box appears on your display.


Optimization Parameters-par_dstub.son
Update
(Update nominal settings with optimization results)
OK
Cancel
Help

X-Cell Size : 10.0 (mils)   Y-Cell Size : 10.0 (mils)

Parameter	Min	Max	Nominal	Opt Result
Lstub	100.0	300.0	220.0	191.806626
Sstub			200.0	200.0

Notice that the nominal value of both parameters is still the value input at the beginning of the optimization. But the optimization results for both parameters are displayed in the last column. Since Sstub was not used in the optimization, its optimization result is the same as the nominal value.

56 Click on the Update button to replace the present nominal values with the optimization results.

Note that the entries in the Nominal text entry boxes are updated with the optimized values.

57 Click on OK to close the dialog box and apply the changes.

Notice that the circuit has been redrawn with the new nominal values for the parameters. Since the parameter lengths are not integer multiples of the cell size, the polygons are no longer exactly on the grid. You can see this by pressing Ctrl-M to turn off the cell fill and looking at the actual polygons. The cell fill represents the actual metal ***em*** analyzes.

The actual metalization analyzed by ***em*** is not the same as the optimized values. ***Em*** actually interpolated from data created from analyzing “on grid” versions of the circuit. If your optimization goals did not include a full frequency sweep, it is a good idea to perform a full sweep across your frequency band to ensure that your entire band shows reasonable results. Running a full frequency sweep is detailed below.

In order for ***em*** to use previously calculated response data, you should edit your parameter value(s) such that they are the closest "on grid" value to the optimization result. For example, in this case the optimized value for Lstub is 191.80662641. You should edit the nominal value of Lstub to change it to 190 which, since the cell size is 10, is on the grid.

58 Select *Analysis* ⇒ *Setup* from the project editor main menu.

The Analysis Setup dialog box appears on your display.

59 Select Adaptive Sweep (ABS) from the Analysis Control drop list.

The appearance of the dialog box is changed to conform with an adaptive sweep. Enter 2.0 GHz in the Start text entry box and 10 GHz in the Stop text entry box to define a frequency band of 2 - 10 GHz for this analysis.

60 Click on OK to close the dialog box and apply the changes.

61 Click on the Analyze button to start the *em* analysis.

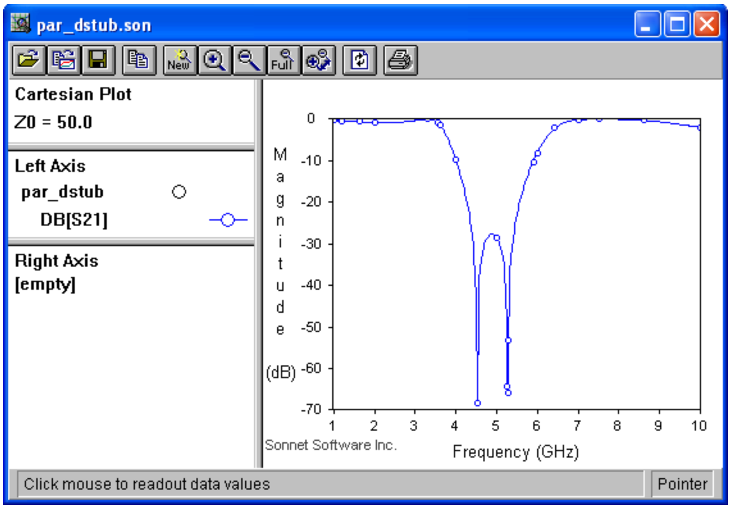
If prompted, save the circuit before analyzing.

62 When the analysis is complete, click on the View Response button on the analysis monitor's tool bar.

The response viewer appears on your display with the curve group, par_dstub, consisting of DB[S11] displayed.

63 Right-click on the curve group, par_dstub, and select Edit Curve Group from the pop-up menu which appears.

Select DB[S21] for display, move DB[S11] to the Unselected list, and close the dialog box. Your plot should appear similar to that shown below.



The results conform closely enough to the design criteria that this optimization is considered a success. As was stressed at the beginning of this tutorial, a simple example was chosen in order to clearly demonstrate the optimization process.

You should be aware, however, that most optimization problems are much more complicated and less straightforward. The designer needs to make decisions about parameters, the parameter sweeps and optimization goals based on knowledge of the circuit and design experience. Often, you must observe an optimization while in progress, judge its viability and, as necessary, stop the optimization and start a new one with new nominal values and data ranges.

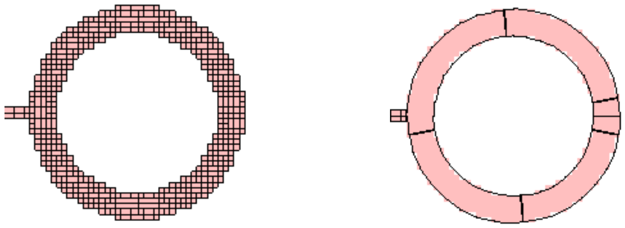
Chapter 12 Conformal Mesh

Introduction

Analyzing circuits which have non-rectangular polygons can require extensive memory and processing time since the number of subsections needed to model the non-rectangular shapes is significantly higher than the number of subsections required for a rectangular polygon. Conformal meshing is a technique which can dramatically reduce the memory and time required for analysis of a circuit with diagonal or curved polygon edges.

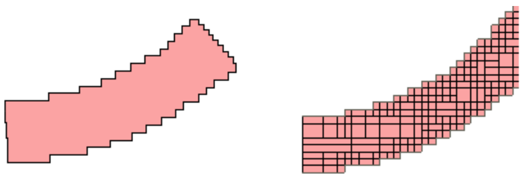
This technique groups together strings of cells following diagonal and curved metal contours. Whereas staircase fill results in numerous small X- and Y-directed subsections, conformal mesh results in a few long conformal subsections. Fewer subsections yields faster processing times with lower memory requirements for your analysis.

In older meshing techniques, large non-rectangular subsections did not include the high concentration of current on the edge of the lines required by Maxwell’s equations. The results could significantly under-estimate loss and inductance. In contrast, the Sonnet conformal meshing automatically includes the high edge current in each conformal section. In conformal meshing, Sonnet can achieve the speed of using large subsections, and at the same time enjoy the accuracy of using small cells. This patented[1] Sonnet capability is unique.



Pictured above is a typical circuit which would be appropriate for Conformal Meshing. The left picture shows the rectangular subsections created by using staircase fill. This results in approximately 800 subsections (unknowns). The right picture shows the conformal sections created by using conformal fill, resulting in only about 130 subsections. Note that each conformal section shown represents multiple subsections.

Conformal sections, like standard subsections, are comprised of cells, so that the actual metalization still shows a "jagged" edge when the polygon has a smooth edge, as pictured below. However, the sections can be much larger due to conformal meshing. You may now make the underlying grid sufficiently small to accurately resolve challenging circuit dimensions without incurring excessive memory and analysis time requirements.



1U.S. Patent No. 6,163,762 issued December 19, 2000.

Conformal meshing should be used in places where it will reduce subsection count. For rectangular polygons with no diagonal or curved edges, it is more efficient to use rectangular subsections (default). However, if a polygon contains a curved edge, conformal meshing provides a quicker analysis.

For a discussion on subsectioning when using Conformal Mesh, see "Conformal Mesh Subsectioning," page 46.

Use Conformal Meshing for Transmission Lines, Not Patches

Conformal meshing assumes most of the current is flowing parallel to the edge of the conformal subsection. This works well for transmission lines. However, this is usually not accurate for geometries like patch antennas. For large areas of metal in both x and y directions, high current can flow parallel to the X axis edges, and parallel to the Y-axis edges at the same time. Conformal meshing can include only one of these currents. Thus, conformal meshing should only be used for transmission line geometries, which have a “line width” that is small compared to wavelength.

Applying Conformal Meshing

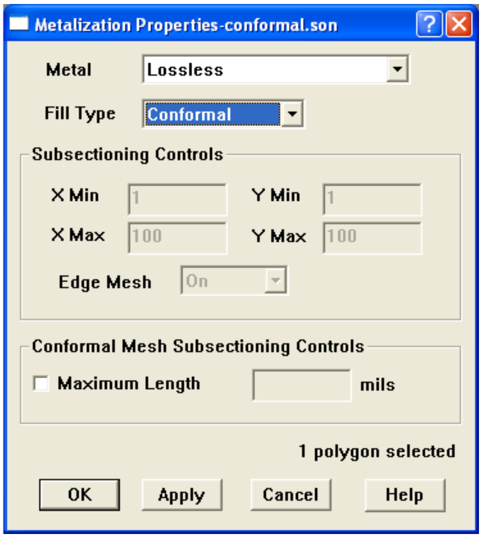
Conformal Meshing is applied as a property of a metal polygon. To use conformal meshing for a polygon, do the following:

1 **Select the desired polygon(s) by clicking or lassoing.**

The selected polygons are highlighted.

2 **Select Modify ⇒ Metal Properties from the main menu.**

The Metal Properties dialog box appears on your display.


Metalization Properties-conformal.son

Metal: Lossless

Fill Type: Conformal

Subsectioning Controls

X Min: 1 Y Min: 1

X Max: 100 Y Max: 100

Edge Mesh: On

Conformal Mesh Subsectioning Controls

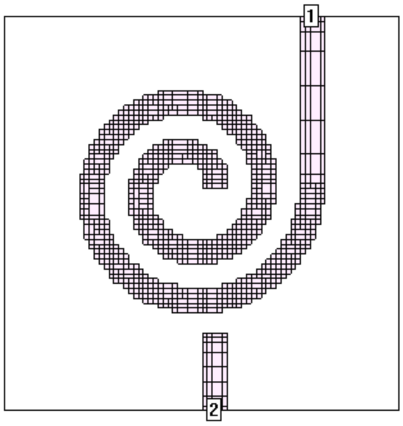
☐ Maximum Length mils

1 polygon selected

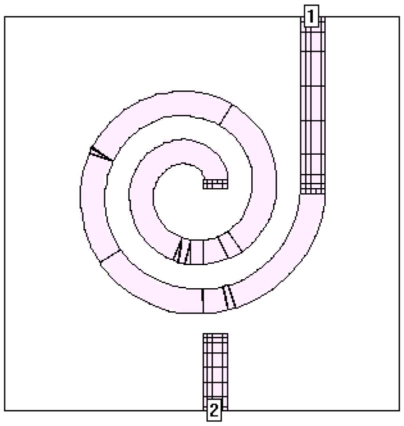
3 Select "Conformal" in the Fill Type drop list.

4 Click on the OK button to apply the changes and close the dialog box.

The polygon does not appear any different in the circuit. To see the difference, you need to use the *Analysis ⇒ Estimate Memory* command. When the Estimate Memory dialog box appears, click on the View Subsections button. Shown below is the subsectioning for the same spiral inductor. The circuit on the left uses rectangular subsections and the one on the right uses conformal subsections. Note that the rectangular subsectioning uses a much higher number of subsections for the spiral inductor than does the conformal meshing. Rectangular subsectioning was used for the feed lines in both cases.



Spiral inductor with rectangular subsections. (Default)



Spiral inductor with conformal subsections.

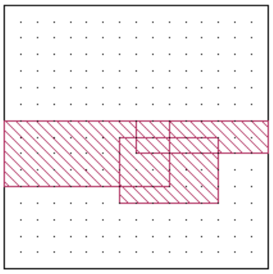
If you chose Conformal meshing, then the subsectioning controls in the Metalization Properties dialog box - Xmin, Ymin, XMax, YMax and Edge Mesh - are disabled and ignored.

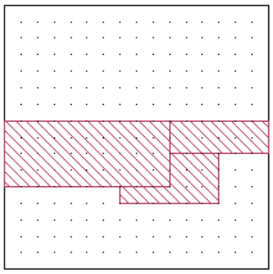
Conformal Meshing Rules

Since conformal meshing is a new feature in the analysis engine, not all conditions which may affect accuracy or processing time are automatically identified in the project editor. Below are some basic rules for using conformal meshing you may follow to prevent causing an error in the analysis engine, ***em***.

Rule 1: Polygon Overlap

Polygons should be drawn or moved in your circuit such that there is no overlap between polygons if any one of the polygons is using conformal meshing. It is possible for two polygons to overlap and not cause an error condition, but the most conservative use would be no overlaps. See the illustration below.

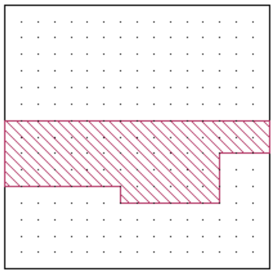




The circuit on the left has three overlapping polygons and the polygon on the bottom is using conformal meshing. This would cause ***em*** to issue an error message and stop running. The circuit shown on the right has no overlap between polygons and would not cause any errors.

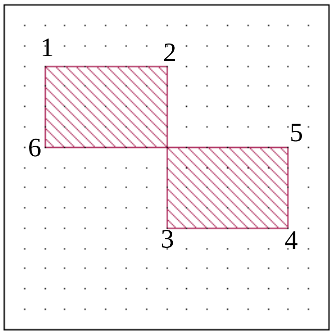
TIP

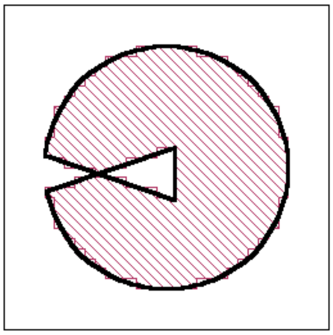
To maintain the same metal in your circuit without any overlap, use the *Edit ⇒ Merge Polygons* command on polygons which use the same metal type. Using the Merge command on the example above, in which all three polygons are the same metal type, is shown below.



Rule 2: Figure Eight Polygons

A conformal mesh polygon should not wrap back around itself; in other words, its vertices should not form a figure eight. This will result in an error message being issued and ***em*** will stop the analysis job. Two examples of this type of polygon are shown below. In the polygon shown on the left, the vertices have been labelled in the order in which they were added.





Rule 3: Adjacent Polygons Should Have No Gap

Any polygon which is adjacent to another polygon using conformal meshing should have its edges exactly touching with no gap existing between the two polygons. Extremely tiny gaps are automatically removed, but should be avoided. Tiny gaps can be easily avoided by using any of the following methods:

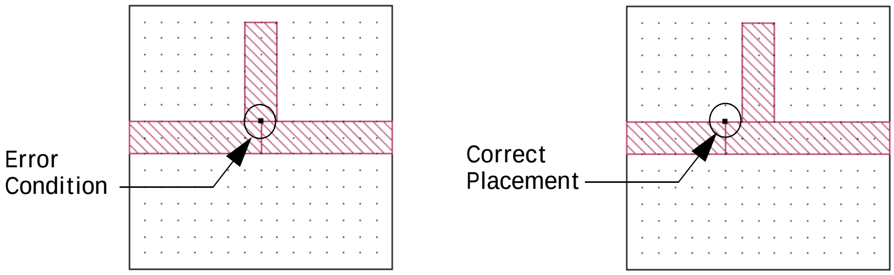
- Using a snap grid while drawing your circuit. (Tools ⇒ Snap Setup)
- Creating a larger polygon, then dividing the polygon (Edit ⇒ Divide Polygons) and applying conformal meshing to one of the resulting polygons. The resultant polygons are adjacent with no space in between.
- Adding a small polygon which bridges the gap and overlaps the two polygons on either side of the gap, then using the Merge Polygon command (Edit ⇒ Merge Polygons).
- Snapping the existing polygons to the grid. (Modify ⇒ Snap To command using the Preserve shape and spacing option).

WARNING

If you are snapping a circuit with curved edges, use the Preserve shape and spacing option in the Snap Objects dialog box. Otherwise, curved edges can become distorted and are difficult to restore in the project editor.

Rule 4: Adjacent Polygons Should Not Have an Interior Vertex

When three polygons are adjacent, a vertex where two polygons meet should not occur between two vertices of the third polygon. See the illustration below.



Memory Save Option

It is recommended that memory save not be enabled when your circuit has polygons using conformal mesh fill. This is because conformal mesh subsections are sensitive to precision error. Since using the memory save option involves reducing the required memory at the expense of increasing precision error, its use may lead to noisy S-parameter results for circuits with conformal mesh fill.

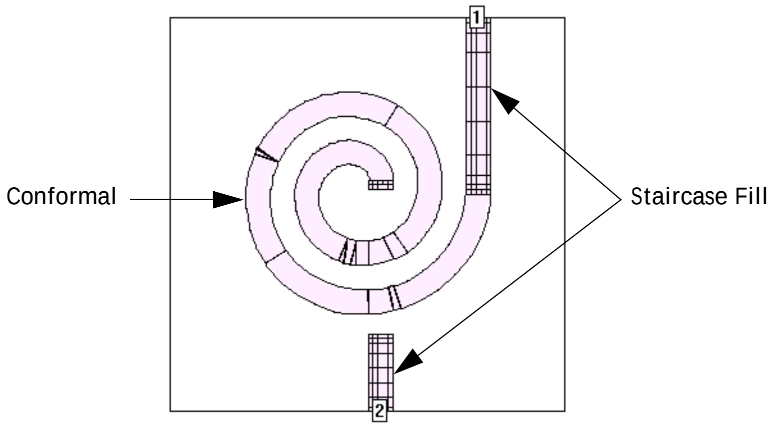
Using Conformal Meshing Effectively

This section discusses some guidelines to use in order to get the most improvement in processing time and memory use and the most accurate results when using conformal meshing. Following these guidelines will help you to use conformal meshing in the most efficient manner.

Use Conformal Meshing for Non-Manhattan Polygons

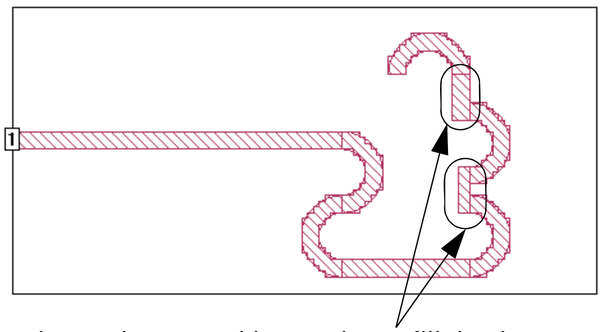
Conformal meshing should be used for non-Manhattan polygons. Manhattan polygons are polygons which only have vertical and horizontal edges, no diagonals or curves. For these types of polygons, rectangular subsections are more efficient.

You should look at your geometry and, if necessary, divide it up into Manhattan and non-Manhattan polygons using the Edit ⇒ Divide Polygon. Then set the Manhattan polygons to staircase fill and the non-Manhattan polygons to Conformal fill. For example, the spiral conductor shown below contains Manhattan sections in the feed lines and non-Manhattan sections in the circular spiral. It should be divided up such that the feedlines are represented by polygons set to staircase fill, and the circular spiral is another polygon set to Conformal fill.



The exception to this rule is when relatively small Manhattan polygons are between conformal mesh polygons. In that case, the inefficiency of switching so frequently between staircase and conformal mesh outweighs the gain of using Manhattan polygons. In that case, conformal mesh should be applied to all the polygons. An example is shown below.

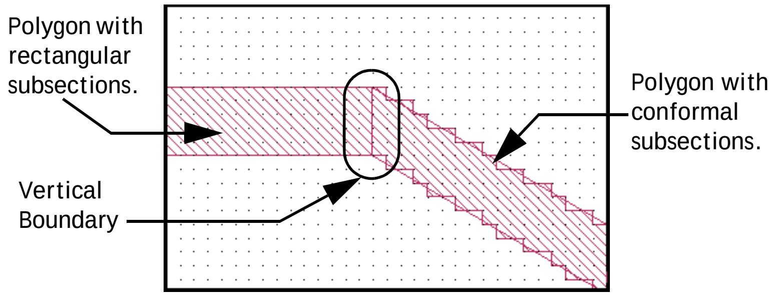
.

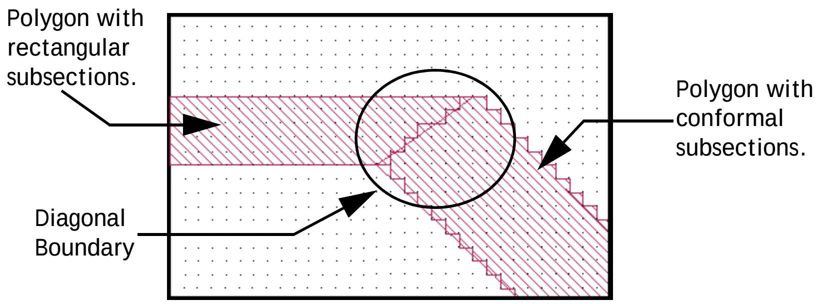


Normally, these polygons would use staircase fill, but because they are relatively small areas and in between polygons on which you would use conformal mesh, it is more efficient to apply conformal meshing to these Manhattan polygons.

Boundaries Should Be Vertical or Horizontal

For the most efficient results, the boundaries between polygons using conformal meshing and rectangular subsectioning should be vertical or horizontal as shown in the first picture below. Diagonal boundaries, as shown in the second picture, make the analysis less efficient.


Polygon with rectangular subsections.
Vertical Boundary
Polygon with conformal subsections.


Polygon with rectangular subsections.
Diagonal Boundary
Polygon with conformal subsections.

Cell Size and Processing Time

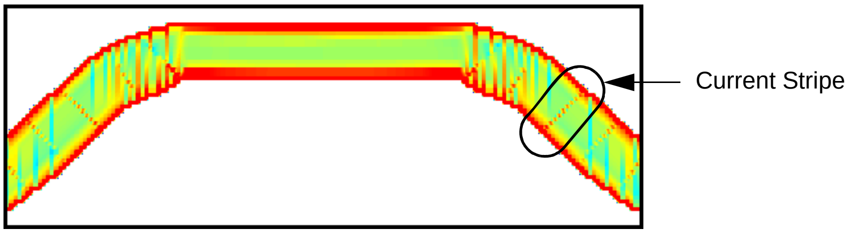
Care should be taken when choosing your cell size when using conformal mesh. Many users, especially experienced Sonnet users, will estimate processing time based on the amount of memory required to analyze a circuit. The amount of memory used for conformal mesh can be deceptive. Using a smaller cell size in a circuit which uses conformal mesh may not increase the required memory but will have a noticeable effect on processing time. The significant factor in determining processing time with conformal meshing is the number of metalized cells needed to construct a conformal section. The number of conformal mesh cells displayed as the result of the Estimate Memory command may be more reliably used as a guideline.

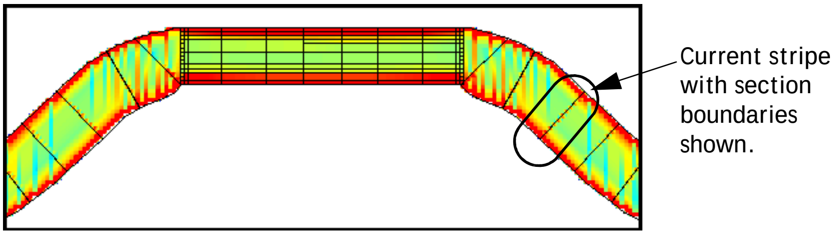
Current Density Viewing

You may view the current of circuits using conformal mesh just like any other circuit. However, the current density of conformal mesh polygons might show unusual "striping". These stripes do not represent real current, but are a by product of the conformal meshing algorithm.

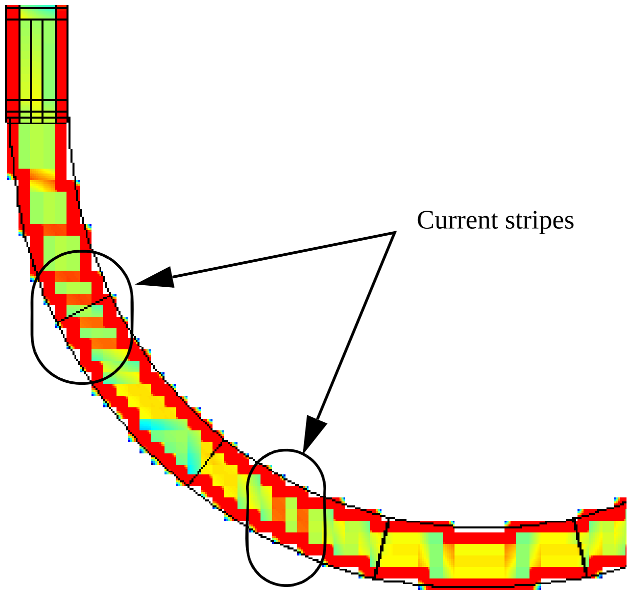
There are two types of current striping:

1 A single stripe of current can appear on the junction between two conformal sections as shown below.





2 Horizontal or vertical stripes may appear within a curved conformal section producing a "ripple" effect as shown below.



For a tutorial on using conformal meshing please see the “Conformal Mesh” topic under Tips and App notes in online help. You may access online help by selecting *Help* ⇒ *Contents* from the menu of any Sonnet application or by clicking on the Help button in any dialog box.

Chapter 13 Netlist Project Analysis

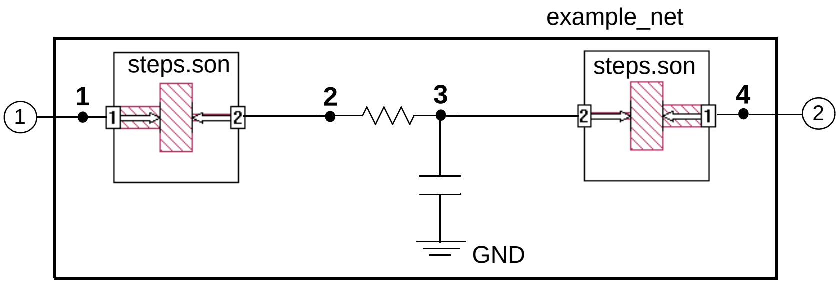
Netlist projects provide you with a powerful circuit analysis tool. Examples of ways in which the netlist may be used include:

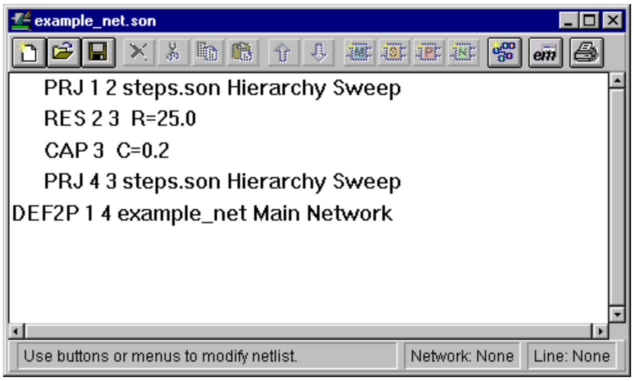
- **Cascading Sonnet projects:** You can analyze and combine multiple projects using previously existing data for the subprojects if it is available. This is particularly useful when analyzing large, complex circuits which require circuit subdivision for an em analysis. When analyzing a netlist project, em will automatically interpolate between frequencies if there are differences between the frequency sweeps used in the subprojects. It is also possible to impose the same frequency sweep on all the subprojects in a netlist. For more information about circuit subdivision, see Chapter 14, "Circuit Subdivision".

- **Cascading S-, Y- and Z- parameter data files:** You can read and combine multiple sets of S-, Y- and Z-parameter data files. This is particularly useful if you wish to combine results from another vendor's software for use in an analysis by em. When analyzing a netlist project, em will automatically interpolate between frequencies if there are differences in the frequencies between the data files.
- **Inserting modeled elements into a circuit.** Modeled elements, such as resistors, capacitors, inductors and transmission lines, can be combined with geometry subprojects and S-, Y- and Z-parameter data files.

Networks

A netlist project contains a netlist which consists of one or more networks with elements connected together. The netlist provides a map in which the ports of individual elements in the netlist are connected to the ports of other elements by the use of nodes. Nodes represent a connection between netlist elements.





```
    PRJ 1 2 steps.son Hierarchy Sweep
    RES 2 3  R=25.0
    CAP 3  C=0.2
    PRJ 4 3 steps.son Hierarchy Sweep
DEF2P 1 4 example_net Main Network
```

Use buttons or menus to modify netlist. | Network: None | Line: None

The picture above shows the network represented by the netlist shown in the project editor below it. The nodes are represented by the numbered black dots. The geometry project, steps.son, is connected between nodes 1 and 2 with node 1 corresponding to Port 1 in the geometry project and node 2 corresponding to Port 2. A resistor is connected between nodes 2 and 3. A capacitor is connected between node 3 and ground. The project steps.son is also connected between nodes 3 and 4, with Port 1 corresponding to node 4 and Port 2 corresponding to node 3. Port 1 of the network example_net corresponds to node 1 and port 2 of the network corresponds to node 4.

A netlist project is simply a list of these elements, as you can see in the netlist pictured above. Notice that the first number after the name of the element is the network node which corresponds to port 1 of the element, the second number is the network node which corresponds to port 2 of the element, and so on, for all the ports in an element.

Netlist Project Analyses

The sequence of steps for a netlist project analysis may be summarized as follows:

1 You input the netlist using the project editor in netlist mode. The project editor allows you to create and edit networks, network elements, project elements, modeled elements, and data file elements in your netlist. You also input the analysis controls which may include defining parameters in the netlist.

2 ***Em*** reads the netlist project which contains circuit and analysis control information. This includes S-, Y- and Z-parameter data files, modeled elements, geometry subprojects (project elements) and network elements.

3 ***Em*** uses the analysis controls input as part of the netlist project to run each electromagnetic analysis invoked by the network file. It is possible to configure the analysis controls in such a way that geometry subprojects are analyzed using their own analysis controls. Netlist subprojects always inherit their analysis controls from the present netlist.

4 Once the analysis of geometry subprojects is complete, ***em*** performs the circuit analysis specified in the netlist.

5 ***Em*** combines the electromagnetic results with the circuit results to obtain the desired output results.

Note that the above sequence of steps is generalized for analyses which include both electromagnetic and circuit analysis. In cases where the overall analysis is restricted to either electromagnetic analysis or circuit analysis, some of the steps are omitted.

Creating a Netlist

You create a netlist using the project editor. To create a new netlist, select *File ⇒ New Netlist* from the main menu of the project editor. The project editor tool bar and menus change for the netlist editor, to allow you to add elements and networks to your netlist.

The initial netlist file contains a default two-port network named Net. The last network in the netlist is the main network. The main network is the network whose solution you are solving for in this netlist. When you analyze the netlist, the response data produced in the analysis is for the main network.

You can edit the name and attributes of this network including the number of ports by double-clicking on the entry. This is true of all entries made in the netlist; you must double-click on them to open the dialog box which allows you to edit the entry or select the item, then select the *Tools* ⇒ *Modify* command from the main menu.

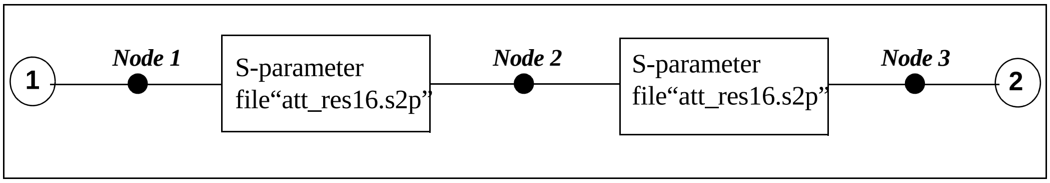
Netlist Example Files

All of the example files used in this chapter are available in the Att example in the Sonnet examples. You should copy the entire folder into your working directory if you wish to execute the examples. For directions on obtaining a Sonnet example, select *Help* ⇒ *Examples* from the menu of any Sonnet program, then click on the Instructions button.

Cascading S-, Y- and Z-Parameter Data Files

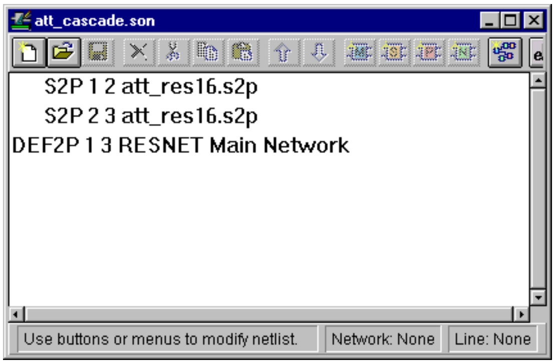
A particularly useful feature provided by a netlist project is the ability to cascade multiple S-, Y- and Z-parameter data files. There are no restrictions on the file formats which may be cascaded. For example, you can cascade ***em*** Z-parameter data in Touchstone format with measured S-parameter data in Super-Compact format. In addition, ***em*** can analyze at frequencies which are not included in the data files. ***Em*** automatically interpolates if there are any differences between the requested frequency points and those in the data files.

A good example of a cascading operation is the project att_cascade.son, which is included in the Att example for this chapter. A schematic representation of the two-port circuit is shown below. This circuit consists of two identical thin film resistors connected in series. The S-parameters from the geometry project analysis on the thin-film resistor are used as a data file element in the netlist. The desired output network is the series combination of resistors. The S-Parameter data file, att_res16.s2p, as well as the geometry project, att_res16.son, used to generate the data file, are included in the examples for this chapter.


1
Node 1
S-parameter file“att_res16.s2p”
Node 2
S-parameter file“att_res16.s2p”
Node 3
2

The two-port S-parameters contained in file “att_res16.s2p” are cascaded to obtain an overall set of two-port S-parameters.

The netlist, att_cascade.son, for the circuit is pictured below.



```
    S2P 1 2 att_res16.s2p
    S2P 2 3 att_res16.s2p
DEF2P 1 3 RESNET Main Network
```

The main network, Resnet, has two ports indicated by the “2” in DEF2P. Port 1 corresponds to node 1 in the network. Port 2 corresponds to node 3. There are two data file elements in the network. The first entry is the response file att_res16.s2p with 2 ports. Port 1 corresponds to node 1 of the network, which, as mentioned above, is port 1 of the whole circuit. Port 2 for the data file corresponds to node 2 of the network. The other entry is also for the data file att_res16.s2p except that port 1 of the data file goes to node 2 of the network which means that port 1 of the second data file is connected to port 2 of the first data file. Port 2 of the second data file corresponds to node 3 of the network. Node 3 of the network is Port 2 of the network “RESNET”.

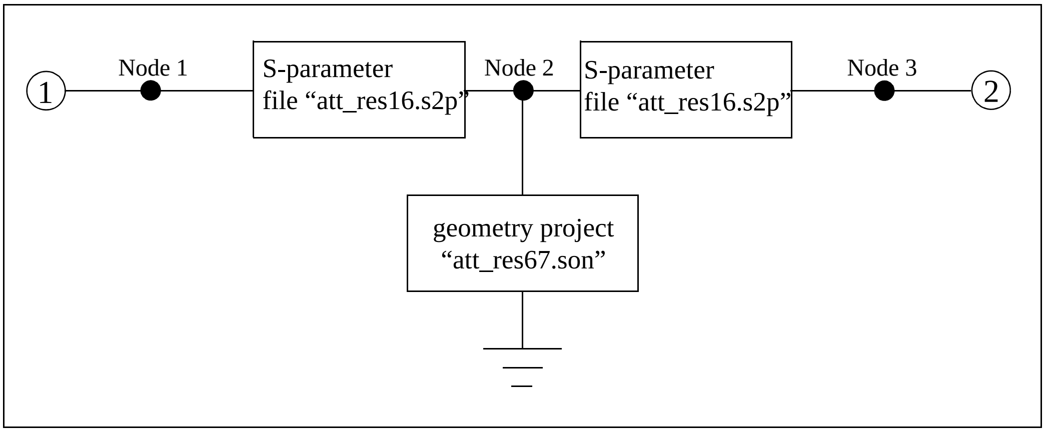
The S-Parameters for an analysis of the netlist are shown below.

```
Frequency:  200 MHz
50-Ohm S-Params. Mag/Ang. Touchstone Format. (S11 S21 S12 S22).
200.000000 0.250782 -5.309 0.748778 -6.263 0.748778 -6.263 0.250782 -5.309

Frequency:  300 MHz
50-Ohm S-Params. Mag/Ang. Touchstone Format. (S11 S21 S12 S22).
300.000000 0.250310 -7.963 0.748702 -9.395 0.748702 -9.395 0.250310 -7.963

Frequency:  400 MHz
50-Ohm S-Params. Mag/Ang. Touchstone Format. (S11 S21 S12 S22).
400.000000 0.249650 -10.62 0.748595 -12.53 0.748595 -12.53 0.249650 -10.62
```

A Network File with Geometry Project

The next example demonstrates a netlist project analysis which invokes a geometry project analysis in conjunction with using previously generated data.

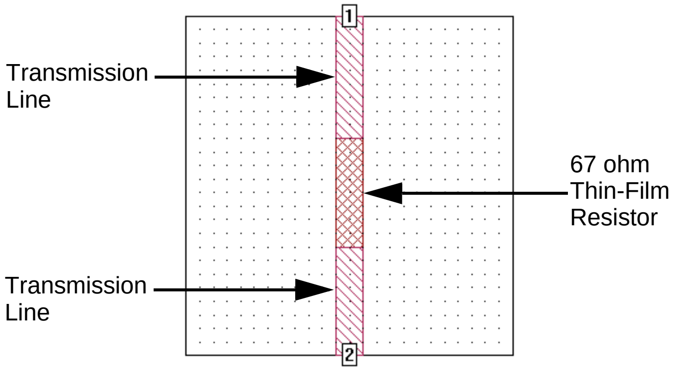
To demonstrate a netlist with a geometry project, the two-port T-attenuator shown below will be analyzed.



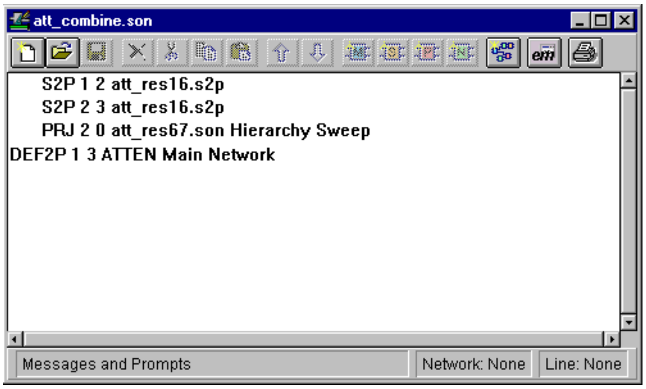
1
Node 1
S-parameter file "att_res16.s2p"
Node 2
S-parameter file "att_res16.s2p"
Node 3
2
geometry project "att_res67.son"

The two-port T-attenuator will be analyzed with *em* to demonstrate a combined electromagnetic/circuit analysis.

Pictured below is the geometry project “att_res67.son”, which is a 67 ohm thin-film resistor. This project is read by ***em*** and analyzed during the netlist analysis. The results of the project analysis are used to compute the results for the netlist.



The netlist project, att_combine.son is shown below. The project att_combine.son is available as part of the Att example for this chapter.



```
    S2P 1 2 att_res16.s2p
    S2P 2 3 att_res16.s2p
    PRJ 2 0 att_res67.son Hierarchy Sweep
DEF2P 1 3 ATTEN Main Network
```

The primary distinction between the netlist shown above and the previous netlist is that this netlist contains an instruction to perform a project analysis. The PRJ keyword instructs ***em*** to run an electromagnetic analysis on the project “att_res67.son” using the analysis controls from the netlist. The analysis control use is indicated by “Hierarchy Sweep” in the PRJ statement. When control is set to “Hierarchy Sweep”, ***em*** automatically analyzes the subproject at the same frequency sweep and run options as the netlist.

During the analysis, ***em*** performs the following steps:

1 Reads S-parameter data from the file “att_res16.s2p”.

2 Performs an electromagnetic analysis of the geometry project “att_res67.son”, a 67 ohm thin-film resistor.

3 Combines the S-parameter results from the electromagnetic analysis with the S-parameter results from "att_res16.s2p" to obtain an overall set of S-parameters for the T-attenuator.

TIP

Before executing a PRJ statement, ***em*** checks for the existence of data at the specified control frequencies. If the data already exists, and the project has not changed since the data was generated, ***em*** does not execute an electromagnetic analysis, but uses the available data.

The listing below shows the output of the netlist analysis, as it appears in the analysis monitor, which contains the overall set of S-parameters for the T-attenuator.

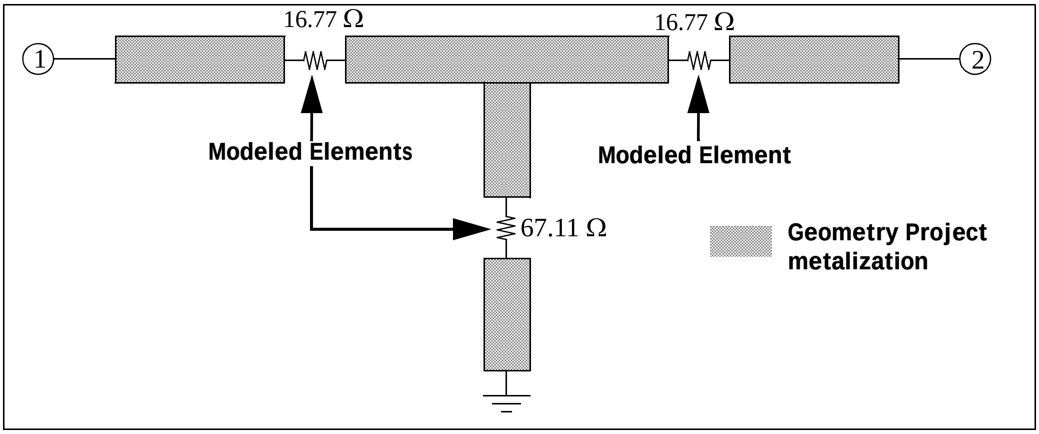
```
Frequency:  200 MHz
50-Ohm S-Params. Mag/Ang. Touchstone Format. (S11 S21 S12 S22).
200.000000 0.008924 67.700 0.500516 -5.758 0.500516 -5.758 0.008924 67.700

Frequency:  300 MHz
50-Ohm S-Params. Mag/Ang. Touchstone Format. (S11 S21 S12 S22).
300.000000 0.013072 68.918 0.501160 -8.647 0.501160 -8.647 0.013072 68.918

Frequency:  400 MHz
50-Ohm S-Params. Mag/Ang. Touchstone Format. (S11 S21 S12 S22).
400.000000 0.017177 67.763 0.502055 -11.54 0.502055 -11.54 0.017177 67.763
```

Inserting Modeled Elements into a Geometry

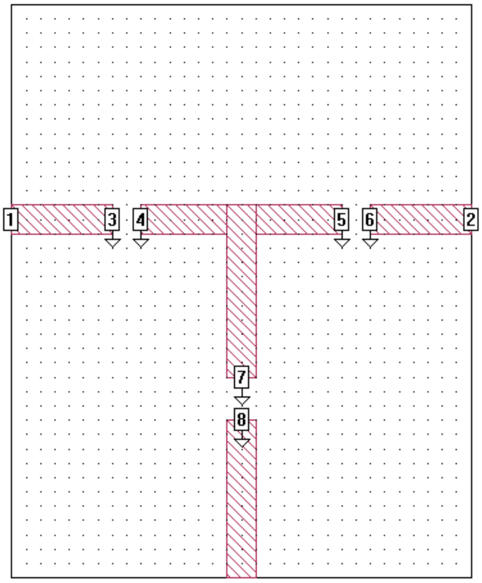
Another very useful feature of the netlist project is the ability to insert modeled elements into a geometry project after an electromagnetic analysis has been performed on that circuit. A modeled element is an ideal element such as a resistor, inductor, capacitor or transmission line, which has a closed-form solution. No electromagnetic analyses are performed on modeled elements.

To demonstrate the use of modeled elements, we will again analyze the T attenuator. However, instead of the attenuator being the result of connecting the results of electromagnetic analyses as shown previously in the chapter, in this case, the geometry project, att_lgeo.son, has the full attenuator with cutouts where the modeled elements need to be inserted. The three resistors will not be analyzed as part of the geometry project, but will be inserted as modeled elements in the netlist. The figure below shows the circuit layout with the modeled resistor elements. A geometry project for the transmission line structures are created first. A netlist project will then be used to insert the three resistors and calculate two-port S-parameters for the overall circuit.

To accomplish this task, it is necessary to create a geometry project with the transmission line structure and three “holes” where modeled elements will eventually be inserted. The figure on page 194 shows such a geometry project. Here, pairs of auto-grounded ports have been placed on the edges of each modeled element “hole”. When the modeled elements are inserted later on, each is connected across the corresponding pair of auto-grounded ports. Note that under certain conditions, ungrounded-internal ports can be used instead of auto-grounded ports. See “Using Ungrounded-Internal Ports,” page 195, for details.

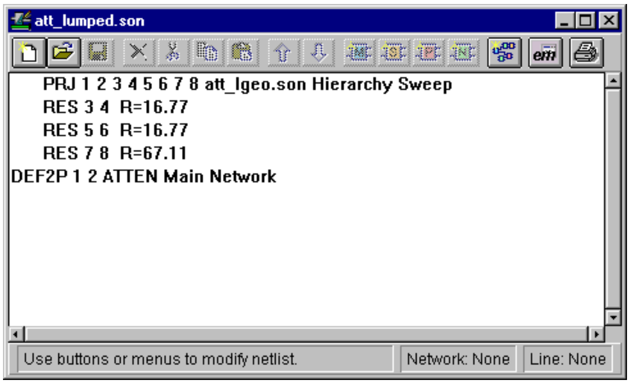


The two-port T attenuator will be re-analyzed to demonstrate the use of modeled elements.



The geometry file "att_lgeo.son" contains three sets of auto-grounded ports placed at locations where modeled elements will eventually be inserted. This file is available as part of the Att example used for this chapter.

Below is the netlist, att_lumped.son, that will be used for this example.



```
    PRJ 1 2 3 4 5 6 7 8 att_lgeo.son Hierarchy Sweep
    RES 3 4  R=16.77
    RES 5 6  R=16.77
    RES 7 8  R=67.11
DEF2P 1 2 ATTEN Main Network
```

Use buttons or menus to modify netlist. | Network: None | Line: None

The netlist above instructs ***em*** to perform the following steps:

1 Perform an electromagnetic analysis on the geometry file "att_lgeo.son" using the Frequency sweep and run options defined for this netlist. Note that according to the PRJ line, Ports 1-8 correspond to nodes 1-8 respectively in the main network, atten. The node numbers are listed after the PRJ keyword in the order of ports in the circuit.

2 Insert a 16.77 ohm resistor between nodes 3 and 4 which is the equivalent of inserting the resistor between autogrounded ports 3 and 4 in the geometry project.

3 Insert a 16.77 ohm resistor between nodes 5 and 6.

4 Insert a 67.11 ohm resistor between nodes 7 and 8.

5 Calculate an overall set of S-parameters for the T attenuator.

The two projects, att_lgeo.son and att_lumped.son are available in the Att example for this chapter.

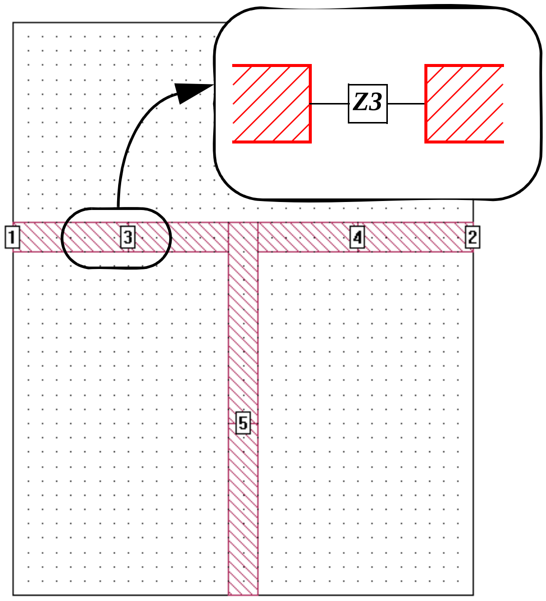
The listing below is the analysis output as it appears in the analysis monitor. Note that these results are similar to the results given above for distributed elements.

```
Frequency:  200 MHz
50-Ohm S-Params. Mag/Ang. Touchstone Format. (S11 S21 S12 S22).
200.000000 0.007889 66.619 0.500390 -4.888 0.500390 -4.888 0.007889 66.619

Frequency:  300 MHz
50-Ohm S-Params. Mag/Ang. Touchstone Format. (S11 S21 S12 S22).
300.000000 0.011495 69.396 0.500788 -7.336 0.500788 -7.336 0.011495 69.396

Frequency:  400 MHz
50-Ohm S-Params. Mag/Ang. Touchstone Format. (S11 S21 S12 S22).
400.000000 0.015119 69.443 0.501342 -9.787 0.501342 -9.787 0.015119 69.443
```

Using Ungrounded-Internal Ports

In the example presented above, a pair of auto-grounded ports was placed at each location in the ***em*** circuit layout where a modeled element would eventually be inserted. It is also possible to perform the same analysis using ungrounded-internal ports, because each resistor in this example is a series modeled element without access to ground. Any time access to ground is not required for a modeled element, you can replace the pair of auto-grounded ports with a single ungrounded-internal port.

The figure below shows a geometry project for the T attenuator with ungrounded-internal ports at each modeled element location. Note that the gaps between polygons at these locations have been removed. This is because you must attach ungrounded-internal ports between two abutted polygons. This slightly impacts the overall performance of the attenuator.



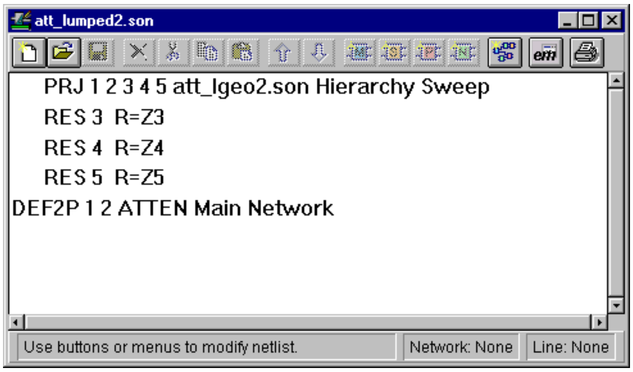
The geometry project "att_lgeo2.son" uses ungrounded-internal ports at locations where modeled elements will eventually be

The network file shown below connects the desired resistors across the ungrounded-internal ports of the network shown on page 196. Since ungrounded-internal ports do not have access to ground, only a single node is specified when connecting an element across them.

WARNING

Ungrounded-internal ports have one terminal connected to an edge of a polygon and the second terminal connected to an abutted edge of a second polygon. Ungrounded-internal ports do not have access to ground. Therefore, only 1-port elements or 1-port networks may be connected across ungrounded-internal ports. Resistors, capacitors, and inductors are technically one-port elements and therefore, may be inserted in place of an ungrounded-internal port in a netlist.

The netlist for this circuit, att_lumped2.son, is shown below. Both the geometry project, att_lgeo2.son, and this netlist are available in the Att example provided for this chapter.



```
    PRJ 1 2 3 4 5 att_lgeo2.son Hierarchy Sweep
    RES 3  R=Z3
    RES 4  R=Z4
    RES 5  R=Z5
DEF2P 1 2 ATTEN Main Network
```

An important feature to notice in this netlist is the use of parameters. Three parameters, Z3, Z4 and Z5 have been defined in the netlist project and their values used for the three resistor modeled elements. Parameters are defined in a netlist by selecting *Circuit* ⇒ *Parameters* from the main menu, then entering the parameter name and nominal value in the Parameters dialog box which appears. Z3 and Z4 are equal to 16.77 and Z5 is equal to 67.11.

The listing below shows the S-parameter results obtained from the analysis with ungrounded-internal ports. These results are very similar, but not identical, to the results for auto-grounded ports. The differences are primarily due to the change in the gap size between polygons at the points where lumped elements are inserted.

```
Frequency:  200 MHz
50-Ohm S-Params. Mag/Ang. Touchstone Format. (S11 S21 S12 S22).
200.000000 0.009217 68.496 0.500482 -5.785 0.500482 -5.785 0.009217 68.496

Frequency:  300 MHz
50-Ohm S-Params. Mag/Ang. Touchstone Format. (S11 S21 S12 S22).
300.000000 0.013510 70.114 0.500994 -8.683 0.500994 -8.683 0.013510 70.114

Frequency:  400 MHz
50-Ohm S-Params. Mag/Ang. Touchstone Format. (S11 S21 S12 S22).
400.000000 0.017788 69.364 0.501707 -11.59 0.501707 -11.59 0.017788 69.364
```

Chapter 14 Circuit Subdivision

Introduction

Sonnet provides the capability to take a large circuit and split it into any number of smaller projects, then connect the results in a netlist project to produce a response for the whole circuit. This method can significantly reduce the required processing time and memory necessary to analyze the circuit while still obtaining an accurate answer.

The number of subsections in a circuit is one of the most important factors in determining processing time since the matrix solve time is proportional to N^3. To illustrate how circuit subdivision reduces processing time, consider two subprojects each with half as many subsections as the source project. The total matrix solve time is now four times faster:

$$2(N/2)^3 = N^3/4$$

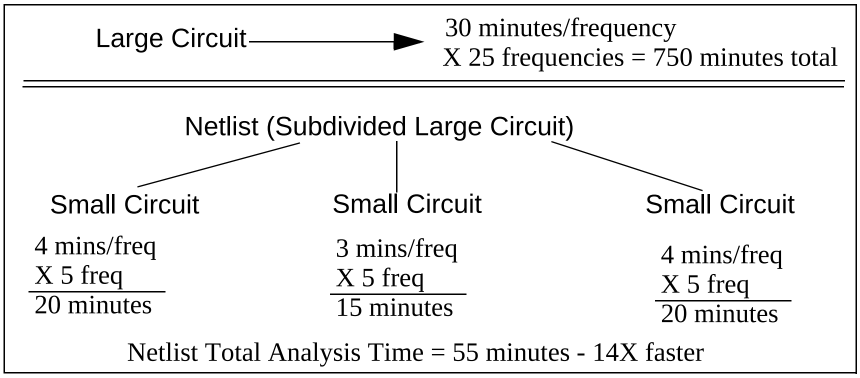
Circuit subdivision allows you to take advantage of this technique by breaking your circuit into smaller parts with fewer subsections, hence, requiring less processing time and memory to analyze. The trade off is that you introduce some error into the analysis. However, by subdividing the circuit appropriately you can minimize the error while still obtaining the reduction in processing time.

The circuit should be split where there is no coupling across the subdivision line. Areas where significant coupling occurs must be contained within a subproject. In this way, all the significant coupling in the circuit is accounted for. If care is taken when subdividing the circuit, the accuracy of the results is very high.

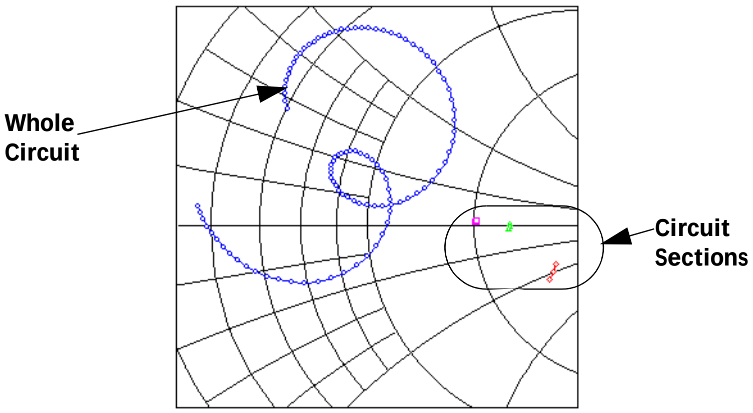
Circuit subdivision is not appropriate for every design, but in the cases of large circuits (5-10 minutes processing time per frequency) where it is applicable, you can obtain marked increases in processing efficiency.

Another advantage of circuit subdivision is the use of frequency interpolation in the master netlist analysis. A netlist is used to connect the response data of the subprojects of the circuit to simulate the full circuit. If the subprojects are chosen in such a way that their response data does not vary significantly over the frequency band, very few frequency points need to be calculated for the subproject. So not only do the smaller files require less time and memory because of their smaller size, but you can also analyze these smaller circuits at fewer frequency points. Interpolating in the netlist file requires much less processing than calculating data for a frequency point in a geometry project.

Shown below is an example showing the typical advantages of using this approach.



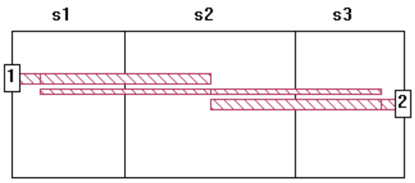
When the netlist analysis is performed, ***em*** will interpolate to provide simulation data at frequencies not specified in the subprojects. Each subproject should be analyzed at the same minimum and maximum frequency as the overall analysis and at enough points in between to provide for reasonable interpolation of data at frequencies which fall between these values. As you can see from the Smith chart below, while you need many frequency points to obtain reasonable response data for the whole circuit, you need far fewer frequency points to obtain accurate data for the smaller pieces of the whole circuit, whose response data does not vary appreciably.



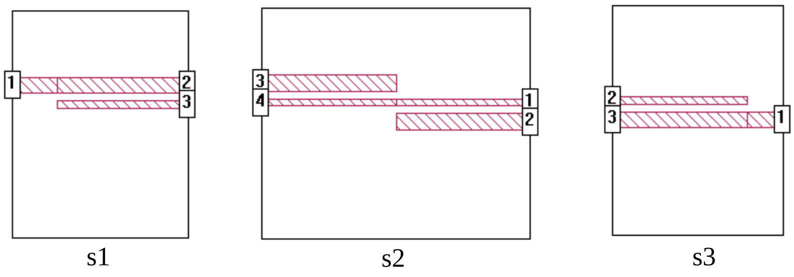
Be aware, however, that in some cases, you may need the added precision of analyzing all the pieces at the same resolution of the frequency band. Interpolation is best used when the response of a subproject varies little over the frequency band and the analysis time of the subproject is appreciable.

Circuit Subdivision in Sonnet

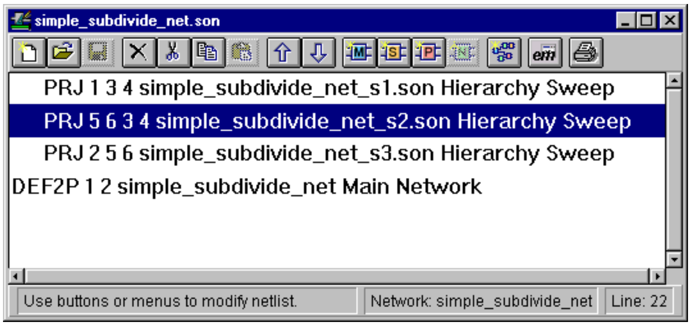
Circuit subdivision in Sonnet allows you to insert subdivision lines in your geometry in the project editor. These subdivision lines create the sections from which the subdivide command makes geometry subprojects. When you select the subdivide command, the software creates a main netlist file and the geometry subprojects. The main netlist connects the subprojects so that the response data for the netlist may be substituted for the response data of the source project.



Source Circuit with Subdivision Lines Added



Generated Subprojects



PRJ 1 3 4 simple_subdivide_net_s1.son Hierarchy Sweep
PRJ 5 6 3 4 simple_subdivide_net_s2.son Hierarchy Sweep
PRJ 2 5 6 simple_subdivide_net_s3.son Hierarchy Sweep
DEF2P 1 2 simple_subdivide_net Main Network

Use buttons or menus to modify netlist. | Network: simple_subdivide_net | Line: 22

Generated Main Netlist

You should also be aware that if your main circuit contains any parameters or dimensions, they are removed during the subdivision process. After the subprojects are created, you may enter parameters in any of the geometries. In fact, it is possible to run optimizations on the main netlist project using a parameter in one of the subprojects.

Performing circuit subdivision as a method of analysis should, in general, be done as follows:

1 You should input as many of the circuit properties as possible before subdividing. Dielectric layers, dielectric brick and metal types, grid size, top cover height, etc. are inherited by the created geometry subprojects.

2 Decide where to subdivide your circuit. This step often requires expertise and experience to avoid splitting the circuit at a junction where there is coupling across the subdivision line.

3 Create the subdivision lines in the project editor. These lines are used to create the subprojects. A geometry project is created for each segment of your circuit. These geometry projects contain significantly smaller geometries that may be analyzed faster using less memory.

4 If you plan to take advantage of the netlist interpolation feature, set up the analysis frequency controls as a coarse resolution of the entire desired frequency band in the project before subdividing. Both the netlist and geometry subprojects all inherit these frequency specifications. Entering these frequency controls now in the Analysis Setup dialog box saves having to enter them in each individual subproject.

5 Subdivide the circuit in the project editor to create the subprojects and netlist project which connects the individual subprojects in a network equivalent to the circuit as a whole. Ports and reference planes are added to the subprojects as needed to connect to the larger circuit.

6 Edit the subprojects to fine tune the geometries, if needed. Possible adjustments would include the use of a binary box, adjusting the grid size, setting z-partitions for bricks, changing the frequency sweep specification, and adding parameters.

TIP

If you add parameters to a subproject in a netlist, the parameters are not automatically displayed in the netlist. You must save the main netlist and re-open it to display the parameters and make them available for editing.

7 Set up the analysis controls in the netlist to use the complete set of desired analysis frequencies if the subprojects are already set to analyze the coarse frequency sweep. When the analysis is performed on the master netlist project, ***em*** interpolates between the frequency points in the subprojects, saving processing time.

You may also use a Hierarchy Sweep in which the frequency band set up in the master netlist is imposed on the analyses of all the subprojects. This is useful when additional accuracy is needed in the data and you do not wish to use interpolation. This is accomplished by setting the Hierarchy Sweep option in the Analysis Setup dialog box in the project editor.

8 Analyze the netlist project. The data response for the netlist project provides analysis results that may be used for the whole circuit.

9 It is often a good idea after analyses are complete on the resultant sub-projects to check the response data to verify that data was calculated for enough frequency points to provide accurate interpolated data.

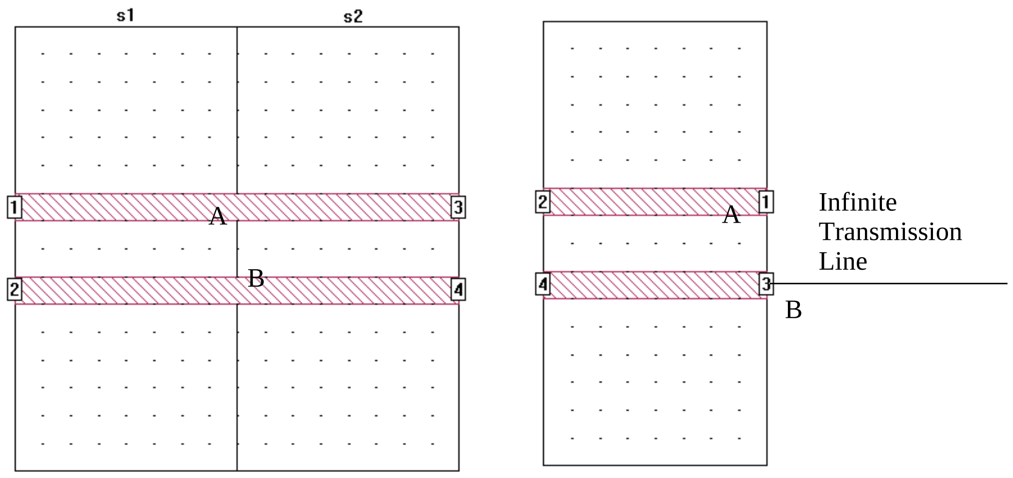
Since it is possible for a netlist project to include a netlist subproject, it is possible to use "double" subdivision. After subdividing your initial circuit, you then may use subdivision on one of the resulting geometry subprojects. In this case, you would need to change the name on the appropriate PRJ line from the old geometry subproject to the new netlist subproject.

Choosing Subdivision Line Placement

As mentioned above, the difficult part in using circuit subdivision is to decide where to place your subdivision lines to split the circuit. The subdivision lines should be placed between polygons which have negligible coupling. Places on the circuit where a high degree of coupling or rapidly varying currents are present should be kept within an individual subproject.

The de-embedding of the port discontinuity in Sonnet is done by essentially modeling infinitely long transmission lines at the port. This allows transmission lines to be subdivided with very little loss of accuracy. This includes microstrip lines, stripline, and coupled lines including coplanar. This point is illustrated below.

The circuit shown below, on the left, consists of a coupled transmission line. This is too simple a circuit to require subdivision but is very useful in demonstrating the principle. When subdivided, the circuit is split into two subprojects both of which would resemble the circuit shown on the right. Since the port discontinuity is modeled as an infinite transmission line when the port is de-embedded the coupling between points A and B is accounted for.

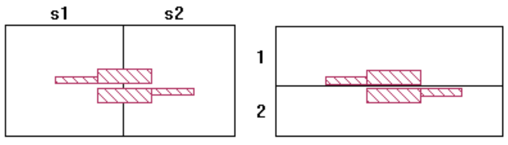


It is important to avoid areas where there is coupling across the subdivision line. Subdivision lines should not split any diagonal polygon edges. Illustrated below are good placements and bad placements of subdivision lines.

Good and Bad Placements of Subdivision Lines

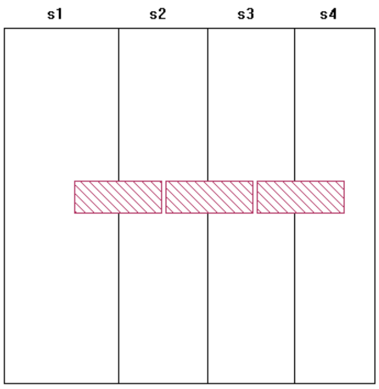
This section contains a series of illustrations each showing the good placement of a subdivision line in a circuit and its counterpart showing a bad (and in some cases illegal) placement of a subdivision line. Setting a subdivision line perpendicular to one or more transmission lines provides a good general guideline for line placement.

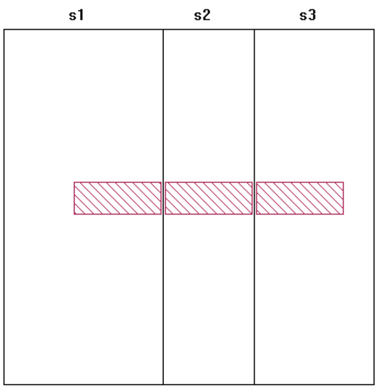
The first example is a pair of coupled lines. As explained above, when you split coupled lines as on the left, very little loss of accuracy results. However, on the right, you have split the coupled pair along the axis where significant interaction takes place. The subprojects have no way to account for this coupling and will produce bad data.



Good Bad

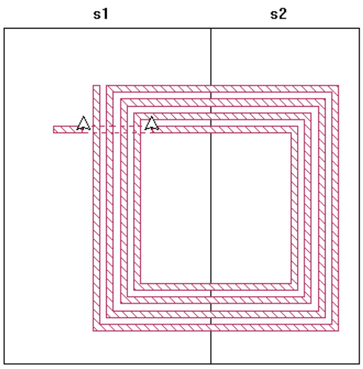
The second example shows how to split a series of resonators. In this type of structure, there is strong coupling at the gaps between adjacent resonators. The example on the left is good since the subdivision lines do not prevent this inter-resonator coupling. The example on the right is incorrect since the resulting subprojects do not contain the inter-resonator coupling.

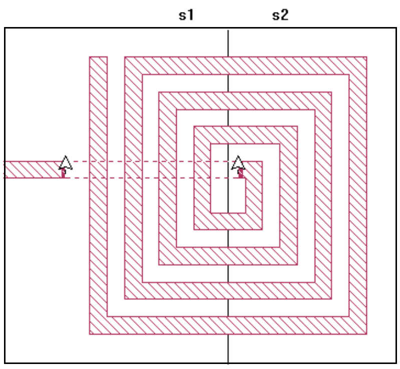




Good Bad

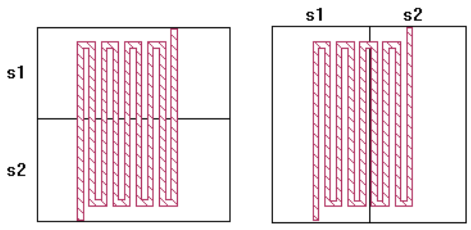
The third example shows a square spiral. The example on the left is a good placement since the location where the spiral is divided is essentially a group of coupled transmission lines and the subdivision line is perpendicular to those lines. Here, the left side of the spiral is sufficiently far from the right side so that coupling is negligible. The example on the right is bad because the lines on the left side of the spiral do couple strongly with the lines on the right side.





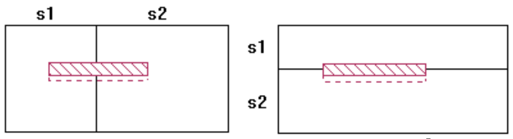
Good Bad

The meander line on the left is split in such a way that Sonnet provides an accurate answer since the bends on the top are far enough away from the bends on the bottom that coupling between them is negligible. The example on the right provides an inaccurate result because the coupling between two close transmission lines is eliminated by the subdivision.



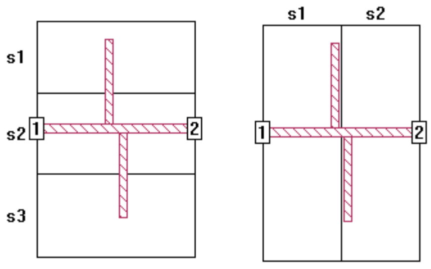
Good Bad

The circuit shown below has coupled transmission lines on two different layers. Once again, it is correct to place a subdivision line perpendicular to the transmissions lines, but not parallel to them. Subdivision is valid for multi-layer structures as long as the coupling across the subdivider is negligible.



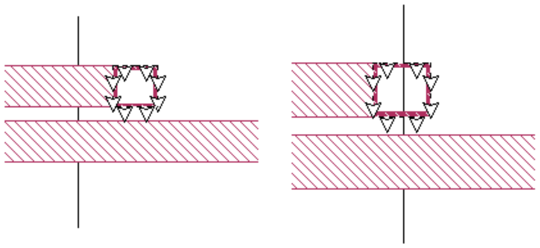
Good Bad

In the double stub circuit shown on the left, the subdivision lines split the polygon perpendicular to the direction of current flow and far from any discontinuities. The circuit on the right however, shows the subdivision line splitting the bases of the two stubs which may be coupled.



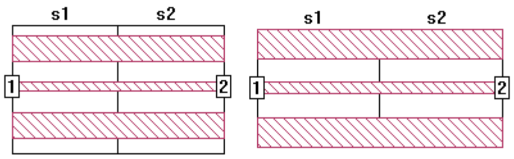
Good Bad

The subdivision line shown in the circuit on the right is wrong since the circuit is split in the middle of a via between layers. In general, subdivision lines should never be placed on top of discontinuities, such as vias. The subdivision line on the left is the correct placement.



Good Bad

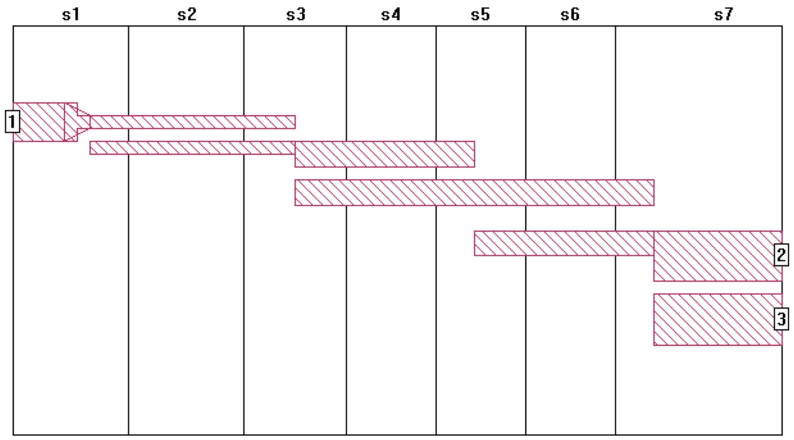
The subdivision line shown in the circuit on the right splits a polygon at the box wall which is an illegal placement for a subdivision line. It is illegal to subdivide polygons grounded to the box walls since such polygons do not behave like transmission lines. Also, the new ports added during the subdivide would be shorted to the boxwall. The circuit on the left is correct since there is no contact between the top and bottom polygons with the top and bottom box wall.



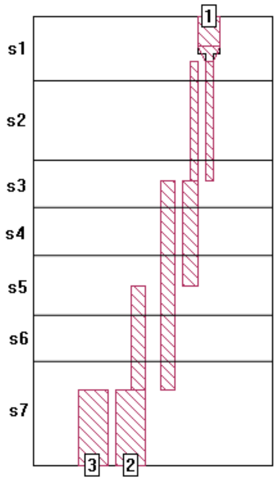
Good Bad

Subdivision Line Orientation

Subdividers may split the circuit on a horizontal axis or a vertical axis, but you may not mix orientation. Choosing the direction in which you split your circuit is dependent upon the structure of your circuit. Shown below is a typical circuit in which you would use the vertical orientation and another example in which you would use the horizontal orientation.



Example of Vertical Subdividers



Example of Horizontal Subdividers

You may use both orientations by using double subdivision mentioned earlier. The first time you subdivide your main circuit you choose an orientation for your subdivision lines. Then use circuit subdivision on the resulting geometry sub-projects, this time using the opposite orientation for your subdivision lines.

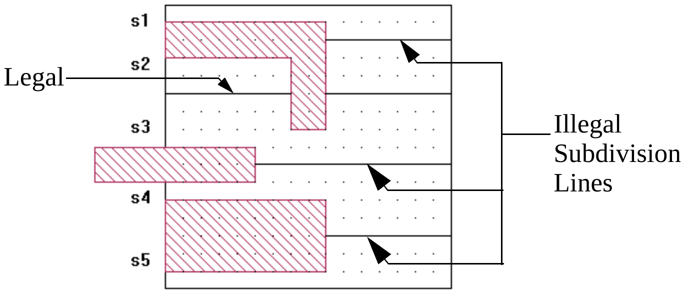
Before adding subdividers to your geometry project, you should ensure that specification of your circuit is complete. Subprojects created when you execute the subdivision inherit their properties from the source project. Such properties as cell size, metal types, properties of the dielectric layers, dielectric bricks, metal levels, etc. are all used in the resultant subprojects.

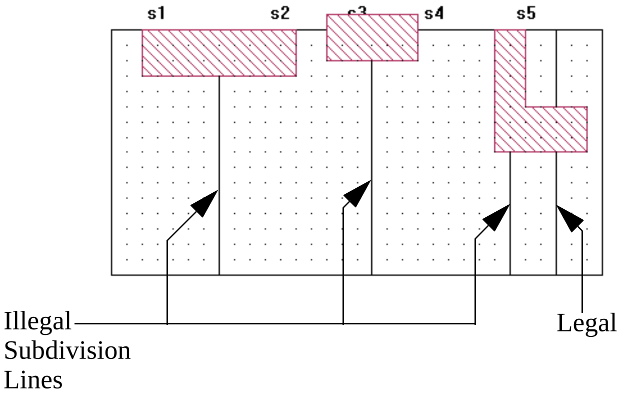
When you place a subdivider in your circuit, a line representing the subdivider appears in the horizontal or vertical plane running through the point at which you clicked. The resultant sections of the circuit are automatically labeled. Subdivision sections are labeled from left to right, or top to bottom, depending upon orientation. These labels are always sequential and are non-editable.

Once a subdivider has been added to your circuit, you may edit the subdivider as you would any other object in your geometry. You may click on the subdivider and move it. You may also control the display and selection of the subdivider lines and labels in the Object Visibility dialog box and the Selection Filter dialog box.

The following are illegal conditions for subdivision lines:

- May not be off grid.
- Should not be placed where there is coupling across the subdivision line.
- May not be colinear with polygon edges.
- May not split a diagonal polygon edge.
- May not split a port.
- May not be below the line of symmetry.
- May not split a polygon at a box wall. See the picture below.





Once you have completed adding all the desired subdividers to your circuit, you must save the project before performing the subdivision.

Setting Up Circuit Properties

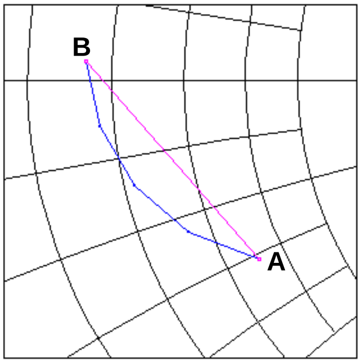
Since the geometry subprojects created by the subdivide inherit their properties from the source project, you should complete entering all the desired attributes for your circuit before performing the subdivide. This includes such things as defining the dielectric layers (which includes the height of the box top), top and bottom box metals, metal and dielectric brick materials, cell size and box size. This saves the effort of having to enter these values in each of the subprojects.

Setting Up the Coarse Step Size Frequency Sweep

If you plan to use interpolation to obtain response data when analyzing the master netlist project, you should input the coarse frequency sweep at which you wish to analyze the geometry subprojects before subdividing the circuit. These frequencies should cover the same frequency range as the analysis frequencies for the whole circuit but use a coarser step size. The subprojects should be analyzed at the same minimum and maximum frequency as the overall analysis and at enough points in between to provide for reasonable interpolation of the response.

By inputting the coarse frequency sweep prior to subdivision, the master netlist and geometry subprojects created by the subdivide command will all inherit the analysis setup. After subdividing, you will need to enter the desired finer frequency step size in the master netlist project before analyzing it. In addition, you will need to turn off Hierarchy Sweep.

The figure below shows a Smith chart with a circuit analyzed at five frequency points, next to the same circuit analyzed at only two points. As you can see, using only two data points would result in more interpolating error than using five data points. Whether or not two data points is acceptable depends upon the proximity of points A and B. If A and B are very close, then two data points are sufficient. If A and B are far away, then five or more data points should be used.



It is always a good idea to check the Smith chart for the response data of your subprojects to ensure that you have chosen enough frequency points at which to calculate data so that any interpolated data is reasonably accurate.

Subdividing Your Circuit

The actual subdividing of your circuit into separate geometry subprojects and a master netlist project is performed by the software. You enter the desired names for the master netlist and geometry subprojects. You may also automatically add feedlines of lossless metal to any ports generated in the subprojects.

Feedlines should be added when discontinuities contained in sections of your source circuit need to be moved away from the boxwall to prevent interaction between the boxwalls and the discontinuity. The use of feedlines are optional; if you choose to add a feedline, you may use the suggested length calculated by the software or input your own value. By default, the software creates feedlines using the suggested length.

When the subdivide is executed, Sonnet creates a geometry subproject for each section of the circuit in which you placed the subdividers. It also creates a master netlist that connects the geometry subprojects together to produce an equivalent circuit for the original geometry project that you subdivided.

Each of the geometry subprojects uses the properties of the original circuit: cell size, dielectric layers, dielectric and metal materials, analysis setup, etc. Therefore, all the geometry subprojects contain the same analysis setup with the same analysis frequencies specified.

Analyzing Your Subdivided Circuit

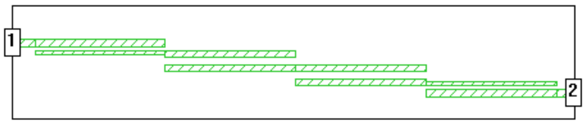
To obtain the desired response data, edit the analysis setup for the master netlist so that all of the desired analysis frequencies are specified. Each of the geometry subprojects are set up with the coarser resolution of analysis frequencies. When the netlist is analyzed, ***em*** runs the geometry project analyses first to produce response data for each part of the network. Then the analysis of the whole network is executed. Em interpolates to produce data for frequency points in between those available from the analysis of the geometry subprojects.

If properly subdivided, the results of the netlist analysis should provide an accurate solution for your difficult to handle circuit using fewer resources. The use of circuit subdivision is demonstrated in Chapter 15 "Circuit Subdivision Tutorial" on page 215.

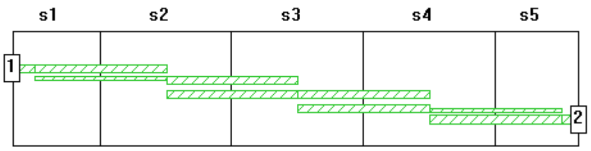
Chapter 15 Circuit Subdivision Tutorial

This tutorial walks you through how to add subdivision lines, subdivide your circuit, and analyze the final netlist. The results of this subdivision are compared to the analysis of the complete circuit in order to demonstrate the accuracy of the results of the subdivision and the savings in memory. For a detailed discussion of circuit subdivision and the use of subdividers, please refer to Chapter 14 .

The circuit, an edge-coupled microstrip bandpass filter, is a fairly simple example of a circuit which you might decide to subdivide. In addition, it is not a very good filter design. This circuit was chosen for the purposes of clarity in explaining circuit subdivision.



You will use four vertical subdivision lines to split the circuit into five sections as shown below.

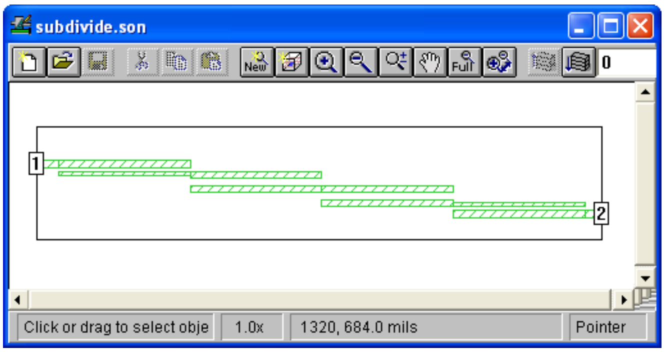


Obtaining the Example File

You use the example file, subdivide.son, for this example. You can obtain a copy of this file from the Sonnet Examples. If you do not know how to obtain a Sonnet example, select *Help* ⇒ *Examples* from any program menu, then click on the **Instructions** button. If you are reading this in PDF format, click on the link above.

1 **Open the project subdivide.son in the project editor.**

The circuit appears as shown below.



Click or drag to select obje | 1.0x | 1320, 684.0 mils | Pointer

Adding the Subdivision Lines

The first step in subdividing a circuit, as discussed in "Choosing Subdivision Line Placement" on page 204, is to place the subdivision lines that indicate where you wish to split your circuit. Subdivision lines should be placed in locations where there is negligible coupling across the lines. The best place to put subdivision lines in the example used here is at points in the circuit on the coupled lines as far from the discontinuities as possible. Therefore, a vertical subdivision line will be placed in the middle of each coupled pair of polygons.

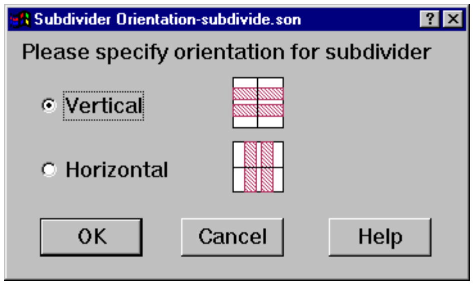
Each coupled pair of polygons is 595 mils in the x direction. Subdivision lines must be placed on the grid. The closest value to halfway which still remains on the grid is 295 mils. For the first subdivider, you must take into account the feedline polygon which is 100 mils in length. Therefore, the first subdivision line should be placed at 100 mils + 295 mils = 395 mils from the left box wall.

2 **Select *Tools* ⇒ *Add Subdivider* from the project editor menu while holding down the shift key.**

TIP

Holding down the shift key allows you to enter multiple subdivision lines without having to select the command multiple times.

Since there were no subdivision lines in the circuit when you selected the Add Subdivider command, the Subdivider Orientation dialog box appears on your display.


Subdivider Orientation-subdivide.son

Please specify orientation for subdivider

[✓ Vertical]

Horizontal

All subdividers in your circuit must have either a vertical (up-down) orientation or a horizontal (left-right) orientation on the substrate.

3 **Click on the vertical radio button to select the vertical orientation for your subdividers.**

This sets the orientation for all subdividers subsequently added to your circuit.

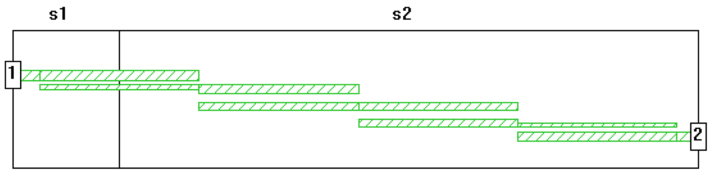
This dialog box does not appear again if you select *Tools* ⇒ *Add Subdivider*. The new subdivider assumes the same orientation. If all the subdividers are deleted from a circuit, then when the Add Subdivider command is used again, this dialog box appears.

4 **Click on the OK button to apply your selections and close the dialog box.**

The cursor changes to indicate that you are adding subdivision lines and a line appears which moves with your cursor.

5 **Move your cursor until the X coordinate of the cursor position in the status bar is 395.0 and click.**

A line representing the subdivider appears in the vertical plane running through the point at which you clicked. The sections of the circuit are now labeled "s1" and "s2". Subdivision sections are labeled from left to right, or top to bottom, depending upon orientation. These labels are always sequential and are non-editable.

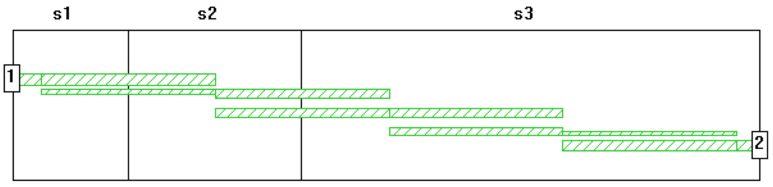


Subdivision lines are always snapped to the grid and may not be placed on top of each other. Once a subdivider has been added to your circuit, you may edit the subdivider as you would any other object in your geometry. You may click on the subdivider and move it. You may also control the display of the subdivider lines and labels in the Object Visibility dialog box, invoked by selecting *View* ⇒ *Object Visibility* from the project editor's main menu.

Since each of the coupled line segments are 595 mils long and you wish to place the subdivision lines at the halfway point, each subsequent subdivision line should be placed 595 mils further to the right in the circuit. So the second subdivision line should be placed at 990 mils from the left box wall.

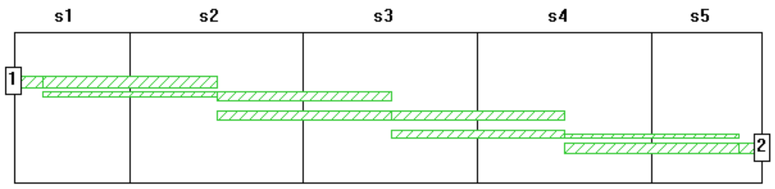
6 **Move the cursor until the X coordinate is 990.0 in the status bar and click to place the second subdivision line.**

The subdivision line appears on your circuit and the sections are relabeled as shown below.



7 **Add subdividers at 1585 mils and 2180 mils from the left box wall.**

Once you have completed adding all the subdivision lines, press the Escape key to return to pointer mode. Your circuit should now appear like this:



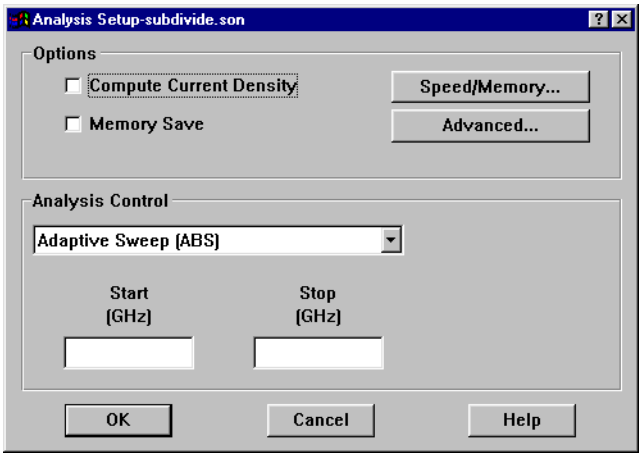
Setting Up Circuit Properties

For this example, the circuit properties such as box size, dielectric layers, metal materials, etc. have already been input in the example circuit. It is important to have the circuit properties input before performing the subdivide since these are the properties used for all the subprojects created as the result of the subdivide. If you do not enter all the desired properties, you will need to enter them individually in each subproject or modify the original source project and execute the subdivide again.

For this example, you will analyze the netlist using an adaptive sweep (ABS) with Hierarchy Sweep turned on. When the Hierarchy Sweep option is used, the analysis control settings for the netlist are used to analyze all the subprojects in the netlist. The desired frequency band for the circuit is 2.3 GHz to 2.5 GHz. An adaptive sweep provides approximately 300 data points. For more information on the Adaptive Band Synthesis technique, see Chapter 10.

8 **Select *Analysis* ⇒ *Setup* from the main menu.**

The Analysis Setup dialog box appears on your display.


Analysis Setup-subdivide.son

Options

☐ Compute Current Density

☐ Memory Save

Analysis Control: Adaptive Sweep (ABS)

Start [GHz]:

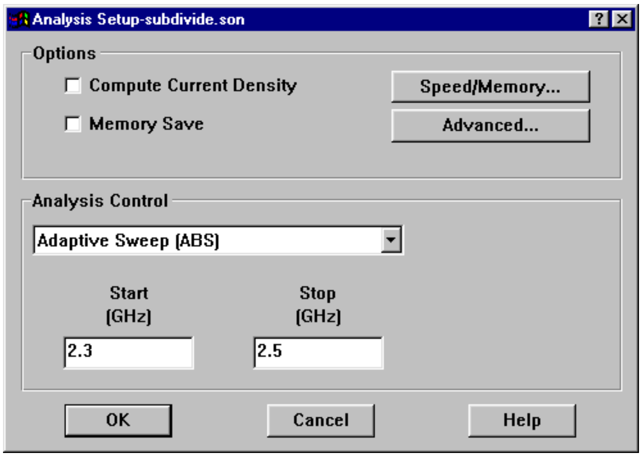
Stop [GHz]:

9 **Select "Adaptive Sweep (ABS)" from the Analysis Control drop list if it is not already selected.**

This selects the Adaptive Sweep as your type of analysis. The adaptive sweep provides a fine resolution of response data over the given frequency band. Note that the text entry boxes are updated to reflect your choice of analysis.

10 **Enter 2.3 in the Start box and 2.5 in the Stop box.**

This sets up the analysis frequency band. This analysis setup is duplicated in all of the geometry subprojects when the subdivide is executed, as well as in the main netlist. The Analysis Setup dialog box should appears as shown below.


Analysis Setup-subdivide.son

Options

☐ Compute Current Density

☐ Memory Save

Analysis Control: Adaptive Sweep (ABS)

Start [GHz]: 2.3

Stop [GHz]: 2.5

11 **Click on the OK button to save the analysis setup and close the dialog box.**

12 **Select *File* ⇒ *Save* from the main menu.**

The file must be saved before executing the subdivide. The position of the subdivision lines are saved as part of your source project.

Subdividing Your Circuit

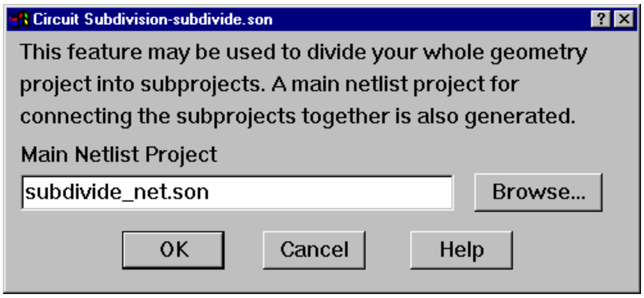
The actual subdivision of the project is executed by the software but you must enter names for the resulting main netlist file and subproject files produced as well as, optionally, defining a feedline length to be added to the subprojects.

Feedlines should be added to the subprojects if you feel it necessary to move discontinuities in the various sections of the circuit further away from the boxwalls to prevent any interaction between the discontinuities and boxwalls. This can provide a more accurate analysis result for each section of the circuit. Any added feedlines are of lossless metal, regardless of the metal type to which they are attached.

Sonnet software provides a default recommended value for the feedline or you may enter your own value.

13 **Select *Tools* ⇒ *Subdivide Circuit* from the project editor main menu.**

The Circuit Subdivision dialog box appears on your display.


Circuit Subdivision-subdivide.son

This feature may be used to divide your whole geometry project into subprojects. A main netlist project for connecting the subprojects together is also generated.

Main Netlist Project

subdivide_net.son

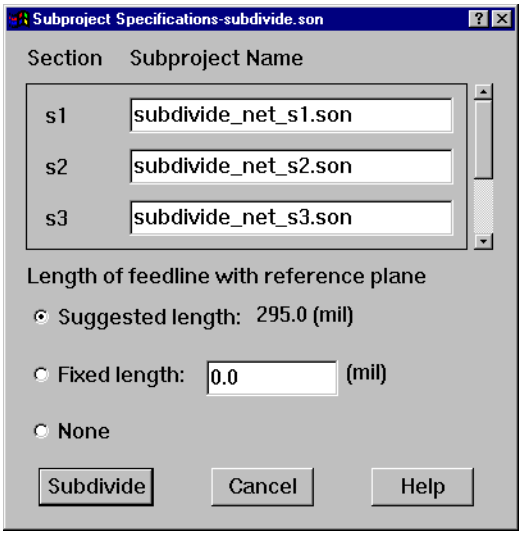
14 **The name “subdivide_net.son” is provided by default in the Main Netlist Project text entry box.**

This name is used for the main netlist which connects the geometry projects resulting from the subdivide. The default name is the basename of the source project with a “_net” added on. You may use any project name you wish but it must be different than the project name of the source file.

If you wish to change the directory in which the resulting files are created, click on the Browse button to open a browse window. If you select an existing project file, you are prompted if you wish to overwrite the existing file.

15 Click on OK to set the name and close the dialog box.

The Subproject Specifications dialog box appears on your display as shown below. This dialog box allows you to enter names for each of the geometry subprojects that result from performing the subdivide. Default names, consisting of the main netlist project name with the section number added, are provided but may be edited. For this example, use the default names.



Section	Subproject Name
s1	subdivide_net_s1.son
s2	subdivide_net_s2.son
s3	subdivide_net_s3.son

Length of feedline with reference plane

[✓ Suggested length: 295.0 (mil)]

Fixed length: 0.0 (mil)

None

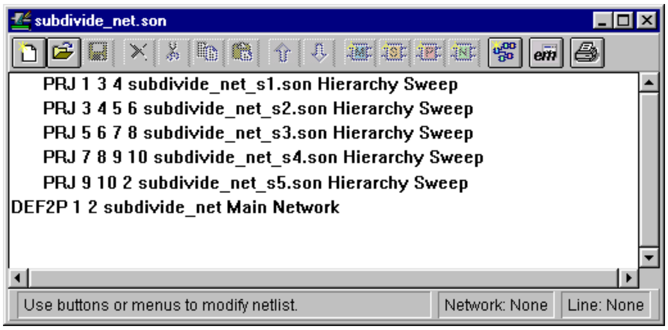
The names for the subprojects must be unique and must be different from the source project name and main netlist name.

The suggested length option is already selected for the feedline length. This feedline of lossless metal is added to ports generated when the subdivide is executed.

To enter your own feedline length, you would select the fixed length radio button and enter the value in the corresponding text entry box. Select the None radio button if you do not wish to add a feedline.

16 Click on the Subdivide button to execute the subdivide.

The main netlist and subprojects are created using the names input by you. The main netlist project is opened in the project editor.

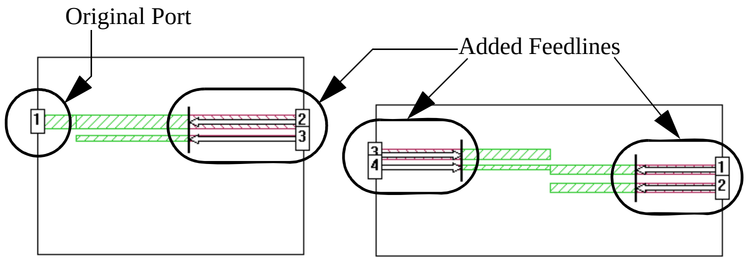


```
    PRJ 1 3 4 subdivide_net_s1.son Hierarchy Sweep
    PRJ 3 4 5 6 subdivide_net_s2.son Hierarchy Sweep
    PRJ 5 6 7 8 subdivide_net_s3.son Hierarchy Sweep
    PRJ 7 8 9 10 subdivide_net_s4.son Hierarchy Sweep
    PRJ 9 10 2 subdivide_net_s5.son Hierarchy Sweep
DEF2P 1 2 subdivide_net Main Network
```

Use buttons or menus to modify netlist. | Network: None | Line: None

The main network is defined as subdivide_net and has two ports. This corresponds to the source circuit. There is a project (PRJ) entry line for each of the subprojects. The project line includes the setting for the source of the analysis frequencies. A Hierarchy sweep, in which the netlist frequency sweep is imposed on all the project elements, is on by default. If you turn this off, the project default setting of using its own sweep is displayed.

Pictured below are the geometries for the first two sections, subdivide_net_s1.son and subdivide_net_s2.son. Note that in subdivide_net_s1.son, feedlines with a reference plane have only been added to ports 2 and 3, the ports created in the subdivide, but not port 1 which is contained in the source project. All the ports in subdivide_net_s2 have feedlines since all were created in the subdivide. Note that the feedlines are all of lossless metal.



subdivide_net_s1.son **subdivide_net_s2.son**

Analysis of the Network File

The last step to complete the analysis of the filter is to analyze the netlist project created by the subdivide. The analysis controls you entered in the original project are the ones you wish to use to analyze the netlist, so the analysis setup is already complete. An adaptive sweep from 2.3 GHz to 2.5 GHz will be performed on the netlist.

17 **Click on the project editor window containing the netlist to make this the active file.**

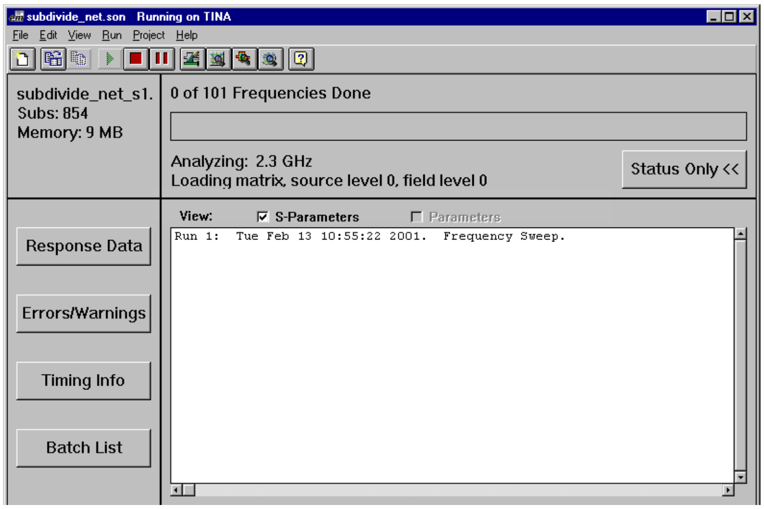
This is indicated by the title bar on the netlist being highlighted.

TIP

You can switch the active file in the project editor by clicking on the title bar of the project window or by selecting the project from the Windows menu on the main menu.

18 Click on the Analyze button to launch the netlist analysis.

The analysis monitor appears on your display.


subdivide_net.son Running on TINA
File Edit View Run Project Help
Status Only <<
View: S-Parameters Parameters
Response Data
Errors/Warnings
Timing Info
Batch List

subdivide_net_s1.
Subs: 854
Memory: 9 MB

0 of 101 Frequencies Done

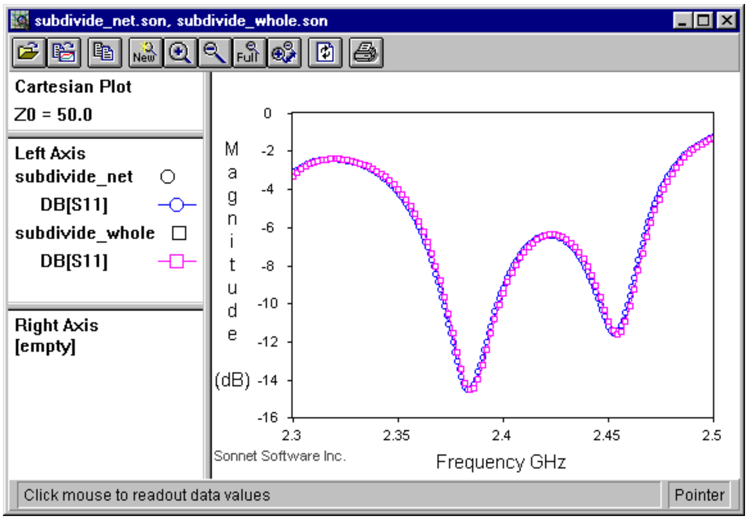
Analyzing: 2.3 GHz
Loading matrix, source level 0, field level 0

```
Run 1:  Tue Feb 13 10:55:22 2001.  Frequency Sweep.
```

The project legend indicates that subdivide_net_s1.son is being analyzed. ***Em*** will perform an adaptive sweep on each of the five subprojects and then use the resulting data to analyze the network. Status messages are output under the progress bar.

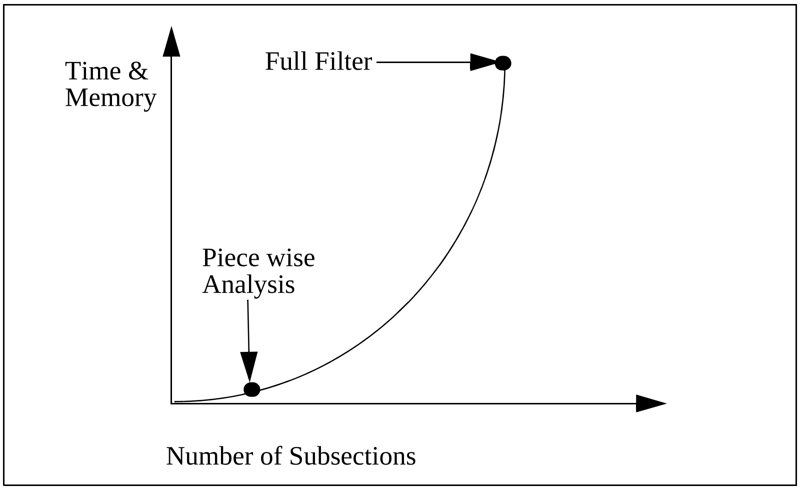
There are two results that are significant to observe. A comparison of the netlist analysis data with the analysis data from the source circuit, and a comparison of the amount of time and memory each analysis used. We have provided the source project file including analysis data under the example sub_whole.son available in the Sonnet Examples.

The graph below shows the results of the netlist analysis versus the results of a full analysis of the source project.



As you can see there is very good agreement between the two analysis results. Both files were analyzed on the same computer. The time required for the netlist was actually longer than the time required to analyze the circuit as a whole because this was a simple example chosen for clarity, and the benefits of circuit subdivision are only seen for larger circuits.

Using circuit subdivision reduces your memory requirements for analysis of a large circuit. Each of the subprojects requires less subsections to analyze than the complete circuit. This improvement comes as a result of reducing the number of subsections for any given analysis since both computation time and memory requirements rise sharply as the subsections go up, as shown on the chart below. For this example, the entire filter circuit used 2006 subsections while the largest individual piece only required 1400 subsections and the smallest only required 854 subsections.



On many larger circuits the use of the automatic circuit subdivision features in Sonnet can greatly improve the efficiency of your ***em*** usage.

Additional Improvements

There are two other ways this circuit could have been made even more efficient. You could have refrained from adding the automatic feedlines and you could have taken advantage of the fact that some of the subprojects were virtually identical.

For the purpose of illustration, this tutorial added feedlines to all ports generated in the subdivide using the recommended length. Feedlines are added to a circuit to move the discontinuities in the subprojects far enough from the boxwalls to prevent interaction. In the case of this example, either discontinuities were not present or they were already far enough from the box wall that additional feedlines were unnecessary.

If you leave the feedlines out by selecting None in the Subprojects Specifications dialog box, the netlist analysis runs 1.5X faster than previously.

The last method that would allow you to decrease the processing time would be to use fewer subprojects in the netlist to create the circuit. Observation of the circuit geometry and response data shows that subdivide_net_s1.son and subdivide_net_s5.son are virtually identical. The same is true for subdivide_net_s2.son and subdivide_net_s4.son. You could edit the main netlist, subdivide_net.son so that you only use three files: subdivide_s1.son, subidivide_net_s2.son and subdivide_net_s3.son to create the whole circuit. This eliminates the need to calculate data for two out of five subprojects. This analysis is 2X faster than the analysis using feedlines and all five subprojects.

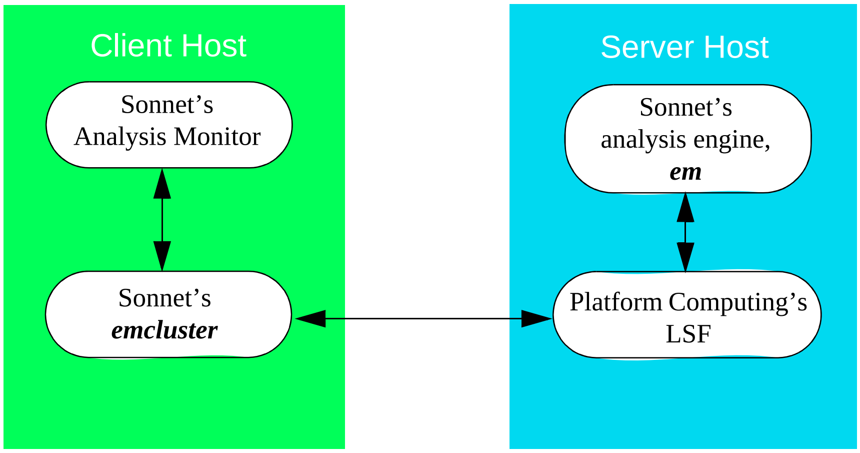
Chapter 16 *emCluster* using Platform LSF (LSF Cluster)

For instructions on setting up your ***emCluster*** Computing using Platform LSF, see the Setting Up emCluster manual, available in the Administration and Installation page of the manuals interface which you access by clicking on the Manuals button on the Sonnet task bar or by selecting *Help* ⇒ *Manuals* from the menu of any Sonnet application.

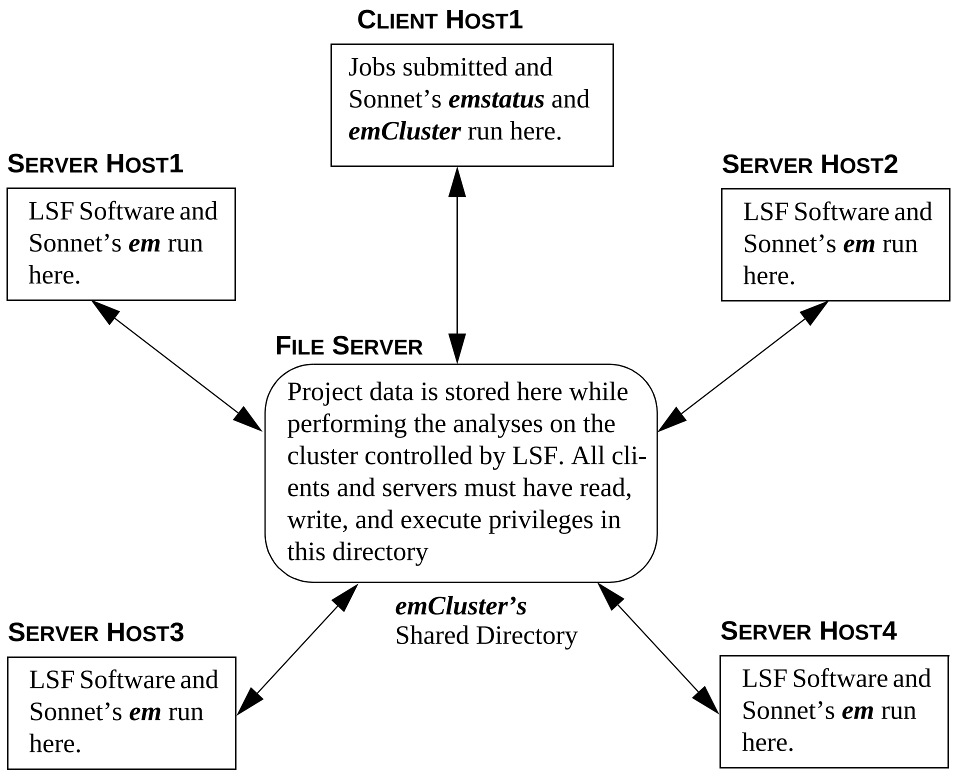
Sonnet's LSF Cluster allows your Sonnet ***em*** analysis to interface with Platform Computing's Load Sharing Facility (LSF) cluster computing software to improve the efficiency and processing time of your Sonnet analyses. This feature provides you with the ability to split your analysis project into multiple jobs which may then be processed in parallel to greatly reduce your processing time. You may also take advantage of LSF Cluster's ability to choose a server host computer based on analysis size, licensing considerations, loading, time of day, etc. For example, smaller jobs may be sent to a computing host reserved just for them to avoid waiting behind a larger job which requires substantially more processing time.

Your processing cluster is made up of Server hosts and Client hosts. Servers are the computers, of any platform type, that are available as a computing resource. In our case, the servers would be used to actually run the ***em*** analysis jobs. Clients are computers in the cluster from which a user may submit jobs but they do not themselves perform processing tasks. Clients may not be used as servers, but all servers may act as clients to the cluster.

You will use the analysis monitor on your client server to submit your ***em*** jobs to the computer cluster for processing. The program, ***emCluster***, provides the interface between the analysis monitor and your processing cluster server hosts upon which the Sonnet analysis engine, ***em***, will run. The relationship between the programs is shown in the illustration below. Note that this illustration contains only one Server host. Your processing cluster will have multiple Server hosts and possibly multiple client hosts.



When you submit your job for processing, ***emCluster*** copies your project to an ***emCluster*** shared directory. There, depending on the mode in which you are operating, your project is split into multiple copies and/or sent to specified servers in your computer cluster for processing. The results are written to the ***emCluster*** shared area. If post-processing is needed, ***emCluster*** again submits your project to the computer cluster using the shared area for the project data. Once all processing is complete, the project, including its newly calculated response data, is copied back to the client machine from which the ***em*** job originated. Once this transfer is complete, the temporary files in the ***emCluster*** shared area are deleted. The data flow in a cluster with one client and four servers is pictured below.


CLIENT HOST1
Jobs submitted and Sonnet's emstatus and emCluster run here.
SERVER HOST1
LSF Software and Sonnet's em run here.
SERVER HOST2
LSF Software and Sonnet's em run here.
FILE SERVER
Project data is stored here while performing the analyses on the cluster controlled by LSF. All clients and servers must have read, write, and execute privileges in this directory
emCluster's Shared Directory
SERVER HOST3
LSF Software and Sonnet's em run here.
SERVER HOST4
LSF Software and Sonnet's em run here.

Which server host(s) the job is submitted to depends on the way in which the computer cluster is being used. One possible way to increase your processing efficiency, when analyzing a large circuit which requires a long processing time per frequency, is to have your project split into multiple identical projects, each analyzed at a subset of the analysis frequencies. For example, you have 4 frequencies specified in your analysis, so the project is split into four jobs, each analyzed at one of the frequencies. These jobs are then submitted to the processing cluster and analyzed in parallel, reducing the analysis of the whole circuit to the time required to analyze at only one frequency. The interface between ***emCluster*** and LSF allows you to control how your frequencies are split so that you may maximize your efficiency based on how your computer cluster is configured. See "Frequency Splitting," page 232 for details on controlling the frequency splitting.

Another way to use the computer cluster is to designate server hosts based on their memory capacity and processing speed. For example, you might wish to send smaller jobs to one server host and larger jobs to another server host which has more processing capacity. You may set up queues in the LSF software and use ***emCluster*** to assign your ***em*** processing job to the appropriate queue.

Running *emCluster*

Using ***emCluster*** allows you to take advantage of your computer cluster to improve the efficiency of your Sonnet ***em*** analysis. The discussion below provides some suggestions on how to use Sonnet with a computer cluster followed by several sections with instructions on the interface to ***emCluster***.

Frequency Splitting

One way to increase the efficiency of your processing using LSF Computing is frequency splitting. Multiple duplicate projects are created, each analyzing at some subset of the desired frequency points and simultaneously submitted to the LSF cluster so that you are performing your ***em*** processing in parallel.

The default setting in the ***emCluster*** initialization file for running ***emCluster*** is to split the analysis into one ***em*** job per analysis frequency submitted to the LSF cluster. Therefore, if you are analyzing at 10 discrete frequencies, 10 ***em*** jobs, each containing the same circuit, are submitted to the LSF cluster, one for each frequency. The setting in the ***emCluster*** initialization file which controls frequency splitting is SplitJob. In order to submit one job per analysis frequency, the SplitJob field is set to "-1."

You may also turn the frequency splitting off so that the analysis is submitted to the cluster as one job. **SplitJob** should be set equal to "0" in order to turn frequency splitting off.

You may want to the limit the number of jobs into which you split an analysis. For example, if you want to limit the number of jobs to the number of server hosts in your cluster. To do so, you set SplitJob in the ***emCluster*** initialization file to the upper limit of the number of jobs. For example, if you set SplitJob to 5, and are analyzing 10 frequencies, each ***em*** job will analyze 2 frequencies.

NOTE: **You may not use frequency splitting when running an optimization or parameter sweep.**

ABS Processing

The Adaptive Band Synthesis (ABS) technique provides a fine resolution response for a frequency band requiring only a small number of analysis points. ***Em*** performs a full analysis at a few points and uses the resulting internal, or cache, data to synthesize a fine resolution band. The output data consists of the discrete data points, frequencies at which the analysis engine, ***em***, performs an electromagnetic analysis, and the adaptive data, which is data calculated using a rational polynomial fit. This is often the most efficient process in Sonnet by which you can obtain response data over a band. For more information about ABS, please refer to **Chapter 9**.

By using your cluster to perform the analyses at the discrete data points in parallel, you can further increase the efficiency of an ABS sweep. There are two ways of accomplishing an ABS sweep when using a computer cluster. You may submit an ABS sweep and allow ***emCluster*** to automatically calculate at which discrete data points to run a full analysis (automatic) or you may define linear sweeps or single frequency points in which you determine at which discrete data points you run an analysis before attempting the ABS sweep (user-defined). You must use the Frequency Sweep combinations to combine the different types of sweeps when doing the user-defined ABS. The ABS sweep should be the last sweep specified.

Automatic Calculation of Discrete Data Points

The automatic calculation of discrete data points is used when you submit an Adaptive sweep to the LSF cluster for analysis. In this case, ***em*** analyzes at 7 discrete data points. These discrete data points always include the starting and ending frequencies of the band and the rest of the points are evenly distributed across the band. These discrete data points are then split up according to your present frequency splitting settings (see , “SplitJob=<nsplit>,” in Appendix II, “The LSF Cluster Initialization File,”) and submitted for analysis to the LSF cluster. Once all the results from the discrete data points are complete, ***em*** solves for the rational polynomial and produces the adaptive data. The default of seven data points is conservative to ensure that there are enough data points to produce an accurate model. An adaptive sweep run on your local computer would solve one discrete data point at a time and attempt to “fit” a polynomial after solving at each data point. Setting up seven discrete data points beforehand allows you to take advantage of the frequency splitting capabilities of cluster computing.

If the seven discrete data points are not enough to produce a model, then ***em*** runs an analysis at additional discrete data points until there is sufficient data to create an accurate model. In this case, the additional frequencies are done sequentially on the same server until the model is achieved.

You may use the NumFixedAbsFreq entry in the ***emCluster*** initialization file to control the number of data points used when automatically calculating the discrete data points for an ABS sweep. The default values is seven. If you consistently see that an ABS sweep could produce adaptive data using less data points, you can change the default so that your analyses can complete using less processing time. Alternately, if you find that seven discrete data points is often not enough, you can raise the number of discrete data points.

User Defined Discrete Data Points

For some ABS sweeps, you may have knowledge about your circuit such that you know the number of discrete data points needed or you have specific data points at which you desire a full analysis. In these cases, it may be more efficient to set up your analysis with a linear sweep first which analyzes the circuit at the desired frequency points before performing the ABS sweep. The linear sweep and the ABS sweep should be set up together using the Frequency Sweep Combinations option for Analysis Control. The linear sweep will be split according to your frequency splitting settings and sent to the cluster. Once those analyses are complete the ABS sweep is submitted. Since ***em*** always uses data already calculated in processing the Frequency Sweep Combinations in its first attempt to create a “fit” to the data, ***em*** will attempt to complete the ABS sweep without analyzing any more discrete data points.

This method will be faster than the automatic algorithm if the number of user defined discrete data points is less than the number estimated by the algorithm. The algorithm is designed to be conservative so that enough data is usually available to produce an accurate rational polynomial. Therefore, the number of points chosen by the algorithm will typically be higher than the number required by an ABS sweep on a local machine. If you know how many data points are needed to perform an adaptive sweep on your circuit, you may be able to obtain results in less processing time than the automatic algorithm.

This method also allows you to produce data for a specific frequency that is critical in your design.

Limiting the Discrete Data Points

Using the AbsMaxDiscrete entry in the ***emCluster*** initialization file is another way to improve your efficiency when performing an analysis on a cluster. This option controls how many more discrete frequencies are analyzed before solving for the ABS solution. If this setting indicates that no additional frequencies are to be analyzed, then if pre-existing cache data is sufficient to get converged ABS solution, that solution is written to output. Otherwise, no processing is performed. You may also set this option so that ***em*** will continue analyzing at discrete data points until an ABS solution can be produced; this is the default setting. You may also set a maximum number of additional points. See the entry in the ***emCluster*** Initialization File appendix for details.

Using Queues

You may use queues in a number of ways to make your Sonnet processing more efficient. Queues allow you to sort your jobs based on processing time or time of day. You will first define the desired queues in your LSF software, then use the queue entry in the ***emcluster*** initialization file to map the LSF queues.

NOTE: **If specify a queue for your LSF job, any computer which appears in your HostList MUST also be included in the queue. If you have a computer in your host list upon which your queue may not run, LSF issues an error message and does not process the job.**

For example, you may wish to designate one or more of your computers for small processing jobs and other computers for the larger processing jobs to prevent your smaller jobs from being stuck behind a large processing job which requires significantly more processing time. In this case, you would use the memory settings in the queue entry to define what size file is assigned to what LSF queue.

Another example of using a queue would be use some of your computing resources for Sonnet only during night or weekend hours. If you have a server host in your cluster which is used by an individual during the day for all their computer needs, but would normally sit idle during the night or on weekends, you can define a queue that is only available during certain hours on certain days.

Limitations

NOTE: **If you lose your connection to the cluster when an analysis submitted from your client machine is running, it is not possible to reconnect to the ongoing job. You must re-submit the job to the cluster. If this occurs, "orphan" files may be left in the *emCluster* shared memory. You should occasionally clean out the *emCluster* shared directory. For directions on how to do so, see "Cleaning the emCluster Shared Directory," page 241 in the Setting Up LSF Cluster.**

When you run an optimization or a parameter sweep in your analysis, you may not use Frequency Splitting. The job must be submitted to one server host in the cluster and run interactively. When running interactively, response data and status information, such as you would see with a local analysis, is sent to the analysis monitor during the processing.

You may only use LSF Computing with geometry projects. LSF Computing is not available for Netlist projects. Analyzing netlist projects would require a separate ***em*** license not associated with the LSF cluster.

The use of external frequency files is not supported by LSF Computing.

All optional files are calculated locally, not on your cluster.

Running an Analysis on your LSF Cluster

In order to run an analysis on the cluster, LSF must be up and Sonnet must be installed and configured on all the cluster server hosts and clients. For directions on doing this, refer to "Sonnet Setup," page 13 in the **Setting Up LSF Cluster** which is available in PDF format from the Help menu of any Sonnet application.

To run an analysis on the cluster, do the following:

1 **Open a Sonnet project that is ready for analysis in the project editor and click on the Analyze button on the project editor's tool bar.**

2 **The New Batch Creation dialog box appears on your display.**

Note that this dialog box only appears if you have selected the Prompt for server checkbox in the Preferences dialog box of the analysis monitor when you setup your cluster computing. This dialog box contains a list of clusters available to which you may submit jobs. (Only LSF is presently supported). If any remote servers have been configured they will also appear in this list.

If you are not prompted, then the LSF cluster is your default processing server, and you may continue at Step 5.

3 **Click on the LSF Cluster to select it for the analysis.**

The selected server is highlighted.

4 **Click on the OK button in the New Batch Creation dialog box.**

This closes the dialog box. The LSF cluster is now associated with the analysis monitor window which will subsequently open. All jobs added to the batch list of the analysis monitor will be analyzed on the LSF cluster.

5 **When the New Batch Creation dialog box is closed, the analysis monitor appears on your display and your analysis job starts running.**

Status is posted to the analysis monitor at the polling interval set in your ***emCluster*** initialization file. The types of information which appear will depending on the splitting, if any, of your project. If any errors occur with the cluster, a status message is posted in the status section of the analysis monitor just under the progress bar.

Overriding Cluster Computing Options

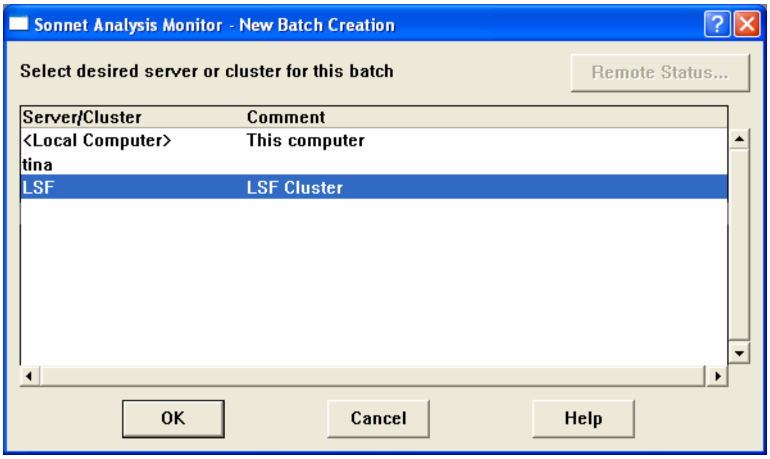
When installing Sonnet's cluster computing software, you should configure the ***emCluster*** initialization file, "emcluster.ini," with the control parameters that you would like to use on the majority of your cluster computing. However, it may be necessary in some cases, to change the parameters with which you perform your cluster computing. There is a command available in the analysis monitor which allows you to override some of the more frequently used settings in the initialization file. These changes will only apply to jobs run out of that batch window. If you open another batch window, the parameters from the initialization file will be used. To override your initialization file settings, do the following:

1 **Open the Sonnet task bar and click on the Analyze Project button.**

A pop-up menu appears on your display.

2 **Select “New Batch” from the pop-up window.**

If you have the “Prompt for Server” option enabled in your Preferences, then the New Batch Creation window will appear on your display. If the New Batch Creation window does not appear and LSF is selected as your default processing server, continue at Step 5.



Select desired server or cluster for this batch

Server/Cluster	Comment
<Local Computer>	This computer
tina	
LSF	LSF Cluster

3 **Select LSF from the Server/Cluster list in the New Batch Creation window.**

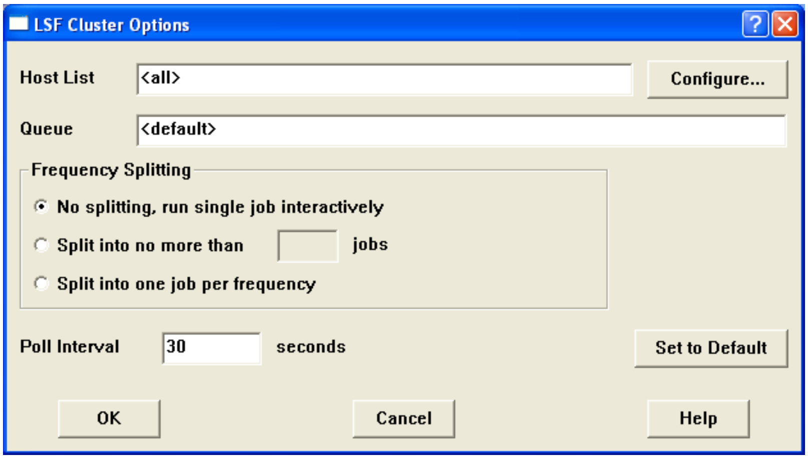
This selects the LSF cluster to perform your processing.

4 **Click OK to close the window and execute the changes.**

The analysis monitor window appears in batch list mode.

5 **Select Run ⇒ Override Cluster Options from the analysis monitor main menu.**

The LSF Cluster Options dialog box appears on your display. The values which appear in this dialog box are the present settings in the initialization file.


LSF Cluster Options

Host List: <all>

Queue: <default>

Frequency Splitting
- [✓ No splitting, run single job interactively]
- Split into no more than ____ jobs
- Split into one job per frequency

Poll Interval: 30 seconds

6 **Enter the desired server host(s) in the Host List.**

You may directly edit the host list or click on the Configure button to the right which opens the Host List Selection dialog box which allows you to select the desired server hosts. All of the server hosts in your LSF cluster appear here. Note that it is possible to have a server host in your list which is not capable of running a Sonnet analysis. Check with your system administrator to determine which servers on your cluster may run ***em***.

If you do not enter any hosts in the host list, then ***emCluster*** uses the default, which is all the servers available in the cluster. If this is true, then <all> appears in the list.

NOTE: **If you specify a queue for your LSF job, any computer which appears in your HostList MUST also be included in the queue. If you have a computer in your host list upon which your queue may not run, LSF issues an error message and does not process the job.**

7 Enter the desired Queue in the Queue text entry box.

You may enter the desired LSF queue for this job in the Queue text entry box. The queue name should be the name of a queue defined in the LSF software. If there are no entries in this field, then the default "normal" queue is used. If this is true, then <default> appears in this field.

8 Select the desired radio button to control the Frequency Splitting for the job.

If you select No splitting then the job is submitted as one analysis job to the cluster and one server host analyzes your circuit at all the specified analysis frequencies. When this option is selected, then response data and status information, such as you would see with a local analysis, is sent to the analysis monitor. This is defined as running interactively.

The Split into no more than <n> jobs selection limits the number of jobs your analysis may be split into. The project is duplicated the number of times you enter in the adjacent text entry box and each duplicate project analyzes the circuit for a subset of the requested analysis frequencies. For example, if your analysis is for the frequencies 2, 4, 6, 8, 10, 12, 14, and 16 GHz and you have entered 4 as the maximum number of jobs then the first job analyzes at 2 and 4 GHz, the second project at 6 and 8 GHz and so on.

The Split into one job per frequency option splits the project into one job per requested analysis frequency. If more jobs are created than there are server hosts in your cluster, then multiple jobs will be submitted to some server hosts. If you have a sufficient number of server hosts in your cluster, this option results in the greatest efficiency for your processing.

9 Enter the desired time for the poll interval.

Enter the amount of time, in seconds, between updates from ***emCluster*** on the progress of the analysis. The value should be an integer between the values of 5 and 300.

10 If you want to reset the dialog box to the original values obtained from the initialization file, then click on the Set to Defaults button.

You will lose any changes made up until then in the dialog box.

11 **Once all your entries are complete, click on the OK button to close the dialog box and apply the changes.**

This batch window will now run any jobs submitted to the cluster using the operating parameters input to the Override Cluster Options dialog box. These changes will only apply to this batch window. If a new batch window is opened, it will use the default values from the ***emCluster*** initialization file unless you once again override those options.

12 **Add the projects you wish to use the cluster to analyze to the batch list.**

You may add projects by selecting File ⇒ Add Project(s) from the main menu of the analysis monitor window or by clicking on the Add Projects button on the analysis monitor tool bar.

13 **Click on the Run button on the analysis monitor tool bar to analyze the projects in the batch list.**

Cleaning the *emCluster* Shared Directory

If communication errors occur while running an ***em*** analysis job on the LSF cluster, the job may not complete. If this happens, then “orphan” projects may be left in the ***emCluster*** shared directory, since the temporary project files are not deleted until the job is successfully completed. You should periodically check the shared directory and clear out any leftover projects by deleting all files in the following directory:

<Shared_Directory>/sonnet_emcluster/sonnet_emcluster_lsf

where <Shared_Directory> is the ***emCluster*** Shared Directory.

Chapter 17 Vias and 3-D Structures

Introduction

Em can handle full 3-D current as well as 2.5 D structures. The third (Z) dimension of current is handled by a special kind of subsection called a via.

The term “via” commonly refers to a connection from metal on the substrate surface to the ground plate beneath the substrate. However, as used in Sonnet, a via can be used to connect metalization between any substrate or dielectric layer, not just bottom layer to ground. Thus, ***em***’s vias can be used in modeling airbridges, spiral inductors, wire bonds and probes as well as the standard ground via.

Restrictions on Vias

Em’s vias use a uniform distribution of current along their height and thus are not intended to be used to model resonant length vertical structures. The height of the via should be a small fraction of a wavelength. The via height is the same as the thickness of the substrate (or dielectric layer) it penetrates.

If a microstrip substrate is a significant fraction of a wavelength thick, over-moding also becomes a major problem. If vias are used to form, for example, a septum, or an interior wall, you may need to model it with multiple layers to achieve an accurate analysis.

Creating the Vias

Vias may be added to your circuit in a number of ways. Both the direction and type of via is chosen in the *Tools* ⇒ *Add Via* menu. The default may be set to go up one level, down one level, or down to ground, through multiple layers if necessary. Vias may be edge vias, rectangular vias, via polygons or circular vias.

Via Direction

A via which goes up one level extends from the level of metalization to which it is added up through the dielectric layer to the level of metalization above it. For example, if you draw a via on level 2 with the direction set to Up One Level (*Tools* ⇒ *Add Via* ⇒ *Up One Level*), the via extends from level 2 up through the dielectric to level 1 of your circuit.

A via which goes down one level extends from the level of metalization to which it is added down through the dielectric layer to the next level of metalization. For example, you draw a via on level 0 with the direction set to Down One Level (*Tools* ⇒ *Add Vias* ⇒ *Down One Level*). The via extends from level 0 through the dielectric layer to metalization level 1.

A via which goes down to ground extends from the level of metalization to which it is added through all intervening levels until it reaches the ground (bottom) of the enclosing box. For example, a circuit with 5 dielectric layers has four metalization levels (3 - 0). If you add a via on metalization level 1 with the direction set to down to ground (*Tools* ⇒ *Add Vias* ⇒ *Down to Ground*) the via extends from level 1 down through the intervening dielectric layers and metalization levels to the bottom of the enclosing box which is ground. This via is drawn on levels 1, 2, 3 and ground. The ground level is completely metalized, but the via is drawn here to represent the connection from upper levels.

Via Types

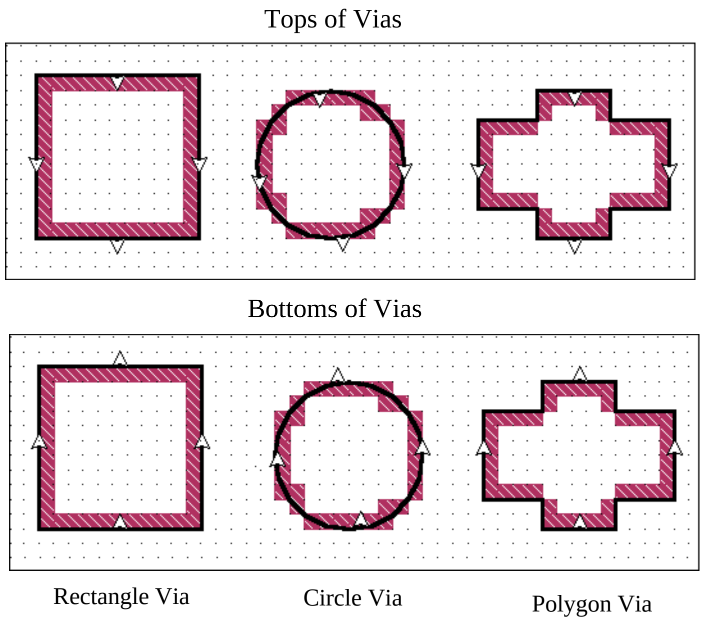
There are basically two types of vias: edge and polygon. The via polygons can be rectangles, circles or any arbitrary shape.

Via polygons are vias which are a separate object from the metalization polygons. They allow you to add vias of any shape whose properties are easy to modify. The via polygon may also be of a different metal type than any metalization polygons to which it is adjacent.

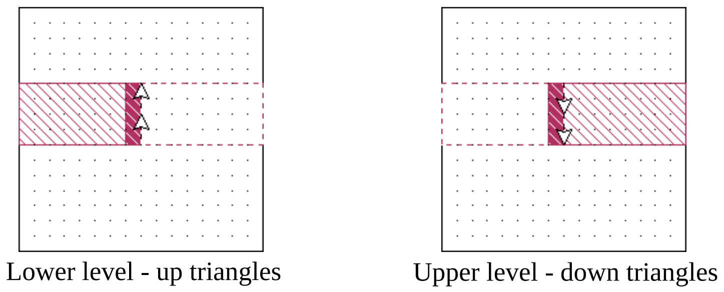
Edge polygons are vias that are attached to the edge of a metal polygon. The via extends for the length of the polygon edge and is one cell wide. The metal type used for an edge via is always the same as the polygon to which the edge via is attached. If the metal type of the polygon is modified, then the metal type of the via is also changed.

Via polygons are added to your circuit in much the same way that metal polygons are added to your circuit. You may add vias in the preset shapes of rectangles or circles or draw an arbitrary polygon by placing each vertex in its desired location. Once the shape is complete, the via polygon is drawn in your circuit. The via consists of a one cell wide wall of via subsections and is hollow in the middle. Via polygons are hollow in the middle since all current moves on the surface of the via and modeling metal which is not used wastes processing resources. If you wish to have metal in the center of a via polygon on a metalization level, you may add a metal polygon on that level.

Examples of via polygons are shown below. The shape drawn by the user appears in black. The actual via metal is shown by the fill pattern which is the video reverse of the metal pattern. Since current travels on the surface of a via, the middle of the via is hollow, filled with the dielectric material of the dielectric layer that the via traverses.

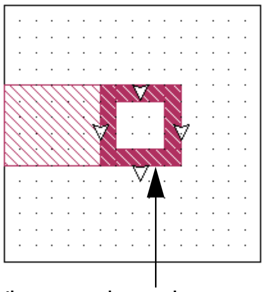


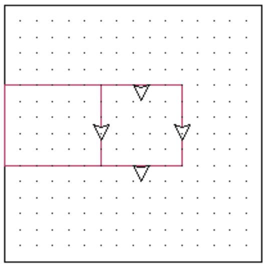
The example shown below uses an edge via to connect two polygons on adjacent levels. The "up" via symbol indicates that the via connects this level to the next level above.   The vias on the upper level are shown with a "down" via symbol which is a "down" triangle. Via symbols were automatically created on the destination level when the via was added to the source level.



Via Posts

With the metalization turned on (default setting), by setting *View* ⇒ *Cell Fill* to “On”, the via subsections, called “via posts”, are also displayed in reverse video as shown below.


Via posts shown in reverse video with cell fill on.


The via is indicated by only triangles and an outline when cell fill is

When ***em*** subsections the circuit, it subsections each edge via or via polygon into subsectional vias called “via posts”. Each via post is a rectangular cylinder of current, extending between the present level to the next level above or below (depending on the direction of the via). A via post has a horizontal cross-sectional area equal to one cell and a height equal to the thickness of the dielectric layer. If you change the cell size, then the via is resubsectioned into via posts with the new cell size. The project editor places enough via posts to cover the entire length of the polygon edge for an edge via and the complete perimeter of a via polygon. A via with the via posts detailed is illustrated on page 249.

To view vias as they are being captured, it is convenient to be able to change the viewed level in the project editor quickly. To do so, just type Ctrl-U to go up one level, towards the box top, or Ctrl-D to go down one level.You may also click on the *Up One Level* or *Down One Level* button on the tool bar in the project editor. Most keyboards also support the up and down arrow keys.

If you want a level to be displayed as a “ghost” outline whenever you are not on that level, make the level visible in the Levels dialog box which appears in response to selecting *View* ⇒ *Metalization Levels*. Then you can see how different levels of metalization line up. You may also use the Levels dialog box to turn off the visibility of any given level. By default, the project editor starts with all levels visible.

Adding a Via to Ground

A via to ground can be added from any metalization level. To add a via to ground, go to the level from which you wish the via to extend downwards and perform the following:

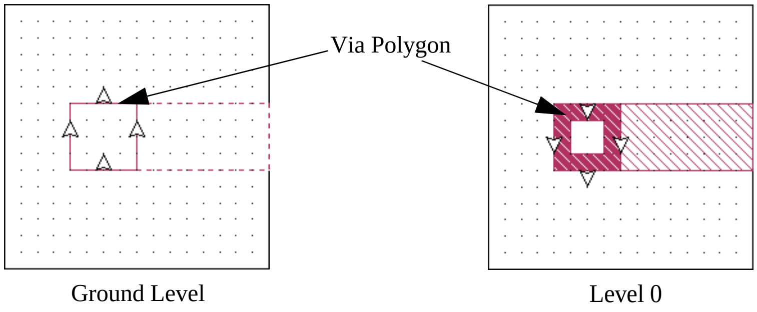
1 **Select Tools ⇒ Add Via ⇒ Down to Ground from the project editor menu.**

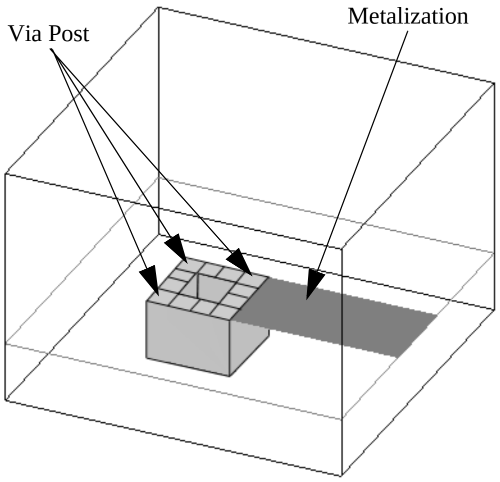
Any vias subsequently added to your circuit will extend from the level to which they are added down through all intervening levels to ground.

2 **Select Tools ⇒ Add Via ⇒ <Via Type> to add the desired type of via.**

The command places you in an add via mode; the type of via is dependent on the command you selected. Draw the desired via. The via you input is drawn on the present level and vias are drawn on each level below up to and including the ground plane at the bottom of the box. If you wanted to add an edge via, you would first have had to drawn a metal polygon to which to attach the edge via. An example of a via polygon going from level 0 to ground in a two level circuit is pictured below.

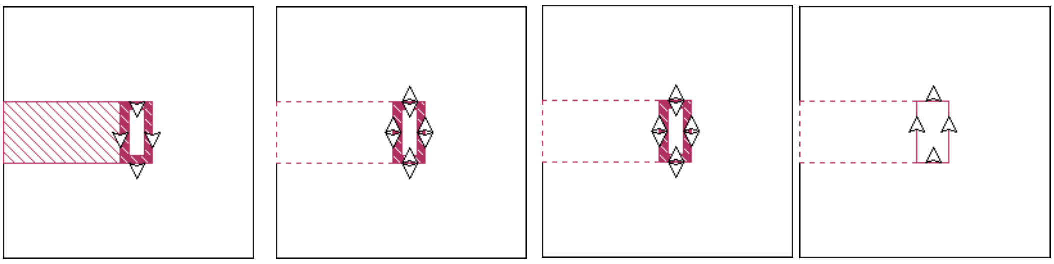
The via polygon metalization is shown on Level 0. Note that the arrows are pointing down, indicating the direction of the via. The center of the via does not contain metalization but is filled with the dielectric of the dielectric layer. The ground level is completely metallized; the outline of the via polygon is drawn on ground level simply as a reference with up arrows indicating that there is a via polygon in the level above.





The lower part of the figure depicts a via going from the single metalization level to ground. The same via is shown in the top of the figure as it appears in the project editor. The rectangular via is subsectioned into via posts which are rectangular cylinders of current, extending between level 0 and the ground plane. A via post has a horizontal cross-sectional area equal to one cell and a height equal to the thickness of the dielectric layer. The via polygon is made up of a single-cell wide “fence” which forms the border of the polygon. The center of the via polygon does not contain metal; it is filled with the dielectric material used in the dielectric layer. If you change the cell size, then the via is resubsectioned into via posts with the new cell size.

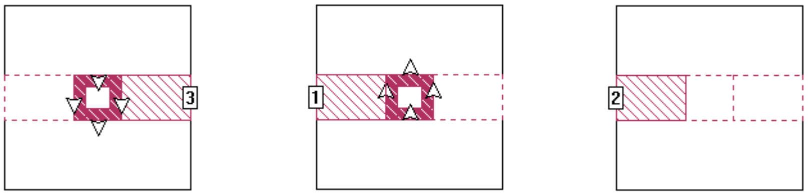
If the via to ground is added when there are multiple intervening metal levels between the present level and ground, the via polygon can be seen on each level. The intervening levels have via arrows pointing in both directions to indicate that the via extends both upward and downward. Below is shown a rectangular via polygon extending from metal level 0 to ground in a three level circuit.



The via shown above extends from level 0, the highest metal level in the circuit down to the ground level. The via arrows on the rectangular via on level 0 point only in the downward direction. The via polygon appears on levels 1 and 2 in the same position but with via arrows pointing in both the upward and downward position indicating that the via extends in both directions from these levels. Only the outline of the via polygon is drawn on the ground plane to indicate its position with the via arrows pointing upward indicating that the via extends upward. Since the complete ground plane is metalization, the via polygon is drawn simply as a reference for the user. Note that the center of the via polygon is not metalization but is a rectangular cylinder of dielectric material.

Multi-layer Vias

It is possible to have a via which traverses more than one dielectric layer. You may insert a via in your circuit originating on any level and ending on any level. The via is automatically drawn on each level it traverses. To create a multi-layer via, first create a via in your circuit, then modify its properties. For example, you have a four level circuit with an existing via polygon which extends from level 1 to level 0 as shown below.



Level 0 Level 1 Level 2

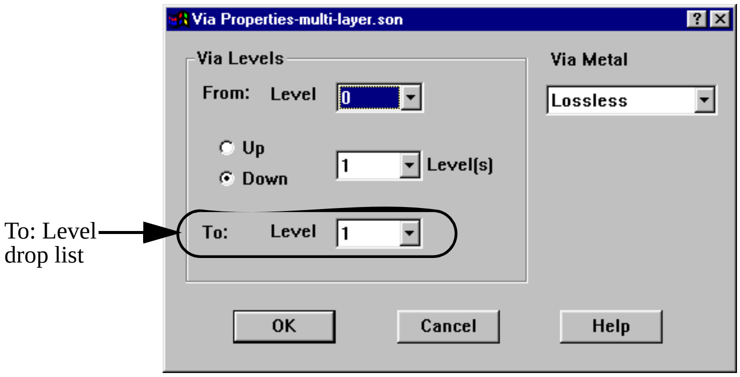
If you want to modify this via such that it extends from level 0 to level 2, you would do the following:

1 **Right-click on the via polygon on any level on which it appears.**

A pop-up menu appears on your display.

2 **Select Properties from the pop-up menu.**

The Via Properties dialog box appears on your display.



Via Levels

From: Level 0

Up [✓ Down] 1 Level(s)

To: Level 1

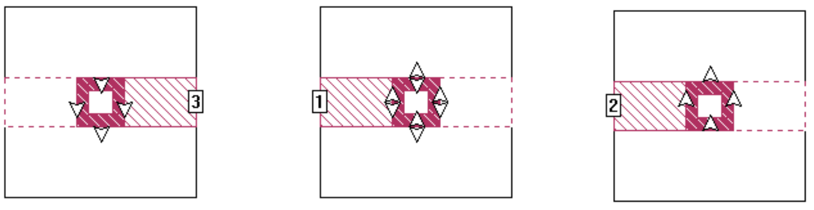
Via Metal: Lossless

3 **Select "2" from the To: Level drop list.**

The via originates on level 0 which you do not wish to change. Selecting 2 from the drop list changes the via so that it goes down to level 2 instead of level 1. Notice that the number of levels is updated from 1 to 2.

4 Click on OK to apply the changes and close the dialog box.

Your circuit is redrawn so that it appears as shown below.



Level 0 Level 1 Level 2

Note that the via polygon which appears on level 1 now has both up and down arrows indicating that the via extends in both direction. The via polygon now appears on level 2, the new endpoint of the modified via.

Deleting Vias

Vias may be deleted on any metalization level on which they appear, even if you are in the middle of the via between the endpoint levels.

Via Polygons

To delete a via polygon, select the via polygon while in pointer mode by clicking anywhere on the via that you wish to delete. Then select *Edit* ⇒ *Cut* from the menu or the Delete key to delete it.

Edge Vias

To delete an edge via, select the via while in pointer mode by clicking on a triangle of the via that you want deleted. Then select *Edit* ⇒ *Cut* from the menu bar or the Delete key to delete it. Deleting a via deletes the via posts associated with it.

You should also note that if you delete or move a polygon from which an edge via originates, the via is moved or deleted from your circuit as well.

Via Loss

The loss for the via post is determined by the metal type of via polygons and the metalization of the polygon that the via is associated with for edge vias. See “Metalization Loss,” page 49 for an explanation on how to set the metalization loss for a metal polygon.

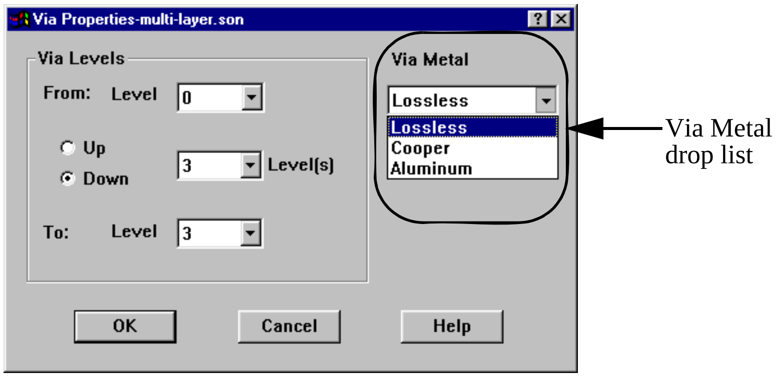
When a via polygon is created, it’s metal type is set to the default metal used for new metalization. This is controlled in the Metal Types dialog box accessed by selecting *Circuit* ⇒ *Metal Types* from the project editor’s menu. You may also change the metal type of the via polygon after it has been added to the circuit. You may use any metal type defined in your circuit for a via polygon.

To change the metal type of a via polygon:

1 **Right-click on the via polygon and select Properties from the pop-up menu which appears on your display.**

The Via Properties dialog box appears on your display.

2 **Select the desired metal type from the Via Metal drop list.**


Via Properties-multi-layer.son

Via Levels
From: Level 0
Up [✓ Down] 3 Level(s)
To: Level 3

Via Metal: Lossless
Lossless
Cooper
Aluminum

OK Cancel Help

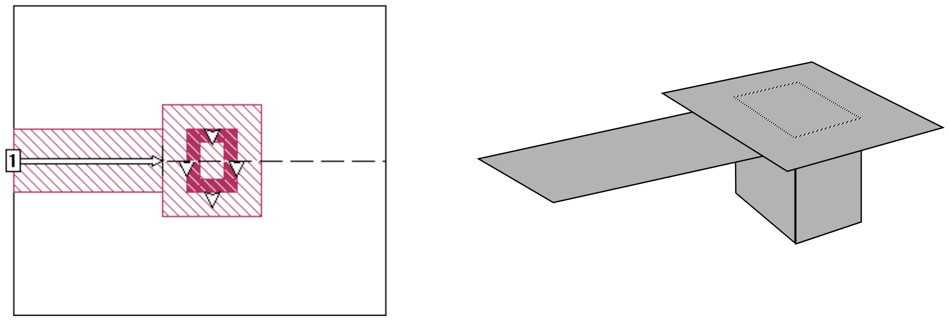
Via Ports

For a detailed discussion of via ports, please see "Via Ports" on page 76.

Simple Via Example

A simple via is stored in the example Via and is shown in the figure on page 254. For directions on obtaining a Sonnet example, select *Help* ⇒ *Examples* from the menu of any Sonnet program, then click on the Instructions button.

Note that the top end of the via, shown below, is a "pad" which is larger than the via itself. There are no restrictions on the polygons at the top of a via. ***Em***'s subsectioning algorithm handles the subsectioning accurately.



A simple via to ground. On the left, as it would appear in the project editor. On the right, a view in perspective.

A Conical Via

One may simulate a conical ground via with a staircase approximation. Simply divide, say, a 100 µM GaAs substrate into four 25 µM substrates. Then put vias at appropriate places to form a step approximation to the conical via sides. For an example, see Cvia in the Sonnet examples. This circuit is a conical via to ground placed in the center of a through line, the purpose being to measure the via inductance. For directions on obtaining a Sonnet example, select *Help* ⇒ *Examples* from the menu of any Sonnet program, then click on the Instructions button.

The "cvia.son" file is a very detailed model of a conical via. If you are modeling a large circuit (say, an inter-stage matching network) with multiple vias, you may want to use a simpler model for faster analysis. Another approach would be to use circuit subdivision where you subdivide the circuit such that the via is simulated separately-thus providing an accurate via simulation. For more information on circuit subdivision, see Chapter 14, "Circuit Subdivision" on page 199.

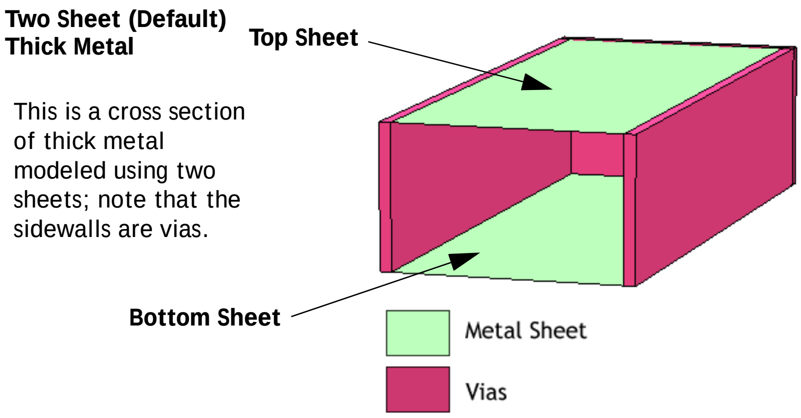
Chapter 18 Thick Metal

Thick Metal Type

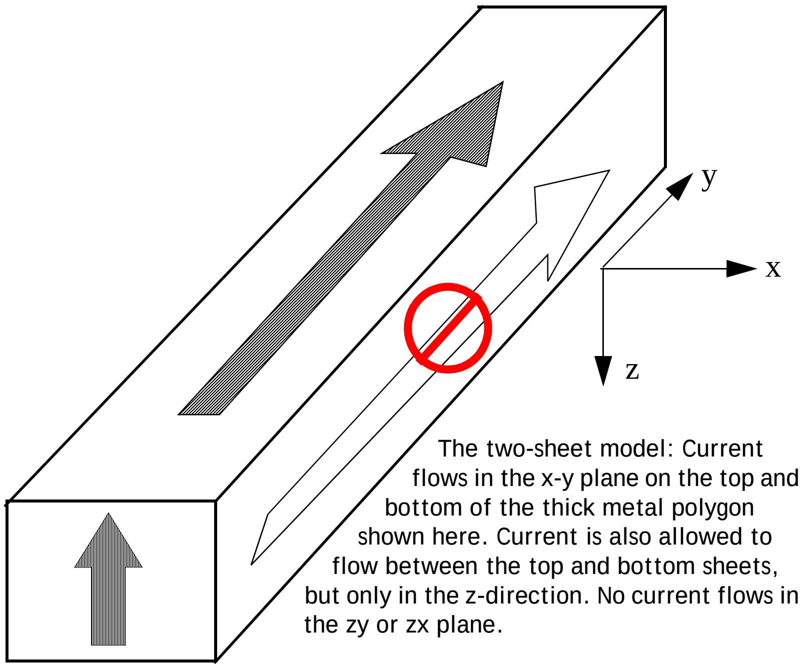
The Thick Metal metal type allows you to model physically thick metal. All other metal types are modeled as having zero thickness where the entered thickness value only affects the metal loss calculations. The Thick Metal type allows you to more accurately model the true 3D characteristics of thick conductors. Using a thick metal model not only allows for proper modeling of loss, but also includes the EM effects of physically thick metal, such as coupling between closely spaced conductors.

Since thick metal increases both your processing time and memory requirements, it should only be used when necessary. Metal is considered to be thick metal when its thickness is comparable to other dimensions in the circuit such as the width of a conductor or gap between conductors.

When using thick metal, the structure is approximated by two or more infinitely thin sheets of metal. For the typical two sheet model, one sheet represents the top surface of the structure and a second sheet represents the bottom surface of the structure. Vias are placed automatically around the perimeter to allow current to flow between the sheets. An example using two sheets is illustrated below.

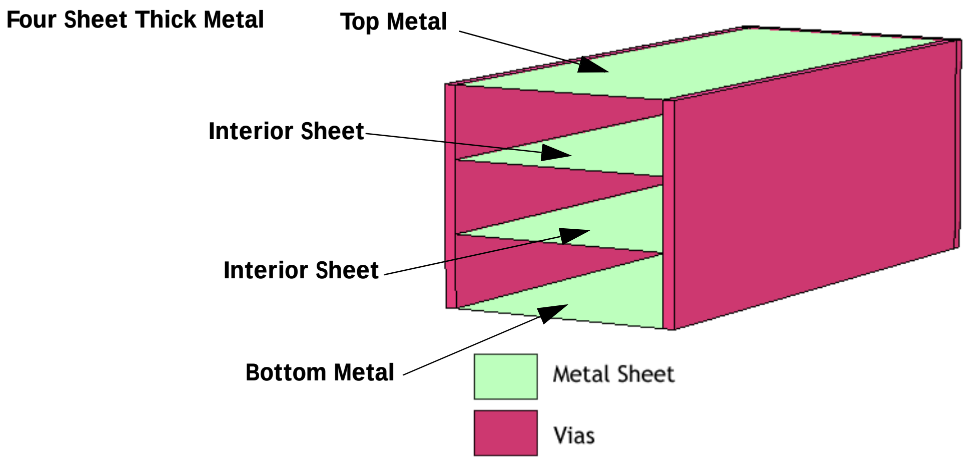

Two Sheet (Default)
Thick Metal
Top Sheet
This is a cross section of thick metal modeled using two sheets; note that the sidewalls are vias.
Bottom Sheet
🟩 Metal Sheet
🟥 Vias

For two sheets, the current travels on only the top and bottom surface of the thick metal. Current on the sides of the thick conductor can be approximated by using three or more sheets.


y
x
z
The two-sheet model: Current flows in the x-y plane on the top and bottom of the thick metal polygon shown here. Current is also allowed to flow between the top and bottom sheets, but only in the z-direction. No current flows in the zy or zx plane.

For most cases, using the default of two sheets provides a high accuracy solution. However for very tightly coupled lines, where the gap between the lines is much less than the metal thickness, the coupling between them may be underestimated. In these cases, you may need to increase the number of sheets. However, increasing the number of sheets increases the memory requirements and processing time.

Increasing the number of sheets adds more layers of infinitely thin metal between the top and bottom metal sheet. A cross section of a four sheet model is shown below.



This is a cross section of thick metal modeled using four sheets; note that the sidewalls are vias.

Creating a Thick Metal Polygon

To create a thick metal polygon in your circuit, you must first define a metal type using the Thick Metal model, then apply that metal type to the polygon in your circuit. This creates a thick metal polygon which extends upwards (toward the box top) from the metal level on which it is created. To do this, perform the following:

1 **In the project editor, select *Circuit* ⇒ *Metal Types* from the main menu.**

The Metal Types dialog box appears on your display.

2 **Click on the Add button in the Metal Types dialog box.**

The Metal Editor dialog box appears on your display.

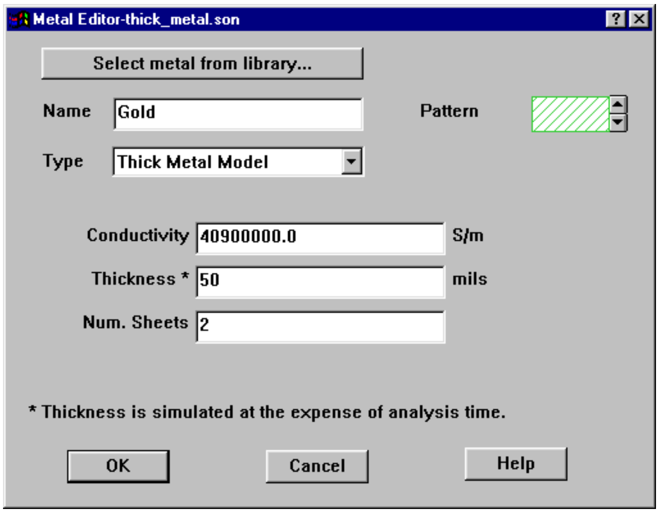
3 **Select Thick Metal Model from the type drop list in the Metal Editor dialog box.**

This updates the dialog box with the text entry boxes for the three parameters needed for the thick metal model: Conductivity, Thickness, and Number of Sheets.

4 **Enter the three parameters in the appropriate text entry boxes.**

5 **If you do not wish to use the default metal name, enter the desired name for the metal type in the Name text entry box.**

The Metal Editor dialog box should appear similar to the picture below.


Metal Editor-thick_metal.son

Name: Gold

Type: Thick Metal Model

Conductivity: 40900000.0 S/m

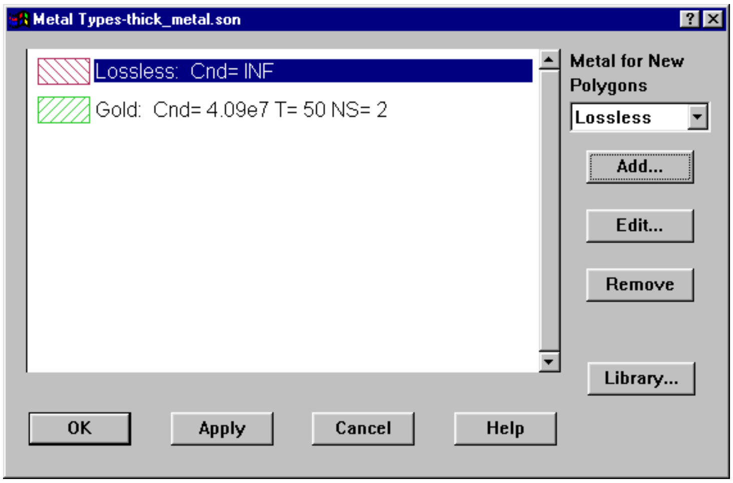
Thickness *: 50 mils

Num. Sheets: 2

* Thickness is simulated at the expense of analysis time.

6 **Click on the OK button to close the Metal Editor dialog box and apply the changes.**

The Metal Types dialog box is updated with the new metal type.



Lossless: Cnd= INF
Gold: Cnd= 4.09e7 T= 50 NS= 2

Metal for New Polygons: Lossless

7 **Click on the OK button to close the Metal Types dialog box.**

The thick metal is now available to use in your project.

8 **Enter the desired polygon, then double-click on the polygon to open the Metalization Properties dialog box.**

9 **Select the thick metal model metal type from the Metal drop list in the Metalization Properties dialog box.**

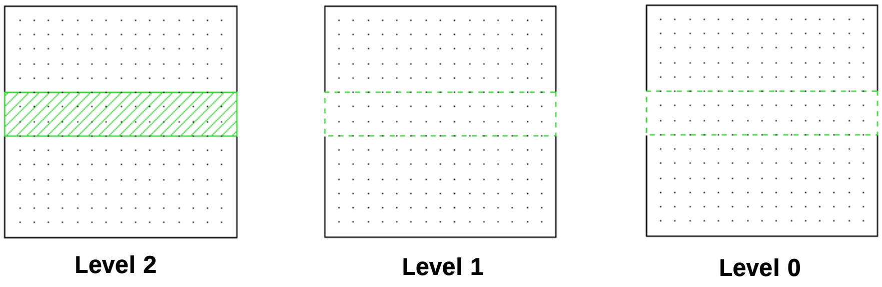
This will apply the metal type which uses thick metal to the selected polygon. The thick metal extends upwards from the level on which the polygon was drawn.

10 **Click on the OK button to close the Metalization Properties dialog box and apply the changes.**

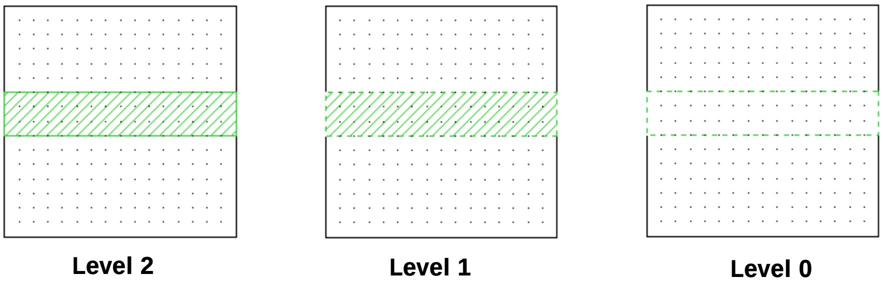
The fill pattern of the polygon changes to the fill pattern used by the thick metal. If the thick metal polygon is thicker than the dielectric layer(s) above it, the polygon also appears on metal levels above.

Viewing Thick Metal in the Project Editor

The thick metal extends upward through the dielectric layer from the level on which the polygon is drawn. If the thick metal is not as thick as the dielectric layer above it, then the polygon only appears on the lower level where it was drawn. If the thick metal is the same thickness as the dielectric layer above it appears on both the metal level where it was drawn and on the metal level above. Examples of both instances are shown below.



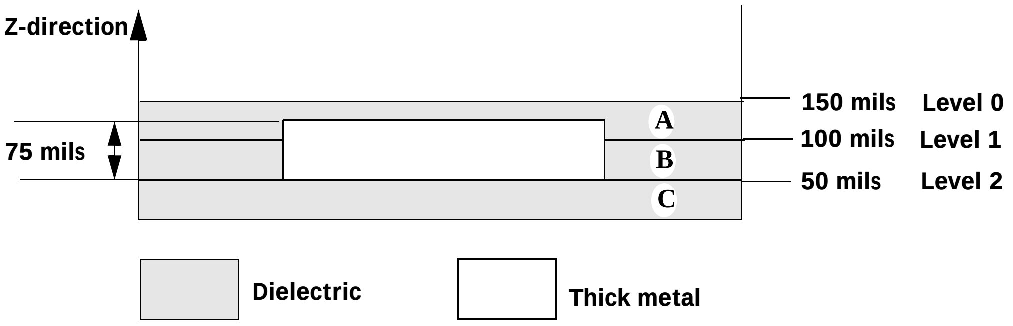
A 3 mil thick metal polygon is drawn on level 2 below a 5 mil thick dielectric layer. The polygon is visible on level 2 where it was drawn, but only the outline is visible on level 1 above since the thick metal does not pierce the dielectric.



A 5 mil thick metal polygon is drawn on level 2 below a 5 mil thick dielectric layer. The polygon is visible on level 2 where it was drawn, and also on level 1 above since it is the same thickness as the dielectric layer. Note that on level 1, the border of the polygon is drawn with a dashed line to indicate that the origin of this polygon is not on this level.

If the thick metal is thicker than the dielectric above, but not thick enough to pierce the next dielectric layer, the polygon appears on the level where it was drawn and on the metal level above. However, note that the top of the thick metal does not appear in the project editor because it is embedded in a dielectric layer. You will be able to view the top sheet of metal in the current density viewer which is discussed later in the chapter.

A side view of a circuit with three 50 mil dielectric layers (A, B, and C) and a 75 mil thick metal polygon on level 2 is shown below. Note that the top of the thick metal only extends halfway through dielectric layer. The top of this thick metal is not visible in the project editor.



Another important thing to note about the modeling of a thick metal which ends in the interior of a dielectric layer is that even though you model the thick metal with 2 sheets, the software actually uses three sheets. The bottom sheet is on level 2 where the polygon originates. The top sheet is in the interior of dielectric layer A. The third sheet is on metal level 1. Whenever a thick metal polygon traverses a metal level, a sheet is added on that level. This adds additional computational time and should be kept in mind when using thick metals which encompass more than one dielectric layer.

If Single Level select is enabled, then you may only select the thick metal polygon on the level where it was drawn.

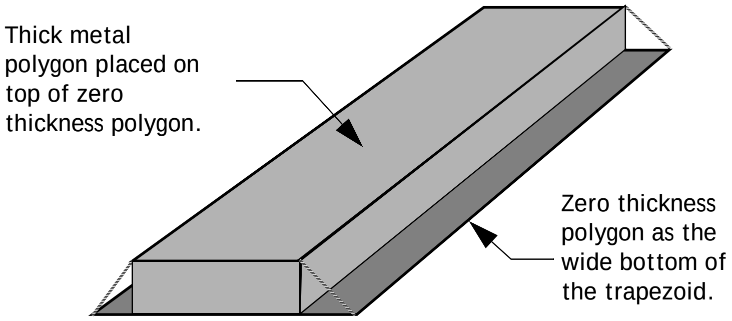
Thick metal polygons are connected to thin metal polygons by drawing the thin metal polygon on the same level on which the thick metal was drawn and placing the thin metal polygon adjacent to or overlapping the thick metal. This connects the two structures electrically.

Restrictions with Thick Metal Polygons

If you are using the thick metal model with more than two sheets of metal, be aware that analyzing a thick metal of 3 or more sheets at low frequencies may introduce error into the DC loss. To avoid this problem, use only 2 sheets for your thick metal when analyzing at very low frequencies.

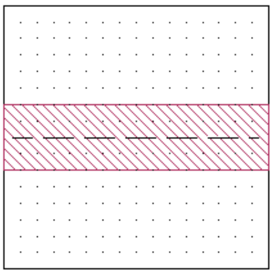
Modeling an Arbitrary Cross-Section

In this section, we use a combination of thick metal and Normal (zero thickness) metal to approximate thick metal lines where the vertical cross-section has an arbitrary geometry. To demonstrate this capability, we use a simple trapezoidal geometry, the cross section shown in the figure below.


Thick metal polygon placed on top of zero thickness polygon.
Zero thickness polygon as the wide bottom of the trapezoid.

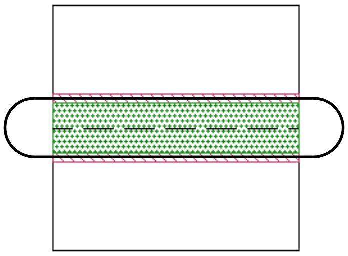
A trapezoidal cross-section transmission line viewed in perspective. If the line has no current going around the edge, it can be modeled, as shown, as two infinitely thin sheets of current, one at the top and the other at the bottom of the actual metal.

To create the thick metal trapezoid, set up the dielectrics so that there is one layer of dielectric with the same thickness as the thick metal. Then, place a polygon representing the wider bottom side of the thick metal on the bottom side of that dielectric layer. This polygon should use the Normal model for the metal type, which is modeled as a zero-thickness metal. To get the proper loss, you should set the thickness of this metal type to one half the total thickness of the metal. This compensates for the fact that current is now flowing through two conductors, instead of the usual single conductor.

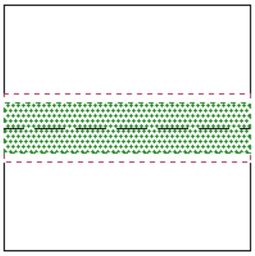


The wide bottom of the trapezoidal line is made up of a polygon using the Normal model for the metal type. This is a zero-thickness

Then place a polygon representing the top side of the thick metal on the bottom side of that dielectric layer using the Thick Metal metal type. Make this polygon as thick as the dielectric layer.



Thick metal polygon on level 1 where it is drawn and placed on top of the wider zero-thickness



The same polygon shown on level 0. Since the thick polygon is the same thickness as the dielectric layer, the metal also appears on this level. Only the outline of the zero-thickness metal is shown on this level.

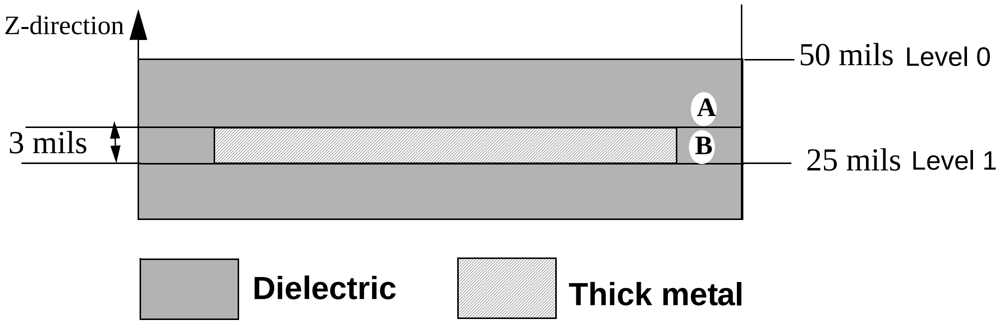
Next, place any desired ports on the thick metal polygon, not on the thin metal polygon. Since the thick metal polygon is placed on top of the zero-thickness polygon, the two are connected electrically and the port is across both polygons.

A circuit implementing the above transmission line is stored in Thkthru and an example of a thick step junction is stored in a project called Thkstep. Copies of these projects can be obtained from the Sonnet examples. For directions on obtaining a Sonnet example, select *Help ⇒ Examples* from the menu of any Sonnet program, then click on the Instructions button.

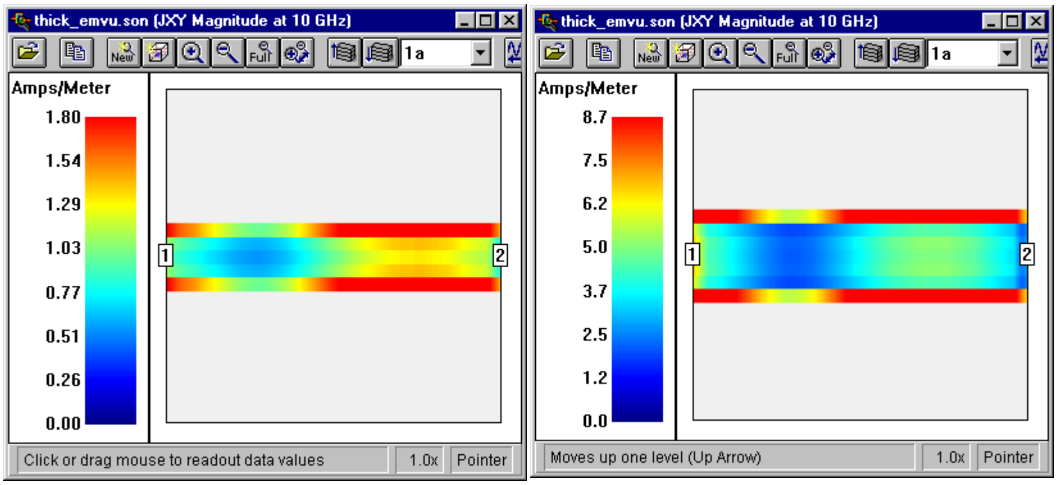
Thick Metal in the Current Density Viewer

The current density viewer allows you to view the current density distribution in your circuit. When you select the Compute Current Density option in the Analysis Setup dialog box in the project editor, ***em*** calculates current density data for all the metal levels in your circuit. When you have thick metal in your circuit which ends in the interior of a dielectric layer, then the current density viewer creates "sublevels" of metal in order to display all the current density data.

For instance, you have a circuit with 3 mil thick metal using the default 2 sheets placed on metal level #1 below a 25 mil dielectric layer as pictured below. The top of the thick metal structure is placed in the interior of the dielectric layer. The current density viewer displays levels 1b and 1a, where 1b is the metal level on which the thick metal was drawn and 1a is the top of the thick metal structure embedded in the dielectric layer.



Below are shown the views of level 1a and 1b in the current density viewer. Note that 1a is the top of the thick metal structure and is not visible in the project editor. 1b is the bottom where the polygon was drawn and is visible in the project editor.


thick_emvu.son (JXY Magnitude at 10 GHz)
1a
Amps/Meter
1.80
1.54
1.29
1.03
0.77
0.51
0.26
0.00
1
2
Click or drag mouse to readout data values
1.0x
Pointer
thick_emvu.son (JXY Magnitude at 10 GHz)
1a
Amps/Meter
8.7
7.5
6.2
5.0
3.7
2.5
1.2
0.0
1
2
Moves up one level (Up Arrow)
1.0x
Pointer

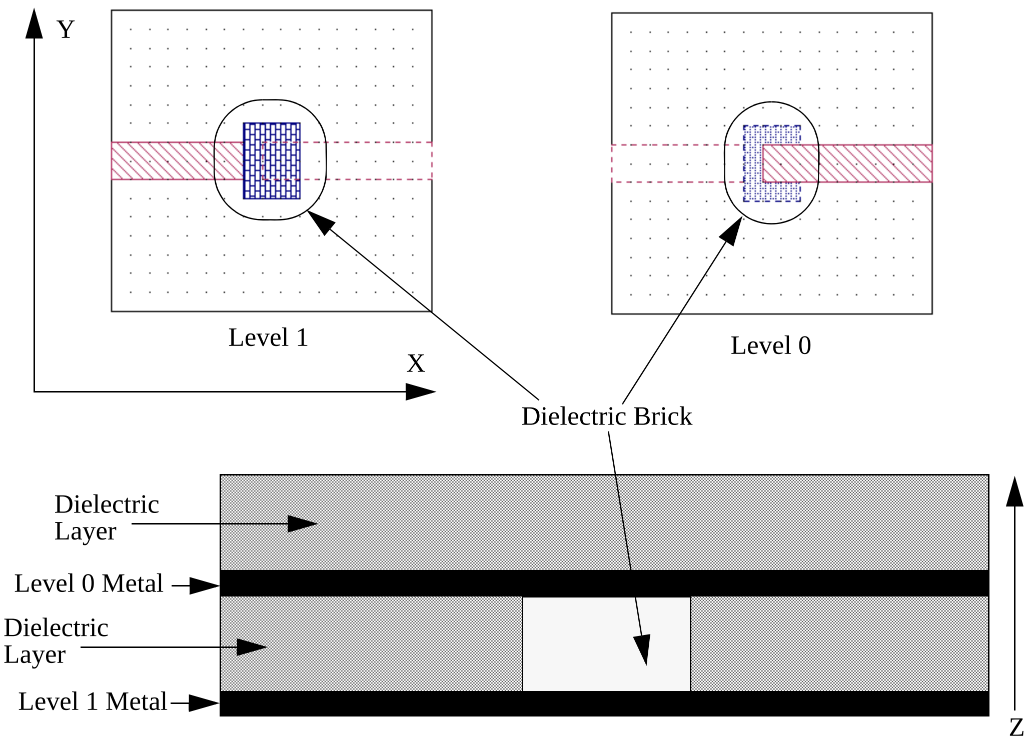
The current density viewer creates as many "sublevels" as are needed. A thick metal which is defined as having 4 sheets placed on level 2 would appear in the current density viewer as 2a, 2b, 2c and 2d with 2a being the top of the thick metal structure and 2d being the bottom drawn on level 2.

Chapter 19 Dielectric Bricks

Although ***em*** is primarily a planar electromagnetic simulator, it also has the capability to add “dielectric brick” material anywhere in your circuit. A dielectric brick is a solid volume of dielectric material embedded within a circuit layer. See the illustration below. Dielectric bricks can be made from any dielectric material (including air) and can be placed in circuit layers made from any other dielectric material (including air). For example, dielectric bricks can be used to simulate structures such as an embedded capacitor in an “air” circuit layer, or an “air hole” in a dielectric substrate circuit layer.

WARNING

Misuse of dielectric bricks can lead to significantly inaccurate results. It is highly recommended that you read this entire chapter before attempting to use dielectric bricks.



Side View of Circuit shown above.

All realizable values for the dielectric constant, loss tangent and bulk conductivity can be used. Furthermore, it is possible to set these parameters independently in each dimension to create anisotropic dielectric bricks.

Em is appropriate for simple structures using very localized dielectric bricks; however, when your design requires large areas of brick material, you may need a full 3-D electromagnetic analysis tool.

You should also be aware that the use of dielectric bricks can dramatically increase the memory requirements, and thus the simulation time, for your circuit. Bricks should only be used where strictly necessary for the accuracy of your simulation.

Care should be taken when using dielectric bricks, since improper modeling of your dielectric brick can yield highly inaccurate data. We recommend that you run a convergence test by doubling (or halving) the number of your Z-partitions, reanalyzing your circuit and comparing the two results to ensure that you are using a sufficient number of Z-partitions. For more information on Z-partitioning, see “Z-Partitioning,” page 272.

Applications of Dielectric Bricks

The use of dielectric bricks is appropriate for applications where the effects of dielectric discontinuities or anisotropic dielectric materials are important. Examples of such applications include dielectric resonators, dielectric overlays, airbridges, microstrip-to-stripline transitions, dielectric bridges and crossovers, microslab transmission lines, capacitors and module walls.

Guidelines for Using Dielectric Bricks

Subsectioning Dielectric Bricks

A dielectric brick simulates a volume of dielectric material. Because a brick simulates a volume, it must be subsectioned in the X, Y and Z dimensions. The more subsections (finer resolution) used in each dimension, the more accurate the analysis.

X/Y subsectioning of dielectric bricks is identical to X/Y subsectioning of metal polygons. You can control the X/Y subsectioning of both through your choice of grid size, XMIN, YMIN, XMAX, YMAX and subsections-per-wavelength. See Chapter 3, “Subsectioning,” for details.

Z subsectioning of dielectric bricks is controlled by the “number of Z-partitions” parameter. This parameter specifies the number of Z subsections for all dielectric bricks on a particular dielectric layer. See the “Z Partitions dialog box” topic in the project editor’s online help for information on setting this parameter.

Using Vias Inside a Dielectric Brick

Vias through dielectric bricks are treated the same as vias through the standard dielectric layers. Note that via ports inside dielectric bricks are not allowed.

Air Dielectric Bricks

Dielectric bricks can be made of any dielectric material and can be placed in any circuit layer. This allows, for instance, “alumina” bricks to be created in an “air” circuit layer. However, it is also possible to reverse this scenario. Dielectric bricks made of “air” can also be created in alumina circuit layers. This is an important consideration to remember. Depending upon the circuit geometry for a given application, this ability to reverse the dielectric characteristics may simplify the circuit and make it faster to analyze.

Limitations of Dielectric Bricks

Diagonal Fill

Diagonal fill is not allowed for dielectric bricks. All dielectric bricks must use “staircase fill”. Thus, dielectric bricks with curved or rounded edges must be stairstep approximated. Note that the error caused by such an approximation decreases as the X and Y cell sizes are decreased. Thus, it is possible to make this error arbitrarily small by choosing sufficiently small X and Y cell sizes.

Antennas and Radiation

The far field viewer does not support dielectric bricks. Circuits containing dielectric bricks can be analyzed with the far field viewer, but the radiation effects of the dielectric bricks are not accounted for in the analysis.

The Agilent Translator, *ebridge*

The Agilent translator does not create dielectric bricks.

Dielectric Brick Concepts

Creating a Dielectric Brick

To create a dielectric brick in the project editor, do the following:

1 **Move to the circuit level where the base of the dielectric brick is to be located.**

The dielectric brick that is created will rest on this circuit level, and will extend upward to the next level. Dielectric bricks can be placed on any level, including the ground plane. If a brick is placed on the highest circuit level (level 0), it will extend up to the top cover of the metal box.

2 **Create a base polygon which defines the cross-section of the brick.**

This is done by selecting either *Tools ⇒ Add Dielectric Brick ⇒ Draw Rectangle* or *Tools ⇒ Add Dielectric Brick ⇒ Draw Polygon* from the project editor's main menu. The first option allows the vertices of arbitrarily shaped base polygons to be entered on a point by point basis. This option is used to create dielectric bricks with any cross-sectional shape. However, if the cross-section is rectangular in shape, it is often quicker to create dielectric bricks using the second option.

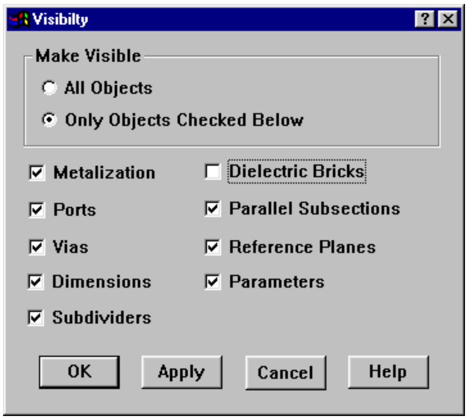
Viewing Dielectric Bricks

Once a dielectric brick has been created in the project editor, it is possible to "see" the brick from both the circuit layer where the base of the brick is located and the circuit layer where the top of the brick is located. On both levels, you will see a polygon which defines the cross-sectional shape of the dielectric brick. The brightness of the polygon, however, will vary. When you are on the top level, you will see a "dim" polygon; on the base level you will see a "bright" polygon.

Only the outline of the dielectric brick is visible from levels other than the origination and termination of the dielectric brick.

Note that while it is possible to "see" a brick from two different circuit levels, "selecting" a brick, for cutting, copying, moving, changing attributes, etc., can only be done from the circuit level where the base of the brick is located if you are in Single layer edit mode. The polygon can be selected on either level if you are in multilayer select.

Finally, it is possible to turn the display of dielectric bricks "on" or "off" in the project editor. You select *View ⇒ Object Visibility* from the main menu of the project editor which opens the Object Visibility dialog box shown below.



Make Visible: All Objects [✓ Only Objects Checked Below]

[✓] Metalization
[✓] Ports
[✓] Vias
[✓] Dimensions
[✓] Subdividers
[ ] Dielectric Bricks
[✓] Parallel Subsections
[✓] Reference Planes
[✓] Parameters

Click on the *Only Objects Checked Below* radio button to enable the object choices, then click on the Dielectric Bricks checkbox to turn off the display of the bricks.

This will make any bricks present in the circuit invisible and unselectable, but does not remove them from the circuit. The dielectric bricks can be turned back "on" by once again selecting *View ⇒ Object Visibility* and clicking the *Dielectric Bricks* checkbox or the *All Objects* radio button.

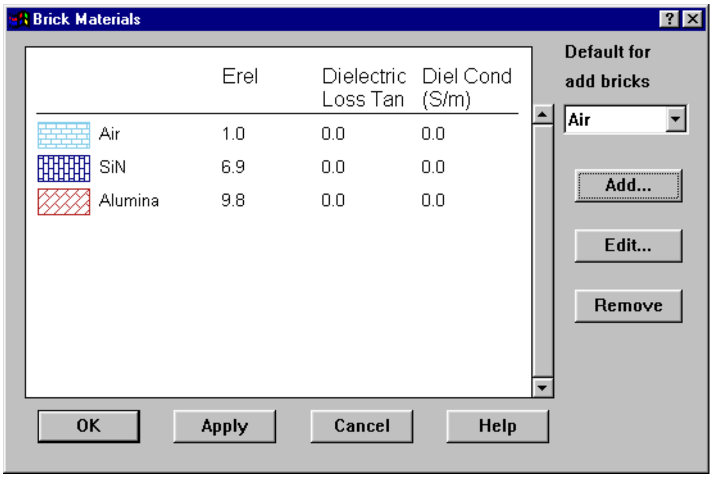
Occasionally, when a circuit contains many layers, with overlapping metal polygons and dielectric bricks, it may be somewhat difficult to distinguish the metal polygons and dielectric bricks from one another. The ability to turn dielectric bricks "off" usually makes it easier to view such circuits.

Defining Dielectric Brick Materials

Just as it is possible to define a variety of metal types, each with different properties, it is also possible to define a variety of dielectric brick materials, each with different values for the dielectric constant, loss tangent, and bulk conductivity.

To define a new dielectric brick material, or to modify the characteristics of an existing material, you use the Brick Materials dialog box, which is opened by selecting *Circuit ⇒ Brick Materials* from the main menu of the project editor.

The Brick Materials dialog box, shown on page 271, shows all the dielectric brick materials previously defined, the color/fill pattern assigned to each brick material, and whether the material is isotropic or anisotropic. To modify the settings for a particular dielectric brick material, edit that materials text entry boxes. Note that for anisotropic materials all the parameters do not fit in the dialog box simultaneously, so that it is necessary to use the scroll bars to access all settings.



	Erel	Dielectric Loss Tan	Diel Cond (S/m)
Air	1.0	0.0	0.0
SiN	6.9	0.0	0.0
Alumina	9.8	0.0	0.0

If the brick type is isotropic only one set of parameters, X, will be set. Conversely, if the brick material is set to anisotropic, each parameter is defined separately for the X, Y, and Z dimensions. If you wish to make a brick material anisotropic, click on the *Ani* checkbox.

The “default” material used when new dielectric bricks are created can also be set in the Brick Materials dialog box. Select a brick type from the *Default for add bricks* drop list. Once the default material has been set, all bricks created thereafter will be made of that material.

Changing Brick Materials

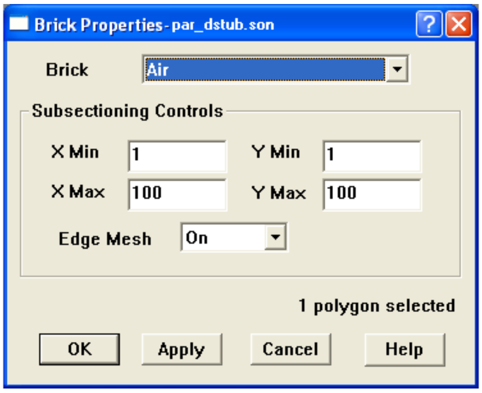
The material type for bricks that already exist in a circuit can be changed by following the procedure given below:

1 **Select the brick(s) by clicking on it or lassoing it.**

The brick is highlighted.

2 Select *Modify* ⇒ *Brick Materials* from the main menu of the project editor.

This will open the Dielectric Brick attributes dialog box, shown below.



Brick Properties - par_dstub.son

Brick: Air

Subsectioning Controls

X Min: 1   Y Min: 1

X Max: 100   Y Max: 100

Edge Mesh: On

1 polygon selected

3 Select the brick material you desire from the drop list labeled Brick.

This drop list contains all the types defined for dielectric bricks including the default type, air.

4 Click on the OK button to apply your selection and close the dialog box.

Z-Partitioning

A dielectric brick simulates a volume of dielectric material. Because a brick simulates a volume, it must be subsectioned in the X, Y, and Z dimensions. The more subsections (finer resolution) used in each dimension, the more accurate the analysis.

X/Y subsectioning of dielectric bricks is identical to X/Y subsectioning of metal polygons. You can control the X/Y subsectioning of both through your choice of grid size, XMIN, YMIN, XMAX, YMAX, and subsections-per-lambda.

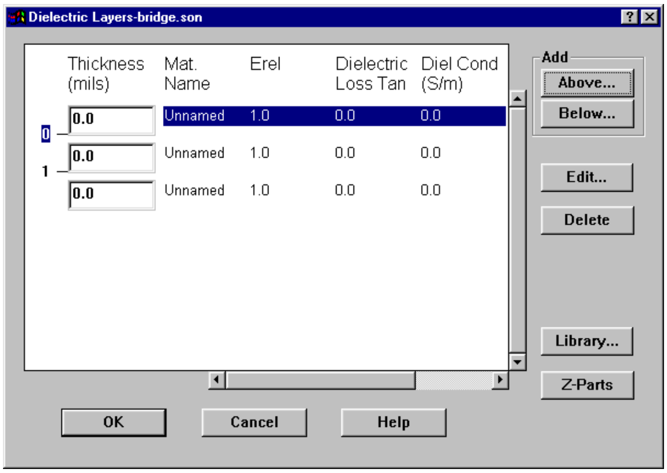
Z subsectioning of dielectric bricks is controlled by the Z Partitions dialog box which is opened when you click on the Z Parts button in the Dielectric Layers dialog box (*Circuit* ⇒ *Dielectric Layers*). You may enter a Z Parts value for each dielectric layer in your circuit. This parameter specifies the number of Z partitions for all dielectric bricks on a particular circuit layer.

The default for this parameter is zero so that you are forced to enter a value for this field. If you use a dielectric brick in a layer, and do not set the z-partitions, ***em*** reports an error and exits the analysis. You must enter a non-zero integer value for this parameter in order to run an analysis. The value of this parameter is highly dependent on your circuit design; therefore, Sonnet cannot determine a "reasonable" value. This is the reason we suggest you run a convergence test, discussed earlier in the chapter, on your circuit to determine the best value for the Z-partitioning.

To set this parameter in the project editor, do the following:

1 **Select *Circuit* ⇒ *Dielectric Layers* from the project editor main menu.**

The Dielectric Layers dialog box, shown below, is displayed.

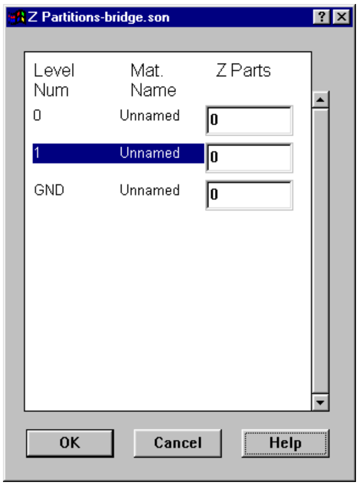


Dielectric Layers-bridge.son

	Thickness (mils)	Mat. Name	Erel	Dielectric Loss Tan	Diel Cond (S/m)
	0.0	Unnamed	1.0	0.0	0.0
0					
	0.0	Unnamed	1.0	0.0	0.0
1					
	0.0	Unnamed	1.0	0.0	0.0

2 **Click on the Z-Parts button in the Dielectric Layers dialog box.**

The Z Partitions dialog box appears on your display.



Z Partitions-bridge.son

Level Num	Mat. Name	Z Parts
0	Unnamed	0
1	Unnamed	0
GND	Unnamed	0

3 Enter the number of z partitions to be used for each dielectric layer in the appropriate Z Parts text entry box.

Note that changing this value for a particular layer will have absolutely no affect on the analysis if there are no bricks on the layer. If there are multiple bricks on the layer, the Z subsectioning for all of those bricks will be identical. It is not possible to apply different Z partitions to brick polygons which appear on the same layer.

Chapter 20 Antennas and Radiation

To this point, this manual has been focused on using Sonnet for the analysis of high frequency circuits and transmission structures. However, there is a large class of radiating structures for which Sonnet has proven very useful. This chapter describes how to use Sonnet to analyze 3-D planar radiating structures, such as microstrip patch arrays and microstrip discontinuities, using the “Open Waveguide Simulator” technique. The underlying assumptions of this technique are described in detail. Common modeling mistakes are also pointed out. Examples are provided to illustrate the correct use of the modeling technique.

This chapter also discusses the far field viewer, an analysis and viewing tool which calculates far field antenna patterns for arbitrary 3-D planar geometries. The far field viewer uses the current distribution data in the project as input, and creates a pattern. The pattern may be viewed as a cartesian, polar or surface plot.

Background

Since ***em*** is an analysis of 3-D planar circuits in a completely enclosing, shielding, rectangular box, the analysis of radiating structures is not an application which immediately comes to mind.

However, ***em*** can be used to simulate infinite arrays using a waveguide simulator. In this technique, as shown in on page 277, a portion of the array is placed within a waveguide. The waveguide tube is vertical, connecting the radiating patches to the termination, which is a matched load. The images formed by the waveguide walls properly model the entire infinite array scanned to a specific angle.

The waveguide simulator inspired what we now call the Open Waveguide Simulator Technique described in the next section.

Modeling Infinite Arrays

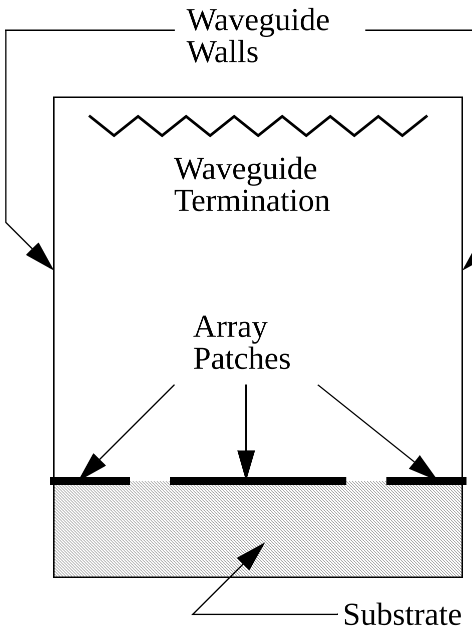
The sidewalls of the shielding box in the ***em*** analysis easily represent the sidewalls of the waveguide in the infinite array waveguide simulator. A side view is shown in the figure on page 277.

Providing a termination for the end of the waveguide requires a little more thought. Any waveguide mode can be perfectly terminated by making the top cover resistivity in ***em*** equal to the waveguide mode impedance. This can be done in the project editor automatically at all frequencies and all modes by selecting "WGLOAD" from the metals in the Top Metal drop list in the Box Settings dialog box.

$$Z_{TE} = \frac{\eta}{\sqrt{1-\left(\frac{f_c}{f}\right)^2}} \qquad f > f_c$$

$$Z_{TM} = \eta\sqrt{1-\left(\frac{f_c}{f}\right)^2} \qquad f > f_c$$

$$f_c = \frac{v_c}{2\pi}\sqrt{\left(\frac{m\pi}{A}\right)^2 + \left(\frac{n\pi}{B}\right)^2}$$



The waveguide simulator for infinite arrays inspired the technique described here. In this side view, the waveguide walls form images of the array of microstrip patches, simulating an infinite array. v_c is the velocity of light in the medium filling the

In a phased array with the array scanned to a specific direction, a single waveguide mode is generated. The ***em*** software can model the waveguide simulator of that infinite array just by setting the top cover impedance to the impedance of the excited waveguide mode.

Modeling an Open Environment

If we can use a closed (i.e., terminated) waveguide to model an infinite array, we can also model radiation from a finite array; although, it must be done under certain conditions. It is important to keep in mind that, unless the analysis is carefully prepared, these conditions are easily violated, yielding incorrect results. When the conditions are met, useful results can be obtained, as shall be demonstrated.

First Condition: *Make both of the lateral substrate dimensions greater than one or two wavelengths.*

When using the Open Waveguide Simulator, we view the sidewalls of the shielding box as forming a waveguide whose tube extends in the vertical direction, propagating energy from the antenna toward the "Termination" as shown on page 277. Radiation is then approximated as a sum of many waveguide modes. If the tube is too small, there are few, if any, propagating modes, violating the First Condition.

There is an easily made mistake when modeling radiation from small discontinuities. Discontinuities are usually small with respect to wavelength. For a discontinuity analysis, the sidewalls are usually placed one or two substrate thicknesses from the discontinuity. In this case, the substrate dimensions are unlikely to meet the First Condition. If the sidewalls form below a cut-off waveguide, there is no radiation.

Second Condition: *Make sure the sidewalls are far enough from the radiating structure that the sidewalls have no affect.*

Another way to look at this condition is to consider the image of the structure (discontinuity or antenna) created by the sidewall. Position the sidewall so that the image it forms has no significant coupling with the desired structure.

Usually two to three wavelengths from the sidewall is sufficient for discontinuities. For single patch antennas, one to three wavelengths is suggested. Requirements for specific structures can easily be greater than these guidelines. If the First Condition requires a larger substrate dimension than the Second Condition, it is very important that the larger dimension is used.

If you are using the far field viewer, the larger the box the better. The far field viewer assumes that S-parameters from ***em*** are from a perfect open environment. If some of the power is reflected due to a box that is too small, the input power calculated by the far field viewer will be slightly incorrect. The far field viewer then calculates antenna efficiencies greater then 100%. If this occurs, the box size should be increased.

Third Condition: *Place the top cover outside the fringing fields (i.e., near field) of the radiating structure, preferably a half wavelength.*

If this condition is violated, the resistive top cover becomes involved in the reactive fringing fields which form the near field of the radiator. This changes what would have been reactive input impedance into resistive input impedance, overestimating the radiation loss.

Do not place the top cover thousands of wavelengths away from the radiator. Extreme aspect ratios of the box should be avoided. Empirical data for patch antennas has shown that a distance of about 1/2 wavelength works best.

Fourth Condition: *Set the top cover to Free Space.*

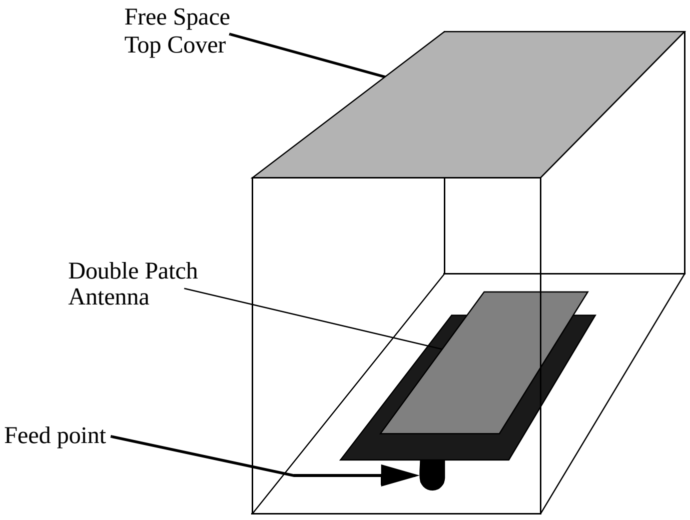
This value is a compromise. As shown by the equations on the previous page, all TE modes have a characteristic impedance larger than 377 ohms (Ω), while all TM modes are lower. Thus, while a 377 Ohms/square top cover does not perfectly terminate any mode, it forms an excellent compromise termination for many modes. This approximates removing the top cover of the box. If the box is large, it, in turn, approximates radiation, as shall be demonstrated.

Fifth Condition: *The radiating structure can not generate a significant surface wave.*

If there is a significant, compared to required accuracy, surface wave, it is reflected by the sidewalls of the box. Unless this is the actual situation, such antennas are inappropriate for this technique. Actually, the Fifth Condition is a special case of the Second Condition, since if there is significant surface wave, the Second Condition cannot be met. This condition is stated explicitly because of its importance.

In general, any surface wave is both reflected and refracted when it encounters the edge of the substrate. This boundary condition is different from either the conducting wall of Sonnet or the infinite substrate provided by a true open space analysis.

A dual patch antenna is illustrated conceptually below.

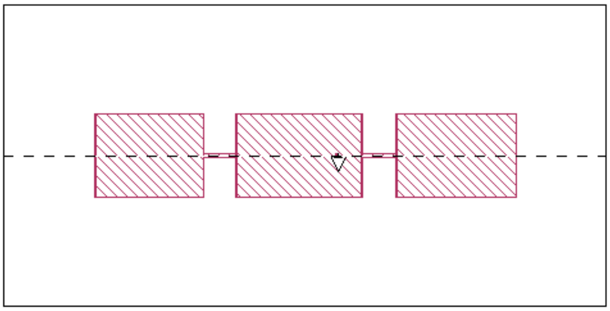


Radiation can be simulated by including a lossy top cover, a lossy dielectric layer (optional) and by placing the sidewalls far from the radiator (drawing not to scale). Place the top cover one half wavelengths from the radiator.

The feed point is created in the project editor by creating a via to ground at the feed point. Then the ground end of that via is specified as a port, just as one would specify a more typical port on the edge of the substrate at a box sidewall. A file showing an antenna similar to this one is named "dual_patch.son" and is available in the Sonnet examples.

Validation Example

For validation, we offer work performed by E. Ongareau of Matra Defense, Antennas & Stealthness Dept., France, as presented at the 1993 EEsof User's Group meeting at HYPER in Paris. (Reprinted with permission.) The antenna is a triple patch structure, with a top view shown below. The antenna is a test realization intended only for validation. It is not designed for optimum VSWR.



Top view of a triple patch antenna (courtesy of Matra Defense). The central patch is fed with a coaxial probe (indicated by a down pointing triangle). Each patch is resonant at a different frequency to increase the overall antenna bandwidth.

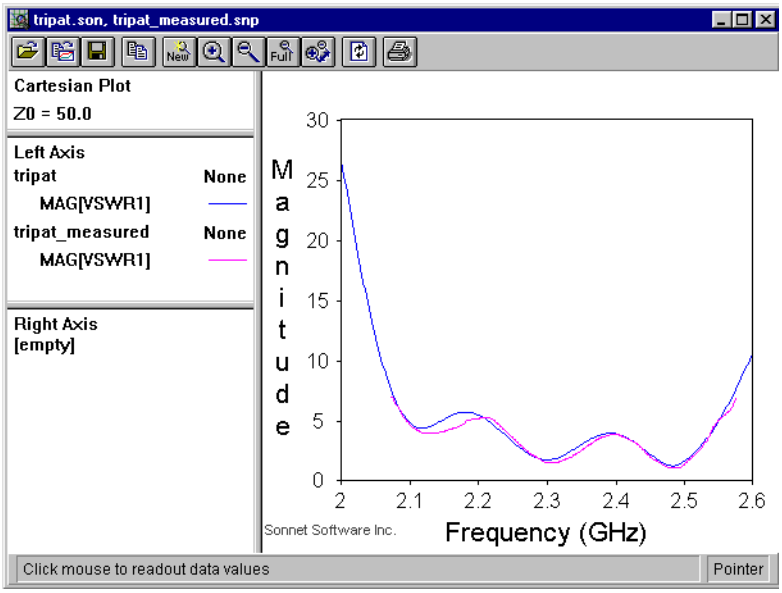
Good results are also regularly obtained on single microstrip patch antennas. We cite this example as one of the more sophisticated antennas analyzed using the Open Waveguide Simulator technique.

In this antenna, each patch has a slightly different resonant frequency, resulting in an increased bandwidth. The antenna is fed from below with a coax probe attached to the central patch. The feed point is indicated with a triangle.

The substrate is 3.04 mm thick with a dielectric constant of 2.94. The drawing is to scale with substrate dimensions of 200 mm x 100 mm. The top cover is 200 mm above the substrate surface. Cell size is 0.78125 mm square. A loss tangent of 0.001 is used in both air and substrate. The small air loss helps terminate the propagating modes.

The antenna project, Tripat, is available in the Sonnet examples. For directions on obtaining a Sonnet example, select *Help* ⇒ *Examples* from the menu of any Sonnet program, then click on the Instructions button.

The chart below shows the result. We see that the low VSWR points of each patch have differences between measured and calculated of about 1%. This is typical of most analyses of patch antennas using this technique. The differences in resonant frequency (i.e., the reflection zeros) then determine the differences in the rest of the plot. The degree to which these differences are due to analysis error, fabrication error and measurement error cannot be determined from this data.



The measured and calculated data for the triple patch antenna were obtained completely separately, so there was no chance to “tweak” the model for agreement.

If the typical differences between measured and calculated data shown above are acceptable, given the specific requirements for a particular project, then the Open Waveguide Simulator technique can provide useful results.

Far Field Viewer

The purpose of the far field viewer is to calculate the far field pattern of an antenna for a given excitation and set of directions (for example, phi and theta ranges). The far field viewer starts by reading the current density data generated by ***em*** for the antenna at the desired frequencies. The far field viewer uses the current distribution information in the project and generates the desired far field antenna pattern information. This pattern information is viewed in one of three ways: Cartesian, polar, or surface plot. A default set of values for directions, port excitations and terminations are used to calculate plots for the first frequency upon start-up of the far field viewer. Thereafter, the user specifies the frequencies, directions for the radiation pattern and the desired port excitations and terminations.

Since the far field viewer uses the current density data generated by ***em***, it can analyze the same types of circuits as ***em***. These include microstrip, coplanar structures, patch antennas, arrays of patches, and any other multi-layer circuit. As with ***em***, the far field viewer can analyze any number of ports, metal types, and frequencies. The far field viewer cannot analyze circuits which radiate sideways, structures with radiation due to vertical components, coaxial structures, wire antennas, surface wave antennas, ferrite components, or structures that require multiple dielectric constants on a single layer.

Be aware that although the current data is calculated in ***em*** with a metal box, the metal box is removed in the far field viewer calculations. The modeling considerations discussed earlier in the chapter are important, however, for the accuracy of the far field viewer data relies on the accuracy of the ***em*** simulation.

By default, the far field viewer analyzes the first frequency in the current density data stored in the project at a default set of angles and port excitations when the file is opened.

To obtain the antenna pattern for other than the first frequency, you must select *Graph* ⇒ *Calculate* from the far field viewer main menu. The Calculate dialog box allows you to set up all the parameters for the data you desire to calculate. The far field viewer calculates the fields radiated by the current that is stored in the project. The analysis is performed in an open environment with a substrate of infinite extent. For details on the Calculate dialog box, please refer to the online help in the far field viewer program.

Please refer to "A Two-Dimensional Far Field Viewer Tutorial," page 289 for a tutorial on using the far field viewer.

Analysis Limitations

The analysis of the far field viewer has the following limitations:

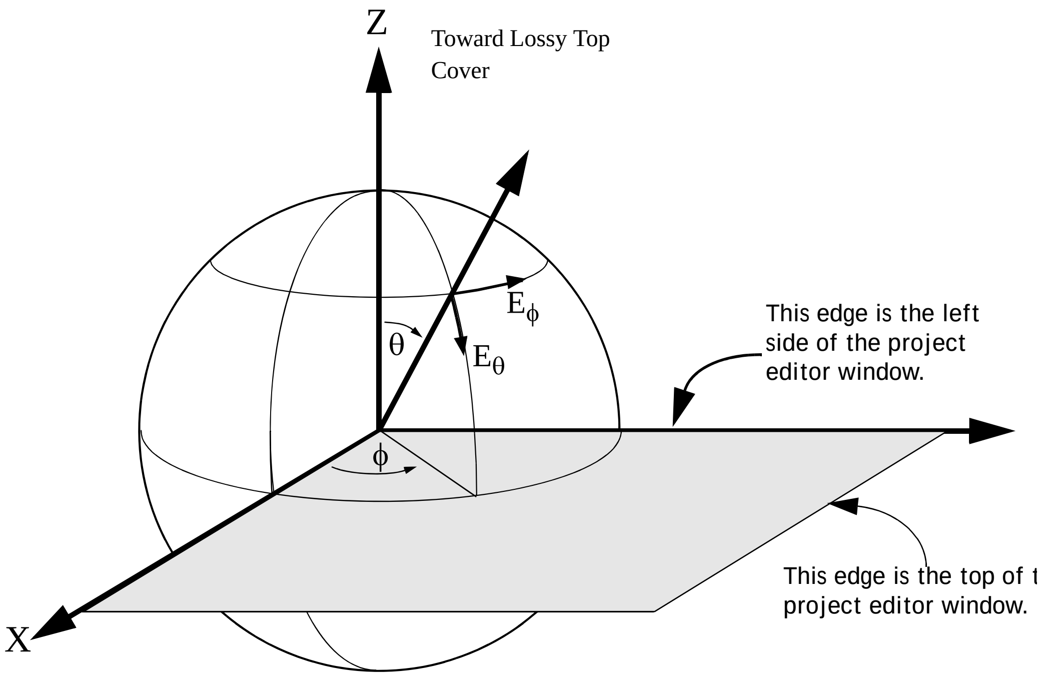
- The plotted antenna patterns do not represent de-embedded data. Therefore, the effect of the port discontinuity is still included even if you specify de-embedding when running ***em***.
- Radiation from triangular subsections (i.e., diagonal fill) is not included.
- The far field viewer patterns are for a substrate which extends to infinity in the lateral dimensions.

Spherical Coordinate System

You view your antenna plot using the spherical coordinate system, which is described below.

To view an antenna plot, the far field viewer uses the spherical coordinate system shown below. The X, Y, and Z coordinates are those used in the analysis engine and the project editor. The XY plane is the plane of your project editor window, with the Z-axis pointing toward the top of the box. The spherical coordinate system uses theta (θ) and phi (ϕ) as shown in the figure below.

.


Z
Toward Lossy Top Cover
E_ϕ
θ
E_θ
This edge is the left side of the project editor window.
ϕ
This edge is the top of t
project editor window.
X

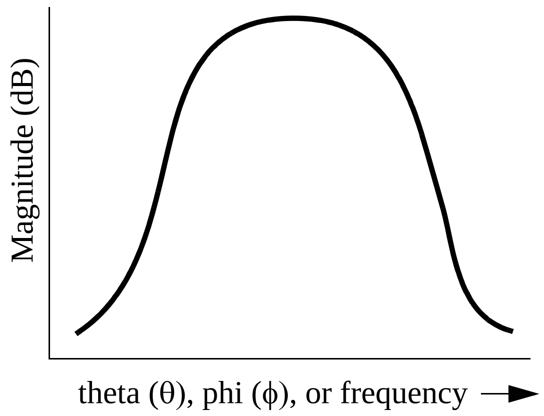
The far field viewer allows values for theta from 0 to 180 degrees. However, values of theta greater than 90 degrees are below the horizon and are only useful for antennas without infinite ground planes. To view just the top hemisphere, sweep theta from 0 to 90 degrees and sweep phi from -180 to + 180 degrees.

The X and Y axes in the figure above correspond to the X and Y axes in the project editor. The origin is always in the lower left corner of the project editor window.

To look at an E-plane cut or an H-plane cut, set phi (ϕ) to 0 or 90 degrees, and sweep theta (θ) from 0 to 90 degrees. To view an azimuthal plot, set θ and sweep ϕ.

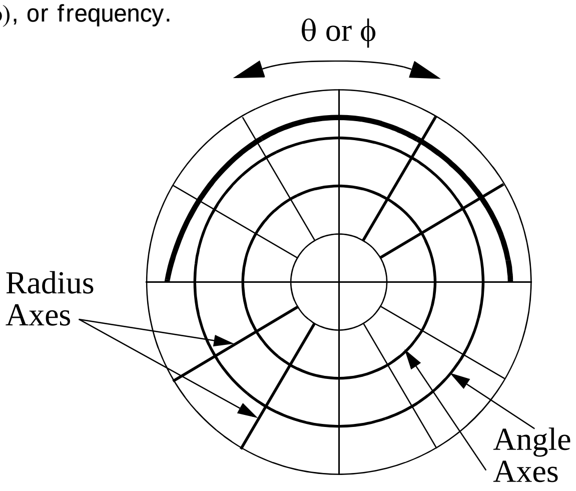
NOTE: **The far field viewer will allow the user to analyze the same space twice with the user determining the appropriate angle ranges for each analysis. For details, see “Graph - Select” in the far field viewer’s help.**

The far field viewer displays three plot types; cartesian, polar, and surface. All three types of plots are shown below. The cartesian plot allows the magnitude (in dB) to be plotted on a rectangular graph with your choice of theta (θ), phi (ϕ), or frequency for the X-axis as shown in the figure below. The polar plot allows you to select either theta (θ) or phi (ϕ) for the angle axis. The surface plot shows all the calculated values of theta and phi plotted against the gain for a single frequency.

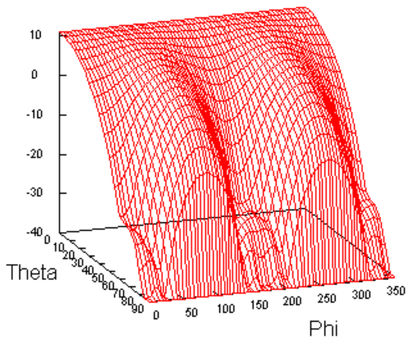


The far field viewer allows you to sweep theta (θ), phi (ϕ), or frequency.

(a) Cartesian



(b) Polar



(c) Surface Plot

Normalization

There are three types of normalization to chose from in the far field viewer. By default, the far field viewer displays the power gain. The far field viewer can also provide directive gain and absolute values. The three types of normalization are discussed below.

The power gain is defined as the radiation intensity divided by the uniform radiation intensity that would exist if the total power supplied to the antenna were radiated isotropically[1].

Directive gain is defined as the radiation intensity from an antenna in a given direction divided by the uniform radiation intensity for an isotropic radiator with the same total radiation power.[2]

The Gain and Directive gain may be displayed relative to the isotropic antenna (i.e. 0 dB), the maximum value of E for the antenna, or an arbitrary value.

Selecting Absolute for the normalization displays the radiated power in Watts/steradian at a given angle.

You may change the normalization in the far field viewer using the Select Normalization dialog box which is opened by selecting *Graph* ⇒ *Normalization* from the far field viewer main menu.

Polarization

The far field viewer displays the magnitude of the electric field vector for a given direction. The magnitude may be represented as the vector sum of two polarization components, E-theta (E_θ) and E-phi (E_ϕ) as shown in the figure describing spherical coordinates on page 284.

The far field viewer allows you to see the total magnitude or either component of the magnitude. Other polarizations are also available in the far field viewer and are discussed in “Graph - Polarization” in the far field viewer help.

References

[1] Simon Ramo, John R. Whinnery and Theodore Van Duzer, Fields and Waves in Communication Electronics, John Wiley & Sons, Inc. 1994, pg. 601.

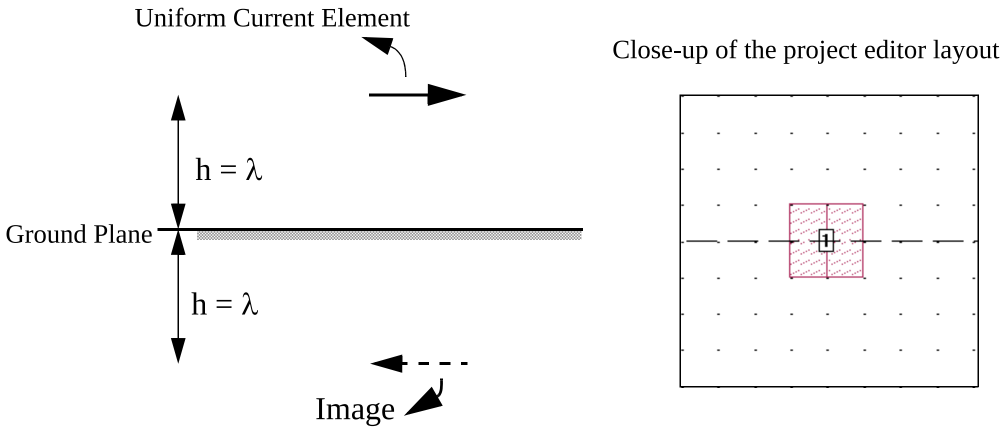
[2] Ibid, pg. 600.

Chapter 21 A Two-Dimensional Far Field Viewer Tutorial

This tutorial describes an example of using the far field viewer to display two-dimensional plots. The far field viewer displays far field radiation patterns using the current density data created during an ***em*** analysis. In this example, we analyze an infinitesimal dipole antenna above a ground plane, shown below, and compare the results to the exact theoretical antenna pattern shown on page 306, as provided by reference 2.

For more information about modeling antennas and using the far field viewer, please refer to Chapter 20.

Although this example is not very practical, it is a good example to use for validation because of its simplicity. The infinitesimal electric dipole is placed one wavelength (300 mm at 1 GHz) above the ground plane (an electric field reflection boundary).



Creating an Antenna Pattern File

This tutorial uses an infinitesimal dipole one wavelength above the ground plane. The project, Infpole, is provided in the Sonnet example files. If you do not know how to obtain a Sonnet example, select *Help* ⇒ *Examples* from any program menu, then click on the **Instructions** button.

1 **Save a copy of “infpole.son” to your working directory.**

The file “infpole.son” is the circuit geometry project file for the dipole antenna which was created using the project editor. The dipole geometry can be viewed by using the project editor.

To allow Sonnet Level2 users to view this example, this project was analyzed with de-embedding enabled and the resulting data was included in the project file. However, analyzing with de-embedding enabled results in non-physical de-embedded S-parameters (the non-de-embedded S-parameters are still valid). This is because the de-embedding algorithm analyzes calibration standards (through lines) with the same dimensions as the polygons connected to the port. In this case, because the distance to the ground plane is a whole wavelength, the calibration standards will contain higher-order transmission line modes. This violates the de-embedding assumptions, and results in incorrect S-parameters (see Chapter 8). However, since the far field viewer always uses the non-de-embedded results to calculate the far field, the far field calculations are valid with or without de-embedding.

It is important to remember that in order to produce data for input into the far field viewer, the Compute Current Density option must be selected in the Analysis Set-up dialog box in the project editor.

Infpole was analyzed at a linear frequency sweep from 0.8 GHz to 1.2 GHz in intervals of 0.1 GHz.

Running the Far Field Viewer

2 **Click on the View Far Field button on the Sonnet task bar to invoke the far field viewer.**

A pop-up menu appears on your display.

3 **Select “Browse for Project” from the pop-up menu.**

A browse window appears on your display.

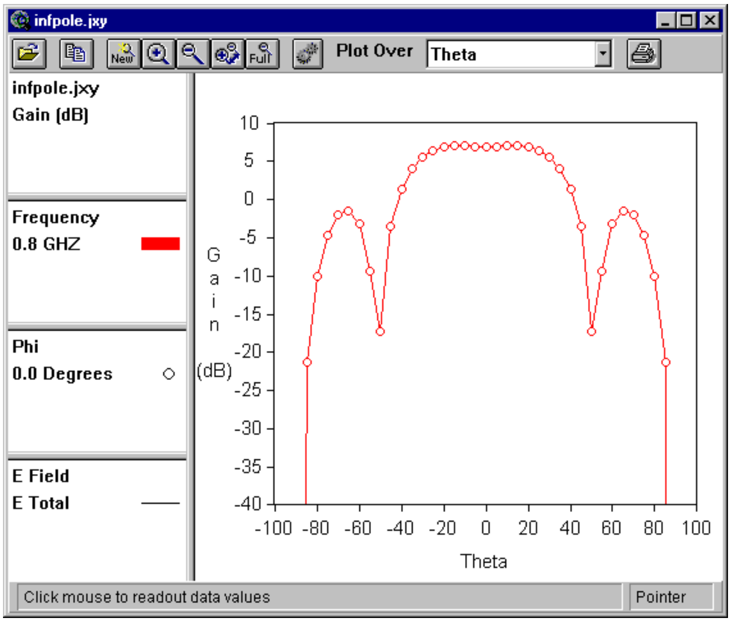
4 **Using the browse window, select your saved copy of “inpole.son”.**

The far field viewer window opens on the project file, “infpole.son”.

After the initial calculation is complete, a plot appears on your display as shown below. When a new file is opened, the far field viewer performs an analysis on the first frequency based on a default set of values for directions, port excitations and terminations and displays the Gain (dB) versus theta for the first value of phi. The calculation defaults are as follows:

- There are two values of phi: 0° and 90°
- Theta ranges from -90° to +90° in 5° intervals.

- Port 1 is set to a 1.0 V source magnitude with a 50.0 Ω load



The far field viewer display defaults to a cartesian plot with theta selected on the X-axis. The polarization defaults to *Theta/Phi*. The Y-axis is set to display the Gain (in dB) of the pattern response and is normalized to power gain of the ideal isotropic antenna.

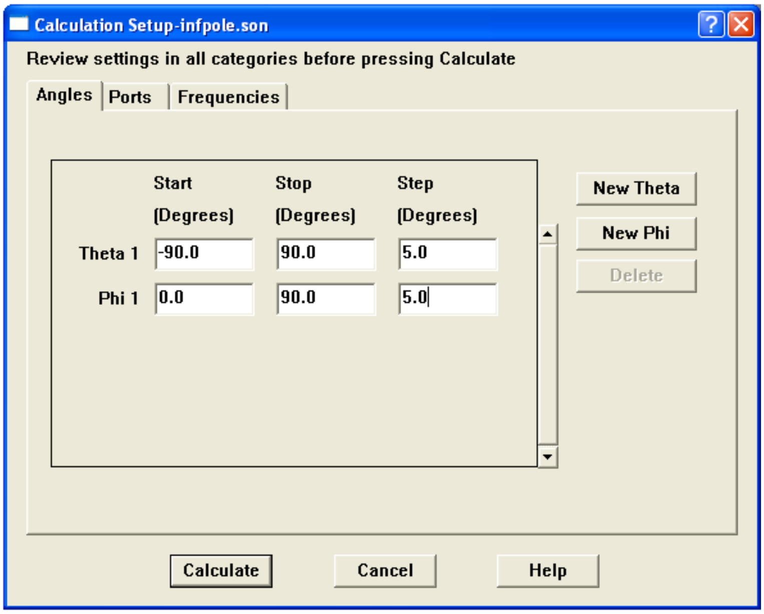
To change the calculation and display defaults, see File - Preferences in the far field viewer's help.

Calculating the Response

As mentioned above, when the far field viewer is invoked, the response data is calculated for only the first frequency in the current response file. To calculate data for the other frequencies at additional angles, perform the following:

5 **Select *Graph* ⇒ *Calculate* from the far field viewer main menu.**

The Calculation Setup dialog box appears on your display with the Angles tab selected as shown below.


Calculation Setup-infpole.son

Review settings in all categories before pressing Calculate

	Start (Degrees)	Stop (Degrees)	Step (Degrees)
Theta 1	-90.0	90.0	5.0
Phi 1	0.0	90.0	5.0

Selecting Phi Values

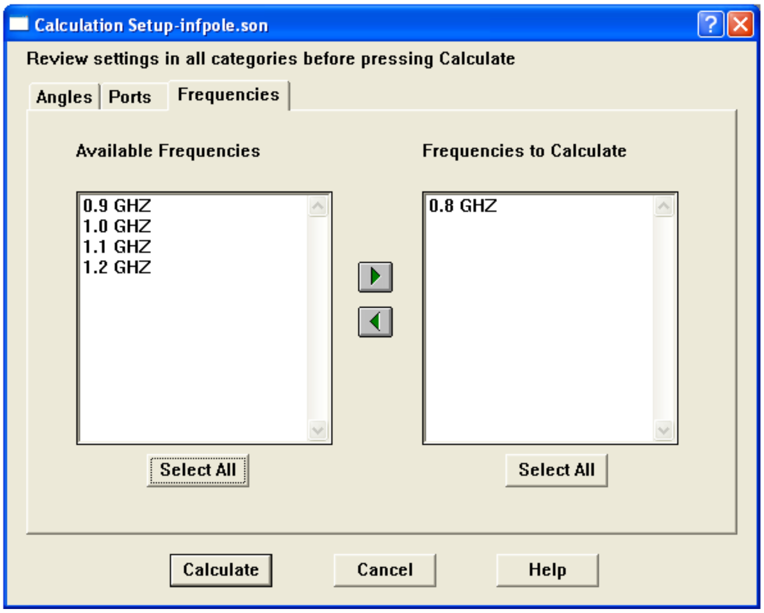
6 **Enter 0 in Start text entry box, 90 in the Stop text entry box and 5 in the Step text entry box of the Phi line.**

This analyzes data points from phi = 0° to 90° in intervals of 5°.

Selecting Frequencies

7 **Click on the Frequencies tab in the Calculation Setup dialog box.**

The Frequencies tab is now displayed, as shown below.



8 **Click on the Select All command button under the Available Frequencies.**

All of the frequencies are highlighted.

9 **Click on the Right Arrow button.**

This moves all the selected frequencies to the Calculated Frequencies column.

10 **Click on the Calculate command button.**

There is a delay while the far field viewer calculates the requested data. The calculations for each frequency are performed using the defaults cited above for phi, theta, port excitation and exclusions, since none of these items were changed before selecting Calculate.

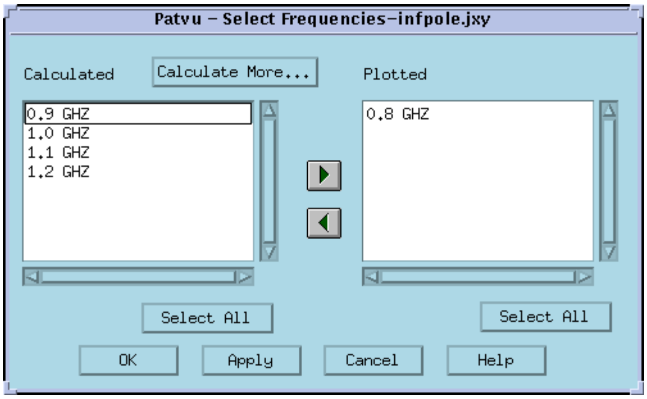
A status box appears on your display to provide updates on calculation progress. The display is updated when the calculation is completed. Be aware that for larger, more complicated circuits, this delay might be a considerable one.

Selecting the Response

The far field viewer allows you to select which data items you wish displayed at any given time. In the next session, you display 1 GHz data at different phi's.

11 **Select *Graph* ⇒ *Select* ⇒ *Frequencies* from the far field viewer main menu.**

The Select Frequencies dialog box appears on your display.



The Calculated column displays the frequencies for which data has been calculated, but is not presently displayed. The Plotted Column shows those frequencies which are presently displayed. In this case, 0.8 GHz.

TIP

You may also open the Select Frequencies dialog box by right-clicking in the Frequency area of the legend and selecting *Select* from the menu which appears on your display.

12 **Double-click on 0.8 in the Plotted column.**

This moves 0.8 to the calculated column, i.e., this frequency is not displayed.

13 **Double-click on 1.0 in the Calculated column.**

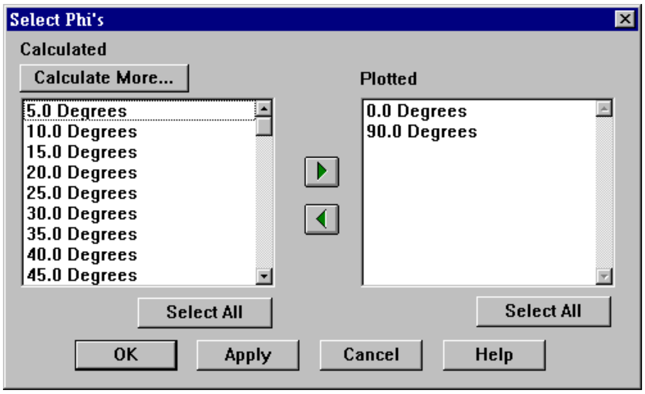
This moves the value 1.0 to the Plotted column.

14 **Click on the OK command button.**

This closes the dialog box and updates the display with the data for 1.0 GHz at Phi = 0°.

15 Select *Graph* ⇒ *Select* ⇒ *Phi* from the far field viewer main menu.

The Select Phi’s dialog box appears on your display.



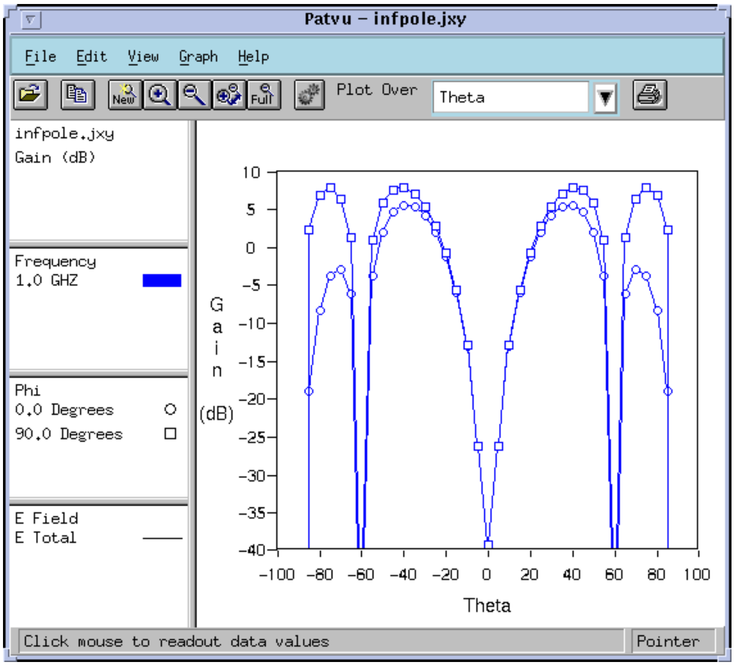
16 Use the scroll bar on the Calculated Column to move down the list until 90.0 Degrees is displayed.

17 Double-click on 90.0 Degrees to move this value to the Plotted column.

Values in this column are displayed in the far field viewer.

18 Click on the OK command button.

The dialog box disappears and the far field viewer display is updated. It should appear similar to the figure below.



The plot is drawn showing two curves: E_{total} at phi = 0 and 90 degrees. The upper curve is the radiation pattern at phi = 90 degrees. The lower curve is the radiation at phi = 0 degrees.

The far field viewer automatically selects an appropriate scale for the plot.

19 Select *Graph* ⇒ *Select* ⇒ *Phi* from the far field viewer main menu.

The Select Phi’s dialog box appears on your display.

TIP

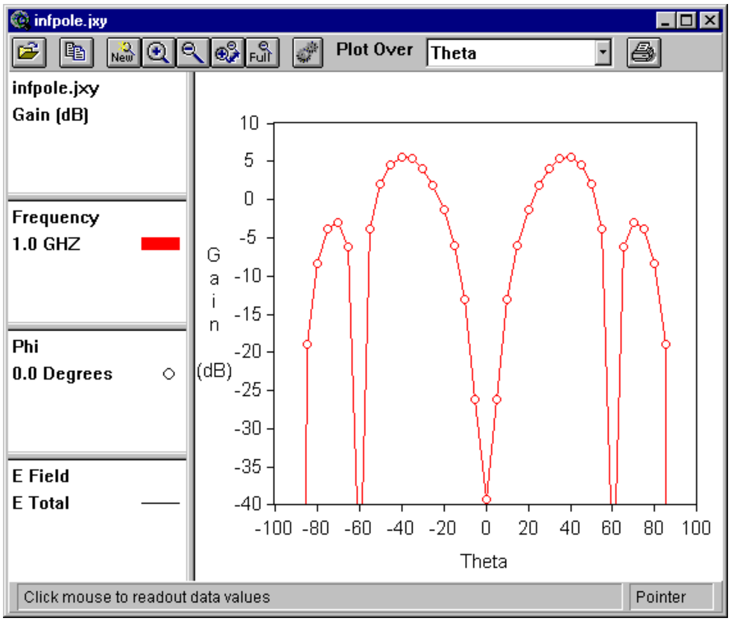
You may also access the Select Phi’s dialog box by right-clicking in the Phi box in the legend and selecting *Select* from the pop-up menu which appears.

20 Double-click on 90.0 degrees in the Plotted column to move it from the Plotted column to the Calculated column.

This removes 90.0 degrees from the plot.

21 **Click on the OK command button.**

The dialog box disappears and the far field viewer plot is updated. It should appear as below.



Zooming

The zoom button, located on the tool bar, may be used to magnify a specific area in the plot.

22 **Click on the Zoom In button on the Tool bar.**

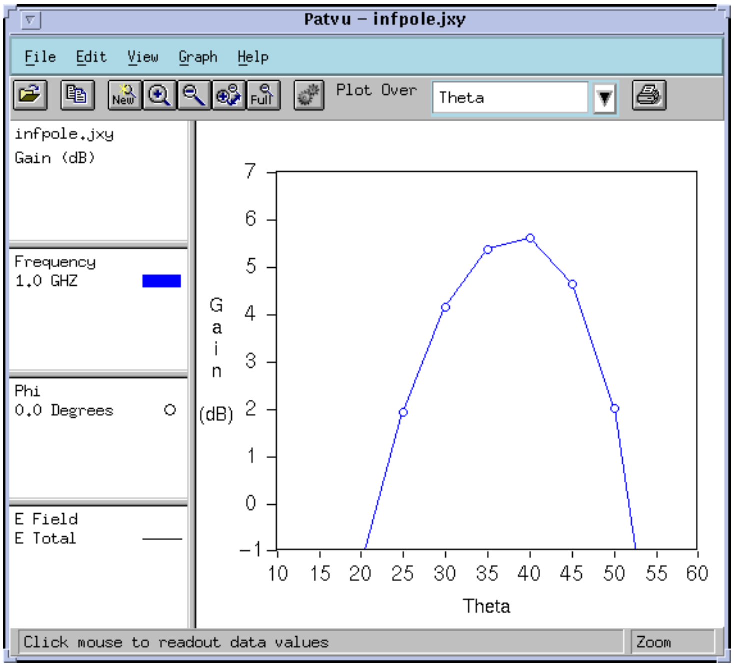
For this example, zoom in on the area from 0 to 10 dB in Gain, where Theta ranges from 20° to 50°.

You may also use *View* ⟹ *Zoom In* or the Space Bar for the zoom function.

23 **Click on the point in the plot corresponding to 0 dB Gain and Theta = 20°, then drag the mouse to the point in the plot corresponding to 10 dB Gain and Theta = 50°**

A rubber band surrounding the area to be magnified follows the mouse.

When the mouse is released, the plot is updated with a magnified view of the selected area, as shown below.



24 Click on the Full View button on the Tool bar.

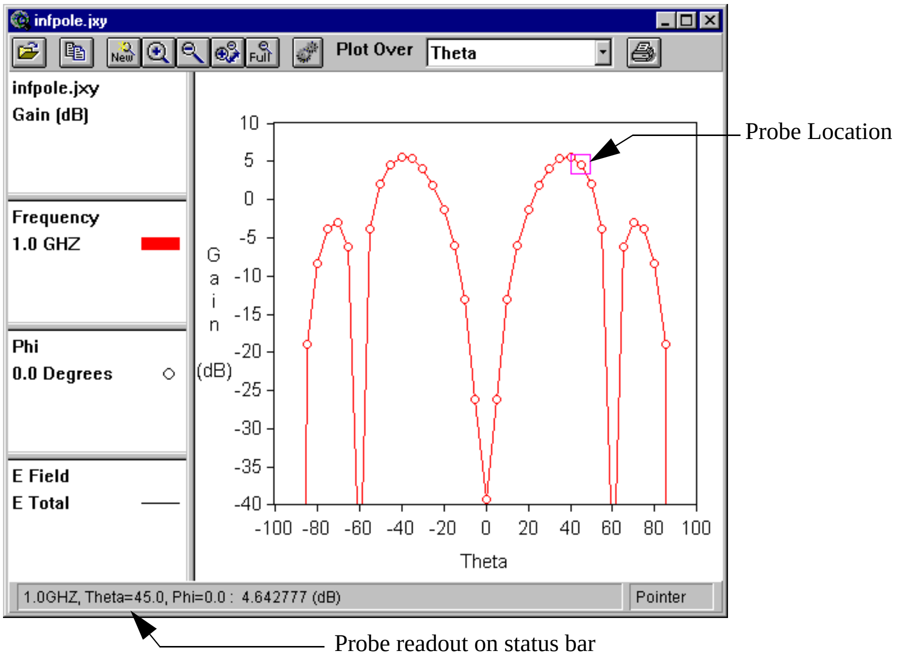
The full plot once again appears on your display.

Probing the Plot

To evaluate the pattern response at any location in your plot you simply click at the desired location.

25 Click on the theta = 45° point on the plot.

A square appears around the point, as shown below. The readout for the point including the frequency, value of theta and phi, and the gain appear in the status bar at the bottom of the far field viewer window.



infpole.jxy
Gain (dB)

Frequency
1.0 GHZ 🟥

Phi
0.0 Degrees ○

E Field
E Total —

1.0GHZ, Theta=45.0, Phi=0.0 : 4.642777 (dB)

26 Press the left arrow key, ←, to move to the theta = 40° point on the plot, or alternately, click on that point.

The probe box now appears at that point and the data is updated in the status bar.

Note that if there is more than one data curve displayed, the up and down arrow keys, ↑ and ↓, would move the data probe between curves, while the left and right arrow keys, ← and →, move between data points on any given curve.

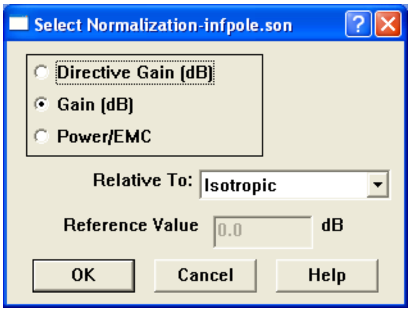
Re-Normalizing the Plot

By default, the far field viewer displays the power gain. The power gain is defined as the radiation intensity divided by the uniform radiation intensity that would exist if the total power supplied to the antenna were radiated isotropically[1].

We shall now normalize the plot to the maximum value.

27 Select *Graph* ⇒ *Normalization* to change the normalization.

The Select Normalization dialog box appears on your display.


Select Normalization-infpole.son

Directive Gain (dB) [✓ Gain (dB)] Power/EMC

Relative To: Isotropic

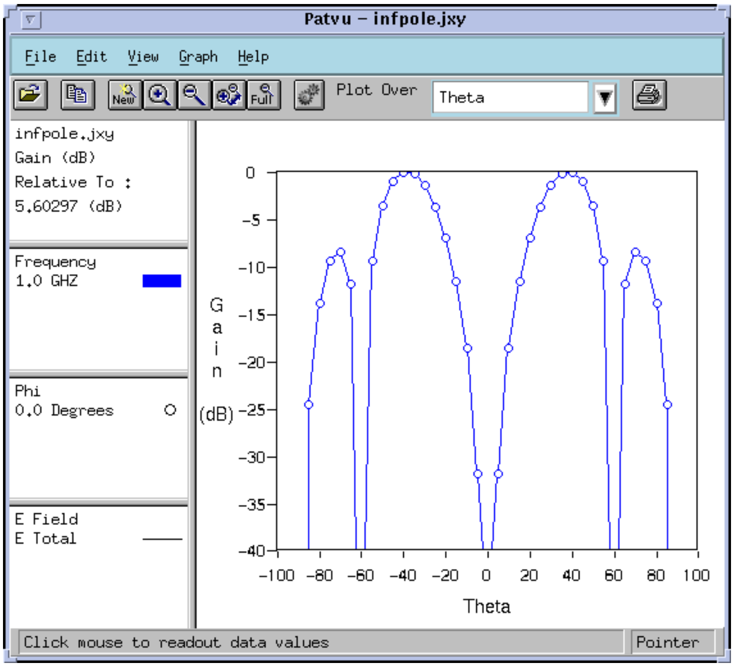
Reference Value 0.0 dB

28 Select Max from the Relative To drop list.

This selects the maximum value of radiation for the plot to be the 0 dB point of the plot.

29 Click on the OK command button.

The dialog box is closed and the display is updated with the data normalized to the maximum value, which in this case is 5.60297 dB.


Patvu – infpole.jxy

infpole.jxy
Gain (dB)
Relative To :
5.60297 (dB)

Frequency
1.0 GHZ

Phi
0.0 Degrees

E Field
E Total

Plot Over Theta

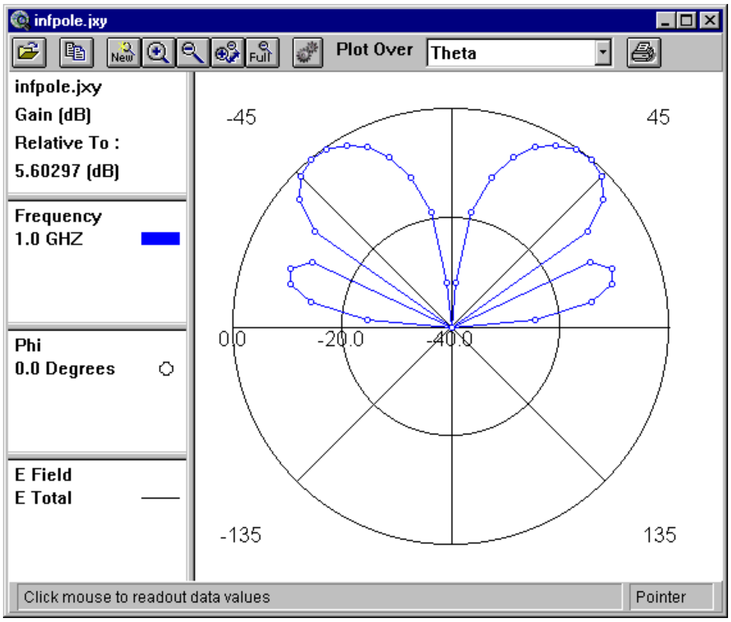
Click mouse to readout data values

Pointer

Changing to a Polar Plot

30 Select *Graph* ⇒ *Type* ⇒ *Polar* to select a polar plot for the display.

A polar plot is chosen since the theoretical data for an infinitesimal dipole is shown in a polar plot. The display is updated using the polar coordinate system. Phi is held constant and theta is swept.



TIP

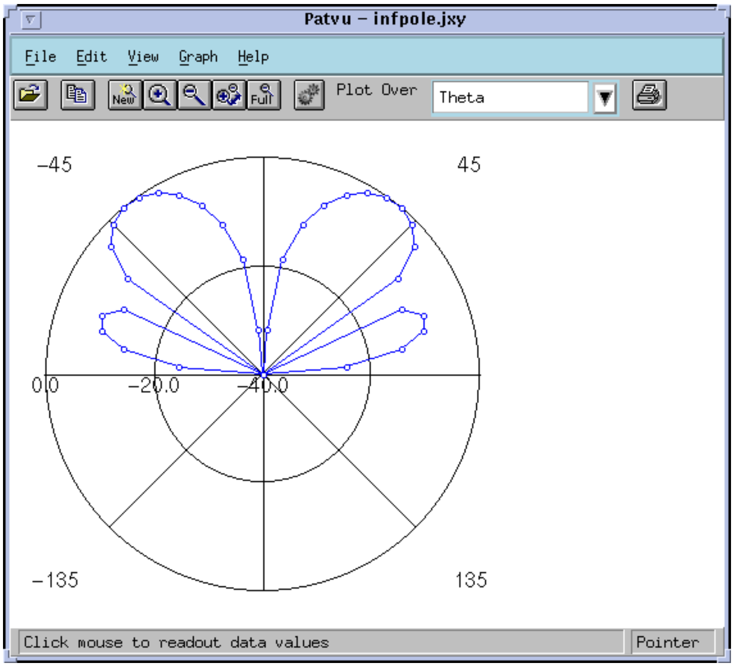
You may select another type of plot by right-clicking in the plot title area of the far field viewer display and selecting *Type* from the pop-up menu which appears.

Turning Off the Legend

Since the legends take up a lot of space on the display, you may turn them off, allowing the plot to fill the extra space.

31 To turn off the legend, select *View* ⇒ *Legend*.

This turns “off” the legend and the far field viewer redraws the plot without the legends. The menu item toggles the display state of the legend, so that selecting *View* ⇒ *Legend* again displays the legend.

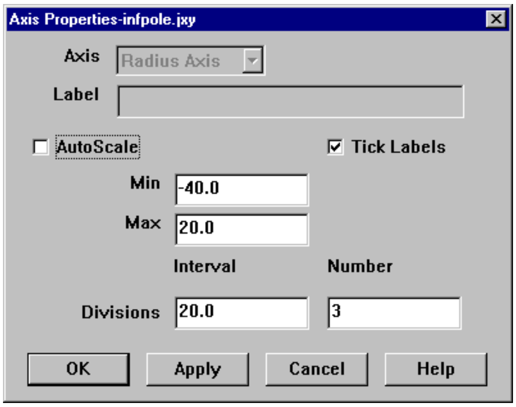


Changing the Radius Axis

You can change the radius axis limits of the plot to another value. For this example, you will change the intervals from 20 dB to 10 dB.

32 **Select *Graph* ⟹ *Axes* from the main** the far field viewer **menu.**

The Axes Properties dialog box appears on your display.


Axis Properties-infpole.jxy

Axis: Radius Axis

Label:

☐ AutoScale

☑ Tick Labels

Min: -40.0

Max: 20.0

	Interval	Number
Divisions	20.0	3

33 **Click on the AutoScale checkbox to turn it "off."**

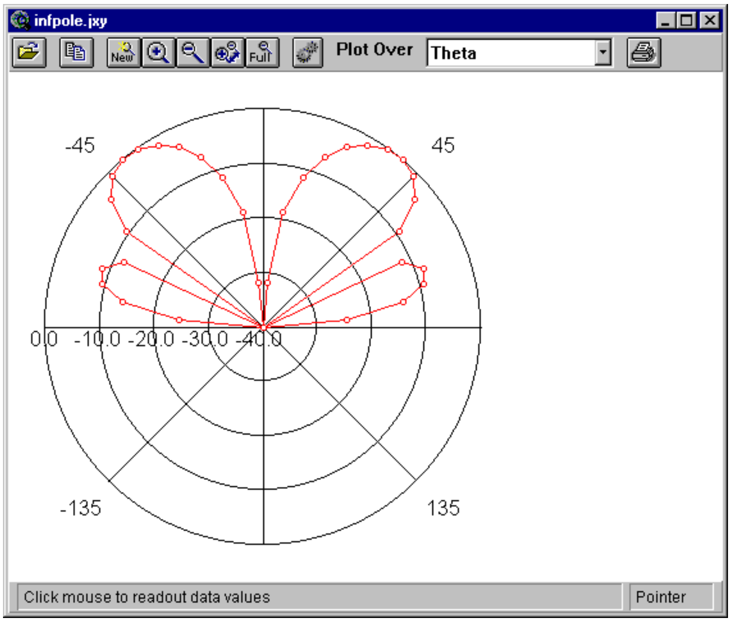
This enables the Min and Max text entry boxes under Autoscale and the Interval and Number text entry boxes under Tick Labels.

34 **Enter "10" in the Interval text entry box.**

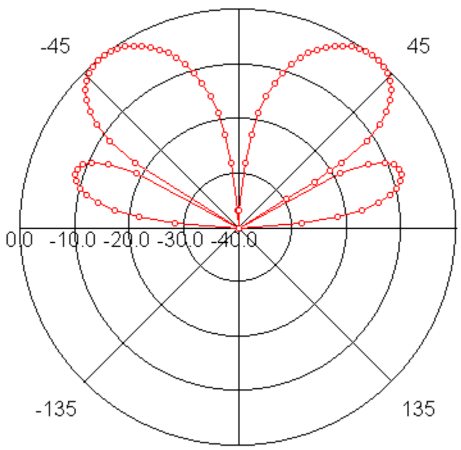
This sets the intervals on the plot grid to 10 dB.

35 Click on the OK command button.

The dialog box disappears and the far field viewer display is updated with the new interval value for the axes. Your display should be similar to the one shown below.



Shown above is the far field viewer calculated far field antenna pattern for the very short dipole in the file infpole.son. The result should be compared with theoretical result in the next figure.



Exact far field antenna pattern from reference [2] of an infinitesimal dipole antenna one wavelength above a ground plane.

Selecting a Frequency Plot

To see how the antenna pattern changes with frequency, you use a frequency plot. Before you can select a frequency plot, you must return to a cartesian plot.

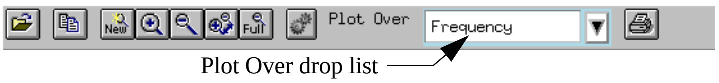
36 Select *Graph* ⇒ *Type* ⇒ *Cartesian* from the far field viewer main menu.

Your display is updated with a cartesian plot. Note that the autoscale is automatically turned back on when you switch plot types.

37 Select *View* ⇒ *Legend* from the far field viewer main menu.

The legend once again appears in your display.

38 Select Frequency from the Plot Over drop list on the far field viewer tool bar.



39 Select *Graph* ⇒ *Select* ⇒ *Theta* from the far field viewer main menu.

The Select Theta's dialog box appears on your display.

40 Double-click on -90.0 degrees in the Plotted list.

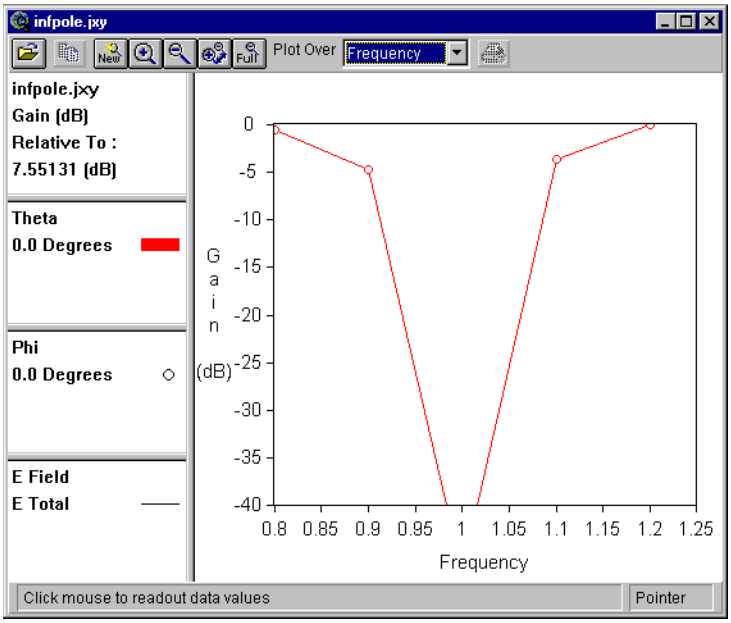
This value moves to the Calculated list which removes it from the display.

41 Double-click on 0.0 degrees in the Calculated list.

This value moves to the Plotted list which adds it to the display.

42 Click on the OK command button.

The display is updated with a frequency plot as shown below. Note that the gain is now calculated relative to 7.55131 dB, since the Normalization is relative to Max and this value is the maximum value of radiation for this plot.



infpole.jxy
Gain (dB)
Relative To :
7.55131 (dB)

Click mouse to readout data values

43 Select *Graph* ⇒ *Select* ⇒ *Phi* from the far field viewer main menu.

The Select Phi’s dialog box appears on your display.

TIP

You may also invoke the Select Phi’s dialog box by right-clicking on the Phi box in legend and selecting *Select* from the pop-up window.

44 Double-click on 0.0 degrees in the Plotted list.

This value moves to the Calculated list which removes it from the display.

45 Double-click on 90.0 degrees in the Calculated list.

This value moves to the Plotted list which adds it to the display.

46 Click on the OK command button.

The dialog box disappears and the display window is updated.

47 Select *Graph* ⇒ *Select* ⇒ *Theta* from the far field viewer main menu.

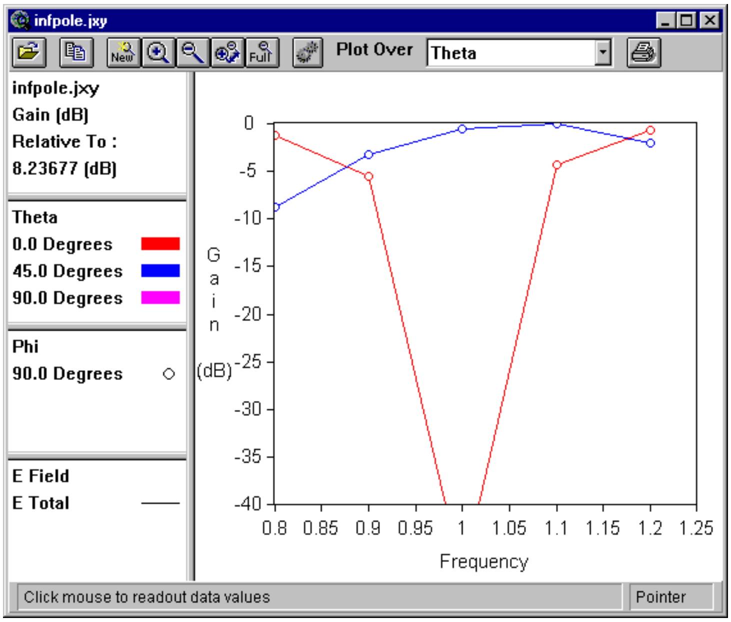
The Select Theta's dialog box appears on your display.

48 Double-click on 45.0 degrees and 90.0 degrees in the Calculated list.

These values move to the Plotted list which adds these values to the display.

49 Click on the OK command button.

The dialog box disappears and the display is updated as shown below.



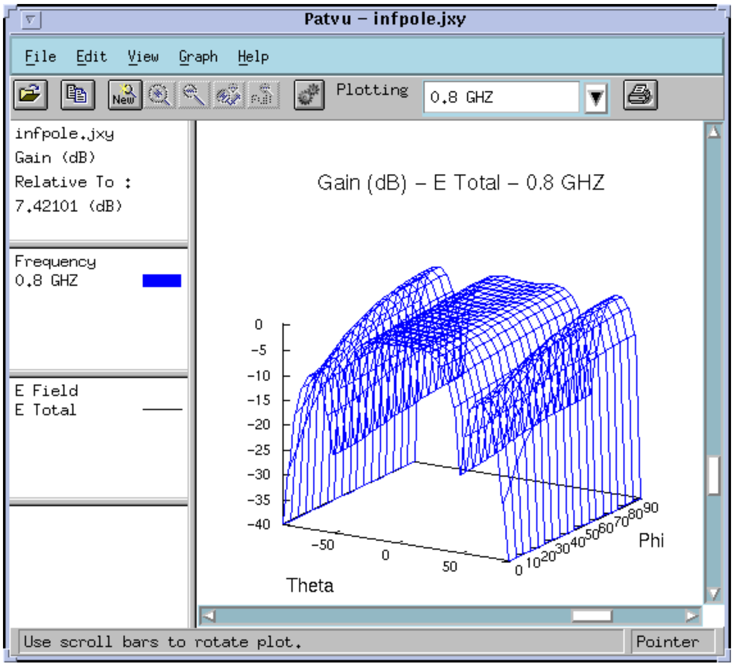
Notice that E-Total at Theta = 90 is shown in the legends, but does not appear on the graph. This occurs because the magnitude is too small to show on the plot.

Viewing a Surface Plot

The surface plot shows all the calculated values of theta and phi plotted against the gain for a single frequency.

50 Select *Graph* ⇒ *Type* ⇒ *Surface* from the main menu.

Your display is updated with a surface plot with the first frequency, 0.8 GHz, selected for display.



infpole.jxy
Gain (dB)
Relative To :
7.42101 (dB)

Frequency
0.8 GHZ 🟦

E Field
E Total ——

Use scroll bars to rotate plot.

Saving the Far Field Viewer File

51 Select *File* ⇒ *Save* from the far field viewer main menu.

The file is saved to the same filename with a ".pat" extension, i.e., "infpole.pat". This saves any data calculated during this the far field viewer session.

Exiting the Far Field Viewer Program

This is the end of the first example of using the far field viewer.

52 To stop the program, select *File* ⇒ *Exit.*

The far field viewer window disappears from your display.

References

[1] Simon Ramo, John R. Whinnery and Theodore Van Duzer, Fields and Waves in Communication Electronics, John Wiley & Sons, Inc. 1994, pg. 601.

[2] Constantine A. Balanis, **Antenna Theory Analysis and Design**; New York; Harper & Row, 1982, section 4.7.3

Chapter 22 SPICE Model Synthesis

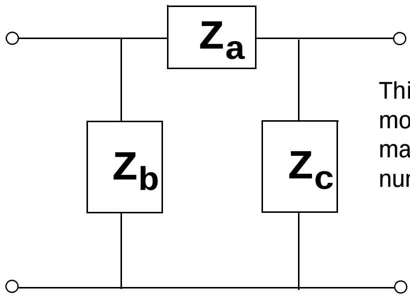
Sonnet's analysis engine, ***em***, provides a frequency domain solution in the form of S- Y- and Z-parameters. Many time domain simulators, such as traditional SPICE engines, do not have the capability to import frequency domain data, or have problems with efficiency, stability, or accuracy when using frequency domain data.

To address these problems, Sonnet provides the capability to output your frequency domain data into a SPICE-compatible file. You may choose from three different models, depending on your needs:

This chapter discusses three solutions provided by Sonnet:

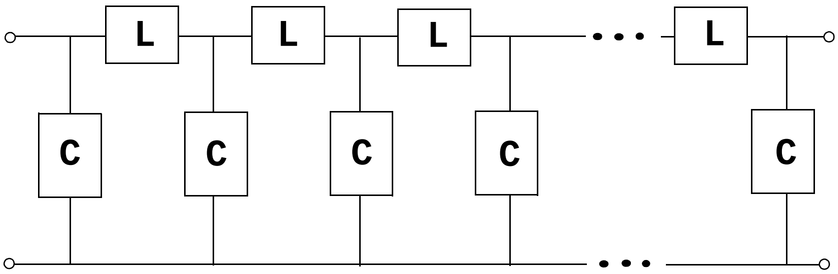
- PI (Lumped Element) Spice Model
- N-Coupled Line (Transmission Line) Spice Model
- Broadband Spice Model using rational polynomial fit (requires a separate Broadband Spice Extractor license)

The first model is a lumped element fit to the S-parameter data. For this type of model, the circuit often resembles the symbol "π," therefore, this type of model is referred to as a PI Model. Sonnet creates this type of model when you specify a PI Model output file in the PSpice or Spectre format (*Analysis* ⇒ *Output Files* in the project editor or *Output ⇒ PI Model File* in the response viewer). The PI model is only applicable for a narrow band. The model that is output is usually one which is intuitive and easily understood by a user as shown below.



This figure shows a 2-port model, but the PI model may be used for any number of ports.

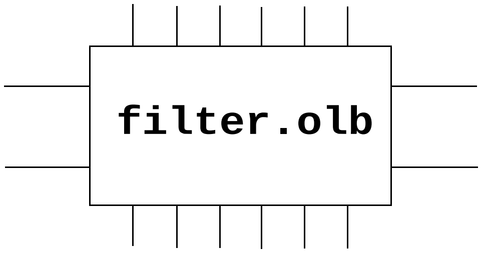
The second model is an N-coupled line (transmission line) model. Sonnet creates this type of model when you specify an N-Coupled Line Model output file in the LCT format (*Analysis ⇒ Output Files* in the project editor or *Output ⇒ N-Coupled Line Model* in the response viewer). This model is valid at only one frequency point. This model produces a RLGC matrix which can be used in many popular Spice programs. The equivalent circuit is shown below for a single lossless transmission line.



There are an infinite number of infinitesimal elements in the model

A third way to bridge the gap between the frequency domain and the time domain is to fit the frequency domain data with a rational polynomial. Sonnet's Broadband Spice Extractor feature uses this method to provide a circuit model which is valid over a broad band. This model, unlike the lumped element model described above, does not yield an intuitive understanding of a design. Instead, the Broadband Spice

Extractor feature generates a model that can be used in Spice as a “black box” representing the broad band behavior of your circuit as shown below. This type of model will be referred to as the Broadband Spice model.



This chapter describes how to use Sonnet to automatically synthesize PI Model, N-Coupled Line Model and Broadband Spice Model files. The PI and N-Coupled Line capabilities are useful for circuits which are small with respect to the wavelength at the highest frequency of interest. This includes structures such as discontinuities like step, tee and cross junctions. Other applications include modeling cross-talk and propagation delay in digital interconnect circuits and multiple spectrum circuits that combine digital, analog and RF functions. The Broadband Spice model is fitted over a wide frequency band and can be used in circuit simulators for AC sweeps and transient simulations.

NOTE: **Broadband Spice Extractor is only available if you have purchased a license from Sonnet which includes the Broadband Spice Extractor feature. Please see your system administrator if you are unsure of the availability of this option.**

PI Spice Model

Specifying an optional PI Model Spice output file automatically takes the results of the electromagnetic analysis of a circuit and synthesizes a model using inductors, capacitors, resistors and mutual inductors. This information is then formatted and saved in one of two SPICE formats: PSpice or Spectre.

The PI model Spice generation capabilities are intended for any circuit which is small with respect to the wavelength at the highest frequency of excitation. Typically, 1/20th wavelength is an appropriate limit. (If a circuit is too large, you can often split it into two or more circuits and analyze each separately.) This limitation is due to the circuit theory limitations of modeling a circuit with just a few lumped elements. The Sonnet electromagnetic analysis is not intrinsically limited in this fashion.

The model generated by the analysis includes any lumped elements (including mutual inductors) between any ports of the circuit layout. Lumped elements from any port to ground are also included. The synthesis capability does not allow internal nodes (nodes which are not connected to a port in the layout) with the single exception of the internal node required to specify a resistor in series with an inductor.

Any circuit which requires internal nodes for an accurate model should be split into several parts so that the required points become nodes. Internal ports without ground reference give incorrect results. Any internal ports should be carefully specified and checked for reasonable results.

Using The PI Model Spice Option

The PI Model synthesis needs electromagnetic results for at least two frequencies to accomplish its work. It is not possible to create a PI model if the circuit is analyzed at only one frequency. A PI model is created for pairs of frequencies. The second frequency is determined by taking the first frequency and adding a percentage specified by the user. The second frequency then becomes the first frequency for the next pair of frequencies for which a SPICE model is generated. The synthesis continues in this way until all the frequencies have been used.

The default value for the separation percentage is 10%. In this case, a SPICE model is generated using the first frequency and the next highest frequency which provides a 10% gap. This continues until there are no more frequencies. For example, for a frequency sweep from 10 - 40 GHz with a 0.1 GHz resolution using a separation of 10%, the first few frequencies used would be 10, 11, 12.1 and 13.3 GHz.

After completing the analysis, always do a “reality check” for reasonable values. If you have bad data, the frequency may be too high or too low. If the frequency is too low, the solution may have unity S-parameters, causing a strange SPICE model. To be absolutely sure your results are good, select a different frequency band and re-analyze the circuit. You should obtain similar results between the two analyses.

You may obtain PI Model Spice data in two different ways. The first is to specify an optional output file before executing your analysis. The second is to generate a PI model from the response viewer. The second method has the advantage of allowing you to perform the data check mentioned above before creating the SPICE data file.

To specify a PI Model Spice output file from the response viewer, perform the following:

1 **Analyze the circuit at the desired frequencies.**

The analysis monitor appears on your display to show the progress of the analysis. It is important to note that if your results contain more than two analysis frequencies, then multiple Spice models, one for each pair of frequencies, will be created in one file.

2 **When the analysis is complete, click on the View Response button on the analysis monitor's tool bar.**

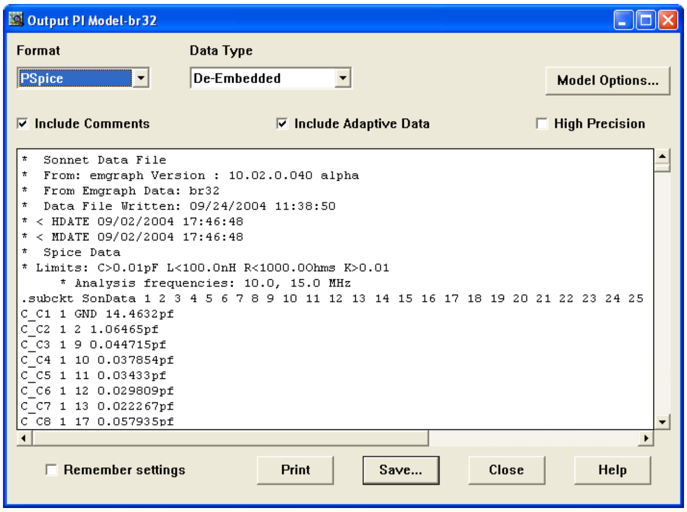
The response viewer is invoked with a plot of your response data.

3 **Click on the project name in the response viewer legend to select it.**

An outline appears around the project name to indicate that it is presently selected. If you have multiple projects open in the response viewer and have not selected a project before using the extraction command, then a window appears which allows you to select the desired project.

4 **Select Output ⇒ PI Model File from the response viewer main menu.**

The Output PI Model dialog box appears on your display. The contents of the output window in the Output PI Model dialog box displays the Spice data for the PI Model in the PSpice format which is the default.



Format: PSpice
Data Type: De-Embedded
[✓] Include Comments
[✓] Include Adaptive Data
☐ High Precision

```
*  Sonnet Data File
*  From: emgraph Version : 10.02.0.040 alpha
*  From Emgraph Data: br32
*  Data File Written: 09/24/2004 11:38:50
* < HDATE 09/02/2004 17:46:48
* < MDATE 09/02/2004 17:46:48
*  Spice Data
* Limits: C>0.01pF L<100.0nH R<1000.0Ohms K>0.01
     * Analysis frequencies: 10.0, 15.0 MHz
.subckt SonData 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
C_C1 1 GND 14.4632pf
C_C2 1 2 1.06465pf
C_C3 1 9 0.044715pf
C_C4 1 10 0.037854pf
C_C5 1 11 0.03433pf
C_C6 1 12 0.029809pf
C_C7 1 13 0.022267pf
C_C8 1 17 0.057935pf
```

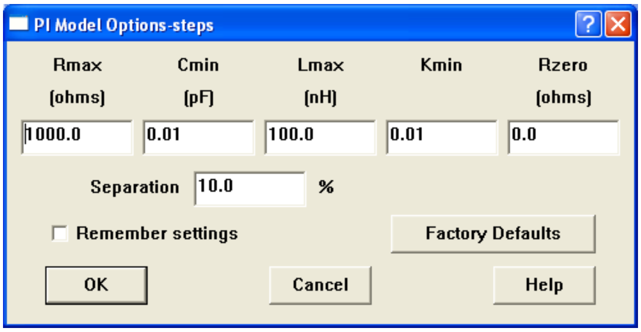
☐ Remember settings

5 **Select the desired file format from the Format drop list.**

If you select Spectre as the Format (PSpice is the default), the contents of the output window is updated.

6 **To change the parameters for the SPICE data, click on the Model Options button.**

The PI Model Options dialog box appears on your display. To reduce the number of lumped elements in the model, open circuit limits can be specified here as shown below.



Rmax (ohms)	Cmin (pF)	Lmax (nH)	Kmin	Rzero (ohms)
1000.0	0.01	100.0	0.01	0.0

Separation 10.0 %

☐ Remember settings

The values are defined as follows:

RMAX: Maximum allowed resistance (ohms). The default value is 1000.0 ohms.

CMIN: Minimum allowed capacitance (pF). The default value is 0.01 pF.

LMAX: Maximum allowed inductance (nH). The default value is 100.0 nH.

KMIN: Minimum allowed mutual inductance (dimensionless ratio). The default value is 0.01.

RZERO: Resistor to go in series with all lossless inductors (resistance in ohms). Needed for some versions of SPICE. The default value is 0.0

Separation: This is the calculation interval between the two frequencies used to generate the SPICE model specified as a percentage. The second frequency is obtained by adding the specified percentage of the first frequency to the second frequency.

All calculated component values which fall outside the allowed range specified by the user in the model options are excluded from the resulting lumped model. The RZERO entry is provided for those versions of SPICE which need inductors to have some small loss to avoid numerical difficulties. The default value of 0.0 disables this capability.

Enter the desired values for the parameters in the PI Model Options dialog box.

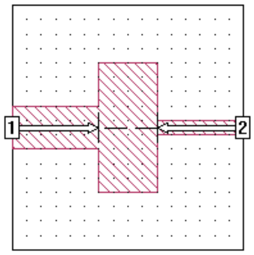
7 **Click on the OK button in the PI Model Options dialog box to apply the changes and close the dialog box.**

8 **Click on the Save button in the Output PI Model dialog box.**

A browse window appears which allows you to save the data displayed in the output window. The file extension depends on which type of SPICE format you have selected.

A Simple Microwave Example

Shown below is the Ste_sym example, a simple step discontinuity followed by the PI model produced when you set up an optional PI Model Spice output file.

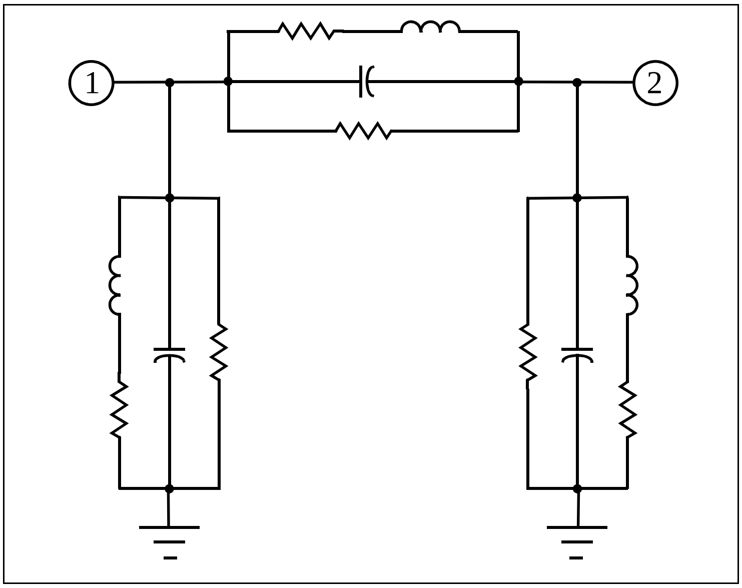


```
* Limits: C>0.01pF L<100.0nH R<1000.0Ohms K>0.01
* Analysis frequencies: 1000.0, 1100.0 MHz
.subckt SonData 1 2 GND
C_C1 1 GND 0.273341pf
C_C2 2 GND 0.232451pf
L_L1 1 2 0.310155nh
.ends SonData
```

There are two capacitors to ground (node GND) and one inductor connected between node 1 and node 2 in the lumped element model.

Topology Used for PI Model Output

The topology of the lumped element model generated by ***em*** depends on the circuit being analyzed. In general, the model contains an inductor (in series with a resistor if using loss), a capacitor and a resistor (when using loss) connected in parallel from each port to ground. A similar parallel RLC network is also connected between each port. Therefore, a four-port circuit can contain more elements than a two-port circuit. Each inductor may also have a mutual inductance to any other inductor in the network. The figure below shows the most complex equivalent circuit possible for a two-port (mutual inductances not shown). Any values that are outside of the open circuit limits are not included.



Equivalent circuit of a two-port structure using the PI Model. Mutual inductances also exist between all inductors, but are not shown. Any component whose value is outside of the open circuit limits are not printed in the SPICE output file.

N-Coupled Line Option

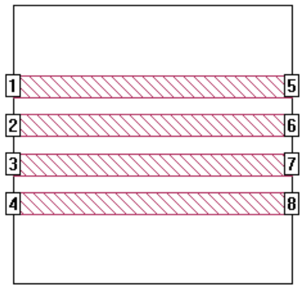
If your circuit is a single or multiple-coupled transmission line, you should use the transmission line models supplied by your Spice program. Most SPICE programs have an element for single and multi-conductor transmission lines in which you enter the capacitance and inductance per unit length for a single line or a capacitance and inductance matrix for multi-coupled lines. Sonnet can produce a LCT formatted Spice file which may, without too much difficulty, be edited to comply with other formats.

Analyses which use such data are much faster than those which use simple lumped models. In addition, accuracy is maintained at all frequencies for which TEM mode propagation is an adequate approximation.

For a single line, the L and C distributed parameters are each a single number. For N-coupled lines, L and C become N by N matrices. When metal loss is included, we now also have an R matrix. The resistance is in series with the inductance. When there is dielectric loss, a G matrix is also calculated. The conductance is in parallel with the capacitance. The synthesis determines whether a G or R matrix is needed only from the calculated S-parameters, not from the circuit geometry.

To generate RLGC matrices, select *Output ⇒ N-Coupled Line Model File* in the response viewer or click on the N-Coupled Line Model button in the Generate Default Output Files dialog box which is opened when you select *Analysis ⇒ Output Files* from the project editor menu. The analysis control needs only one frequency specified. If two frequencies are specified, two RLGC matrix sets are generated and so on.

Your project must be an N-coupled line with ports 1 through N as input and ports N+1 through 2N as output. The input of line M should be port M and its output should be port M+N. The software does not check for this condition, but issues a warning message if the number of ports is not an even number. This restriction does not apply to generating PI Models, only generating N-Coupled Line Model Spice files. There is no limit on N. An example where N = 4 is shown below.



The results are per unit length, where a unit length is the length of the N-coupled line. The length must be short compared to the wavelength at the frequency of analysis.

Broadband SPICE Model

NOTE: **The Broadband Spice Extractor feature is only available if you have purchased a Broadband Spice Extractor license from Sonnet. Please see your system administrator if you are unsure of the availability of this feature.**

In order to create a Spice model which is valid across a broad band, the Sonnet broadband SPICE Extractor feature finds a rational polynomial which "fits" the S-Parameter data. This polynomial is used to generate the equivalent lumped element circuits in either PSpice or Spectre format. Since the S-Parameters are fitted over a wide frequency band, the generated models can be used in circuit simulators for AC sweeps and transient simulations.

To create a Broadband Spice file, you open your project in the response viewer and select *Output ⇒ Broadband Model File* from the main menu. (You may also create a Broadband Model by using the *Analysis ⇒ Output Files* command in the project editor. See online Help for Details) This opens the Output Broadband Model File window which allows you to calculate a broadband SPICE file based on the analysis data for your project. You need a minimum of 50 frequency points in order to generate a Broadband Spice file; therefore, we highly recommend that you use an ABS sweep when analyzing your circuit to ensure the correct number of analysis frequencies. If your circuit contains parameterization or optimization data and you select more than one parameter or iteration combination, then you may choose to create one file which contains all the Broadband Spice Models or multiple files, one for each specified combination.

Class of Problems

Be aware that there are several types of responses for which an accurate Broadband Spice Model may not be produced:

- If your response data contains a data point which sharply deviates from the data curve, such as you would see for a box resonance, or a narrow band spike, the Broadband Spice model may not accurately model that response.
- The Broadband Spice model is generally not accurate for response data below -60 dB.
- A gentle curve may sometimes get fitted with a straight line.
- Broadband Spice Extractor has only been tested for passive circuits.
- Broadband Spice Extractor has only been tested using S-parameters produced by ***em***. However, you should be able to use S-parameters produced by other sources such as other simulators or measured data to create a Broadband Spice model.

If you are concerned with the accuracy of the model, you should visually inspect the predicted S-Parameter data, produced by the same rational polynomial which was used to create the Broadband model, to determine the usefulness of the Broadband Spice model.

NOTE: Be aware that the processing time needed to create your models can be significant. The processing time is proportional to the number of analysis frequencies times the square of the number of ports in your circuit.

Creating a Broadband Spice Model

You use the response data created as the result of an ***em*** analysis to create a Broadband Spice model. For the best results use an Adaptive sweep (ABS) to analyze your circuit and produce response data spread evenly over the frequency band. The following procedure demonstrates the method to be used in the response viewer. For detailed instructions for setting up a Broadband Model file in the project editor, please refer to online help.

Once you have completed the ***em*** analysis of your circuit, do the following to create a Broadband Spice model:

1 **Open your project in the response viewer.**

2 **Select Output ⇒ Broadband Model File from the main menu of the response viewer.**

If you have more than one project open in the response viewer, a window appears which allows you to select the desired project.

3 **Select the desired project from the project drop list.**

You may only create a Broadband Spice Model for one project at a time.

4 **Click on the OK button to select the project and close the dialog box.**

The Output Broadband Model File dialog box appears on your display. You may access online help by clicking on the Help button or use context sensitive help for an explanation of a particular control or entry.

5 **Select the file format of the Broadband Model: PSpice or Spectre from the Format drop list.**

PSpice and Spectre are the two formats of Spice file supported. A PSpice file uses the extension ".lib" and a Spectre file uses the extension ".scs."

6 **Enter the desired name for the Spice model file in the Model File text entry box.**

A default filename is provided which places the Broadband Spice model file in the same directory as your source project. If you have selected multiple parameter combinations, a file is produced for each combination. If you wish to use another name or save the file in another location you may edit the text entry box.

7 **Enter the desired error threshold.**

The lower the error threshold you set, the more processing time is required to calculate the model. The error threshold is the error present between the source data and the fitted curve and is defined as follows:

$$Error = \frac{\left(\sum_{f=1}^{N} \left|s(f)_{Source} - s(f)_{Fit}\right|\right)}{N} \cdot 100$$

where f = the number of the frequency point

N = the total number of frequency points

$s(f)_{Source}$ = the value of the S-parameter at the frequency point f in the project source response

$s(f)_{Fit}$ = the value of the S-parameter at the frequency point f in the fit curve data

The calculation of the Broadband Spice model stops when this error threshold is reached or when it proves impossible to improve the error. We recommend using the default value of 0.5% initially and not setting the threshold below 0.1%.

8 **Select the Generate Predicted S-Parameter data file if it is not already selected.**

This option is selected by default. When this option is selected, the Predicted S-Parameter data upon which the model is based is also output to a file. The name of the file appears below the checkbox and may not be changed. The file is created in the same directory in which your model file is created. Once the creation of the model is completed, you may use the response viewer to compare your original response data to the Predicted S-Parameter data to evaluate the accuracy of the Broadband model.

9 Click on the Create button to create the Broadband Spice model.

A progress window appears on your display. Be aware that the processing time needed to create your models can be significant. The processing time is proportional to the number of analysis frequencies times the square of the number of ports in your circuit. If you wish to stop the process before it is complete, click on the Cancel button in the progress window.

10 Once the calculation is complete, the Broadband Spice details dialog box appears on your display.

A log of the creation process appears in this dialog box. The log contains information on the error for each parameter, which parameter had the greatest error, and the filename of the predicted S-Parameter data. It will also indicate whether the model achieved the error threshold. Use this information to determine which parameters to examine in the response viewer. You should look at the S-parameter with the greatest error as well as any critical S-parameters whose error was greater than 0.1%.

For a detailed explanation of the log, see “Broadband Spice Extractor Log,” page 324.

11 Click on the Plot button to open a plot of your response data versus the predicted S-Parameter data.

The Predicted S-Parameter data is opened in the response viewer along with the original response data. You should view the S-parameter with the greatest error and any other critical response data whose error was greater than 0.1% to judge if the "fit" or accuracy of the model is sufficient for your needs.

If the model is not accurate enough, see “Improving the Accuracy of the Broadband Spice Model,” page 326 for suggestions on improving your Broadband Spice model.

Checking the Accuracy of the Broadband Spice Model

It is possible to save the predicted S-parameter data created while calculating your Broadband Spice model so that you may visually check the accuracy of your model when it is complete. To save the predicted S-parameter data, you should select the **Generate Predicted S-Parameter data file** checkbox in the Output Broadband Model File dialog box when you create your model. The predicted S-parameter data file is created in the same directory as your Broadband Spice model file.

Upon the completion of creating your Broadband model, you should open the original project in the response viewer, then add the predicted S-parameter data file to your graph and compare the two responses. If you are creating your Broadband Model in the response viewer, you may do this automatically by clicking on the Plot button in the Broadband Spice Details dialog box which appears upon completion of your model. Use the log information in the Details window, which is detailed in the next section, to determine which parameter had the highest error and any critical parameters whose error was greater than 0.1%. Check these parameters to see how much the curve fit data varies from your circuit response.

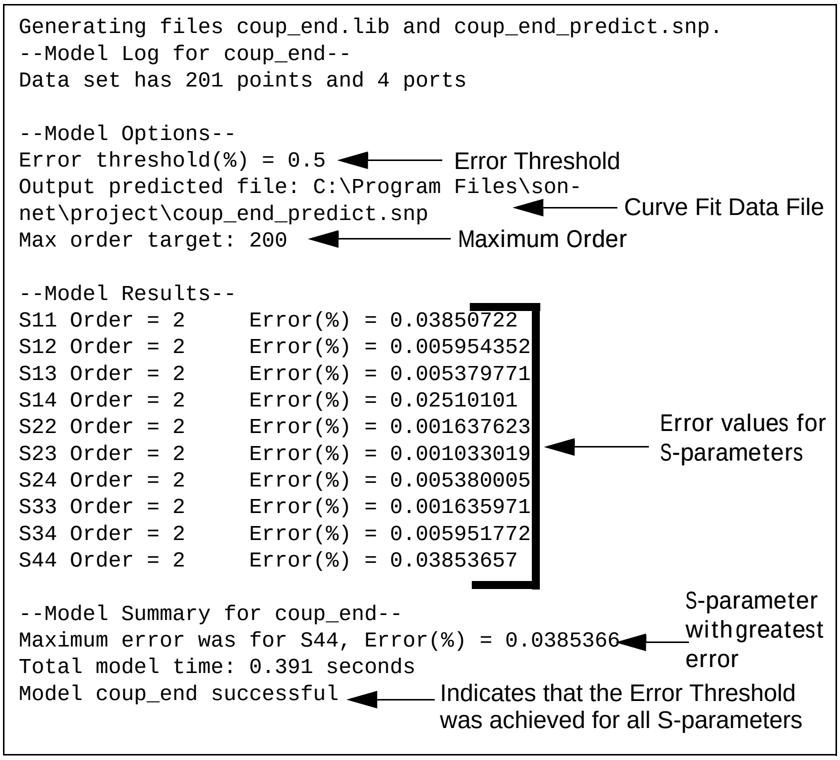
If your Broadband Spice Model is to be used for a transient analysis, be aware that the frequency response of the model up to 1/T where T is the minimum time step of the transient analysis is important. You should use the Advanced Broadband Model options dialog box to specify additional predicted data up to 1/T. You access this dialog box by clicking on the Advanced button in the Broadband Model File entry dialog box in the project editor or in the Output Broadband Model dialog box in the response viewer. This allows you to view the frequency response of your model at data points not included in your ***em*** analysis. You should look for anomalies in the response that indicate a problem with the model, such as S-parameters greater than one or unexpected sharp resonances.

If the model is not accurate enough, see “Improving the Accuracy of the Broadband Spice Model,” page 326 for suggestions on improving your Broadband Spice model.

Broadband Spice Extractor Log

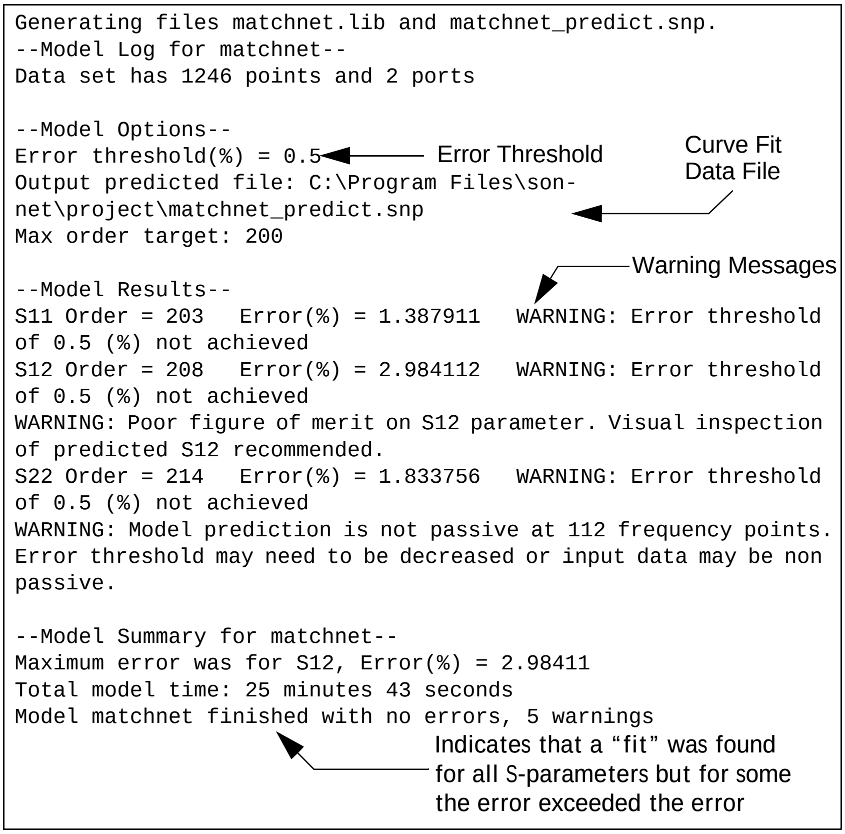
The Broadband Spice Extractor log, displayed in the Broadband Spice details window, contains detailed information about the creation of your Spice model file. You may view a summary of the log or the complete log. To view the summary of the log, click on the Summary button at the bottom of the window. To return to the full log, click on the Complete button.

You use the log to determine which parameters to examine in order to determine if the Spice model is accurate enough for your use. Two log files are shown below, the first log is for a model which achieved the error threshold and the second log is one in which the error threshold was not achieved on all the parameters. A warning message is issued for all S-parameters whose error is greater than the error threshold.



```
Generating files coup_end.lib and coup_end_predict.snp.
--Model Log for coup_end--
Data set has 201 points and 4 ports

--Model Options--
Error threshold(%) = 0.5
Output predicted file: C:\Program Files\son-
net\project\coup_end_predict.snp
Max order target: 200

--Model Results--
S11 Order = 2     Error(%) = 0.03850722
S12 Order = 2     Error(%) = 0.005954352
S13 Order = 2     Error(%) = 0.005379771
S14 Order = 2     Error(%) = 0.02510101
S22 Order = 2     Error(%) = 0.001637623
S23 Order = 2     Error(%) = 0.001033019
S24 Order = 2     Error(%) = 0.005380005
S33 Order = 2     Error(%) = 0.001635971
S34 Order = 2     Error(%) = 0.005951772
S44 Order = 2     Error(%) = 0.03853657

--Model Summary for coup_end--
Maximum error was for S44, Error(%) = 0.0385366
Total model time: 0.391 seconds
Model coup_end successful
```

Error Threshold
Curve Fit Data File
Maximum Order
Error values for S-parameters
S-parameter with greatest error
Indicates that the Error Threshold was achieved for all S-parameters



```
Generating files matchnet.lib and matchnet_predict.snp.
--Model Log for matchnet--
Data set has 1246 points and 2 ports

--Model Options--
Error threshold(%) = 0.5
Output predicted file: C:\Program Files\son-
net\project\matchnet_predict.snp
Max order target: 200

--Model Results--
S11 Order = 203   Error(%) = 1.387911   WARNING: Error threshold
of 0.5 (%) not achieved
S12 Order = 208   Error(%) = 2.984112   WARNING: Error threshold
of 0.5 (%) not achieved
WARNING: Poor figure of merit on S12 parameter. Visual inspection
of predicted S12 recommended.
S22 Order = 214   Error(%) = 1.833756   WARNING: Error threshold
of 0.5 (%) not achieved
WARNING: Model prediction is not passive at 112 frequency points.
Error threshold may need to be decreased or input data may be non
passive.

--Model Summary for matchnet--
Maximum error was for S12, Error(%) = 2.98411
Total model time: 25 minutes 43 seconds
Model matchnet finished with no errors, 5 warnings
```

Error Threshold
Curve Fit Data File
Warning Messages
Indicates that a “fit” was found for all S-parameters but for some the error exceeded the error

Improving the Accuracy of the Broadband Spice Model

If you need to increase the accuracy of your Broadband Spice model, there are several strategies you may use.

- If the Broadband model met your error threshold criteria but is still not acceptable, you may decrease the error threshold to increase the accuracy of the model. Be aware, however, that the processing time may be significantly increased by lowering the error threshold. Typically, values below 0.1% result in unacceptably long analysis times.
- If there are more than 200 frequency points in your response data, try decreasing the number of frequencies in your response data. To do so, use the *Analysis* ⇒ *Clean Data* command in the project editor to remove the response data, then run another Adaptive sweep (ABS)

using a coarser resolution to produce less data points but still more than 50 data points. You may change the resolution of an adaptive sweep in the Advanced Options dialog box in the project editor. Select *Analysis ⇒ Setup*, then click on the Advanced button in the Analysis Setup dialog box which appears.

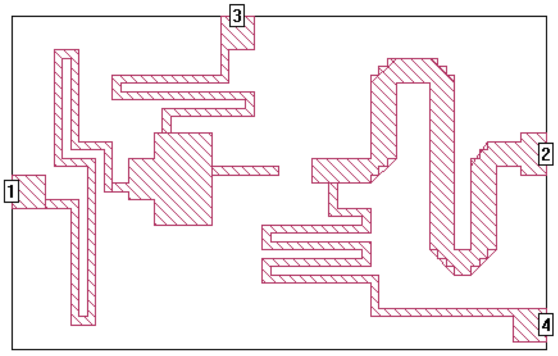
- Increase the number of data points in the critical frequency band in which you are concerned and decrease the number of data points in frequency ranges which are not as important.

Chapter 23 Package Resonances

Simply stated, the Sonnet analysis is a solution of Maxwell’s equations. These general equations are not limited to a purely TEM or Quasi TEM analysis. For a given structure, if a higher order mode (TE or TM) can propagate or an evanescent mode can exist, it will be included in the results. The strongest evidence of the presence of a “waveguide” mode occurs when the 6 conducting sides of the Sonnet box create a resonant cavity. As most microwave designers can attest to, these box resonances occur in practice as well. The designer can use Sonnet to predict unwanted box resonances in the package or module housing the circuit.

In this chapter, we will outline several ways to detect package resonances within the Sonnet simulation based on an example project. As you will see, this is a great way to prove a package design early in the design cycle. We will also outline the use of the Box Resonance Estimator and give some advice as to how to remove box resonances from a structure.

To obtain the example file (package.son) used in this chapter, get the example folder Package_resonances from the Sonnet examples. For directions on obtaining a Sonnet example, select *Help* ⇒ *Examples* from the menu of any Sonnet program, then click on the Instructions button.



The file “package.son” is a model of an amplifier used to check for package resonances. The entire width of the box is not shown.

Box Resonances

The purpose of this section is to give the user a basic understanding of how to detect box resonances in a Sonnet project or simulated data. There are three ways to do so:

1 Runtime warning messages

2 Observations of simulated results

3 The Box Resonance Estimator

Runtime Warning Messages

If the proper selection is made during the analysis setup, Sonnet will detect box resonances and output warning messages in the analysis monitor, while the simulation is being performed. The steps to enable this feature are:

1 Select *Analysis* ⇒ *Setup* from the project editor menu.

2 **In the Analysis Setup dialog box which appears, click on the Advanced button.**

3 **In the Advanced Options dialog box which appears, click on the Box Resonance Info check box.**

4 **Click on the OK button to close the Advanced Options dialog box.**

5 **Click on the OK button to close the Analysis Setup dialog box.**

Warnings

The warning symbol, shown to the left, appears in the analysis monitor when a box resonance is detected. If you click on the Errors/Warning button on the analysis monitor, you can view all of the warning messages associated with that particular analysis.

Below is an example of the first type of box resonance warning message. When this message appears there is a box resonance detected in the primary structure.

```
 Sonnet Warning- EG2680:
Circuit has potential box resonances.
Filename: C:\Program Files\sonnet\project\package9.son
Primary structure.
First few ideal resonant frequencies are:
30.0866 GHz TE Mode 0, 1, 1
31.7587 GHz TE Mode 0, 1, 2
```

Note that the warning message is describing box resonances which appear in the primary structure. The term “primary” refers to the actual structure being analyzed. By “ideal resonant frequency” we mean a theoretical value based on an empty Sonnet box. The specified dielectric stackup is considered, but the effect of any circuit metallization and loss parameters are not.

Below is an example of the second type of box resonance warning message. When this message appears there is a box resonance detected in a calibration standard.

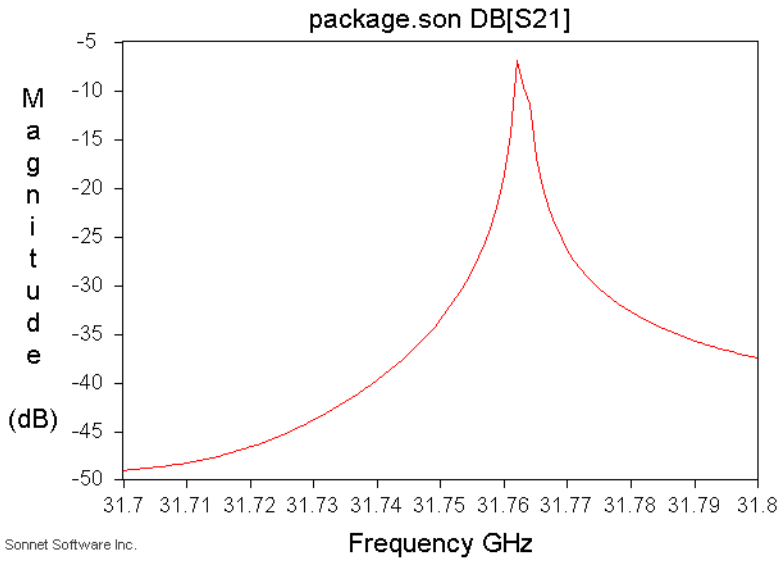
```
Sonnet Warning- EG2680:
    Circuit has potential box resonances.
    Filename: C:\Program Files\sonnet\package.son
    Second de-embedding standard, left box wall.
    First few ideal resonant frequencies are:
    30.0871 GHz TE Mode 0, 1, 1
    31.7625 GHz TE Mode 0, 1, 2
```

Note that the warning message defines which calibration standard is causing the problem. The observant reader will notice that these resonant frequency values are different than with the primary structure. This occurs because Sonnet actually creates and analyzes two calibration standard as a part of the de-embedding procedure. These standards may have a different box size than the primary structure, which causes the change in the resonant frequencies. For more information on the calibration standards and de-embedding, please refer to Chapter 7 and Chapter 8.

Observations of Simulated Results

A second way to detect box resonances is with a manual review of the simulated data. Typically box resonances appear as sharp changes (glitches or spikes) in S-parameter magnitude and phase data.They can also be evident in E_{eff} and Z_0 data. This is because there is a resonance in at least one of the standards that ***em*** creates for de-embedding. Box resonances can also corrupt de-embedding results. Because ***em***'s de-embedding feature is based on circuit theory, it possesses the same limitation that all de-embedding algorithms share. It is unable to de-embed a structure contained inside a resonant cavity (box). This means that if a box resonance exists for a de-embedding calibration standard, the final S-parameters will be suspect.

Below is an S-parameter (S21) curve for the example project "package.son". Notice that at 31.76 GHz there is a sharp change in the data and it approaches unity. This indicates a strong, package resonance induced coupling between the input and output at this frequency.



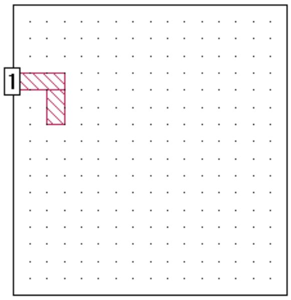
Results of a search for package resonances shows strong coupling between input and output at 31.7625 GHz.

A Box Resonance Example

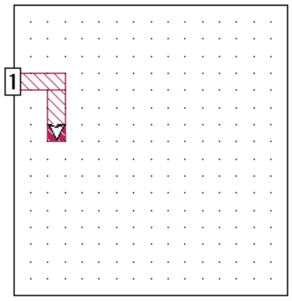
This example describes how to create a simple geometry file you can use to determine box resonance frequencies before you fabricate the wrong enclosure. Errors of less than 0.1% can be achieved with no limit on the number of dielectric layers used.

The basic idea is to re-create the box parameters of your real circuit, using the same substrate size, dielectric layers, etc. but without the metalization.

Once the box parameter setup is complete, you should create a small probe which is used to excite the modes. This is just a small (less than 1/8 wavelength) open stub with a port on it. If you bend the stub, you have a better chance of exciting both X-directed and Y-directed modes.

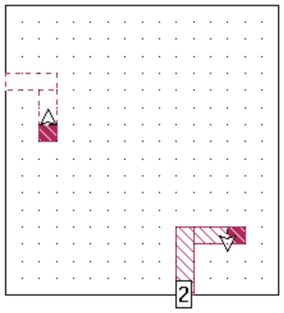


To excite Z-directed modes, connect a via to the end of the probe.

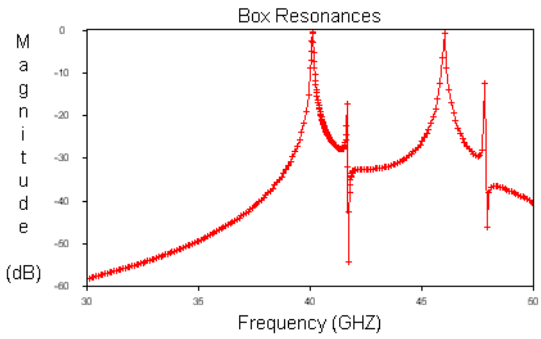


Make sure you don't place the probe precisely in the middle of the box wall. You want to make sure you excite both even and odd modes.

Then create another probe on an adjoining box wall. We do this in order to measure the coupling between the two probes. During a resonant situation, the coupling will increase.



Sweep the frequency in fine steps and look for resonances. You should run the analysis without de-embedding, since de-embedding assumes there are no box resonances which can cause erroneous results.When the box resonates, there should be stronger coupling between your two probes. This can easily be seen by plotting the magnitude of S21.

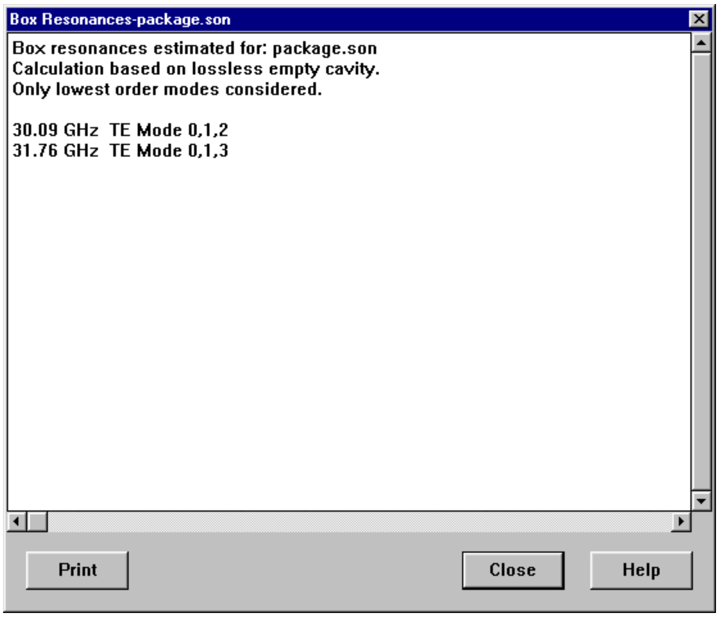


The peaks represent box resonances.

The Box Resonance Estimator

The best way to understand the box resonance situation within your package is to use the Box Resonance Estimator BEFORE running an analysis. It is recommended that this tool be routinely used to prevent wasted simulation time. It is an extremely useful tool because it allows the user to make modifications to the structure and gauge its impact on box resonances. It can also be used after a simulation is complete to help determine which characteristics of a complex data curve are related to box resonances. As with the runtime warning message, these are theoretical values based on an empty Sonnet box. The specified dielectric layers are considered, but the effect of any circuit metallization and loss parameters are not.

To access the Box Resonance Estimator, select *Analysis ⇒ Estimate Box Resonances* from the project editor main menu. The Box Resonances dialog box appears on your display. An example is shown below.



```
Box resonances estimated for: package.son
Calculation based on lossless empty cavity.
Only lowest order modes considered.

30.09 GHz  TE Mode 0,1,2
31.76 GHz  TE Mode 0,1,3
```

The Box Resonance Estimator displays not only the resonant frequencies contained in the simulation frequency range, but also tells the user the particular mode type. It is sophisticated enough to realize that when Symmetry is enabled for a circuit that Even Y modes will not exist.

In this particular instance, two Transverse Electric (TE) modes exist in or around the desired frequency range.   The Box Resonance Estimator will detect Transverse Magnetic (TM) modes as well. For a complete description of propagation modes, please refer to any classic field theory textbook.

NOTE: **The Box Resonance Estimator only checks the primary structure not the de-embedding calibration standards.**

Box Resonances – Simple Removal

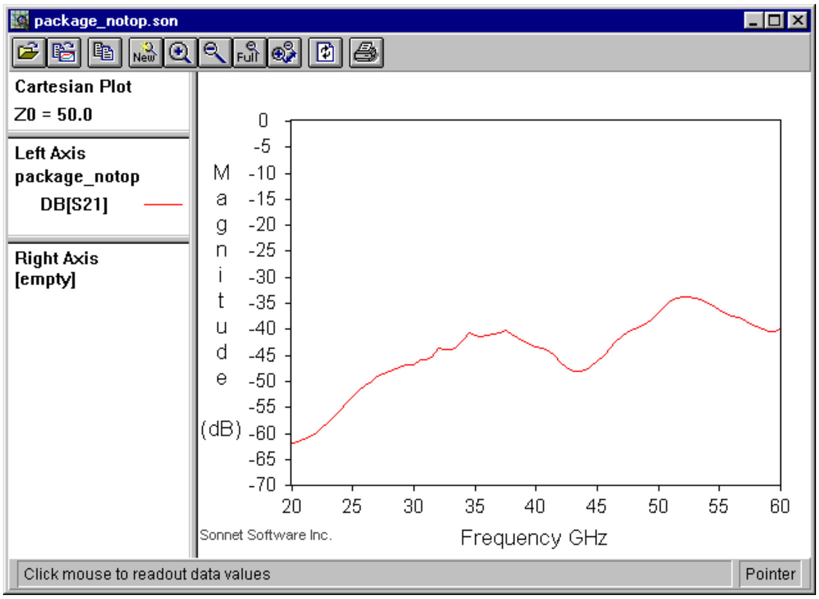
In the preceding section, we have described several ways to detect box resonances within a structure. We would now like to offer some advice as to how to remove them when they are undesirable. By this we mean the case when you simply do not wish to consider their effect and would like them removed from the data. This can occur when you analyze a portion of your overall circuit in Sonnet and the boxwalls artificially introduce resonances. Removal is actually probably not the best term to describe this approach. It is more of an attempt to push the resonances out of the desired frequency band or attenuate their levels.

The best way to remove a box resonance is to change the size of the box, either larger or smaller, to move the resonant frequency out of band. If the problem occurs in de-embedding, you may be able to change the length of the calibration standard in the project editor to move the box resonance out of the band of interest.

Another simple way to remove or at least attenuate the effect of a box resonance is to take off the top cover. We can create an approximation of this condition by setting the top cover resistivity to 377 ohms/square, the impedance of free space. To do this, open the Box Settings dialog window (*Circuit ⇒ Box Settings*) and change top cover to "Free Space". This is an accurate approximation provided the cover is not so close that it interacts with the evanescent fringing fields surrounding the circuit. Please note that it is inaccurate to place the top cover directly on top of the circuit without an intervening dielectric layer.

Using either technique will entail changing basic project parameters making it necessary to analyze the project again.

Below is the resulting S-parameter (S21) curve with the top cover set to free space. Please note that while the resonance is still evident its level has been greatly attenuated. Again, the data is from a simulation of the example project “package.son.”



The package resonances disappear when the top cover is removed.

Taking the top cover off works, provided the sidewalls of the box are large enough to form a propagating waveguide up to the top cover, or you can place the top cover close enough to the substrate surface to catch the fields in the box mode. High order “box” modes tend to be confined primarily to the substrate and can be difficult to remove in this manner. As you make the box bigger by increasing the substrate surface area, the modes “loosen up” so that they can propagate to the top cover and become absorbed.

The Capability to Ask: What if?

In the preceding section we mentioned some simple techniques for removing box resonances from simulated data. But what if your package is well defined physically, and you can’t simply take the cover off? In this situation, Sonnet can be an invaluable tool. It allows the user to make changes to the structure and evaluate the impact on box resonances. As noted earlier, the Box Resonance Estimator is a great tool to judge, almost in real-time, the effect of the package size. From this the user can gain an understanding of which dimension controls any one resonance type (TE or TM) and may provide some insight as to the solution.

Some of the techniques used to mitigate box resonances include:

- Adding grounded metal geometries to your structure – In many cases, ground vias or ground planes will help prevent box resonance modes from forming. In simple terms, they have the effect of dividing the structure into smaller compartments, thus pushing the box resonances higher in frequency. The use of a via fence or CPW type transmission line can help "channelize" the circuit, preventing unwanted coupling between traces and reducing unwanted box resonance effects. All of these features can be included in the Sonnet model.
- Adding an absorptive material to the model – Another approach which is normally used once all other package design features have been optimized, is to add an absorbing material in the housing cavity. The material is normally iron or carbon loaded so it can provide a fairly high magnetic or electric loss tangent. It comes in various forms such as liquid or sheet and is usually placed at a position such that it has a minimal effect on the circuit performance and a great effect on the box resonance. The user can easily model this material in Sonnet by adding a dielectric layer to the stackup.

Chapter 24 Viewing Tangential Electric Fields

One reason ***em*** is so fast is that all of the electric and magnetic fields are solved for analytically, with “pencil,” “paper” and many equations. The computer need only do an FFT and solve for the current distribution.

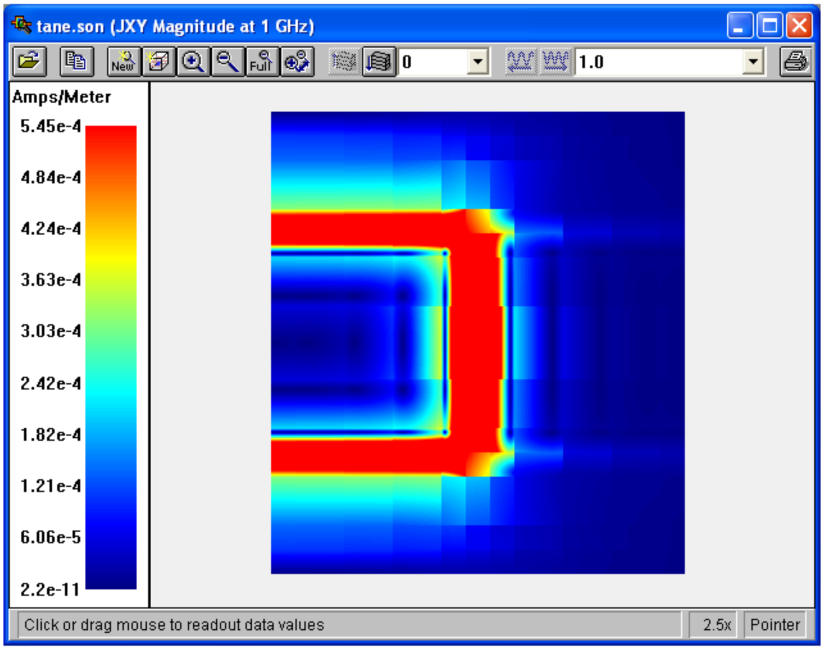
However, on occasion, you want to view the fields, not the current. You do this with what is called a “sense layer”. The sense layer is a rectangular patch of conductor placed where you want to see the tangential electric field.

Actually, describing the sense layer as a conductor is misleading. This is because you set the surface reactance of the conductor to some large value, say 1,000,000 ohms per square and the surface resistance to zero. You may do this by selecting the Sense Metal definition when defining your metal type in the Metal Editor dialog box. To access this dialog box, select *Circuit ⇒ Metal Types* from the main menu in the project editor, then click on the Add button in the Metal Types dialog box which appears on your display.

You set the reactance to such a large value so that the sense layer has little influence on the original fields. An intuitive analogy is to view a sense layer like inserting a sheet of paper (very high reactance) into the fields. Because the reactance of the sense layer is high, the currents are very small. The sheet of paper does not change the fields.

But even though they are small, what are the currents? The current density is proportional to the tangential electric fields over the area of the sense layer. This is just a two dimensional version of Ohms Law: Current is proportional to Voltage.

An example is shown below in the current density viewer. You may use the Manual Examples list in the Examples PDF documents to get a copy of this project, Tane. For directions on obtaining a Sonnet example, select *Help ⇒ Examples* from the menu of any Sonnet program, then click on the Instructions button.



The tangential electric fields just above a gap discontinuity. The input voltage comes from the left. Strong fields are present across the gap, especially at the corners. This analysis was performed at 1 GHz.

Tane is a good example showing tangential E-field. This circuit uses sense metal set to X_{dc} = 1.0e6 ohms/square. So, any current on this metal will be proportional to the E-field.

If you view the current density on level 0, you should see the values in the “red” area are about 0.001 Amps/meter. You can click on the circuit and see the value of the current in the status bar at the bottom of the window. Then, simply use the equation (based on Ohms law):

$$E = JX$$

where,

E= Electric field in Volts/meter

J = Current density in Amps/meter (0.001 A/m)

X = X_{dc} value of the metal in ohms/sq (1.0E6)

This gives E = 1000 V/m. This is assuming a voltage at port 1 of 1.0 Volts (default setting).

Chapter 25 Accuracy Benchmarking

Electromagnetic analyses are often described as providing what is called “Good Agreement Between Measured And Calculated” (GABMAC). However, in the past, there has been little effort to decide just what “good” means. The more useful result is the “Difference Between Measured And Calculated” (DMAC).

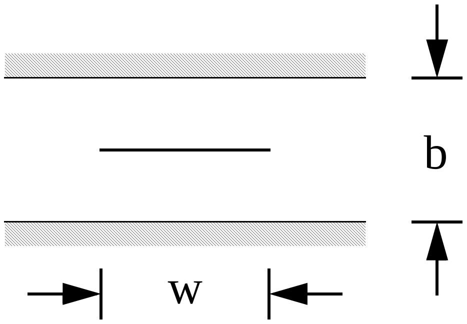
In this chapter, we describe a precise benchmark, based on [21], [22] and [24], which allows the evaluation of DMAC for any 2.5-D or 3-D electromagnetic analysis down to the 1 x 10^{-8} level of accuracy.

There is an example of a coupled stripline benchmark available in online help under Applications.

An Exact Benchmark

What we need to calculate DMAC is an exact benchmark. One source of an exact benchmark is stripline. The characteristic impedance of a stripline has an exact theoretical expression K(k) and is the complete elliptical integral of the first kind.

For evaluation on a computer, a polynomial for K(k) is available in **Abramowitz and Stegun, Handbook of Mathematical Functions**, pp. 590 - 592. (Be sure to note the errata, m1 = 1-m2, not 1-m.):



$$Z_0\sqrt{\varepsilon_r} = \frac{\eta_0}{4}\frac{K(k')}{K(k)}$$

$$k = \tanh\left(\frac{\pi}{2}\frac{w}{b}\right) \qquad k' = \sqrt{1-k^2}$$

$$\eta_0 = 376.7303136$$

The expression for K(k) cited above provides an accuracy of about 1 x 10^{-8}. When programmed on a computer, the following values are obtained for three different transmission line impedances (unity dielectric constant):

Table 1 Stripline Benchmark Dimensions

Z_0 (ohms)	w/b
25.0	3.3260319
50.0	1.4423896
100.0	0.50396767

For a length of stripline, there are two parameters of interest: characteristic impedance and propagation velocity. With the w/b given above, we know the exact answer (to within 1 x 10^{-8}) for Z_0. With a dielectric constant of 1.0, we also know the exact answer for the propagation velocity. It is the speed of light, known to about 1 x 10^{-9}. Any difference from these values is error, or, DMAC.

Each of the above three benchmarks is available in the Sonnet examples. To get the 50 ohm line, get the example S50. The other benchmark circuits are in "S25 and S100. For directions on obtaining a Sonnet example, select *Help* ⇒ *Examples* from the menu of any Sonnet program, then click on the Instructions button.

The "b" dimension is exactly 1.0 mm, the "w" dimension is given by the above table and the length of each line is 4.99654097 mm with a dielectric constant of 1.0. Each of these lines is precisely 0.25 wavelengths long at 15.0 GHz. The geometry projects have the subsectioning set so the lines are 16 cells wide and 128 cells long.

To evaluate DMAC, do an analysis of the line at 15 GHz, with de-embedding enabled. For the error in characteristic impedance, take the percent difference between the calculated value and the exact value, above. For the error in propagation velocity, take the percent difference between the calculated S_{21} phase and -90 degrees. Total error, in percent, is the sum of the two errors.

Some types of analyses do not calculate characteristic impedance. A detailed error analysis shows that, to first order for a 1/4 wavelength long 50 ohm line, the value of $|S_{11}|$ is equal to the error in characteristic impedance. For example, an $|S_{11}| = 0.02$ means that there is about 2% error in characteristic impedance. To use this approximation for, say, a 25 ohm line, the S-parameters must be converted to 25 ohm S-parameters. This may be done by adding transformers in a circuit theory program.

Residual Error Evaluation

We have performed a detailed analysis of the relationship between subsectioning and residual error (DMAC). The simplest way to subsection a line is to use subsections the same width as the line. In Sonnet, and in many other analyses, this results in a uniform current distribution across the width of the line. In reality, the current distribution is singular at the edges of the line.

Since the current distribution is symmetrical about the center line, using either one or two subsections across the width of the line gives the same amount of error.

We find that a one or two subsection wide line gives 5% to 6% error. If there is not much stray coupling, circuit theory can often give a better result. When the line is 16 cells wide, we see about 1% error, much more reasonable. We have found (and you can verify) that convergence is very strong: Double the number of cells per line width and the error is cut in half.

When we vary the number of cells per wavelength, along the length of the line, we see an inverse square relationship. Double the number of cells per wavelength along the length of the line and the percent error decreases by a factor of four.

An equation which expresses the error as a function of subsectioning is:

$$E_T \cong \frac{16}{N_W} + 2\left(\frac{16}{N_L}\right)^2 \qquad N_W \geq 3 \qquad N_L \geq 16$$

where

N_W = Number of cells per line width,

N_L = Number of cells per wavelength along line length,

E_T = Total Error (DMAC) (%).

This equation estimates subsectioning error only. For example, any de-embedding errors are added to the above error. This error estimate should be valid for any electromagnetic analysis which uses roof-top subsectioning.

Notice that the quantities used for the error estimate are in terms of cells, not subsections. Cells are the smallest possible subsections size. In Sonnet, subsections in the corners of polygons are one cell on a side. Subsections along the edge of polygons are one cell wide and can be many cells long. Interior subsections can be many cells in both dimensions.

We have found that, for most cases, the cell size is the important parameter in determining error. Or in other words, the smallest subsection size is important. For example, the stripline benchmark geometry projects, mentioned before, are set to make the lines 16 cells wide, even though those 16 cells may be merged into only 4 or 5 subsections. It is the 16 cells which determine the level of error, not the 4 or 5 subsections.

In performing this error evaluation, we also found that the error in characteristic impedance due to N_W is always high, never low. Also, there is very little variation in the error for different impedance lines. The above equation can be very accurate in evaluating error. And, finally, for N_L above about 40 cells per wavelength, all the error is in the characteristic impedance. The error in velocity of propagation is essentially zero.

The above equation can be very accurate in evaluating error. With this precise knowledge of the error, we can now do something about it.

Using the Error Estimates

The above error estimate can be used to estimate the error for an overall circuit. Let’s say that a cell size is used that makes some high impedance transmission lines only 1 cell wide. Other, low impedance transmission lines, are, say, 30 cells wide. The 1 cell wide lines give us about 5% error. The 30 cell wide lines give about 0.5% error. In non-resonant situations, you can expect the total error to be somewhere between 5% and 0.5%. If most of the circuit is the low impedance line, the error is closer to 0.5%, etc.

However, let’s say that our circuit has resonant structures. Let’s say it is a low pass filter. It is easy to verify by means of circuit theory that the low pass filter is very sensitive to the high impedance lines. This means we can expect about 5% error, even though the high impedance lines only make up half the filter.

Given this information, there are several courses of action. First, if 5% error is acceptable, no further effort is needed.

More likely, we wish to analyze the filter with less error. Since we now know the error in the characteristic impedance is 5%, we can physically widen the line so that the characteristic impedance is 5% lower to compensate for the known increase in characteristic impedance due to subsectioning the line only one cell wide. Very precise analyses are possible using this compensation technique.

Chapter 26 Time Required for Analysis

Em is a memory and computation intensive program. Small circuits are analyzed quickly while large circuits can require a considerable amount of time. In some cases, it may be desirable to run the program in the background.

There is no simple rule for calculating the time required for a particular analysis although there are guidelines, presented below, which will afford you some measure of control over that time.

The amount of time required is closely related to the number of subsections, which is shown in the analysis monitor during an analysis. After a few trials, you will have a good idea of whether an analysis is a few seconds, a few hours, or just totally hopeless by looking at the number of subsections.

The most important factor in the execution time required is the amount of memory required by ***em*** compared with the amount of memory you have. This is also shown in the status in the analysis monitor. If ***em*** says you need 36 Mbytes and you have 16 Mbytes installed, then it is a good idea to kill the run quickly. You can reduce the memory required by using the Memory Save option, which makes the analysis single precision. You can also try to reduce the area of metalization in the circuit. Try to eliminate any metal that is not carrying current and make connecting lines as short as possible (but not too short, see Chapters 7 and 8 on de-embedding).

Another approach, if your memory requirement is right on the edge, is to free up some of your computer's memory. Make sure no one else is also running a memory intensive program at the same time.

The estimate of required memory printed out by ***em*** is just an estimate. It is usually within 1 Mbyte or so, but could be off by much more. To get both the memory estimate and the number of subsections without going on to actually analyze the circuit, use the Calculate Memory Usage option, available in the Additional Options dialog box.

For most circuits, the following equation can be used to estimate the amount of memory that will be used by ***em***:

$$B = K*N^2$$

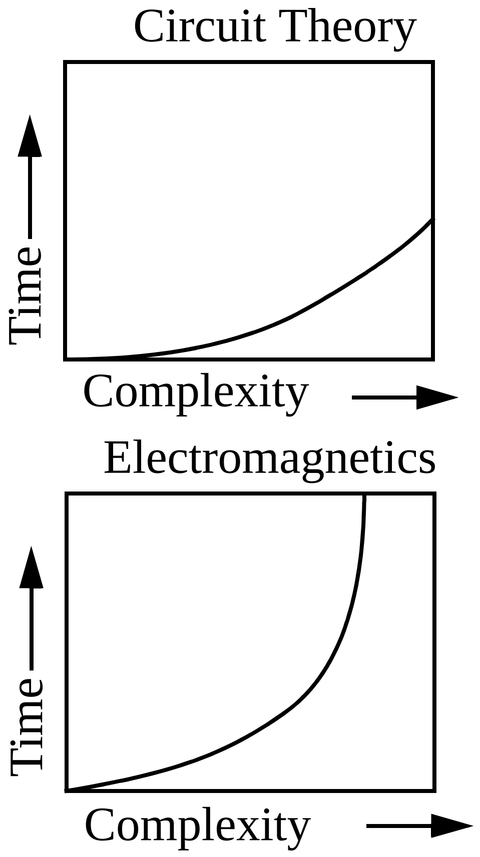
where B is the number of bytes, and N is the number of subsections. K is equal to 8 if running with double precision and loss. This can be circuit metal loss, top or bottom cover loss or dielectric loss. K is equal to 4 if you are running with loss but using Memory Save or running lossless and using double precision. K is equal to 2 if you are running a lossless circuit and using Memory Save. This equation should be used only as an estimate as it only includes the memory used by the final matrix in ***em***. Circuits with large boxes (in terms of number of cells) or many layers require more memory. You should use this equation to calculate an upper limit on the number of subsections for your computer.

For UNIX systems, you can check the memory actually used by typing the "ps" (process status) command. Consult your system administrator or UNIX manuals for details on the "ps" command.

To check how much of your system's memory is actually available for your use, select *Help ⇒ System Info* from the project editor main menu. The System Information dialog box appears on your display and contains the information on system memory use.

The “Wall”

When using circuit theory analysis, an increase in circuit complexity gradually produces an increase in analysis time. With an electromagnetic analysis, the increase happens suddenly. A mere doubling of circuit complexity (say, by using a smaller subsection size) can result in one, or even two, orders of magnitude longer analysis. We call this the “Wall” (see the charts below).



The Wall is frequently encountered when ***em*** runs out of real memory, as described above, and is forced to start swapping out to disk. Execution time can quickly go from a few minutes to a few hours. Either get more memory or modify the circuit so that there are fewer subsections.

To avoid the wall, *start with no loss (metal or dielectric) and use a large subsection size*. Perform the first analysis at a single frequency to evaluate how long an analysis takes. Then, provided you get fast results, try adding loss or making the subsection size smaller. Keep going until the analysis is as long as you can tolerate and then let it run over a full range of frequencies, perhaps overnight.

The main factor in analysis time is the number of subsections. ***Em*** prints out the number of subsections if the Verbose option is used. As you gain experience with ***em***, you will get a good feel for what can be tolerated. For example, on a Sun SPARCstation 1 with 16 Mbytes of memory, up to 1700 subsections (lossless) or 1200 subsections (with loss) can be calculated in an hour or so. At this point the computer runs out of memory and starts swapping to disk, resulting in huge increases in time.

To avoid the frustrations of getting on the slow side of the wall, *start lossless with big subsections*. You may find that big subsections provide all the accuracy you need.

Detailed Parameter Dependencies

How do changes in the various input parameters affect the analysis time?

First, keep in mind that ***em*** has two stages in the analysis. In the first stage, ***em*** fills a large matrix. The matrix has one row/column for each subsection. This is where ***em*** is calculating the coupling between every possible pair of subsections. In the second stage, ***em*** is solving the matrix. Here, ***em*** is performing matrix inversion-like functions and is calculating the currents which allow all boundary conditions to be met. The different parameters affect each stage of the analysis differently.

During analysis of the first frequency in a run, ***em*** prints out the amount of time spent on various portions of the analysis. If the time spent in any particular section of the analysis is less than one second, it is not printed out. Sections which are timed include the waveguide mode calculation (prior to matrix fill), the matrix fill and the matrix inversion.

Parameters which have no effect on analysis time include the substrate thickness, cover height and number of ports. Each of these parameters is unlimited and have no impact on speed while still maintaining complete accuracy.

Including metalization loss increases the matrix solve time only. And this is only if the rest of the structure is lossless. If there is any dielectric loss or ground plane (or top cover) loss, there is virtually no additional impact from also including metalization loss (the whole calculation is already fully complex). The matrix solution time is increased by about a factor of four (if it becomes complex). Metalization loss has no impact on any other segment of the analysis.

Including dielectric loss, or ground plane or top cover loss, makes the entire calculation complex. The matrix solve time is increased by about a factor of four, while the matrix fill time is increased by about a factor of two.

In calculating the values for the matrix elements during the matrix fill, several two dimensional Fourier Transforms must be calculated. The size of the Fourier Transforms is the same size as the substrate in terms of cells. If a substrate is 128 x 64 cell, each Fourier Transform is 128 x 64 elements. Memory storage is required for only one Fourier Transform at a time and this is usually much smaller than the matrix being filled.

In this release, the FFT has been improved for composite box sizes. A composite number is not a prime number, nor does it contain any large prime factors. For example, 1000 is a composite number because its largest prime factor is 5. But 998 is not a composite number because its largest prime factor is 499. So a 998 by 998 box might take 2 to 3 times longer in the FFT calculation portion of the analysis than a 1000 by 1000 box. The FFT portion of the analysis is usually a small percentage of the total analysis time, unless you have a lot of layers or an especially large box. If either of these conditions are true, then it might be worthwhile to use a composite number in your box size.

For all the above detail, keep in mind that if the substrate is small (less than 256x256 cells), the Fourier Transform time is of little consequence.

Matrix fill time is proportional to the number of subsections squared for large circuits.

The number of subsections, for a given cell size, can be reduced by minimizing the number of vertices and the number of diagonal lines in the polygonal description of the circuit. If the circuit is symmetric with no more than two ports, with both ports on the axis of symmetry, invoke the symmetry option for a significant memory and time savings.

The matrix solve time is proportional to the number of subsections cubed and is the main limitation on the analysis at this time.

Appendix I *Em* Command Line for Batch

If you wish to set up batch or script files to run your analyses overnight or at times of the day when the processing load is lighter, it is possible to use command lines to run ***em*** from a batch file. You should also be aware that it is possible to setup batch files with start and stop times using the analysis monitor. For directions on how to do so, please see **How do I create a batch file to run multiple analysis jobs?** in online help.

You should be aware that running from the command line does not provide all of the status information that is provided in the analysis monitor while running an analysis.

The syntax of the command line is as follows:

```
em -[options] <project name> [external frequency file]
```

where:

<options> is one or more of the run options shown in the table below. If you use multiple options they should be typed with no spaces in between after the minus sign. Note that other run options may be set in the Analysis Setup dialog box for your project and will be used during the analysis.

Option	**Meaning**
-Dlicense	Used for debugging ***em*** licensing problems. Displays all environment information relevant to licensing.
-N	Display number of subsections and estimated required memory. ***Em*** then exits without running a full analysis.
-test	Run ***em*** on a test circuit. Used to verify that ***em*** can get a license and run successfully.
-v	Display analysis information as the analysis is performed. The analysis information is output to the command prompt window or terminal from which the batch was executed.
-AbsCacheNone	Disable ABS caching (overrides setting in project file).
-AbsCacheStopRestart	Enable ABS stop-restart caching (overrides setting in project file).
-AbsCacheMultiSweep	Enable ABS multi-sweep plus stop-restart caching (overrides project file).
-AbsNoDiscrete	Used when running ABS with pre-existing cache data. Tells the analysis engine not to do any more discrete frequencies. If pre-existing cache data is sufficient to get converged ABS solution, then that solution is written to output. Otherwise, no processing is performed.

Option	Meaning
-SubFreqHz[value]	where [value] is the subsectioning frequency in Hz. Note there is no space before the value field. This option allows subsectioning frequency to be specified on the command line, thereby overriding the settings in the project file.
-ParamFile <filename>	where <filename> is the name of a file which contains the value(s) which you wish to use for parameter(s) in the circuit being analyzed. These values override the value contained in the geometry project for the analysis, but do not change the contents of the geometry project. The syntax for the parameter file is <parname>=fnum where <parname> is the name of the parameter and fnum is a floating point number which defines the value of the parameter for the analysis.
-64BitThresh<mem>	Memory threshold in MB to enable the 64-bit solver where <mem> contains an integer value identifying the memory threshold at which 64-bit processing is used. If this command is not used the threshold is set to 3600 Mbytes (3.6 Gbytes).
-64BitForce	This option forces the analysis to use 64-bit processing regardless of how much memory is required to analyze your circuit; the memory threshold is not used.
-32BitForce	This option forces the analysis to use 32-bit processing regardless of how much memory is required to analyze your circuit; the memory threshold is not used.
NOTE:	**When using 32-bit processing, *em* can only access up to 4 GB of RAM on 64 bit Windows and 2 GB on 32 bit Windows. If you try to run problems larger than this limit, the analysis will run out of memory (even if you have more RAM) and stop.**

<project name> is the name of the project which you wish to analyze. If there is no extension, then the extension ".son" is assumed. This field is required.

[external frequency file] is the name of an optional external frequency control file whose extension is ".eff". This extension must be included when specifying the control file. You may create an external frequency control file in the project editor. For details see Frequency Sweep Combinations in online help in the project editor. The frequencies in this file override the frequencies in the project.

For example, if you wish to analyze the project steps.son in a batch file using the -v option, the command line would be:

em -v steps.son

An example of a batch file which runs multiple analyses is shown below.

```
em -v steps.son
em -v filter.son filter.eff
em -v airbridge.son filter.eff
em -v airbridge.son
```

To execute a batch file on the PC, you should create a text file containing the command lines with a “.bat” extension. Then open a DOS prompt window and type the filename at the prompt and press return.

To execute a batch file on UNIX, create a text file containing the command lines. The filename does not need any extension. Then change the permissions mode of the file to allow you to execute it. For example:

chmod a+x <filename>

where <filename> is the name of the batch file you wish to execute. Then, type the name of the file at the UNIX prompt and press return.

On UNIX systems there are several additions to the command line which are useful to know. Placing “nice” before the command runs it at lower priority. Placing “&” at the end of the command runs it in background, so you get your cursor back. Entering “nohup” before the command line allows you to log off while the em job(s) keep running. If you are using the “&” or the “nohup”, you might want to consider redirecting the output using “> outfile.” See your system administrator for details on any of these options.

Appendix II Sonnet References

This appendix contains articles written by Sonnet authors or articles which directly impacted the analysis theory used by Sonnet. An extensive list of articles in which Sonnet was used as the analysis tool is available on Sonnet's website at www.sonnetsoftware.com. Search for "References."

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