Empipe™

User's Manual

Optimization Systems Associates Inc.

Empipe™

User's Manual

Version 4.0

July 1997

Optimization Systems Associates Inc.

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Empipe User's Manual Version 4.0 first published in 1997. Printed in Canada.

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Empipe™ User's Manual

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Installation

1

Installation

1.1 Introduction

The installation of Empipe can be done by either a system administrator or a user.

In a Windows NT multi-user environment, the system administrator should install Empipe so that it is accessible to all users. If, on the other hand, Empipe is to be used by a single user, then that user can carry out the installation himself/herself.

Sections 1.2 and 1.3 describe the procedure of loading the software. Only the person who performs the installation needs to follow this procedure.

Empipe drives the electromagnetic simulator *em* from Sonnet Software, Inc.

If you experience difficulties in the installation of Empipe, you can contact our technical support staff at

Tel 905 628 8228
Fax 905 628 8225

Email osa@osacad.com

Home page http://www.osacad.com

1.2 Installing the Software

We recommend that you close all open applications before starting the installation. If there were additional installation instructions provided with the software, please follow them as well.

Insert the floppy disk labelled "Installation Disk 1" in the appropriate drive. Click on the "Start" menu (located on the taskbar) and choose "Run". A dialog box will appear, prompting you for a file location. Enter the following string:

```
a:\setup.exe
```

where "a:" is the drive letter of the 3.5" floppy drive.

The installation program will guide you through the actual installation of Empipe.

After setup has been successfully completed you will see a dialog box which provides directions for installing the Sentinel Pro drivers. Empipe requires these drivers to access the information stored in the hardware lock to function properly.

The software portion of the setup procedure is now complete.

1.3 Installing the Hardware Lock

Provided with the software is a Sentinel Pro hardware lock. The hardware lock should be installed on the first parallel port of the computer (i.e., LPT1). If there are other locks already attached to the computer, be sure to place the Sentinel Pro at the end of the chain. This lock is completely transparent and should not interfere with normal operation of the computer, printers or other devices which may be attached to the computer's parallel port..

After installing the hardware lock, insert the floppy disk labelled either "Win95 Sentinel Setup" or "WinNT Sentinel Setup" (whichever is appropriate for your operating system) in the drive. Click on the "Start" menu (located on the taskbar) and choose "Run". A dialog box will appear, prompting you for a file location. Enter the following string:

```
a:\setup.exe
```

where "a:" is the drive letter of the 3.5" floppy drive.

You will be presented with a screen titled "Sentinel Driver Setup Program". You will see that there is only one menu item available, "Functions". From "Functions", choose "Install Sentinel Driver". You will be prompted for the location of the installation files. The location is the root directory of the installation floppy disk (for example, "a:\").

After a brief period of time, you will be presented with a dialog box informing you of the outcome of the installation and requesting that you reboot your machine. Prior to rebooting the machine, remove the installation floppy disk from the drive.

After rebooting, Empipe is ready to run.

There have been problems reported involving hardware locks attached to enhanced or bidirectional parallel ports. If you experience problems with the hardware lock, please see the documentation for your computer and set the port to "standard" or "normal" mode.

1.4 Empipe Example Directory

The directory hierarchy of the Empipe installation is as follows.

Osa	*OSA Installation Directory*
bin	*executables*
empipe_examples	*examples*
osa90msg	*configuration files*

We recommend that before using the software, you make a working copy of the examples to a suitable directory and work with that copy.

If you need more information on how to copy files and folders, select "Help" from the start menu and search for "copying".

1.5 Uninstalling the Software

To uninstall Empipe and its components, perform the following actions:

- Select “Control Panel” from the “Settings” sub-menu of the “Start” menu.
- Open “Add/Remove Programs”.
- Select the software you wish to uninstall.
- Click the “Add/Remove” button.
- Click “Yes” when the “Confirm File Deletion” dialog box appears.

A message box will appear, informing you whether or not the software was successfully removed.

2

Technical Overview

2

Technical Overview

Empipe is a powerful and friendly software system for automated electromagnetic (EM) design optimization, driving the EM simulator ***em***.

em is a full-wave EM field simulator from Sonnet Software, Inc., for predominantly planar circuits. ***em*** accommodates arbitrary geometries and accounts for dispersion, coupling, surface waves, radiation, metallization and dielectric losses. It is highly recommended for its accuracy and speed (see, e.g., D.G. Swanson, Jr., "Simulating EM fields," *IEEE Spectrum*, November 1991, pp. 34-37, and "CAD benchmark: electromagnetic simulators", *Microwave Engineering Europe*, November 1994, pp. 11-20).

Empipe allows you to designate geometrical and material parameters as candidate variables for optimization in an intuitive and friendly manner. You introduce a set of incremental changes using ***xgeom*** (the same graphical editor you use to set up an ***em*** analysis). The information is then processed by Empipe to parameterize the structure.

To put it simply, any arbitrary structures that you can simulate using ***em*** you can now optimize using Empipe!

Empipe employs the sophisticated optimizers in OSA90, a program supplied as part of the Empipe package. OSA90 offers a comprehensive set of optimizers, including ℓ_1, ℓ_2 (least squares), minimax, Huber, quasi-Newton, conjugate gradient, simplex, simulated annealing and random algorithms, with proven track records in engineering applications. OSA90 also offers a wealth of options for mathematical expressions, response postprocessing, statistical analysis and yield optimization, as well as many graphical display and visualization formats.

Fig. 2.1 illustrates the data flow of the Empipe software system.

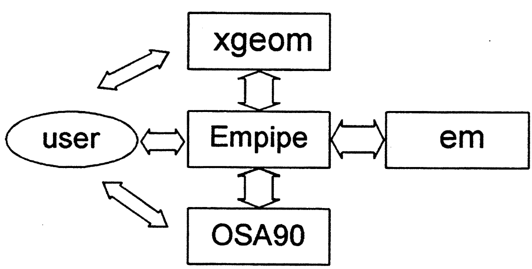


Fig. 2.1 Data flow schematic of the Empipe system.

Functional Relationship Between Empipe and OSA90

The Empipe package includes Empipe and OSA90 as two separate executable programs. Their functional relationship is as follows.

As a user, you start the operation with Empipe. You define the structure to be optimized as an Empipe element. Once the definition of parameters, variables and specifications is completed, you click on a button and OSA90 is invoked. You interact with the OSA90 environment to carry out simulation and optimization. Whenever necessary, OSA90 will call Empipe to obtain ***em*** analysis results. After you are done with the optimization, you exit from OSA90 and return to Empipe.

A series of tutorials is provided in Chapters 3 to 7 to illustrate the various features of Empipe. The tutorials are organized in a progress order, each one introducing something new. We highly recommend that you follow all the tutorials.

Automatic and Intelligent Discretization and Interpolation

em requires discretization of geometrical parameters with respect to a predefined grid (mesh). Empipe automatically handles the discretization so that when ***em*** is invoked all the geometrical coordinates are on the grid. Response interpolation is employed to produce the results for off-grid points. This also facilitates the efficient calculation of gradients for optimization.

The user can select from a number of schemes of interpolation, including linear and quadratic interpolations, based on S, Y or Z parameters.

Empipe Database

The results from all ***em*** analyses are saved in Empipe databases. This eliminates duplicated ***em*** simulation and, when combined with interpolation, are particularly valuable for making EM-based statistical analysis and yield optimization practical.

Flexibility in Analyzing Large Structures

Empipe gives you flexibility in analyzing large, complicated structures. You can decompose a large structure into several substructures, individually simulated by ***em*** and then connected via circuit theory. This may produce less accurate results than analyzing the whole structure as one piece if parasitic couplings exist between the substructures, but it can significantly reduce the CPU time needed for the ***em*** analysis.

Optional Equivalent Circuit Model Library

The Empipe software system can be upgraded with an optional OSA90/hope module. It offers a comprehensive library of equivalent circuit models, including lumped elements, controlled sources, transmission lines and empirical models for microstrip components.

With this option, you can freely mix within the same circuit *em*-simulated structures with equivalent circuit elements. You can use optimization to automate calibration, refinement and new development of models for novel structures.

Nonlinear Harmonic Balance Simulation and Optimization

The optional OSA90/hope upgrade also provides a wealth of nonlinear modeling, simulation and optimization capabilities. It includes a library of nonlinear device models for diodes, FETs, bipolar transistors, HEMTs and user-definable nonlinear controlled sources.

You can perform small-signal, DC and large-signal AC simulation. You can combine EM analysis with harmonic balance analysis to accurately simulate and optimize nonlinear circuits.

3

Tutorial: A Microstrip Line

3

Tutorial: A Microstrip Line

3.1 Introduction

This tutorial chapter is intended to help you learn to use Empipe by going through a simple example step by step. Additional tutorials are provided in Chapters 4 through 7, gradually and systematically introducing you to the various features of the program.

Before we proceed, please make sure that the following steps as described in Chapter 1 have been carried out:

1 Empipe has been properly installed.

2 You have made a copy of the Empipe examples to an alternate directory.

What You Will Learn From This Tutorial

1 The basics of the user interface of Empipe.

2 How to parameterize a geometrical dimension as an optimization variable.

3 How to define a performance specification on the *S* parameters.

4 How to start an ***em*** simulation through Empipe.

5 How to start an optimization.

6 How to save the optimized geometry.

This introductory tutorial is not at all time consuming. Each ***em*** analysis takes less than 1 second. The optimization takes only a few seconds to run.

When this symbol appears on the left-hand side column, it highlights text that describes hands-on actions. You can take a "short-cut" through the tutorial by following this symbol and skip over the commentaries.

Description of the Example

For this introductory tutorial, we consider a very simple example: a microstrip line, as illustrated in Fig. 3.1.

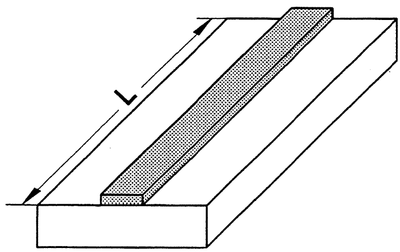


Fig. 3.1 The microstrip line example.

It is nominally a 50 Ω line. The substrate is 25 mil thick, with a dielectric constant of 9.8. The line width is 25 mils. The metallization is assumed to be lossless.

The objectives of our exercise include:

1 Define the length of the line as a designable parameter, identified by the name *L*.

2 Define the line as a two-port, with a port defined at each end of the line.

3 Optimize the parameter *L* to satisfy the specification

PS21 = -120 at frequency = 10 GHz

where PS21 represents the phase of S_{21} in degrees.

3.2 Creating the Geo Files

Structures to be simulated by ***em*** must be described by a ".geo" file. Sonnet Software, Inc. provides the ***xgeom*** program to let you draw the geometry graphically. A utility program to convert GDSII files to ".geo" files is also available from Sonnet Software, Inc.

A ".geo" file contains the description of the geometry by means of a set of coordinates. It also contains other relevant information, such as substrate data and port definitions.

We assume that you already know how to create a ".geo" file to represent a given structure.

For the microstrip line tutorial example, we have created a ".geo" file, under the name em_line0.geo, which is included in your copy of the Empipe example files.
The ***xgeom*** display is depicted in Fig. 3.2.

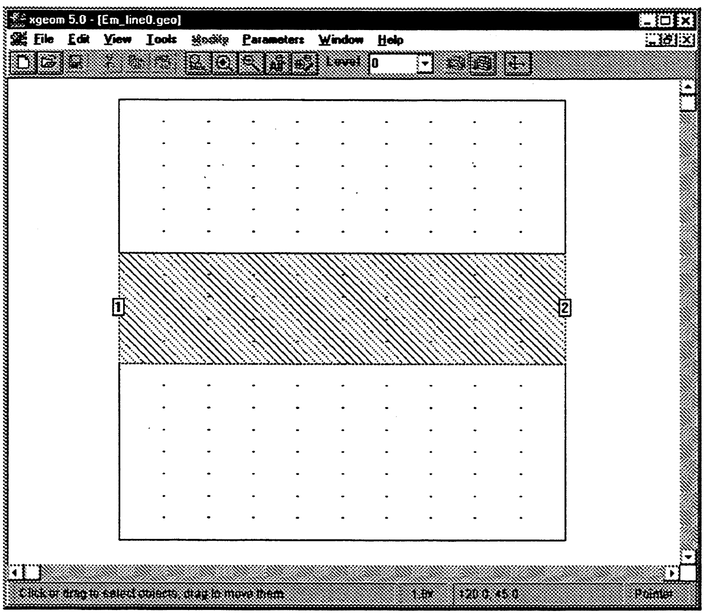


Fig. 3.2 The microstrip line described in em_line0.geo.

Creating a Geo File to Represent an Incremental Change

In the ".geo" file shown in Fig. 3.2, we set the microstrip line length to 100 mils. We call it the nominal value of the length parameter. The nominal value of a parameter may come from an empirical design or it can simply be a reasonable and convenient value.

For Empipe to capture the microstrip line length as a parameter, we need to create an additional ".geo" file to represent an incremental change. For instance, we may change the length from its nominal value of 100 mils to 110 mils, and create a new geometry to correspond to the new line length. The name for the new ".geo" file is em_line1.geo.

Fig. 3.3 illustrates the geometries before and after making the incremental change.

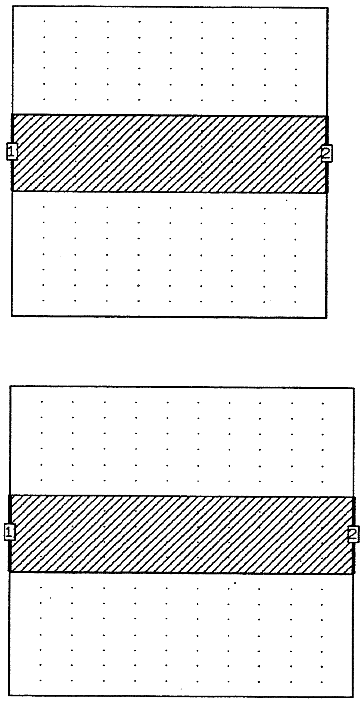


Fig. 3.3 Geometries for L=100 mils and L=110 mils, respectively.

By comparing the two ".geo" files, Empipe automatically extracts the information necessary for translating a given parameter value to the corresponding geometrical coordinates.

Rules for Making Incremental Changes

- The cell size must remain the same as in the nominal ".geo" file.
- The incremental change must be a multiple of the grid size, i.e., the geometry must remain on the grid after the change.
- You cannot add or delete polygons.
- The basic shape of the polygons must remain the same (e.g., you cannot change a polygon from a rectangle to a triangle).

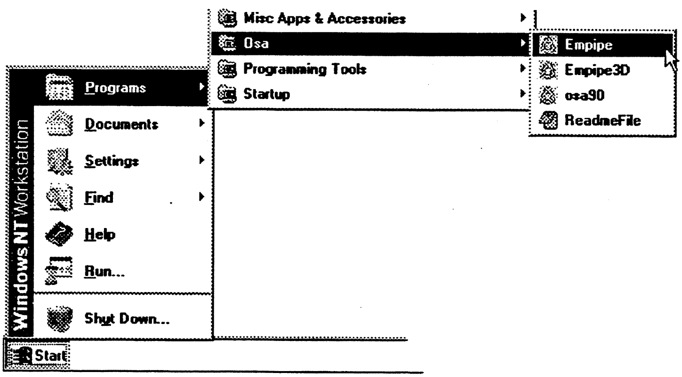
These rules are specified in more precise details in Chapter 8.

3.3 Geometry Capture Form Editor

This section shows how to use Empipe to capture the microstrip line length parameter from the geometries described by the files em_line0.geo and em_line1.geo.

Starting Empipe

To start Empipe, click on the "Empipe" icon located in the "Osa" program group.



When the Empipe main window appears, click on the "Load" button. You will be presented with an "Empipe Open File" dialog box. Select the project "em_line.inc" from your copy of the examples. The Empipe Geometry Capture form editor is then displayed.

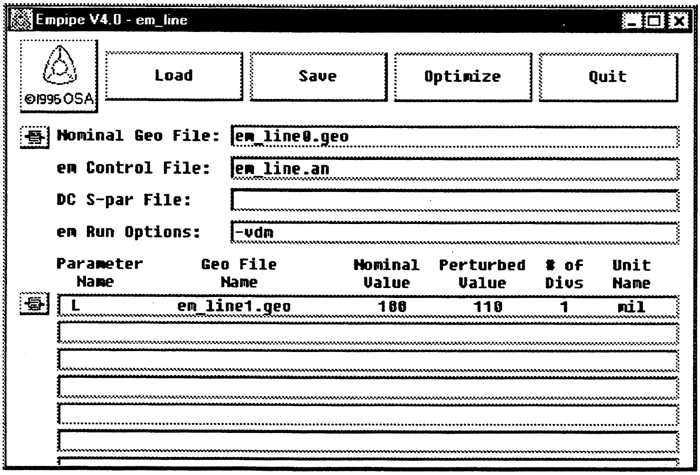


Fig. 3.4 Empipe Geometry Capture form editor.

For this tutorial example, the data is already set up for you. Otherwise, if we were starting a new project from scratch, the form editor would have mostly blank fields. Now we will look at the meaning of each of the entries.

Nominal Geo File

This entry identifies the ".geo" file which represents the structure with all the parameters set to their nominal values.

For the microstrip line tutorial example, this entry should be the file name em_line0.geo.

For a new project, you will see a blank entry box like this:

Nominal Geo File:

Click the left-hand mouse button on the box, and then type in the appropriate file name.

This button appears adjacent to the entry box. If you click on it, ***xgeom*** will be invoked to display the nominal ".geo" file.

em Control File

This entry identifies the *em* analysis control file. An analysis control file is required by *em*. It defines the frequencies for the *em* analysis.

An analysis control file has been created for you and supplied with the microstrip line tutorial example, under the name em_line.an. Its contents are as follows

```
VER 3.0
GHZ
FRE 10
```

It defines a single frequency of 10 GHz for the *em* analysis.

For a new project, you need to prepare an appropriate analysis control file in accordance with the syntax described in the Sonnet User's Manual. Then you click the left-hand mouse button on the entry box and fill in the name of the analysis control file.

DC S-Parameter File

This field allows you to supply a separate *S*-parameter file for DC. This is necessary only if the Empipe element is to become part of a nonlinear circuit for harmonic balance simulation. It does not apply to our example and should be simply left blank.

em Run Options

This field allows you to specify the run-time options for *em*. The default options are -vdm (verbose, automatic de-embedding and memory saver).

Parameter Definition Data

The entries under the heading

```
Parameter   Geo File   Nominal   Perturbed   # of   Unit
  Name        Name      Value      Value     Divs   Name
```

contain the data necessary for defining the parameters. Each line defines one parameter.

For the microstrip line tutorial example, we have just one parameter, namely the line length. The entry that defines this parameter is

```
L    em_line1.geo    100    110    1    mil
```

The meaning of the items is as follows.

Parameter Name is an arbitrary ASCII string of no more than 32 characters. We choose the name "L" to identify the microstrip line length parameter.

Geo File Name identifies the ".geo" file which describes the geometry of the structure after an incremental change in the parameter value is made. The file that represents an incremental change in the microstrip line length parameter is em_line1.geo.

Nominal Value refers to the nominal value of the parameter which is consistent with the nominal ".geo" file. For the microstrip line length parameter, this value is 100 (it should be entered as a plain number, since the physical unit is entered as a separate item).

Perturbed Value refers to the parameter value after the incremental change. For the microstrip line length parameter, this value is 110.

Number of Divs measures the incremental change in terms of the *em* grid size. It is obtained by dividing the difference between the nominal value and the perturbed value by the *em* cell size along the appropriate dimension. For the microstrip line length parameter, the incremental change is 10 mils. Since the geometrical change is along the X dimension of the layout and the grid size for the X dimension is 10 mils, the number of divisions is 1.

If we had changed the line length from 100 mils to 120 mils instead of 110 mils, then the number of divisions would be 2 instead of 1.

This information is needed to ensure that the geometry Empipe generates for *em* analysis is always on the grid (interpolation is used for off-grid points).

Unit Name identifies the physical unit of the parameter. Permissible unit names include IN (inch), MIL (milli-inch), M (meter), CM (centimeter), MM (millimeter), UM (micron) and NONE (without unit). The unit name for the line length parameter is MIL.

Suppose that you had started from scratch and had to enter this data on a blank line. You would first click the left-hand mouse button on the box and then type

```
L em_line1.geo 100 110 1 mil
```

Note that you do not have to manually line up the text with the heading. When you have completed the entry, press the <Enter> key and the text will be automatically formatted to align with the heading.

This button appears on each line that has a parameter defined. If you click on it, ***xgeom*** will be invoked to display the ".geo" file specified on that line.

What's Next?

At this point, Empipe has been given enough information to define the microstrip line structure with an adjustable length parameter. The following section shows how to select the length parameter as an optimization variable and to define a performance specification.

3.4 Defining Variables and Specifications

In the Empipe form editor window, click on the button

Optimize

Selecting Optimization Variables

Two new windows appear on the screen, entitled "Empipe Select Variables" and "Empipe Specifications", respectively.

Listed in the "Select Variables" window is the parameter "L" defined for the microstrip line example.

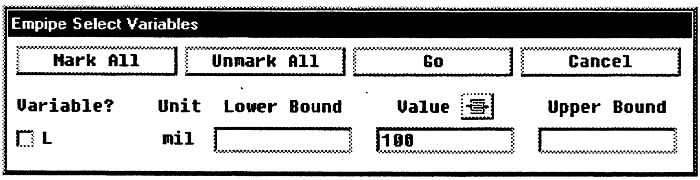


Fig. 3.5 The "Select Variables" window.

Click on the check box next to the parameter name "L", a check mark will appear in the box to indicate that the parameter L has been selected as an optimization variable.

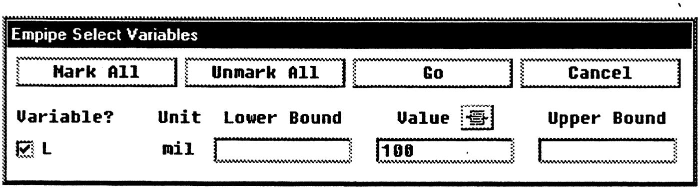


Fig. 3.6 The parameter L is selected as a variable.

In a general case, all parameters defined through Empipe are candidates for optimization variables. You can select an individual parameter as a variable by clicking on the check mark box associated with that parameter. Alternatively, you can click on the button labelled <Mark All> to select all the parameters as variables.

You can undo the selection of a parameter as a variable by clicking on the check mark box again. You can also use the <Unmark All> button.

Value

The current value for each parameter is shown under the heading "Value". In optimization, this value is used as the starting point. By default, it is set to the parameter's nominal value. If you wish to change it, click on the entry box under "Value" and enter the desired value. You can also click on the button to view the geometry of the current point.

Bounds on the Variables

You can specify upper and/or lower bound to limit the parameter value range during optimization. Setting suitable bounds on all the variables is advisable since this prevents the optimizer from changing the structure beyond what can be realized physically.

If the bounds are not given explicitly, they will be determined by the program according to the starting point. Suppose that the starting point of a selected variable is x.

If the lower bound is not given explicitly, it is set to 0 if $x \geq 0$, or $-\infty$ if $x < 0$.

If the upper bound is not given explicitly, it is set to $+\infty$ if $x \geq 0$, or 0 if $x < 0$.

For the tutorial example, we leave all the entries at their default setting, which means that the starting point for the parameter L is 100 (mils), the lower bound is 0 and -the upper bound is $+\infty$.

Specifications for Optimization

The initial appearance of the "Specifications" window is depicted in Fig. 3.7.

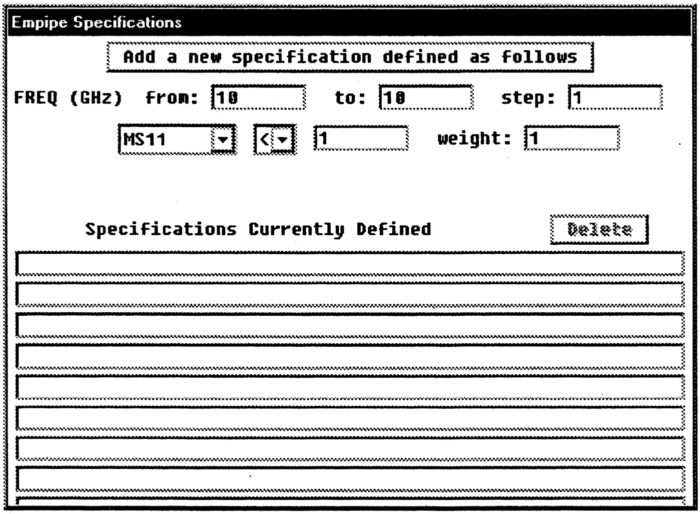


Fig. 3.7 The "Specifications" window.

In general, the definition of a specification involves the following steps:

1 Select a frequency range.

2 Select an S-parameter response.

3 Select a specification type (upper, lower or equality specification).

4 Enter a numerical value as the goal.

5 Optionally, enter a weighting factor.

Recall that in Section 3.1 the specification for this tutorial example is stated as

PS21 = -120 at frequency = 10 GHz

where PS21 represents the phase of S_{21} in degrees.

Selecting a Frequency Range

The line that appears as

FREQ (GHz) from: [10] **to:** [10] **step:** [1]

allows you to select a frequency range from those defined in the *em* analysis control file.

For the tutorial example, we have defined only a single frequency in the analysis control file, namely 10 GHz, which is automatically selected. You do not need to change anything.

Selecting an S-Parameter Response

This is the entry box for selecting an *S*-parameter response:

[MS11 ▾]

Click on the arrow and you will see the list of available responses:

[MS11 ▾]

MS11
MS12
MS21
MS22
PS11
PS12
PS21
PS22
MS11_dB
MS12_dB
MS21_dB
MS22_dB

The label MS*ij* represents the magnitude of S_{ij}, PS*ij* represents the phase of S_{ij} in degrees, and MS*ij*_dB represents the magnitude of S_{ij} in decibels.

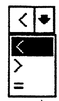
To select a response from the list, simply click on it.

Click on the label PS21.

Selecting the Type of Specification

The entry box for selecting the type of specification appears as

Click on the arrow and you will see the list of available specification types:



The symbols "<", ">" and "=" represent upper, lower and equality specifications, respectively.

Click on the symbol "=".

Entering a Numerical Value as the Goal

The third field on the specification line represents the goal. For the tutorial example, the goal for the response PS21 is -120.

Click on the box and then type in the number -120.

While entering the number, you may use the cursor keys, the <Back Space> key and the <Delete> key to edit the text, if necessary.

Optional Weighting Factor

You can enter an optional weighting factor. The default value is 1. If given, the weighting factor must be a positive number.

For the tutorial example, leave the weighting factor at the default value of 1.

Completing the Definition of a Specification

Click on the button

`Add a new specification defined as follows`

The specification we have just defined will be recorded under the heading "Specifications Currently Defined". The "Specifications" window at this point is shown in Fig. 3.8.

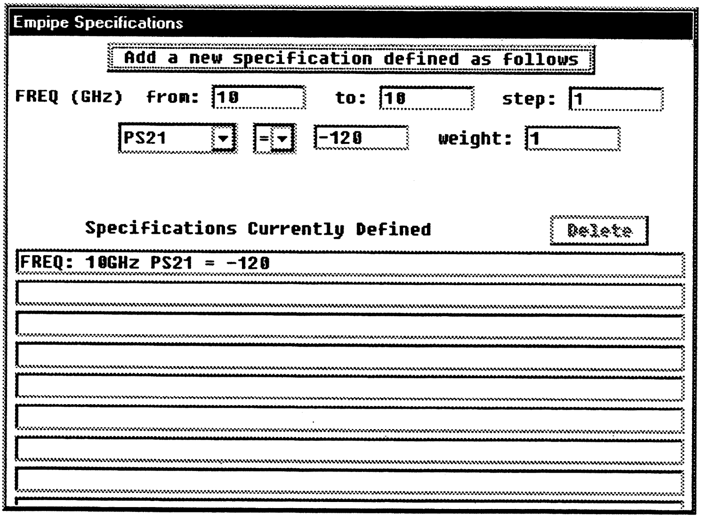
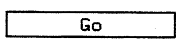


Fig. 3.8 The specification defined for the microstrip line tutorial.

What's Next

We are ready to start EM simulation and optimization. Go to the "Select Variables" window and click on the button



3.5 Simulation

After you click on the "Go" button, Empipe invokes the OSA90 simulation/optimization environment. The OSA90 window appears.

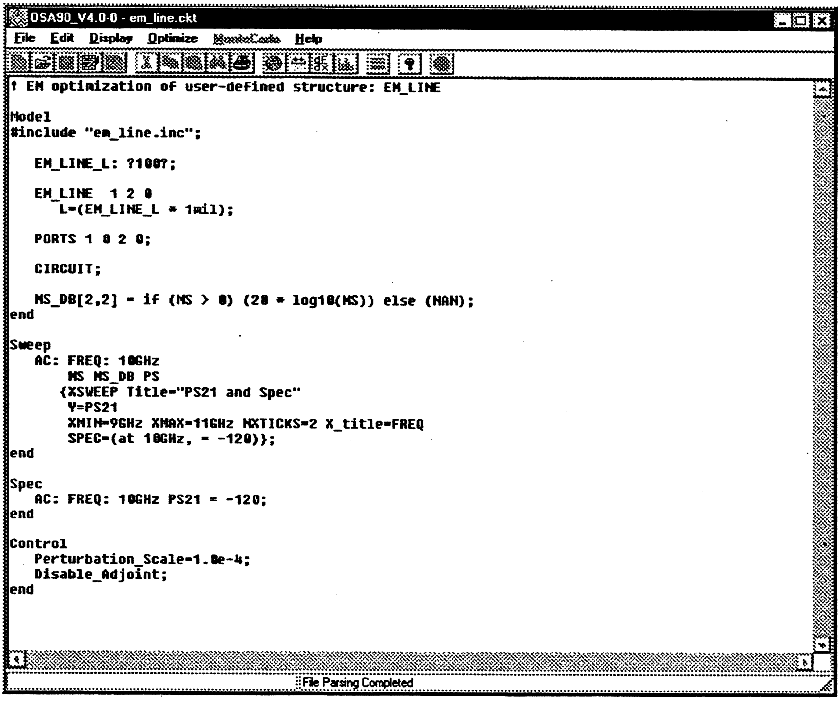


Fig. 3.9 OSA90 window.

The top of the window contains the menu bar and toolbar, the middle portion window is the input file (netlist) and located at the bottom of the window is the status bar.

OSA90 Input File (Netlist)

The OSA90 input file (netlist) consists of a number of "blocks". Each block begins with a block identifier, such as "Model", "Sweep", "Spec" and "Control", and ends with the keyword "end". The Model block describes the circuit, the Sweep block selects the simulation outputs, the Spec block defines the specifications for optimization, and the Control block contains operation options (the input file structure is further discussed in Chapter 9).

In the Model block, notice the statement

```
EM_LINE_L: ?100?;
```

The label EM_LINE_L identifies the parameter L of the element EM_LINE. The pair of question marks denotes an optimization variable, and the value between the question marks is the starting point.

OSA90 Menu Options

At the top of the OSA90 window are the menu options: File, Display, Optimize, etc. As you select an option, the status bar shows a brief summary of the function of the highlighted menu option.

To select (activate) a menu option, you simply click the left-hand mouse button on that menu option.

Starting EM Simulation

Before we optimize the bend, we wish to first perform an EM simulation and check the response against the specification. The options listed on the "Display" menu represent the various options for displaying the simulation results.

Choose "Xsweep" from the "Display".

Empipe will invoke *em* in the background. For this simple structure, the *em* analysis should be completed very quickly.

When the *em* analysis is finished, a dialog box will appear.

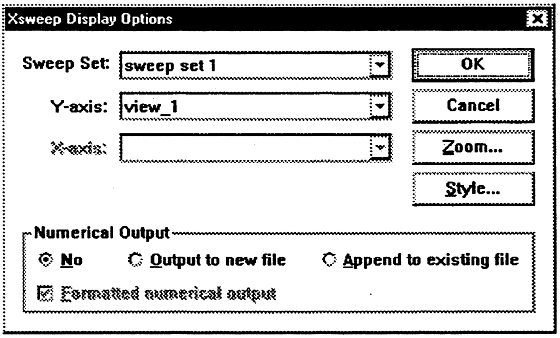


Fig. 3.10 The "Xsweep Display Options" dialog box.

Simply press <Enter> or click "OK" to accept the default setting.

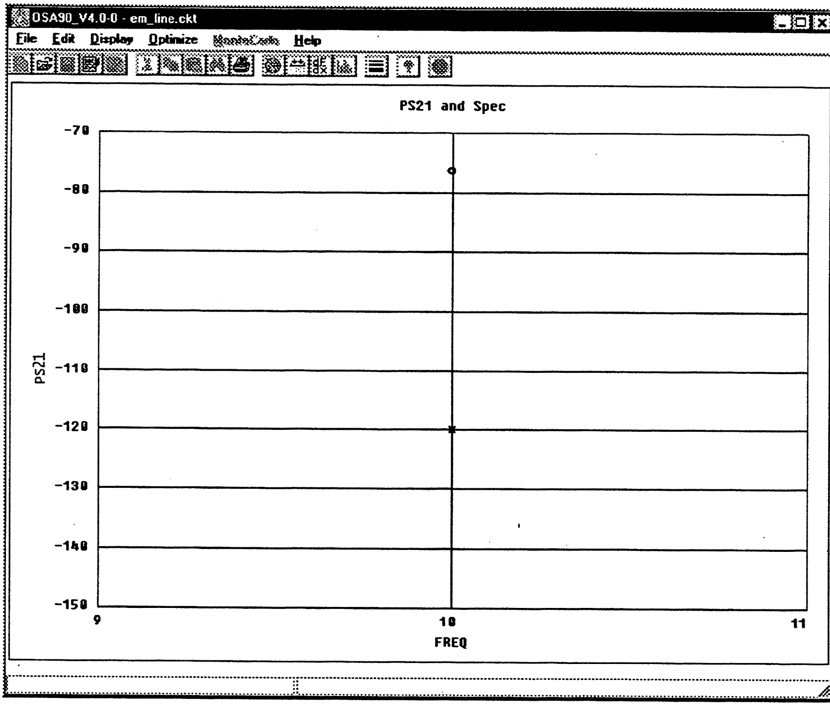


Fig. 3.11 The PS21 response before optimization.

3.6 Optimization

The *em* simulation result shows that the design specification of PS21 = -120 is not satisfied. In order to meet the specification, we need to perform optimization.

To start optimization, click on the "Optimize" button on the toolbar. A dialog box appears, showing a number of options related to optimization.

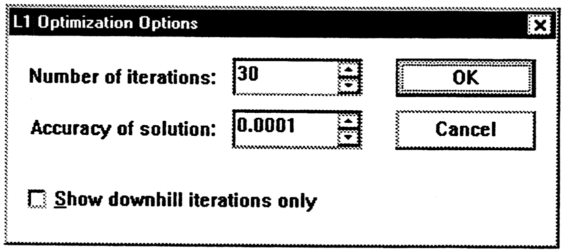


Fig. 3.12 the "L1 Optimization Options" dialog box.

Press the <Enter> key or click "OK" to accept the default setting.

During the optimization, *em* is invoked in the background whenever a new EM analysis is required. On the screen, the progress of optimization is reported:

```
Iteration   1/30 L1 Objective=43.67
Iteration   2/30 L1 Objective=42.8941
Iteration   3/30 L1 Objective=41.3189
Iteration   4/30 L1 Objective=38.0724
Iteration   5/30 L1 Objective=31.2506
Iteration   6/30 L1 Objective=15.9797
Iteration   7/30 L1 Objective=1.39943
Iteration   8/30 L1 Objective=0.00756073
Iteration   9/30 L1 Objective=1.52588e-05
Solution  L1 Objective=1.52588e-05
```

Simulation of the Optimized Microstrip Line

Select "Xsweep" from the "Display" menu. When the "Xsweep Display Options" dialog box appears, press <Enter> or click "OK" to accept the default setting.

The optimized result is plotted on screen, it shows that the specification on PS21 is met.

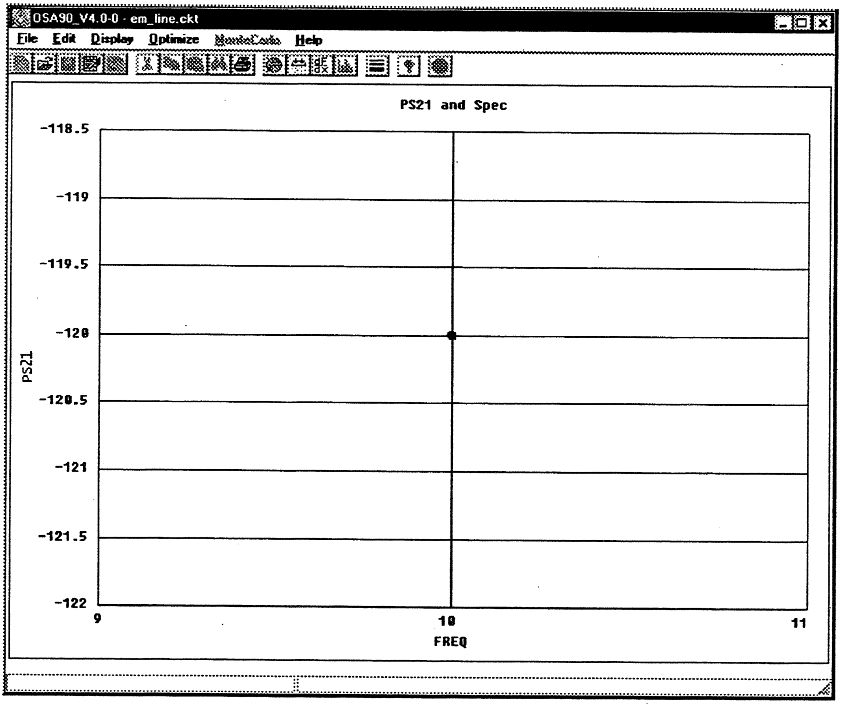


Fig. 3.13 The PS21 response after optimization.

3.7 Saving the Optimized Geometry

We have completed the tasks within the OSA90 simulation/optimization environment.

Select "Exit" from the "File" menu.

A window will appear, asking you to confirm that you wish to exit. Click the "Yes" button.

Upon exit from OSA90, the Empipe windows reappear on the screen. A dialog box is also displayed

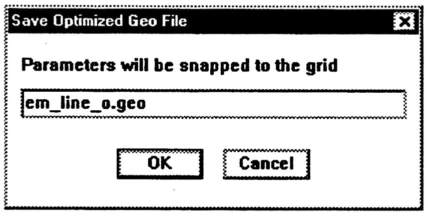


Fig. 3.14 Dialogue box for the optimized ".geo" file name.

The dialogue box allows you to specify the name of a ".geo" file in which the optimized geometry will be saved.

Click on the "OK" button to accept the default file name. The optimized microstrip line will be saved to a disk file under the name "em_line_o.geo", and ***xgeom*** will be automatically invoked to display the geometry.

When saving the ".geo" file, the optimized parameters are snapped to the nearest grid. In the microstrip line example, the optimized value for the length parameter is 157.013 mils and the grid size is 10 mils. Hence, the line length saved in em_line_o.geo is 160 mils.

The optimized solution without truncation is displayed in the "Select Variables" window.

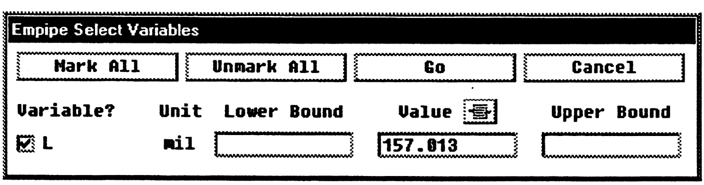


Fig. 3.15 The optimized solution displayed.

Concluding the Tutorial

Click on the "Cancel" button in the "Select Variables" window. This brings you back to the main window of Empipe. Click on the "Quit" button. You will then be asked whether you wish to save the file. Click "No".

4

Tutorial: Double Folded Stub Filter

4

Tutorial: Double Folded Stub Filter

4

Tutorial: Double Folded Stub Filter

4.1 Introduction

This chapter is the second segment of the series of tutorials which systematically introduces you to the various features of Empipe.

We assume that you have already been given a basic overview of Empipe by going through the introductory tutorial provided in Chapter 3. If you have not, then please follow Chapter 3 first.

What You Will Learn From This Tutorial

1. In Chapter 3, you have learned how to apply Geometry Capture to a simple structure with one variable. This chapter demonstrates a more complex example which involves three designable parameters.

2. The example in Chapter 3 was analyzed at a single frequency. In this chapter, we learn how to define upper and lower specifications over different frequency bands.

3. How to select the minimax optimizer for filter design.

4. Another feature of Empipe: tracking *em* simulation in real time and plotting the *S* parameters while the *em* simulation is still in progress.

The *em* simulation of the double folded stub filter takes approximately 1/8 second per frequency on a 200MHz Pentium and the total number of frequencies is 61. All the *em* analysis results necessary for this tutorial have been saved in a database, therefore we can carry out the tutorial without actually invoking *em*.

When this symbol appears on the left-hand side column, it highlights text that describes hands-on actions. You can take a "short-cut" through the tutorial by following this symbol and skip over the commentaries.

Description of the Example

The example we will use is a double folded stub microstrip bandstop filter, as depicted in Fig. 4.1 (J.C. Rautio, Sonnet Software, Inc., 1992).

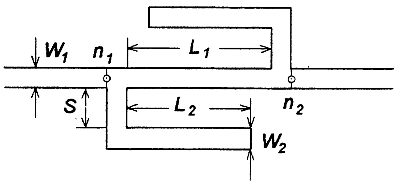


Fig. 4.1 The double folded stub microstrip filter.

The substrate is 5 mil thick with a relative dielectric constant of 9.9. Three designable parameters are defined: L_1, L_2 and S. The widths W_1 and W_2 are fixed at 4.8 mils.

The design specifications for the double folded stub filter are

$|S_{21}| \leq -30$ dB for 12 GHz $\leq f \leq$ 14 GHz

$|S_{21}| \geq -3$ dB for $f \leq$ 9.5 GHz or $f \geq$ 16.5 GHz

where f represents frequency.

The frequency band for ***em*** simulation is chosen to be from 5 GHz to 20 GHz with a step of 0.25 GHz, for a total of 61 frequencies.

4.2 Geometry Capture From a Set of Geo Files

First, we choose a nominal geometry for the filter with the following parameter values:

$L_1 = 86.4$ mils

$L_2 = 81.6$ mils

$S = 4.8$ mils

(The definition of these parameters are illustrated in Fig. 4.1.)

The nominal geometry is described by the file dfstub0.geo, which is included in the set of Empipe example files.

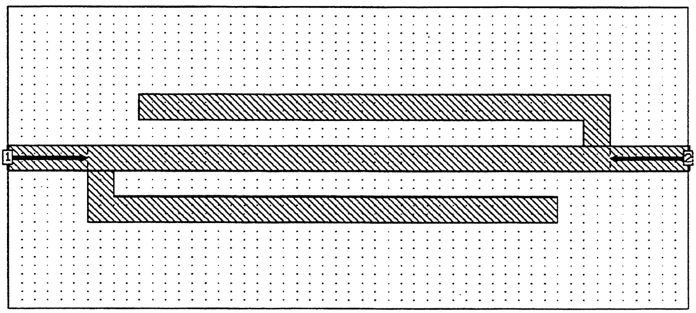


Fig. 4.2 The nominal geometry of the double folded stub filter.

The cell size defined in dfstub0.geo is 2.4 × 1.6 mils.

Creating the Incremental Change Geo Files

We need to create three additional ".geo" files to represent incremental changes in the parameters with respect to their nominal values. You can find these files among the Empipe example files under the names dfstub1.geo, dfstub2.geo and dfstub3.geo, representing the parameters L_1, L_2 and S, respectively.

For instance, Fig. 4.3 compares the geometries described by dfstub0.geo and dfstub3.geo. The value of the parameter S is 4.8 mils in `dfstub0.geo` and is changed to 11.2 mils in dfstub3.geo.

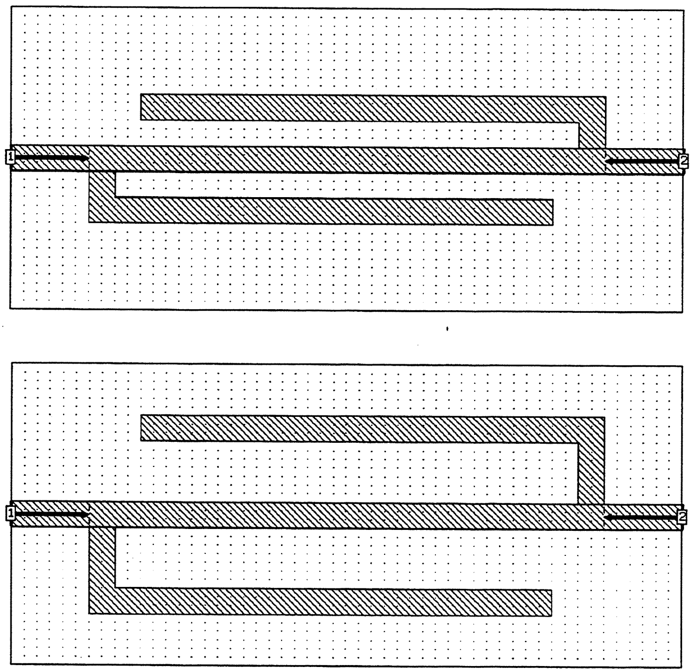


Fig. 4.3 Geometries for S=4.8 mils and S=11.2 mils, respectively.

Note that when we change the value of S we have the option of keeping the size of the substrate box constant or increasing the box size proportionally along the Y dimension. We can make a choice based on convenience or other practical consideration. In dfstub3.geo, we chose to keep the size of the substrate box constant. As a consequence, we should impose bounds on the value of S such that the folded stub will not be increased beyond the substrate box. We will show how to define the bounds in Section 4.3.

Using the Geometry Capture Form Editor

Starting Empipe

To start Empipe, click on the "Empipe" icon located in the "Osa" program group.

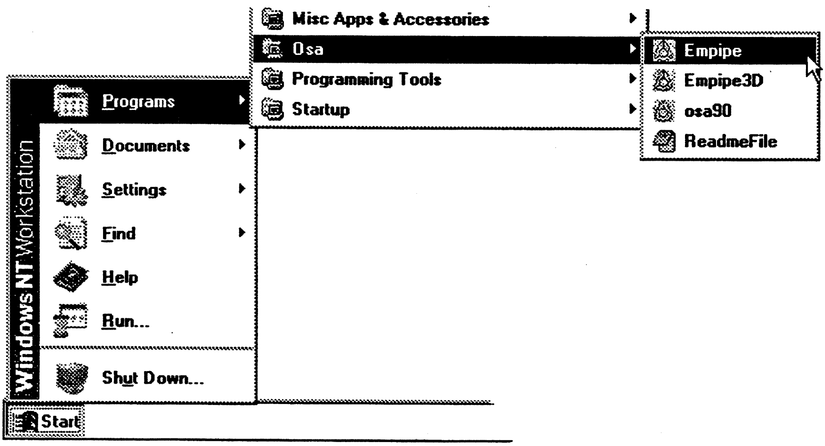


Fig. 4.4 Location of Empipe *on the Start Menu*

When the Empipe main window appears, click on the "Load" button. You will be presented with an "Empipe Open File" dialog box. Select the project "dfstub.inc" from your copy of the examples. The Empipe Geometry Capture form editor is then displayed.

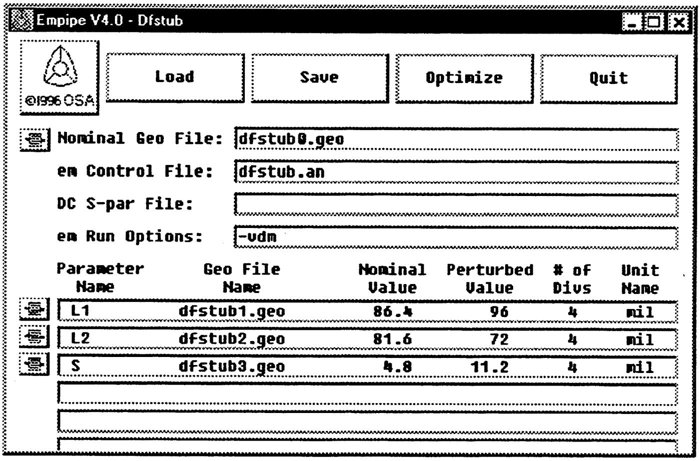


Fig. 4.5 Empipe Geometry Capture form editor.

The data shown in the form editor is retrieved from the file dfstub.inc which is provided with the Empipe example files. Once a structure has been captured, Empipe stores the relevant data in a "*name*.inc" file, where *name* is the identifier (which is dfstub in our example).

Nominal Geo File

This entry identifies the nominal ".geo" file which in this case is dfstub0.geo.

This button appears adjacent to the entry box. If you click on it, ***xgeom*** will be invoked to display the nominal ".geo" file.

em Control File

This entry identifies the ***em*** analysis control file which defines the frequencies.

The analysis control file which has been created for the double folded stub filter is named dfstub.an. It contains

```
VER 3.0
GHZ
FRE 5.0  20.0  0.25
```

which defines a frequency sweep from 5 GHz to 20 GHz with a step of 0.25 GHz, for a total of 61 frequencies.

DC S-Parameter File

This field allows you to supply a separate *S*-parameter file for DC. This is necessary only if the Empipe element is to become part of a nonlinear circuit for harmonic balance simulation. It does not apply to our example and should be simply left blank.

em Run Options

This field allows you to specify the run-time options for *em*. The default options are -vdm (verbose, automatic de-embedding and memory saver).

Parameter Definition Data

Parameter Name	Geo File Name	Nominal Value	Perturbed Value	# of Divs	Unit Name
L1	dfstub1.geo	86.4	96	4	mil
L2	dfstub2.geo	81.6	72	4	mil
S	dfstub3.geo	4.8	11.2	4	mil

Parameter Name is an arbitrary ASCII string of no more than 32 characters. We choose the names L1, L2 and S to identify the parameters L_1, L_2 and S, respectively.

Geo File Name identifies the ".geo" file which describes the geometry of the structure after an incremental change in the parameter value is made. The files in this case are dfstub1.geo, dfstub2.geo and dfstub3.geo for the parameters L1, L2 and S, respectively.

Nominal Value refers to the nominal value of the parameter which is consistent with the nominal ".geo" file. The nominal values for L1, L2 and S is 86.4, 81.6 and 4.8, respectively (these should be entered as plain numbers, since the physical unit mil is entered as a separate item).

Perturbed Value refers to the parameter value after the incremental change. The perturbed values for L1, L2 and S are 96, 72 and 11.2 (mils), respectively. Note that the incremental change does not always have to be an increase in the parameter value. For instance, we decrease the value of L2 from 81.6 to 72 (mils).

Number of Divs is obtained by dividing the incremental change by the *em* cell size along the appropriate dimension. For instance, the incremental change in the parameter L1 is 9.6 mils. This change is along the X dimension of the layout and the grid size for the X dimension is 2.4 mils, therefore the number of divisions is 4.

We chose the increments to be 4 times the grid size instead of 1 merely for the purpose of illustration. In general, you can choose any reasonable and convenient number. Also, the number may vary for different parameters.

This information is needed to ensure that the geometry Empipe generates for *em* analysis is always on the grid (interpolation is used for off-grid points).

Unit Name identifies the physical unit of the parameter. For this example, the unit name is MIL for all three parameters.

4.3 Selecting the Optimization Variables

In the Empipe form editor window, click on the button

Optimize

Selecting Optimization Variables

Two new windows appear on the screen, entitled "Empipe Select Variables" and "Empipe Specifications", respectively.

The parameters L1, L2 and S are listed in the "Select Variables" window. Initially none of the parameters are selected.

Click on the button labelled <Mark All> to select all the parameters as variables.

You should see a check mark appear in the check boxes next to the parameters, indicating that they have been selected as optimization variables.

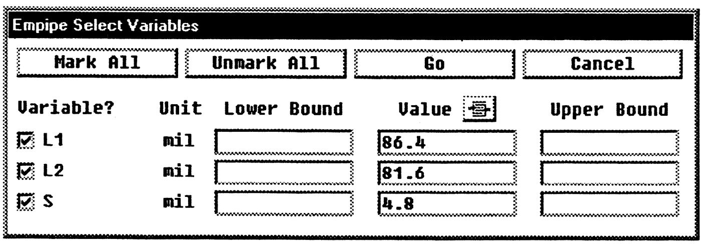


Fig. 4.6 The "Select Variables" window.

Value

The current value for each parameter is shown under the heading "Value". In optimization, this value is used as the starting point. By default, it is set to the parameter's nominal value. If you wish to change it, click on the entry box under "Value" and enter the desired value. You can also click on the button to view the geometry of the current point.

Imposing an Upper Bound on S

Recall that when we made the incremental change to the parameter S, we kept the substrate box size constant. Consequently, we need to impose an upper bound on the variable S so that during optimization the filter structure will not grow beyond the substrate box (see also the discussion following Fig. 4.3 in Section 4.2).

Click on the entry box on the line for the parameter S and in the column under the heading "UpperBound". Then type "16" followed by <Enter>. In other words, we impose an upper bound of 16 mils on S, so that during optimization the value of S is not allowed to exceed 16 mils.

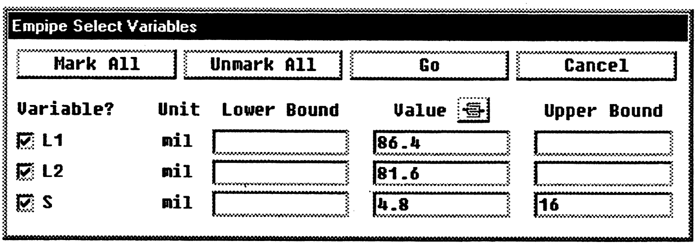


Fig. 4.7 Window showing the upper bound on the variable S.

We leave all the other entries at their default setting.

4.4 Passband and Stopband Specifications

In general, to define a specification we need to carry out the following steps in the "Specifications" window:

1 Select a frequency range.

2 Select an S-parameter response.

3 Select a specification type (upper, lower or equality specification).

4 Enter a numerical value as the goal.

5 Optionally, enter a weighting factor.

The design specifications for the double folded stub filter are

$|S_{21}| \le -30$ dB for 12 GHz $\le f \le$ 14 GHz

$|S_{21}| \ge -3$ dB for $f \le$ 9.5 GHz or $f \ge$ 16.5 GHz

where f represents frequency.

First, we show step by step how to define the stopband specification

$|S_{21}| \le -30$ dB for 12 GHz $\le f \le$ 14 GHz

Selecting the Frequency Range

Initially the frequency entry line appears as

FREQ (GHz) from: [5] to: [20] step: [0.25]

The default setting represents the ***em*** analysis frequencies defined in the file dfstub.an.

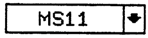
To define the stopband, click on the "from:" box and type "12"; then click on the "to:" box and type "14".

The frequency range is now shown as

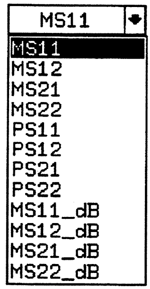
FREQ (GHz) from: [12] to: [14] step: [0.25]

Selecting the S-Parameter Response

This is the entry box for selecting an *S*-parameter response:



Click on the arrow and you will see the list of available responses:



The label MS*ij* represents the magnitude of S_{ij}, PS*ij* represents the phase of S_{ij} in degrees, and MS*ij*_dB represents the magnitude of S_{ij} in decibels.

We wish to select the magnitude of S_{21} in dB. Click on the label MS21_dB.

Selecting the Type of Specification

The entry box for selecting the type of specification appears as

The symbol "<" represents an upper specification. Since this is what we need, do not change it.

Entering a Numerical Value as the Goal

The third field on the specification line represents the goal. The goal for MS21_dB in the stopband is -30.

Click on the box and then type "-30".

Optional Weighting Factor

You can enter an optional weighting factor. The default value is 1. If given, the weighting factor must be a positive number.

For the tutorial example, leave the weighting factor at the default value of 1.

Completing the Definition of the Stopband Specification

Click on the button

Add a new specification defined as follows

The specification we have just defined will be recorded under the heading "Specifications Currently Defined". The "Specifications" is updated using the data provided.

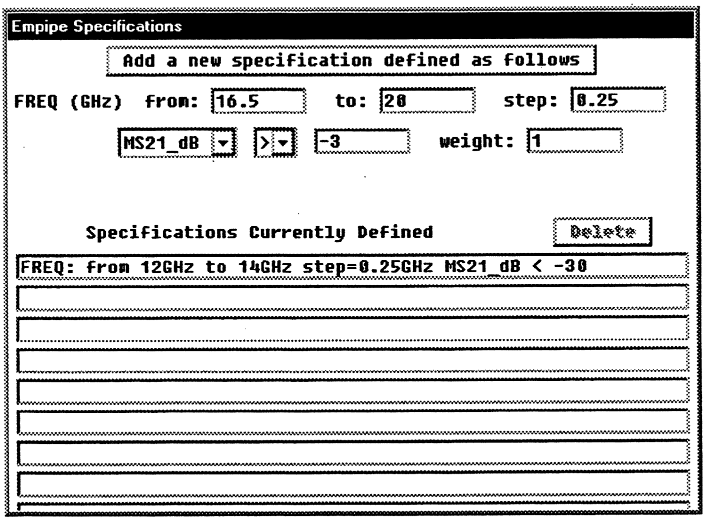


Fig. 4.8 The "Specifications" window.

Defining the Passband Specifications

In similar manner we define the specifications for the lower passband, as

$|S_{21}| \geq -3$ dB for $f \leq 9.5$ GHz

and the upper passband, as

$|S_{21}| \geq -3$ dB for $f \geq 16.5$ GHz

where f represents frequency.

The procedure for defining the passband specifications is described step by step as follows.

1 Modify the frequency range. Click on the "from:" box and type "5"; then click on the "to:" box and type "9.5".

2 Change the specification type. The entry box for selecting the type of specification appears as

Click on the arrow and you will see the list of available specification types:

Click on the symbol ">".

3 Change the goal from -30 to -3. Click on the goal box and type "-3".

4 Click on the button

`Add a new specification defined as follows`

The lower passband specification is added to the list of "Specifications Currently Defined".

5 Modify the frequency range. Click on the "from:" box and type "16.5"; then click on the "to:" box and type "20".

6 Click on the button

`Add a new specification defined as follows`

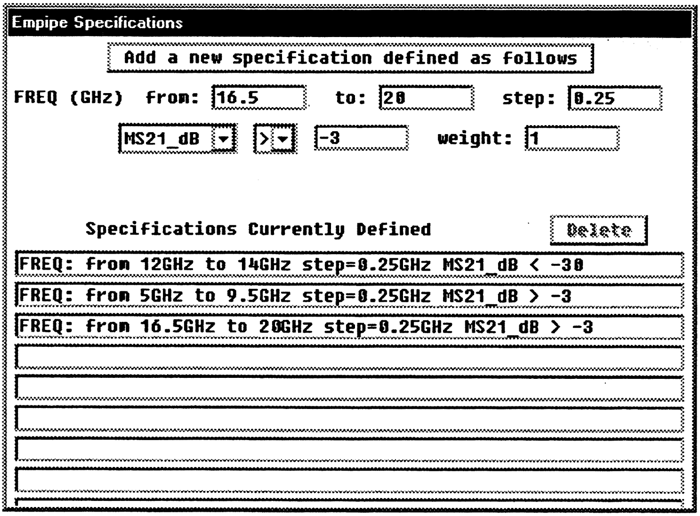


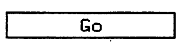
Fig. 4.9 The complete set of specifications.

Deleting an Existing Specification

In case you made a mistake, you can delete a specification and redefine it. To delete an entry under the heading "Specifications Currently Defined", click on the entry. The button "Delete" will turn from a shade of grey to a solid color ("clickable"). A click on this button will delete the highlighted specification line.

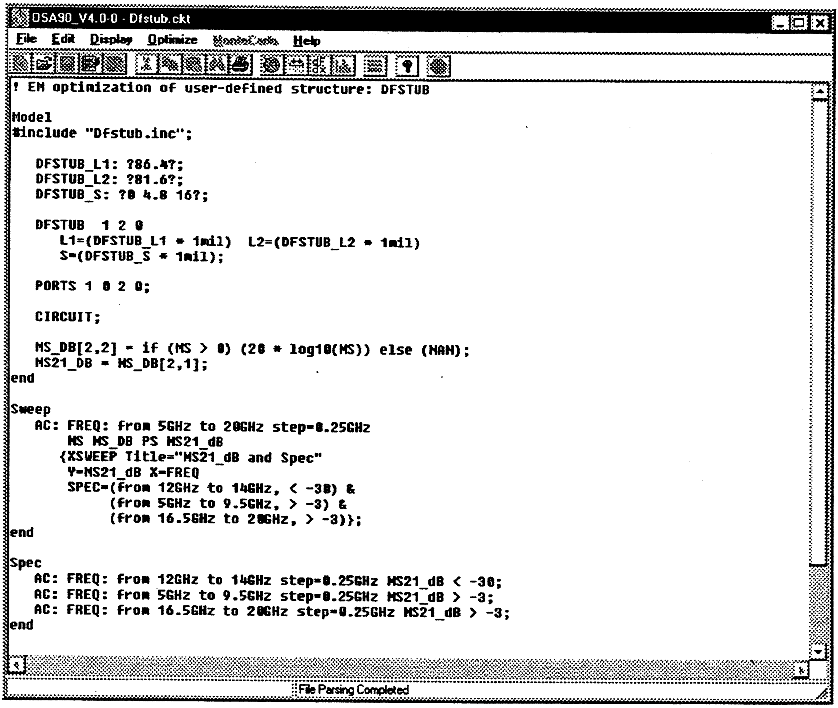
What's Next

We are ready to start EM simulation and optimization. Go to the "Select Variables" window and click on the button



4.5 Minimax Optimization

After you click on the "Go" button, Empipe activates the OSA90 simulation/optimization environment.




```
! EM optimization of user-defined structure: DFSTUB

Model
#include "Dfstub.inc";

   DFSTUB_L1: ?86.4?;
   DFSTUB_L2: ?81.6?;
   DFSTUB_S: ?0 4.8 16?;

   DFSTUB  1 2 0
      L1=(DFSTUB_L1 * 1mil)  L2=(DFSTUB_L2 * 1mil)
      S=(DFSTUB_S * 1mil);

   PORTS 1 0 2 0;

   CIRCUIT;

   MS_DB[2,2] = if (MS > 0) (20 * log10(MS)) else (NAN);
   MS21_DB = MS_DB[2,1];
end

Sweep
   AC: FREQ: from 5GHz to 20GHz step=0.25GHz
       MS MS_DB PS MS21_dB
      {XSWEEP Title="MS21_dB and Spec"
       Y=MS21_dB X=FREQ
       SPEC=(from 12GHz to 14GHz, < -30) &
            (from 5GHz to 9.5GHz, > -3) &
            (from 16.5GHz to 20GHz, > -3)};
end

Spec
   AC: FREQ: from 12GHz to 14GHz step=0.25GHz MS21_dB < -30;
   AC: FREQ: from 5GHz to 9.5GHz step=0.25GHz MS21_dB > -3;
   AC: FREQ: from 16.5GHz to 20GHz step=0.25GHz MS21_dB > -3;
end
```

Fig. 4.10 OSA90 window.

The top of the window contains the menu bar and toolbar, the middle portion window is the input file (netlist) and located at the bottom of the window is the status bar.

Simulation and Display the Response

Choose "Xsweep" from the "Display" menu. The "Xsweep Display Options" dialog box will appear. Press <ENTER> or click on "OK" to accept the default settings.

You will notice that the simulation seems to finish very quickly. This is because that the *em* analysis has already been done when we prepared the tutorial example and the results have been stored in a database. Empipe simply retrieved the appropriate data from the database, without actually invoking ***em***. An actual ***em*** simulation of this filter would take approximately 7 minutes of CPU time on a 200MHz Pentium.

The results of the simulation are plotted on the screen, they show the response MS21_dB versus the frequency. The specification is also shown. Clearly, the filter response does not satisfy the specifications with the initial parameter values.

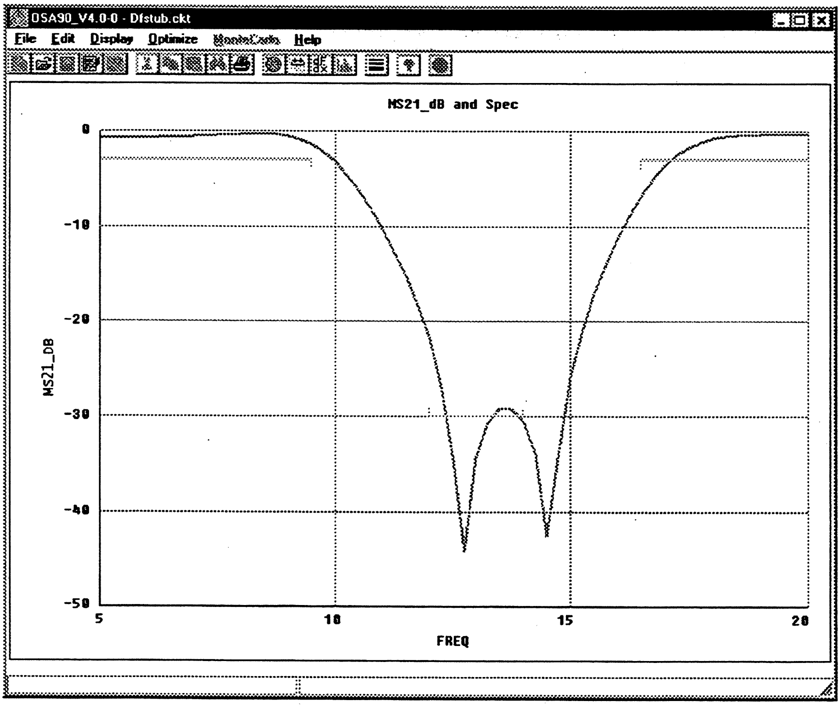


Fig. 4.11 Double folded stub filter response before optimization.

Start Optimization

To start optimization, click on the "Optimize" button on the toolbar. A dialog box appears, showing a number of options related to this particular optimization.

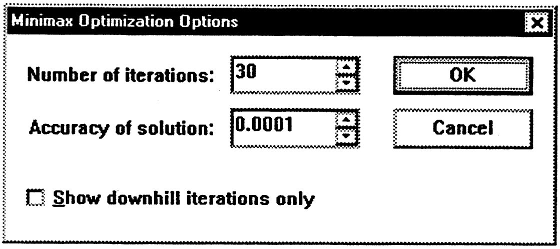


Fig. 4.12 The "Minimax Optimization Options" dialog box.

Notice that the optimizer is shown as "Minimax". Empipe automatically chooses the optimizer for you according to the type of specifications defined. For the microstrip line example in Chapter 3, the "L1" optimizer was chosen, since the specification was to match the calculated PS21 to -120 degrees. The filter example we are considering here involves upper and lower specifications, hence Empipe chooses the minimax optimizer.

It is possible for you to change the default optimizer as well as the setting for the maximum number of iterations and the desired accuracy of solution (see Chapter 9).

Press <Enter> or click on "OK" to accept the default setting.

The progress of optimization is reported on the screen:

```
Iteration   1/30 Max Error=8.14511
Iteration   2/30 Max Error=6.34936
Iteration   3/30 Max Error=1.53442
Iteration   4/30 Max Error=0.553539
Iteration   5/30 Max Error=-0.19606
Iteration   6/30 Max Error=-0.213403
Iteration   7/30 Max Error=-0.213773
Solution  Max Error=-0.213773
```

The optimization seems to go very quickly. This is because all the necessary *em* analysis results are already available from the database.

The numerical values you actually see may be slightly different from those shown here, due to differences in the computer hardware and/or software versions.

Simulation of the Optimized Filter

Choose “Xsweep” from the "Display" menu. The “Xsweep Display Options” dialog box will appear. Press <ENTER> or click on “OK” to accept the default settings.

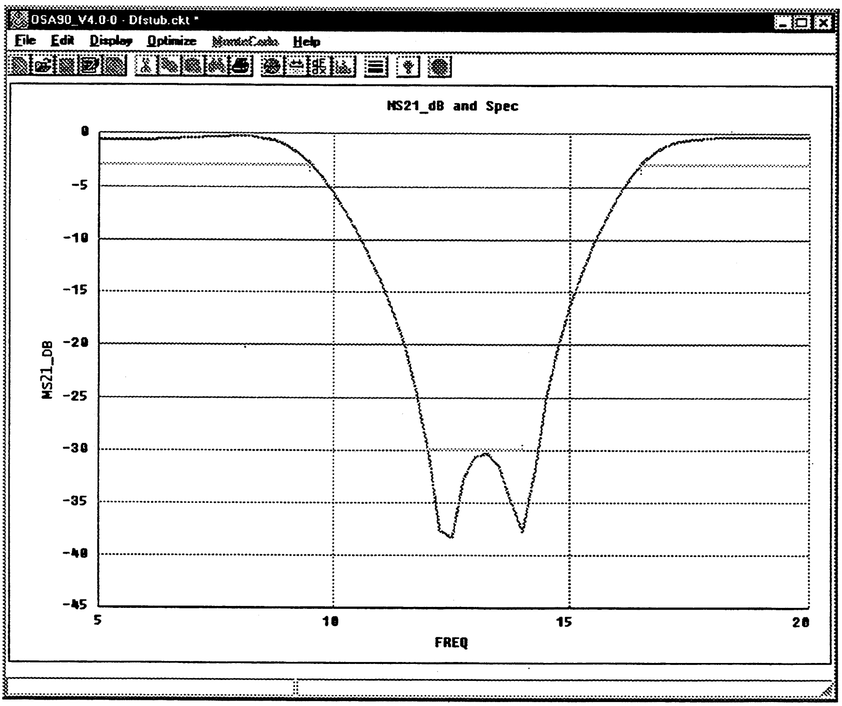


Fig. 4.13 Double folded stub filter response after optimization.

4.6 Saving the Optimized Geometry

We have completed the tasks within the OSA90 simulation/optimization environment.

Select "Exit" from the "File" menu.

A window will appear, asking you to confirm that you wish to exit. Click the "Yes" button.

Upon exiting from OSA90, the Empipe windows reappear on the screen. A dialog box is also displayed.

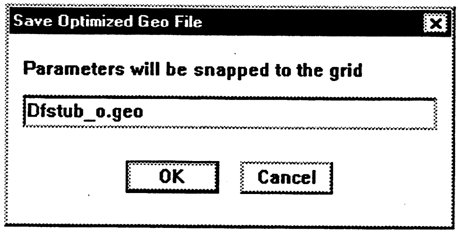


Fig. 4.14 Dialog box for the optimized ".geo" file name.

The dialog box allows you to specify the name of a ".geo" file in which the optimized geometry will be saved.

When saving the ".geo" file, the optimized parameters are snapped to the nearest grid. For example, the optimized value for the parameter L1 is 92.1059 mils. In dfstub_o.geo, L1 is rounded to 91.2 mils, since the corresponding grid size is 2.4 mils.

However, you can see the optimized solution without truncation in the "Select Variables" window.

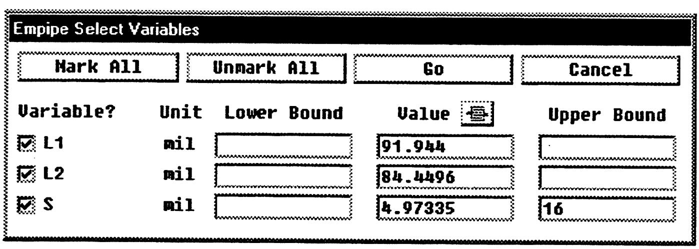


Fig. 4.15 The optimized solution without truncation.

Concluding the Tutorial

Click on the "Cancel" button in the "Select Variables" window. This brings you back to the main window of Empipe. Click on the "Quit" button, you will then be asked whether you wish to save the file. Click "No" and Empipe will exit.

5

Tutorial: 10-dB Distributed Attenuator

5

Tutorial: 10-dB Distributed Attenuator

5.1 Introduction

This chapter is the third segment of the series of tutorials which systematically introduces you to the various features of Empipe.

We recommend that you follow the tutorials in the order that they are presented. At least you should study the introductory tutorial in Chapter 3 before any other chapters.

What You Will Learn From This Tutorial

1 How to capture parameters with symmetrical incremental changes in order to preserve geometrical symmetry during optimization.

2 In the preceding chapters the design specifications involve only a single *S* parameter response. This chapter demonstrates specifications on multiple responses.

3 How to assign weighting factors to different responses.

4 How to change the display options in OSA90 to view the simulation results in different formats.

The *em* simulation of the attenuator takes approximately 1.5 minutes per frequency on a 200MHz Pentium and the total number of frequencies is 5. All the *em* analysis results necessary for this tutorial have been saved in a database, therefore we can carry out the tutorial without actually invoking *em*.

When this symbol appears on the left-hand side column, it highlights text that describes hands-on actions. You can take a "short-cut" through the tutorial by following this symbol and skip over the commentaries.

Description of the Example

We consider the 10-dB distributed attenuator depicted in Fig. 5.1 (D.G. Swanson, Jr., Watkins-Johnson Company, Palo Alto, CA 94304-1204, private communication, 1994).

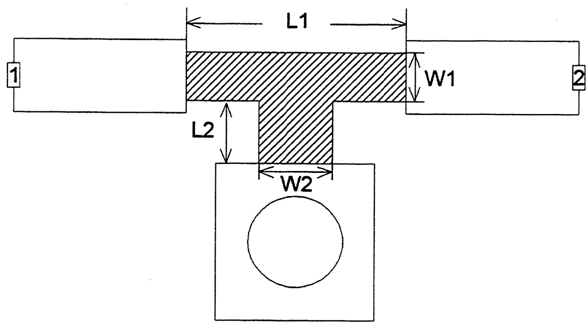


Fig. 5.1 The 10-dB distributed attenuator.

The substrate is 15 mil thick with a relative dielectric constant of 9.8. Two types of metallization are defined: the shaded area in Fig. 5.1 has a high resistivity of 50 Ohms/sq; the feed lines and the grounding pad are assumed to be lossless.

Four designable parameters are defined: L1, L2, W1 and W2.

The design specifications for the attenuator are

$$|S_{21}| = -10 \text{ dB}$$

$$|S_{11}| \leq -10 \text{ dB}$$

for the frequency range of 2 GHz to 18 GHz. Choosing a step of 4 GHz, we have a total of 5 frequencies.

5.2 Geometry Capture

First, we choose the nominal parameter values for the attenuator as

L1 = 22 mils
L2 = 7 mils
W1 = 11 mils
W2 = 10 mils

(The definition of these parameters is illustrated in Fig. 5.1.)

The geometry which corresponds to the nominal parameter values is defined by the file tpad0.geo (we pick the name "tpad" for the fact that the resistive pad is shaped like a tee). You can find the file tpad0.geo among the Empipe example files.

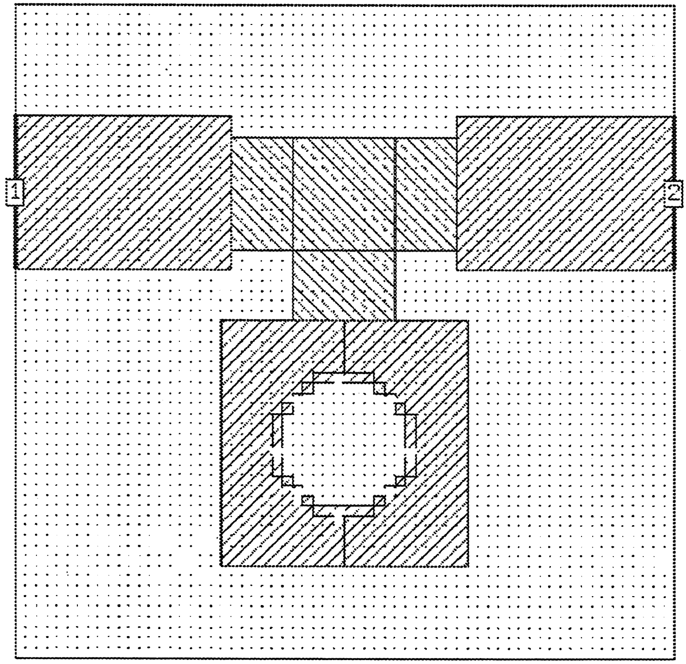


Fig. 5.2 The nominal geometry of the 10-dB distributed attenuator.

The cell size defined in tpad0.geo is 1 mil × 1 mil.

Creating the Incremental Change Geo Files

We need to create additional ".geo" files to represent incremental changes in the parameters with respect to their nominal values. The basic approach to creating the incremental change ".geo" files has already been illustrated in the tutorials in Chapters 3 and 4.

The ".geo" files for the attenuator can be found among the Empipe example files, under the names tpad1.geo, tpad2.geo, tpad3.geo and tpad4.geo, representing the parameters L1, L2, W1 and W2, respectively.

Starting Empipe

To start Empipe, click on the "Empipe" icon located in the "Osa" program group.

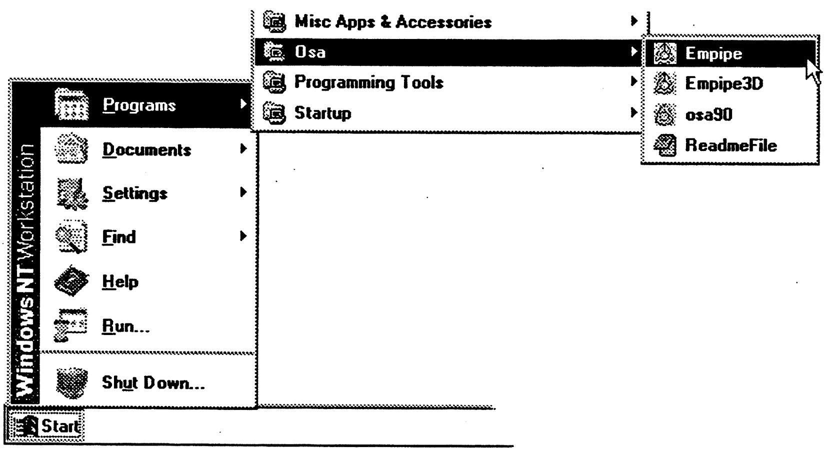


Fig. 5.3 Location of Empipe *on the Start Menu*

When the Empipe main window appears, click on the "Load" button. You will be presented with an "Empipe Open File" dialog box. Select the project "tpad.inc" from your copy of the examples. The Empipe Geometry Capture form editor is then displayed.

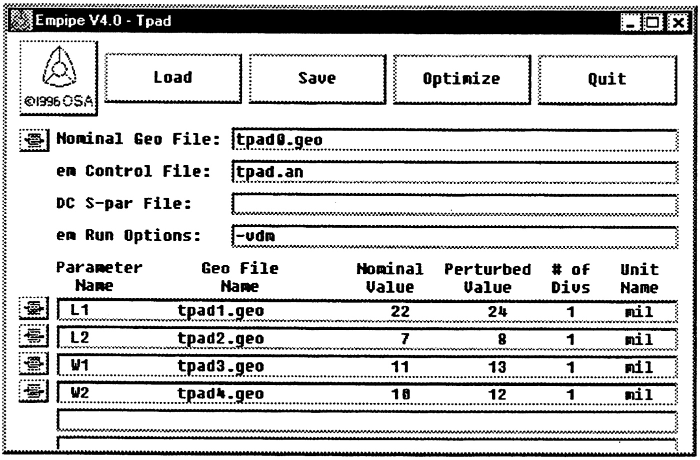


Fig. 5.4 Empipe Geometry Capture form editor.

Parameters with Symmetrical Perturbations

We assume that you already understand the meaning of the entries in the Empipe Geometry Capture form editor. If necessary, please review the descriptions in Chapters 3 and 4.

Here, we would like to focus our attention on a new issue, namely the definition of parameters with symmetrical perturbations.

Note this entry in the Empipe Geometry Capture window:

Parameter Name	Geo File Name	Nominal Value	Perturbed Value	# of Divs	Unit Name
L1	tpad1.geo	22	24	1	mil

It indicates that the value of the parameter L1 has been changed from 22 mils to 24 mils, which means the incremental change is 2 mils. Since the *em* cell size is 1 mil × 1 mil, the number of divisions would seem to be 2. Why, then, is the entry under "# of Divs" 1 instead of 2? It is because we wish to preserve the geometrical symmetry when the parameter L1 changes.

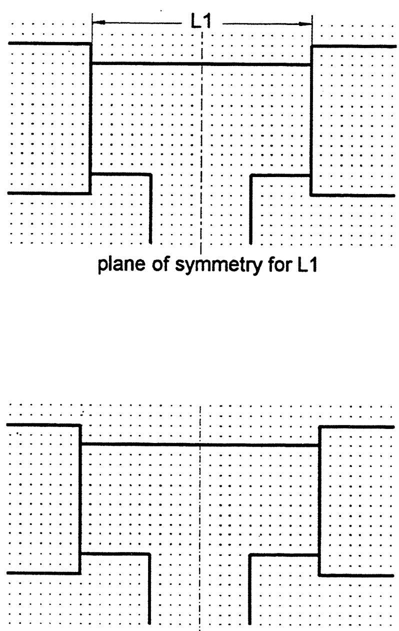


Fig. 5.5 Preserving the symmetry when L1 changes from 22 mils to 24 mils.

As shown in Fig. 5.5, in order to preserve geometrical symmetry, when we increment L1, we have to modify the geometry on both sides of the plane of symmetry. Since the smallest on-grid adjustment on each side is 1 mil (one *em* cell), the perturbation to L1, when taking both sides into account, is 2 mils. Since this is the smallest increment that can be made to L1 without destroying the symmetry, we define the number of divisions as 1, although the perturbation is twice the *em* cell size.

In other words, the "# of Divs" entry should be interpreted as the parameter discretization grid. It represents a unit change to the parameter while satisfying a set of implied conditions. In many cases, we are concerned with only one condition, namely to stay on the *em* grid. In such cases, the parameter discretization grid coincides with the *em* grid. If the conditions also include the preservation of symmetry, as in the case of the parameter L1 of the attenuator, then the parameter discretization grid may be different from the *em* grid. Typically in such cases the parameter discretization grid is two times the *em* cell size along the appropriate dimension.

For the attenuator, three of the four parameters, namely L1, W1 and W2, are defined with symmetrical perturbations.

5.3 Variables, Specifications and Weighting Factors

In the Empipe main window, click on the button

`Optimize`

As the "Select Variables" window appears, click on the <Mark All> button. You should see all the parameters marked as optimization variables.

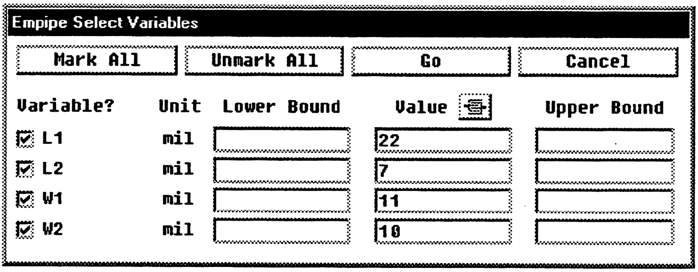


Fig. 5.6 The "Select Variables" window.

Reformulating the Specifications

The design specifications for the 10-dB distributed attenuator are

$$|S_{21}| = -10 \text{ dB}$$

$$|S_{11}| \leq -10 \text{ dB}$$

for the frequency range from 2 GHz to 18 GHz.

The equality specification on $|S_{21}|$ is poorly suited for the minimax optimizer which we wish to use. It can be reformulated into a pair of upper and lower specifications:

$$|S_{21}| \leq -9 \text{ dB}$$

$$|S_{21}| \geq -11 \text{ dB}$$

We will assign a weighting factor of 5 to this pair of specifications. By doing so we attach a greater emphasis to these specifications than the specification on $|S_{11}|$ which by default has a weighting factor of 1.

Steps for Entering the Specifications

1 Select the frequency range. In the "Specifications" window, the default frequency range is shown as

```
FREQ (GHz)  from: [2      ]  to: [18     ]  step: [4      ]
```

No change is needed.

2 Select the *S*-parameter response. This is the entry box for selecting an *S*-parameter response:

```
[ MS11 ▼]
```

Click on the arrow and you will see the list of available responses:

```
[ MS11 ▼]
MS11
MS12
MS21
MS22
PS11
PS12
PS21
PS22
MS11_dB
MS12_dB
MS21_dB
MS22_dB
```

The label MS*ij* represents the magnitude of S_{ij}, PS*ij* represents the phase of S_{ij} in degrees, and MS*ij*_dB represents the magnitude of S_{ij} in decibels.

We wish to select the magnitude of S_{21} in dB. Click on the label MS21_dB.

3 Selecting the type of specification. Initially, the specification type box shows "<". Since this happens to be what we need for the first specification, no change is needed.

4 Enter a numerical goal. Click on the goal box (the third field on the specification line) and type "-9".

5 Enter the weighting factor. Click on the box labelled "weight:" and type "5".

6 Click on the button labelled "Add a new specification defined as follows". The first specification is added to the list under the heading "Specifications Currently Defined".

7 Make the necessary changes for the second specification.

Change the specification type symbol from "<" to ">".

Click on the numerical goal box and type "-11".

Click on the button labelled "Add a new specification defined as follows". The second specification is added to the list under the heading "Specifications Currently Defined".

8 Make the necessary changes for the third specification.

Change the response label from MS21_dB to MS11_dB.

Change the specification type symbol from ">" to "<".

Click on the numerical goal box and type "-10".

Click on the box labelled "weight:" and type "1".

Click on the button labelled "Add a new specification defined as follows". All three specifications are now defined in the "Specifications" window.

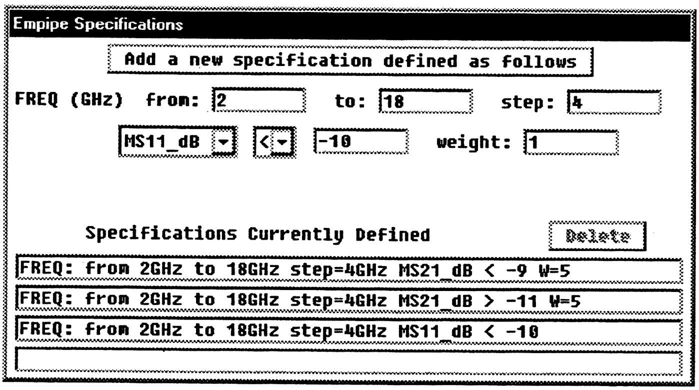


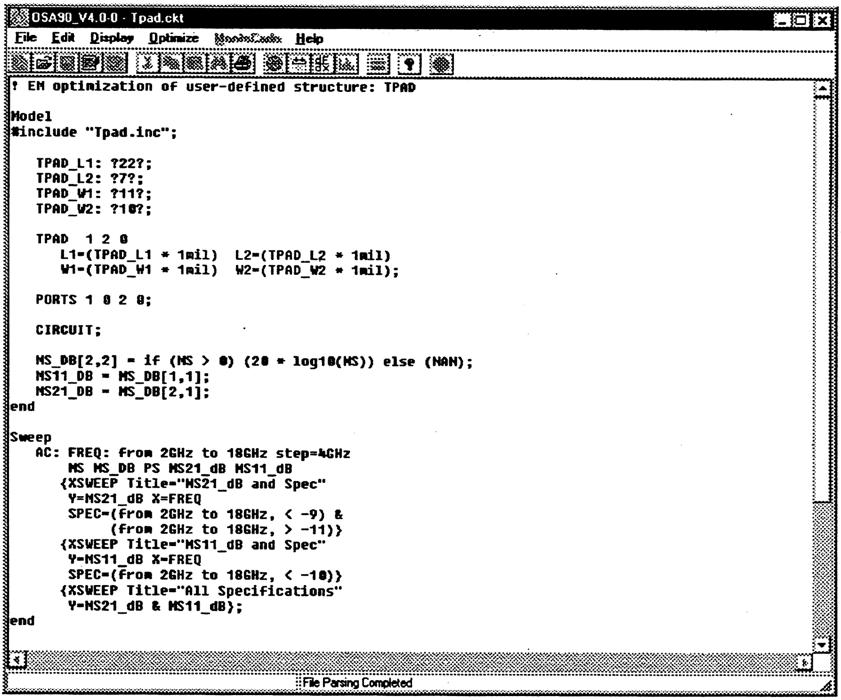
Fig. 5.7 The "Specifications" window.

What's Next

We are ready to start EM simulation and optimization. Proceed by clicking on the "Go" button in the "Select Variables" window.

5.4 Selecting Display Options

After you click on the "Go" button, Empipe activates the OSA90 simulation/optimization environment. The OSA90 window then appears.




```
! EM optimization of user-defined structure: TPAD

Model
#include "Tpad.inc";

   TPAD_L1: ?22?;
   TPAD_L2: ?7?;
   TPAD_W1: ?11?;
   TPAD_W2: ?10?;

   TPAD  1 2 0
      L1=(TPAD_L1 * 1mil)  L2=(TPAD_L2 * 1mil)
      W1=(TPAD_W1 * 1mil)  W2=(TPAD_W2 * 1mil);

   PORTS 1 0 2 0;

   CIRCUIT;

   MS_DB[2,2] = if (MS > 0) (20 * log10(MS)) else (NAN);
   MS11_DB = MS_DB[1,1];
   MS21_DB = MS_DB[2,1];
end

Sweep
   AC: FREQ: from 2GHz to 18GHz step=4GHz
       MS MS_DB PS MS21_dB MS11_dB
      {XSWEEP Title="MS21_dB and Spec"
       Y=MS21_dB X=FREQ
       SPEC=(from 2GHz to 18GHz, < -9) &
            (from 2GHz to 18GHz, > -11)}
      {XSWEEP Title="MS11_dB and Spec"
       Y=MS11_dB X=FREQ
       SPEC=(from 2GHz to 18GHz, < -10)}
      {XSWEEP Title="All Specifications"
       Y=MS21_dB & MS11_dB};
end
```

Fig. 5.8 OSA90 window.

The top of the window contains the menu bar and toolbar, the middle portion window is the input file (netlist) and located at the bottom of the window is the status bar.

Simulation and Display of the Response

Choose "Xsweep" from the "Display" menu.

Empipe will invoke *em* in the background. You will notice that the simulation seems to finish very quickly. This is because that the *em* analysis has already been performed when we prepared the tutorial example and the results have been stored in a database. An actual *em* simulation of the attenuator takes approximately 1.5 minutes of CPU time per frequency (7.5 minutes for all five frequencies) on a 200MHz Pentium.

The "Xsweep Display Options" dialog box now appears. Press <Enter> or click on "OK" to accept the default setting.

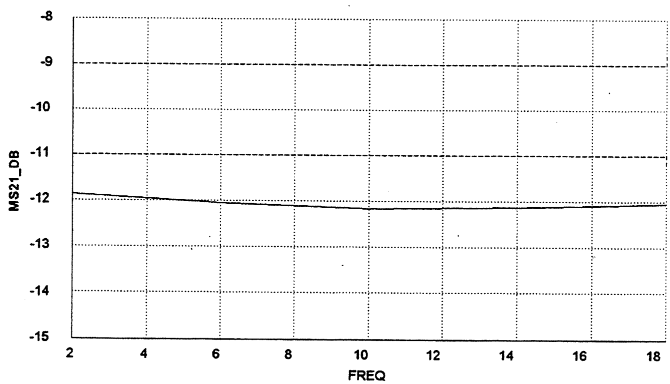


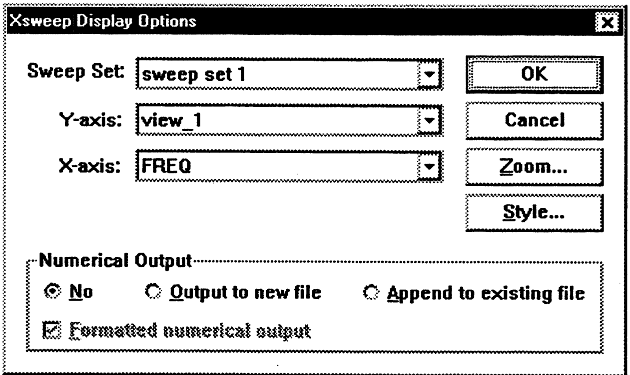
Fig. 5.9 Attenuator response MS21_dB.

Fig. 5.9 shows the response MS21_dB versus the frequency. The specifications on this response are also shown as dashed lines (on the screen they are shown in a distinct color). Clearly, the specifications are not satisfied at this point.

We also have a specification on MS11_dB. Next, we will show how to select the response MS11_dB for display.

Selecting Responses for Display

Choose "Xsweep" from the "Display" menu. A the "Xsweep Display Options" dialog box appears.



Click on the option "Y-axis" and you will see a list of choices. Click on the choice "view_2". The "Y-axis" option in the dialog box now shows "view_2". Click on "OK". The response MS11_dB is displayed on screen.

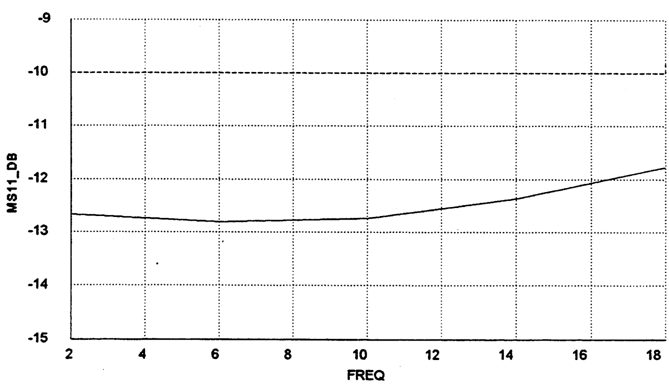


Fig. 5.10 Attenuator response MS11_dB.

Displaying Both MS21_dB and MS11_dB

Choose "Xsweep" from the "Display" menu. The "Xsweep Display Options" dialog box will reappear, click on the option "Y-axis". From the list of choices, click on "view_3". The "Y-axis" option now shows "view_3". Click on "OK".

The graphical display now contains both responses MS21_dB and MS11_dB (on the screen the two curves are shown in two different colors).

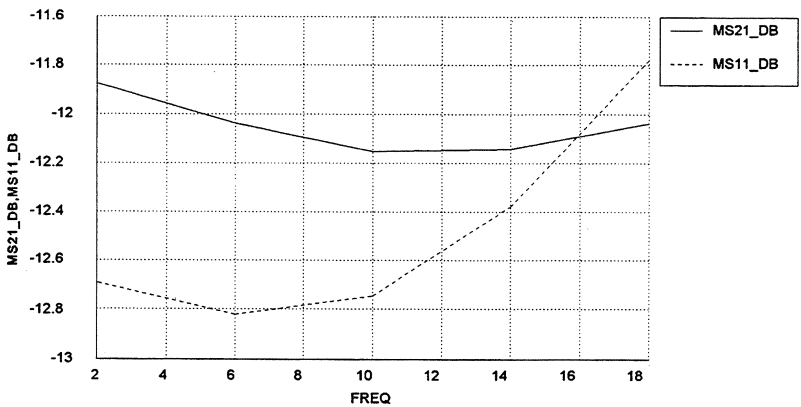


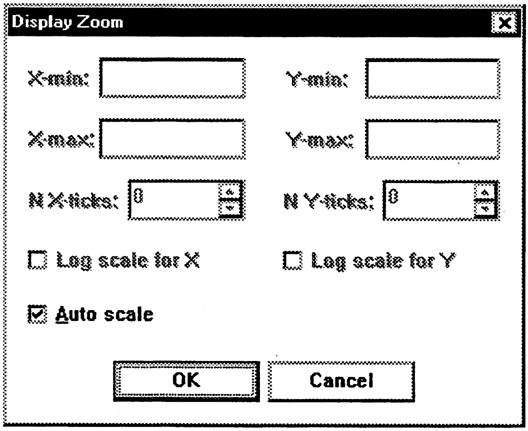
Fig. 5.11 Graphical display of both MS21_dB and MS11_dB.

Customizing the Display Scale

By default, the scale of the Y-axis is automatically determined by the program according to the minimum and maximum values of the responses.

For instance, in Fig. 5.11, the Y-axis has the range of -11.6 to -13 with ticks for 0.2 intervals. On this scale, it is difficult to check the responses against the specifications. We would like to change the default setting to a more convenient one.

Choose Xsweep from the "Display" menu. When the "Xsweep Display Options" dialog box appears, click on "Zoom...". This leads to another dialog box.



The parameters "X-min", "X-max", "Y-min" and "Y-max" define the corners of the display. The parameters "N X-ticks" and "N Y- ticks" specify the number of intervals (divisions) on the X-axis and Y-axis, respectively. The "Log scale for X" and "Log scale for Y" check boxes allow you to specify logarithmic scale for the X and Y axes respectively. The "Auto scale" option allows the program to display the data in a "best fit" scenario.

We will change the display scale as follows.

1 Remove the check mark from the "Auto Scale" check box. This will activate the various other options.

2 Click on the box labelled "Y-min:" and type "-20".

3 Click on the box labelled "Y-max:" and type "0".

4 Click on the box labelled "N Y-ticks:" and type "4".

5 Click on "OK". The "Zoom scale"dialog box disappears. Click on "OK" in the "Xsweep Display Options" dialog box.

The graphical display with the modified scale is plotted on screen. The new scale allows us to see more clearly the position of the responses relative to the specifications.

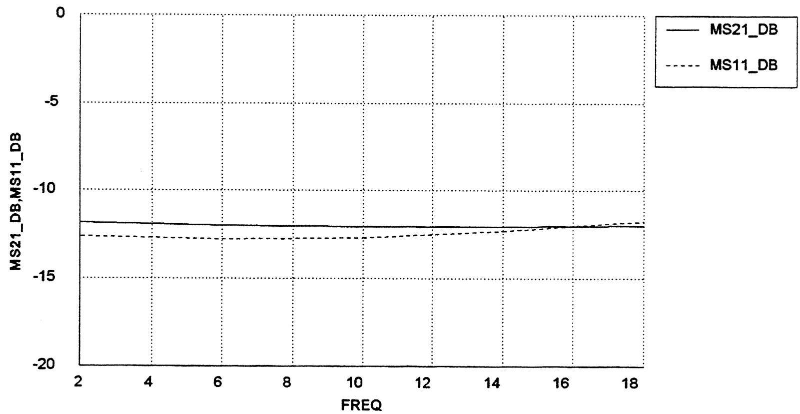


Fig. 5.12 Graphical display with customized scale.

What's Next

We are ready to proceed to optimization. .

5.5 Minimax Optimization

To start optimization, click on the "Optimize" button on the toolbar. A dialog box appears, showing a number of options related to optimization.

Notice that the optimizer is shown as "Minimax". Empipe automatically chooses the optimizer for you according to the type of specifications defined. This tutorial example involves upper and lower specifications, hence Empipe chooses the minimax optimizer.

Press <Enter> or click on "OK" to accept the default setting.

The progress of optimization is reported on the screen:

```
Iteration   1/30 Max Error=5.74648
Iteration   2/30 Max Error=5.26174
Iteration   3/30 Max Error=4.31002
Iteration   4/30 Max Error=2.45741
Iteration   5/30 Max Error=-0.987392
    ...
    ...

Iteration  25/30 Max Error=-4.94847
Iteration  26/30 Max Error=-4.95548
Iteration  27/30 Max Error=-4.94672
Iteration  28/30 Max Error=-4.95954
Iteration  29/30 Max Error=-4.93807
Iteration  30/30 Max Error=-4.94534
Solution  Max Error=-4.95954
```

The numerical values you actually see may be slightly different from those shown here, due to differences in the computer hardware and/or software versions.

The optimization goes very quickly, since all the necessary *em* analysis results are already available from the database.

Displaying the Optimized Attenuator Responses

Choose "Xsweep" from the "Display" menu.. In the "Xsweep Display Options" dialog box, click on the "Y-axis" option. From the list of available choices, click on "view_3" to display both MS21_dB and MS11_dB. Then click on "OK".

The graphical display is plotted on screen. It shows that after optimization the response MS21_dB is almost exactly -10 dB and the response MS11_dB is well below -10 dB.

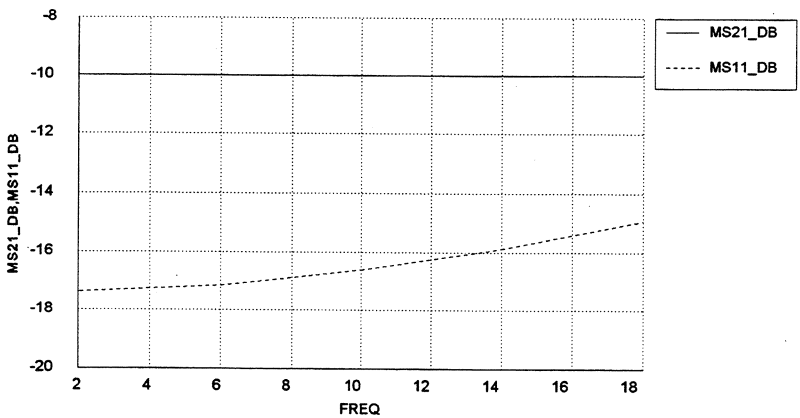


Fig. 5.13 Responses of the optimized attenuator.

Saving the Optimized Geometry

Select "Exit" from the "File" menu.

A window will appear, asking you to confirm that you wish to exit. Click the "Yes" button.

Upon exit from OSA90, the Empipe windows reappear on the screen. A dialog box appears, allowing you to specify the file name for saving the optimized geometry.

Click on the "OK" button to accept the default file name "tpad_o.geo".

Empipe automatically invokes *xgeom* to display the geometry.

The optimized geometry saved in tpad_o.geo is snapped to the nearest grid. For example, the optimized value for the parameter L1 is 13.1518 mils. In tpad_o.geo, L1 is rounded, with respect to the cell size 1 mil × 1 mil, to 13 mils.

However, you can see the optimized solution without truncation in the "Select Variables" window.

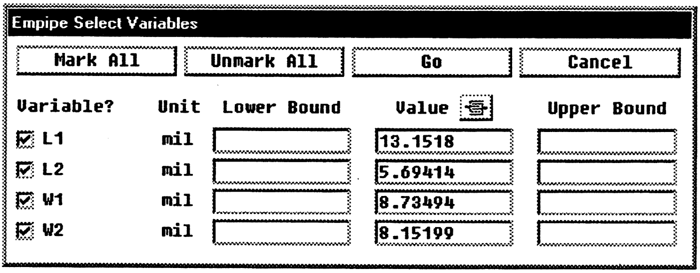


Fig. 5.14 The optimized solution without truncation.

Concluding the Tutorial

Click on the "Cancel" button in the "Select Variables" window. This brings you back to the main window of Empipe. Click on the "Quit" button. You will be prompted whether you wish to save the project file. Click “No”.

6

Tutorial: A Resistor

6

Tutorial: A Resistor

6.1 Introduction

This chapter is the fourth segment of the series of tutorials which systematically introduces you to the various features of Empipe.

We recommend that you follow the tutorials in the order that they are presented. At least you should study the introductory tutorial in Chapter 3 before any other chapters.

What You Will Learn From This Tutorial

1. How to capture metallization resistivity loss as an Empipe element parameter.

2. How to modify the OSA90 input file to redefine the ports.

3. How to display *Z* parameters which are converted by OSA90 from the *S* parameters calculated by ***em***.

4. How to define a parameter sweep for simulation and display.

The ***em*** simulation of this simple circuit takes approximately 2 seconds per frequency on a 200MHz Pentium.

When this symbol appears on the left-hand side column, it highlights text that describes hands-on actions. You can take a "short-cut" through the tutorial by following this symbol and skip over the commentaries.

Description of the Example

The structure considered in this tutorial is based on one of the standard examples provided by Sonnet Software for ***em*** ("res400.geo" in the Sonnet example subdirectory). It is a simple resistor consisting of metallization squares.

The modified ".geo" file for this tutorial is named "em_res0.geo" in the Empipe example subdirectory.

You can invoke ***xgeom*** to view the "geo" file. The ***xgeom*** display is shown in Fig. 6.1.

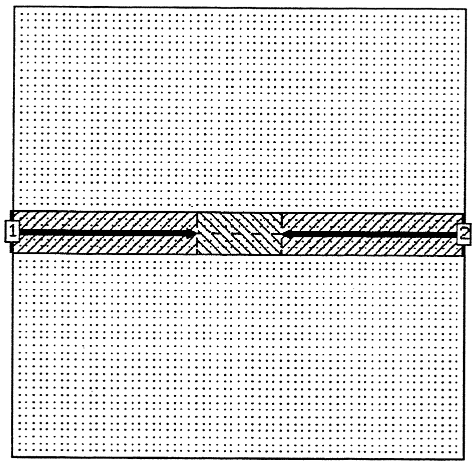


Fig. 6.1 The nominal geometry of the resistor.

The substrate is 100 micron thick with a relative dielectric constant of 12.9. The cell size is 10 × 10 microns.

6.2 Defining Metallization Loss as a Parameter

The resistor is constructed from squares of high resistivity metallization. In em_res0.geo, the DC resistivity is defined as 150 ohms/square and the structure consists of two squares. This produces a nominal resistance of 300 ohms.

We wish to capture two parameters for the resistor: the DC resistivity and the number of squares.

Changing the DC Resistivity Using *xgeom*

We can use ***xgeom*** to edit the DC resistivity parameter.

In *xgeom*, select "Metal Types..." from the "Parameters" menu. A dialog box will appear allowing you to change the metallization parameters. The DC resistivity for the metal type "resis" is shown as 150 ohms/square. To change it, you would simply click the appropriate box and change the number "150" to a new value.

The Empipe example file set includes the file "em_res1.geo" which represents an incremental change in the DC resistivity. The DC resistivity is changed from 150 ohms/square in em_res0.geo to 160 ohms/square in em_res1.geo.

Parameterizing the Number of Squares

In addition to the resistivity parameter, the resistance of the resistor is also controlled by the length of the metal. But instead of defining the length as a parameter, we choose to define the number of squares as a parameter. This serves to illustrate Empipe's ability to handle abstract, non-geometrical parameters.

The number of squares is 2 for the nominal geometry in em_res0.geo. We created an additional file "em_res2.geo", in which the number of squares is changed to 3, as illustrated in Fig. 6.2.

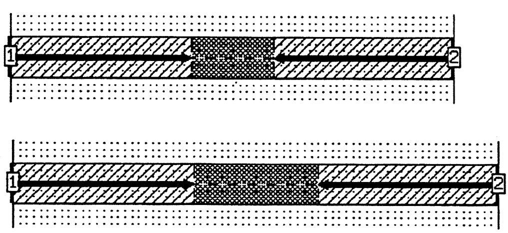


Fig. 6.2 Incremental change in the number of squares.

Starting Empipe

To start Empipe, click on the "Empipe" icon located in the "Osa" program group.

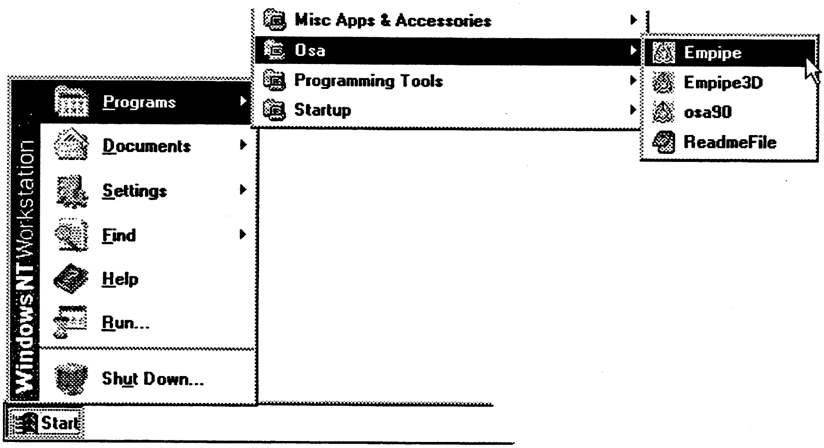


Fig. 6.3 Location of Empipe on the Start Menu

When the Empipe main window appears, click on the "Load" button.

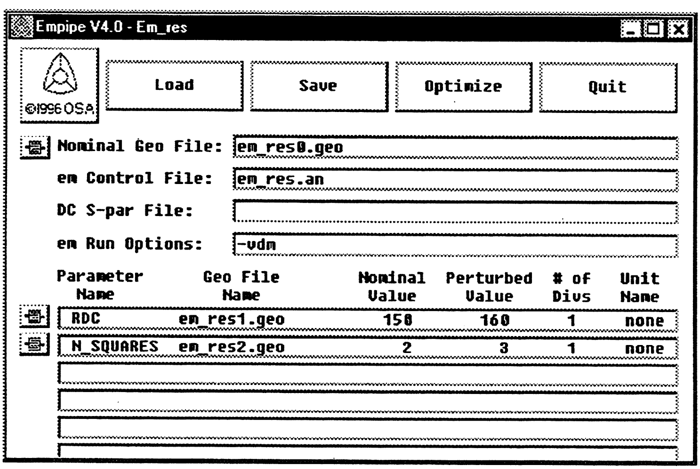


Fig. 6.4 Empipe Geometry Capture form editor.

You will be presented with an "Empipe Open File" dialog box. Select the project "em_res.inc" from your copy of the examples. The Empipe Geometry Capture form editor is then displayed. The *em* analysis control file "em_res.an" contains a single frequency of 2 GHz.

We name the parameters RDC and N_SQUARES. These names are of course arbitrary and we could choose other names if so desired.

The incremental change we made to RDC is from 150 to 160, and the number of divisions is specified as 1. This means a grid size of 10. This grid is not imposed by *em*, since it allows arbitrary resistivity values. We assign a discretization grid to the parameter RDC, not because it is necessary, but because it reduces the number of potential *em* simulations. Empipe will invoke *em* only if RDC changes by more than one grid (10 ohms/square). For changes in RDC within one grid, Empipe will rely on interpolation to obtain simulation results. So long as we choose a grid that is reasonably small, this scheme will improve the efficiency without excessive loss of accuracy.

A similar rationale applies to the parameter N_SQUARES. Between the files em_res0.geo and em_res2.geo, the parameter N_SQUARES is increased by 1. The size of one square is 60 × 60 microns. If we directly use the *em* cell size, which is 10 × 10 microns, as the parameter grid, then the perturbation would be 6 times the grid size. Instead we specify the "# of Divs" for N_SQUARES as 1, in order to reduce *em* simulations and expand the interval of interpolation.

Note also the "Unit Name" entry is "none" for both parameters. The parameter N_SQUARES does not have a physical unit, and the unit for RDC (ohms/square) is not used by Empipe. Empipe recognizes physical units for geometrical measurement only, including IN, MIL, M, CM, MM and UM.

6.3 S-Parameter Optimization

Our design objective is to find, by automated optimization, the value of RDC such that the resistance is 400 ohms (with N_SQUARES kept constant at 2). The answer to this simple problem is easy to determine (200 ohms/square).

By default, Empipe deals with the *S* parameters. We have to reformulate the specification on the resistance into a specification on the *S* parameters. The desired resistance of 400 ohms translates into a value of 0.8 for MS11 (with respect to the reference impedance of 50 ohms). In Section 6.4, we will show how to obtain the *Z* parameters directly in the OSA90 environment.

In the Empipe main window, click on the button

`Optimize`

In the "Select Variables" window, click on the check box beside the parameter RDC to select it as an optimization variable. We will keep the parameter N_SQUARES constant, as depicted in Fig. 6.5.

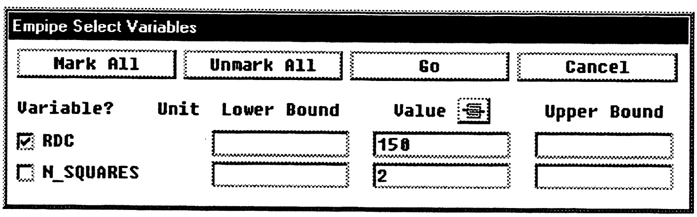


Fig. 6.5 The "Select Variables" window.

In the "Specifications" window, leave the response at the default (MS11). Change the type of specification from the default "<" to "=". Click on the goal box and type "0.8". Then click on the button

`Add a new specification defined as follows`

The "Specification" window should now contain

```
Specifications Currently Defined          Delete
FREQ: 2GHz MS11 = 0.8
```

Simulation Before Optimization

Choose "Xsweep" from the "Display" menu. The "Xsweep Display Options" dialog box now appears. Press <Enter> or click on "OK" to accept the default setting. The simulation result is shown in Fig. 6.6.

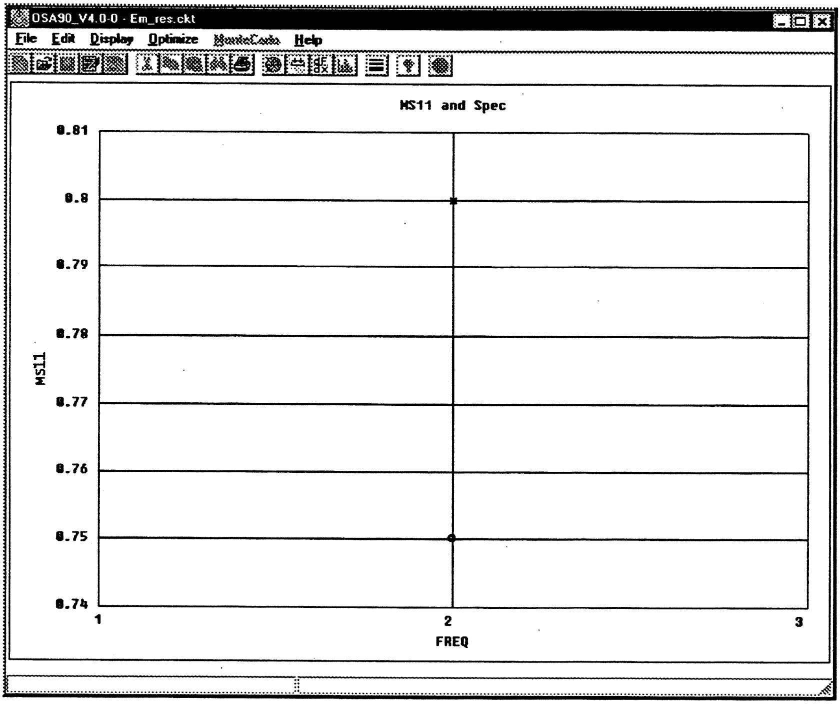


Fig. 6.6 MS11 and specification before optimization.

L1 Optimization

To start optimization, click on the "Optimize" button on the toolbar. Notice that the "L1" optimizer is automatically chosen, since we are trying to match the calculated MS11 to a specific value. Press <Enter> or click on "OK" to accept the default setting.

The progress of optimization is reported on the screen:

```
Iteration   1/30 L1 Objective=0.050248
Iteration   2/30 L1 Objective=0.0484073
Iteration   3/30 L1 Objective=0.0446703
Iteration   4/30 L1 Objective=0.0370872
Iteration   5/30 L1 Objective=0.0229221
Iteration   6/30 L1 Objective=0.00123237
Iteration   7/30 L1 Objective=1.477e-05
Iteration   8/30 L1 Objective=1.19209e-08
Solution  L1 Objective=1.19209e-08
```

Displaying the Optimized Responses

Choose "Xsweep" from the "Display" menu. Press <Enter> or click on "OK" to accept the default setting. As shown in Fig. 6.7, the specification is met.

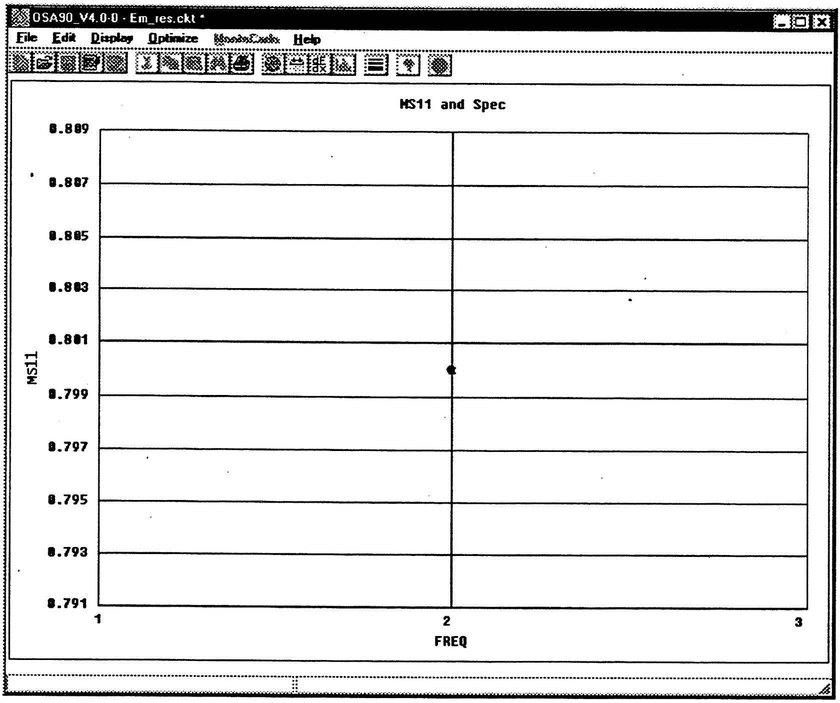


Fig. 6.7 MS11 meets specification after optimization.

6.4 Calculating Z Parameters

Select "Edit Input File" from the "File" menu.

The Empipe element is defined in the Model block:

```
Model
#include "em_res.inc";

   EM_RES_RDC: ?200.343?;
   EM_RES_N_SQUARES: 2;

   EM_RES  1 2 0
      RDC=EM_RES_RDC  N_SQUARES=EM_RES_N_SQUARES;

   PORTS 1 0 2 0;

   CIRCUIT;

   MS_DB[2,2] = if (MS > 0) (20 * log10(MS)) else (NAN);
end
```

The labels "EM_RES_RDC" and "EM_RES_N_SQUARES" represent the two parameters of the Empipe element "EM_RES". The pair of question marks following the label "EM_RES_RDC" indicates that the "RDC" parameter is defined as an optimization variable. Notice that the optimized value is 200.343 (ohms/square) which is very close to the expected value of 200 ohms/square.

Redefining the Ports

The Model block contains this statement:

```
PORTS 1 0 2 0;
```

It reflects the fact that in the ".geo" file the resistor is defined as a two-port, as illustrated in Fig. 6.8, where nodes 1 and 2 represent the edges of the metal and node 0 represents the ground.

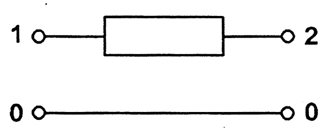


Fig. 6.8 The em port configuration for the resistor.

It will be more convenient to analyze the characteristics of the resistor if we redefine the circuit as a one-port, as shown in Fig. 6.9.

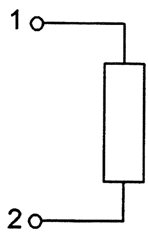


Fig. 6.9 The resistor defined as a one-port.

We can redefine the ports by editing the **Model** block. Change this statement

```
PORTS 1 0 2 0;
```

to

```
PORT 1 2;
```

OSA90 will automatically convert the two-port data produced by ***em*** to the appropriate one-port data.

We need to modify another statement in the **Model** block:

```
MS_DB[2,2] = if (MS > 0) (20 * log10(MS)) else (NAN);
```

This is meant to calculate the two-port *S* parameters in dB. Since now we have only one port, we can either change the array dimension or delete the statement entirely.

The easiest thing to do is to comment out the statement by inserting an exclamation mark at the beginning of the statement, as

```
!  MS_DB[2,2] = if (MS > 0) (20 * log10(MS)) else (NAN);
```

OSA90 treats any text following an exclamation mark as a comment (until the end of line).

Modifying the Sweep Block

The Sweep block of the OSA90 input file controls the circuit simulation. For the resistor, the initial contents of the Sweep block are as follows.

```
Sweep
   AC: FREQ: 2GHz
       MS MS_DB PS
      {XSWEEP Title="MS11 and Spec"
       Y=MS11
       XMIN=1GHz XMAX=3GHz NXTICKS=2 X_title=FREQ
       SPEC=(at 2GHz, = 0.8)};
end
```

The keyword "AC" signals a small-signal AC simulation. The labels "MS", "MS_DB" and "PS" represent the *S*-parameter responses of interest.

For the resistor, it is much more convenient to interpret the *Z* parameters than the *S* parameters. The OSA90 built-in label RZ11 represents the real part of the Z_{11} parameter, which directly gives us the resistance of the resistor.

Modify the Sweep block to

```
Sweep
   AC: FREQ: 2GHz
       RZ11;
end
```

Modifying the Specification Block

The initial contents of the Specification block of the OSA90 input file are as follows.

```
Spec
   AC: FREQ: 2GHz MS11 = 0.8;
end
```

Modify the Specification block to

```
Spec
   AC: FREQ: 2GHz RZ11 = 400;
end
```

The Modified OSA90 Input File

The modified OSA90 input file is as follows.

```
Model
#include "em_res.inc";

   EM_RES_RDC: ?200.343?;
   EM_RES_N_SQUARES: 2;

   EM_RES  1 2 0
      RDC=EM_RES_RDC  N_SQUARES=EM_RES_N_SQUARES;

   PORT 1 2;

   CIRCUIT;

  ! MS_DB[2,2] = if (MS > 0) (20 * log10(MS)) else (NAN);
end

Sweep
   AC: FREQ: 2GHz
       RZ11;
end

Spec
   AC: FREQ: 2GHz RZ11 = 400;
end

Control
   Perturbation_Scale=1.0e-4;
end
```

Simulation and Display of the Z Parameters

Select "Compile Input File" from the "File" menu or press <F7>. Choose "Xsweep" from the "Display" menu. The "Xsweep Display Options" dialog box now appears.

Here we would like to demonstrate the OSA90 feature of numerical display. The selected circuit responses are printed on the screen as numerical outputs instead of graphical plots.

The "Xsweep Display Options" dialog box contains a heading "Numerical Output". The default choice for this options is "No" which produces no numerical output. Click on "Output to new file" and press <Enter> or click on "OK" to continue.

A copy of the program "Notepad" will be started, containing the response RZ11 in numerical format.

```
! Parameter Sweep
 PARAMETER FREQ=2;
 FORMAT RZ11;
        400.4
```

It shows that the resistance is very close to the desired value of 400 ohms. The reason that it is not exactly 400 ohms is that we did not directly specify the *Z*-parameter response for optimization but reformulated it into a specification on the *S*-parameter response. The specification of 0.8 on MS11 was determined without considering the structure reactance at 2 GHz, so it does not translate precisely to a 400 ohms resistance. Now we can re-optimize the circuit with the explicit specification on RZ11.

Optimization of the Z-Parameter Response

To start optimization, click on the "Optimize" button on the toolbar and press <Enter> or click on "OK" to continue.

The progress of optimization is reported on the screen:

```
Iteration   1/30 L1 Objective=0.372966
Iteration   2/30 L1 Objective=0.000610983
Iteration   3/30 L1 Objective=2.25717e-05
Solution  L1 Objective=2.25717e-05
```

Click on the "Display" toolbar button, or select "Xsweep" from the Display menu. Ensure that "Output to new file" is selected and then press <Enter> or click on "OK".

The response RZ11 is displayed numerically on the screen:

```
! Parameter Sweep
 PARAMETER FREQ=2;
 FORMAT RZ11;
        400
```

As expected, we have obtained a more precise solution by defining the specification for optimization directly on the *Z*-parameter response.

You can close the "Notepad" windows when the numerical output is no longer needed.

6.5 Defining a Parameter Sweep

This section demonstrates parameter sweeps. We are already familiar with frequency sweep. In a similar manner, we define a range in which a selected parameter is swept with a given step size. We will be able then to plot the responses versus the swept parameter.

Using the resistor example, we will create two parameter sweeps, involving RDC and N_SQUARES, respectively.

Defining the Parameter Sweep of RDC

Select "Edit Input File" from the "File" menu.

Following the modification of the preceding section, the **Sweep** block contains:

```
Sweep
   AC: FREQ: 2GHz
       RZ11;
end
```

Insert one line of text into the **Sweep** block as follows.

```
Sweep
   AC: FREQ: 2GHz
       EM_RES_RDC: 150 200 250
       RZ11;
end
```

The added line defines a sweep of the label EM_RES_RDC which represents the parameter RDC of the element EM_RES.

In OSA90, the range of a parameter sweep can be defined by either

label: from *x1* to *x2* step=*x3*

or

label: *x1 x2 ... xn*

In the first case, the parameter represented by *label* is swept from the starting value *x1* to the stop value *x2* with the uniform step given by *x3*. In the second case, the parameter sweep is defined over *n* discrete values, given by *x1, x2, ..., xn*, which are not necessarily uniformly spaced.

Hence, the sweep of EM_RES_RDC can also be defined as

```
EM_RES_RDC: from 150 to 250 step=50
```

Displaying the Parameter Sweep of RDC

Select "Compile Input File" from the "File" menu or press <F7>. Select "Xsweep" from the "Display" menu. In the "Xsweep Display Options" dialog box, click on "OK" or press <Enter>.

The graphical display of the response RZ11 versus the parameter RDC is shown in Fig. 6.10.

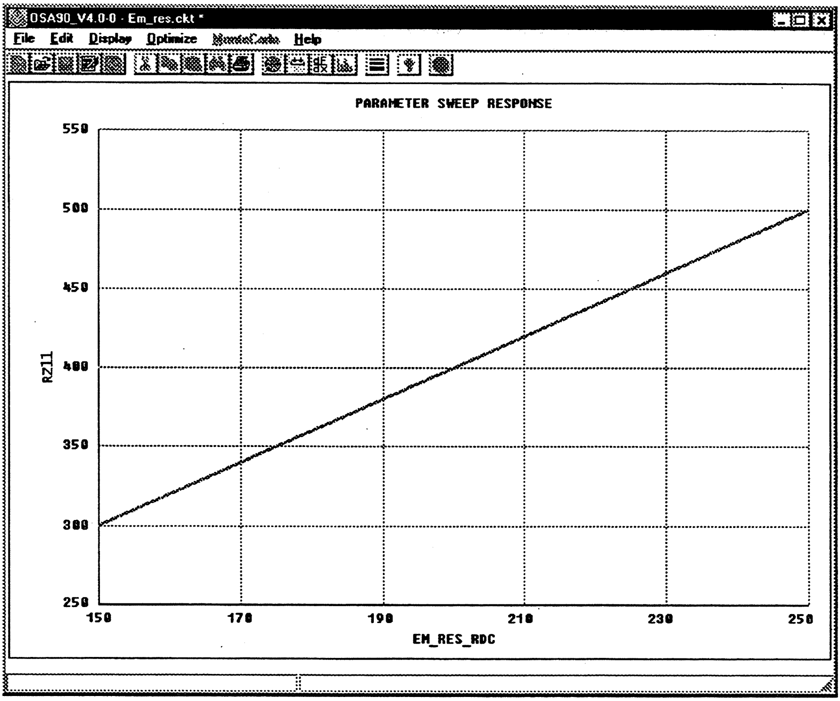


Fig. 6.10 Parameter sweep of RDC.

Defining the Parameter Sweep of N_SQUARES

Select "Edit Input File" from the "File" menu.

We wish to define an additional sweep of the parameter N_SQUARES.

Insert a new statement to the Sweep block as follows.

```
Sweep
   AC: FREQ: 2GHz
       EM_RES_RDC: 150 200 250
       EM_RES_N_SQUARES: 1 2 3
       RZ11;
end
```

Select "Compile Input File" from the "File" menu or press <F7>. Select "Xsweep" from the "Display" menu. Press <Enter> or click on "OK".

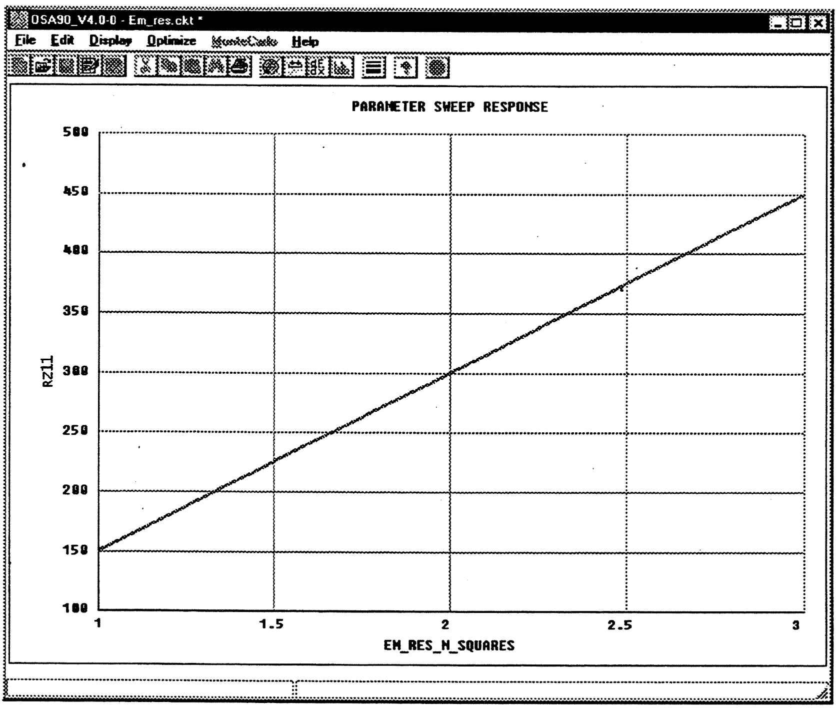
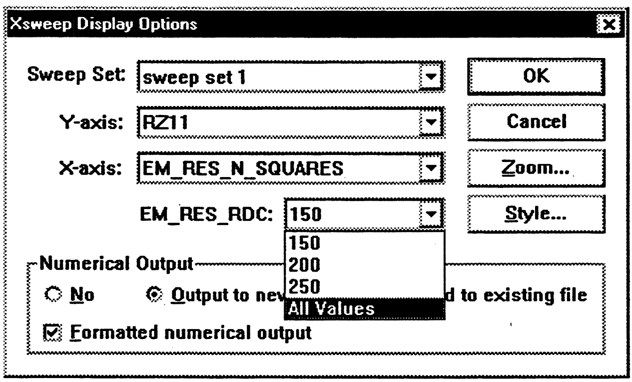


Fig. 6.11 Parameter sweep of N_SQUARES.

Displaying Both Sweep Parameters

Since we have defined two sweep parameters, we can choose either one of them to be displayed as the X-axis. By default, the second sweep parameter is chosen as the X-axis, which in this case is "EM_RES_N_SQUARES". In other words, the display will show the response RZ11 versus the parameter sweep of "EM_RES_N_SQUARES". For the other sweep parameter, namely "EM_RES_RDC", we can select one of the available values (in this case 150, 200 and 250). The default setting shows the value for "EM_RES_RDC" as 150.

Select "Xsweep" from the "Display "menu. In the "Xsweep Display Options" dialog box, click on the line "EM_RES_RDC:". A list of available choices appears as



Select the last choice "All Values". Then press <Enter> or click on "OK". The graphical display is shown in Fig. 6.12.

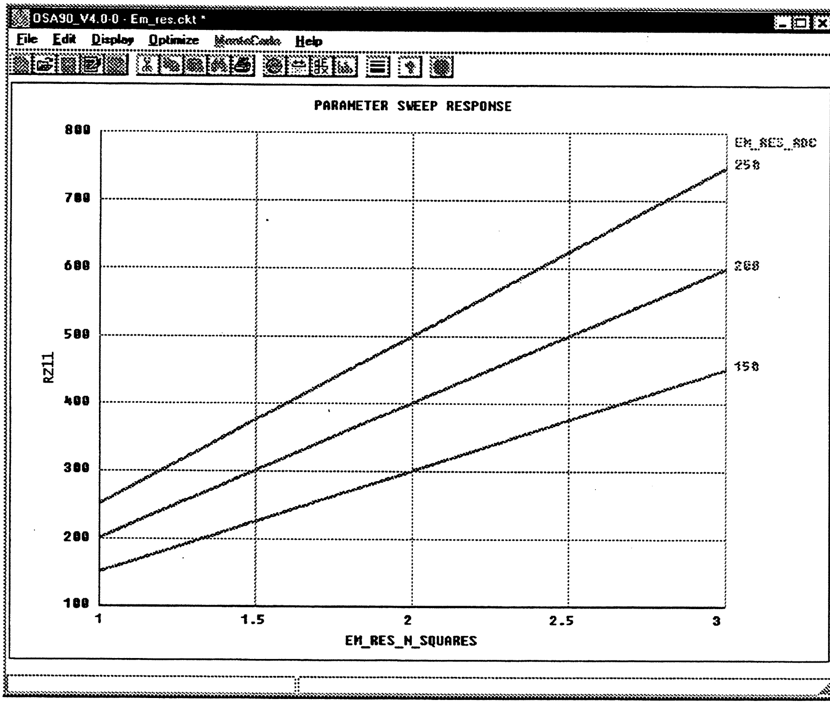


Fig. 6.12 Parameter sweep of both RDC and N_SQUARES.

Concluding the Tutorial

Click on the "Cancel" button in the "Select Variables" window. This brings you back to the main window of Empipe. Click on the "Quit" button. You will be prompted whether you wish to save the project file. Click "No".

7

Tutorial: An MIM Capacitor

7

Tutorial: An MIM Capacitor

7.1 Introduction

This chapter is the last segment of the series of tutorials which systematically introduces you to the various features of Empipe.

We recommend that you follow the tutorials in the order that they are presented. At least you should study the introductory tutorial in Chapter 3 before any other chapters.

What You Will Learn From This Tutorial

1 How to capture parameters for the dielectric layer.

2 How to use OSA90 to convert the S parameters calculated by *em* to Y parameters.

3 How to formulate user-defined responses in OSA90.

4 How to display parametric plots.

The *em* simulation involved in this tutorial takes less than 5 seconds per frequency on a 200MHz Pentium.

When this symbol appears on the left-hand side column, it highlights text that describes hands-on actions. You can take a "short-cut" through the tutorial by following this symbol and skip over the commentaries.

Description of the Example

The structure considered in this tutorial is based on one of the standard examples provided for ***em*** ("cap.geo" in the Sonnet example subdirectory). It is an MIM capacitor with a nominal capacitance of 1.4 pF.

The modified ".geo" file for this tutorial is named "em_cap0.geo" in the Empipe example subdirectory.

You can invoke ***xgeom*** to view the "geo" file. The ***xgeom*** display is shown in Fig. 7.1.

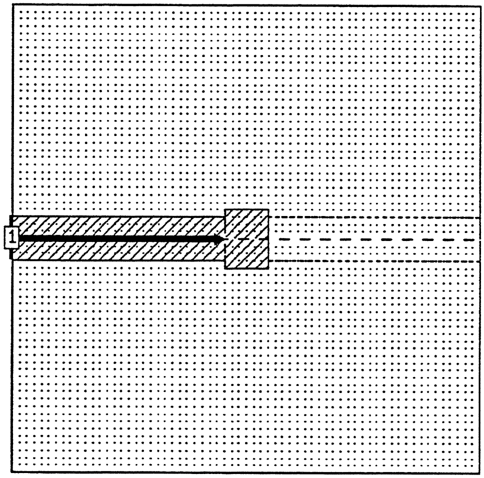


Fig. 7.1 The nominal geometry of the capacitor.

The substrate is 50 micron thick with a relative dielectric constant of 12.88. The cell size is 10 × 10 microns.

7.2 Parameterizing the Dielectric Layer

For the MIM capacitor, the capacitance depends on both the dimension of the metal patches and the characteristics of the dielectric layer between the patches.

The preceding tutorials have provided ample examples of parameterizing geometrical dimensions. Therefore, we turn our attention here to the dielectric layer. We wish to define two parameters: the dielectric constant and the thickness of the dielectric layer (i.e., the spacing between the two metallic patches).

Editing the Dielectric Layers Using *xgeom*

We can use *xgeom* to edit the dielectric layers.

In *xgeom* , select "Dielectric Layers..." from the "Parameters" menu. A dialog box will appear allowing you to change the dielectric parameters.

Changing the Dielectric Constant

In the *xgeom* window, the dielectric constant is listed under the heading "Erel". The dielectric constant of the middle layer is shown as 6.8. This is the value recorded in the nominal ".geo" file em_cap0.geo.

To change the value, click on the number "6.8" and type a new value.

To create an incremental change for Geometry Capture, we have changed the dielectric constant from 6.8 to 6.9. The change is saved in the file "em_cap1.geo" (included in the Empipe example files).

Changing the Dielectric Layer Thickness

The thickness of the middle layer is shown as 0.2 micron. To change the value, click on the number "0.2" and enter a new value.

To create an incremental change for Geometry Capture, we have changed the dielectric layer thickness from 0.2 to 0.3 micron. The change is saved in the file "em_cap2.geo" (included in the Empipe example files).

Starting Empipe

To start Empipe, click on the "Empipe" icon located in the "Osa" program group.

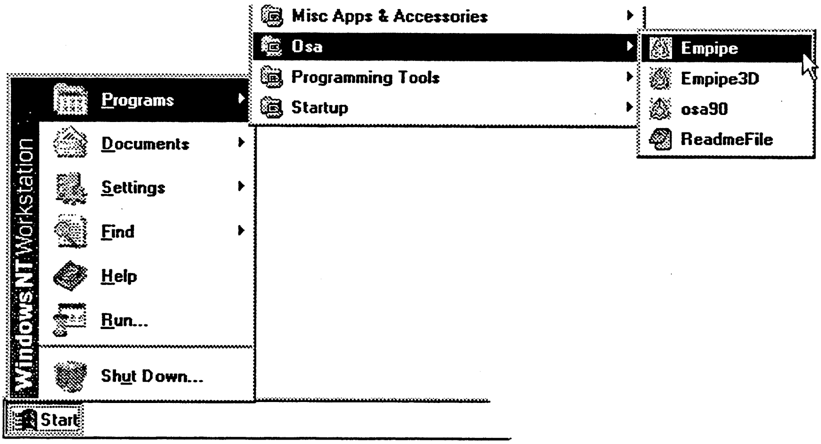


Fig. 7.2 Location of Empipe on the Start Menu

When the Empipe main window appears, click on the "Load" button.

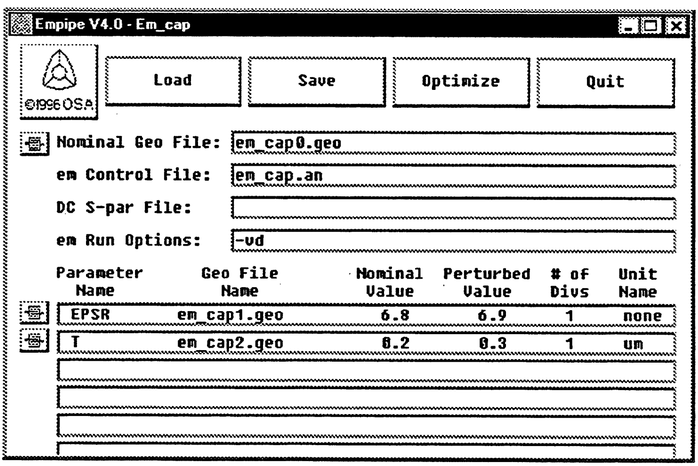


Fig. 7.3 Empipe Geometry Capture form editor.

You will be presented with an "Empipe Open File" dialog box. Select the project "em_cap.inc" from your copy of the examples. The *em* analysis control file "em_cap.an" contains one single frequency of 800 MHz.

We choose the names EPSR and T to identify the dielectric constant and dielectric layer thickness parameters, respectively.

The incremental change we made to EPSR is from 6.8 to 6.9. Although *em* allows arbitrary values for the dielectric constant, we treat EPSR as a discretized variable with a grid of 0.1. The reason for doing so is to reduce the number of potential *em* simulations. Empipe will invoke *em* only if EPSR changes by a significant amount (more than one grid, or 0.1). For smaller variations of EPSR, Empipe will utilize interpolation to provide results. So long as the grid selected is reasonably small, this scheme will improve the efficiency without excessive loss of accuracy.

Similarly, we impose a discretization grid of 0.1 micron on the parameter T, not because it is necessary, but in order to improve the efficiency.

Em Run-Time Options

Notice that the *em* run-time options for this example are defined as "-vd". The memory saver option "-m" is not included. The reason is that the simulation frequency is below the threshold recommended by *em*. If you include the "-m" option, you will get a warning message: "use of Memory Saver (-m) may result in error".

7.3 S-Parameter Optimization

Our design objective is to determine, by automated optimization, the thickness of the dielectric layer (parameter T) such that the capacitance is 2 pF (with EPSR kept constant).

By default, Empipe deals with the *S* parameters. We have to reformulate the specification on the capacitance into a specification on the *S* parameters. The desired capacitance of 2 pF roughly translates into a value of 0.7 for MS11 (with respect to the reference impedance of 50 ohms). In Section 7.4, we will show how to define the capacitance as a user-defined response in the OSA90 environment.

In the Empipe main window, click on the button

`Optimize`

In the "Select Variables" window, click on the check box beside the parameter T to make it an optimization variable. We will keep the parameter EPSR constant, as shown in Fig. 7.4.

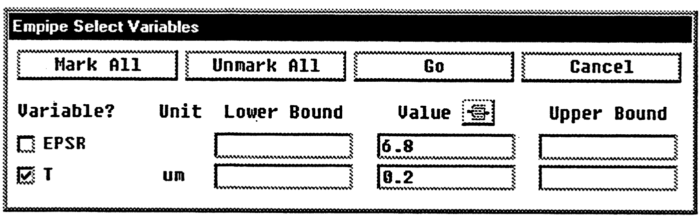


Fig. 7.4 The "Select Variables" window.

In the "Specifications" window, leave the response at the default (MS11). Change the type of specification from the default "<" to "=". Click on the goal box and type "0.7". Then click on the button

`Add a new specification defined as follows`

The "Specification" window should now read

Specifications Currently Defined   Delete

`FREQ: 800MHz MS11 = 0.7`

Simulation Before Optimization

In the "Select Variables" window, click on "Go". Choose "Xsweep" from the "Display" menu. The "Xsweep Display Options" dialog box now appears. Press <Enter> or click on "OK" to accept the default setting. The simulation result is shown in Fig. 7.5.

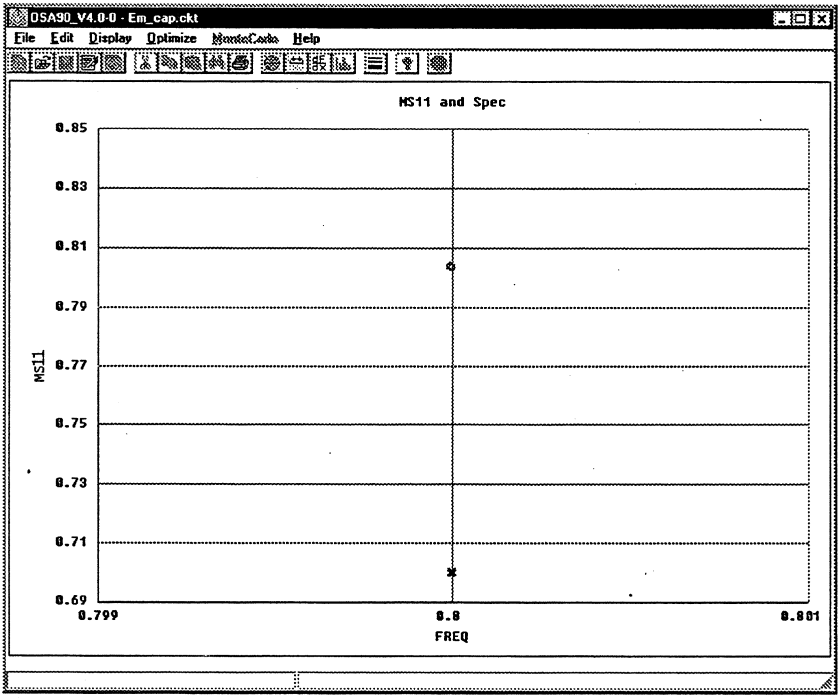


Fig. 7.5 MS11 and specification before optimization.

L1 Optimization

To start optimization, click on the "Optimize" button on the toolbar. Press <Enter> or click on "OK" to accept the default setting.

The progress of optimization is reported on the screen:

```
Iteration   1/30 L1 Objective=0.103289
Iteration   2/30 L1 Objective=0.0984599
Iteration   3/30 L1 Objective=0.0889454
Iteration   4/30 L1 Objective=0.0704778
Iteration   5/30 L1 Objective=0.0356867
Iteration   6/30 L1 Objective=0.00149159
Iteration   7/30 L1 Objective=4.22001e-06
Iteration   8/30 L1 Objective=1.19209e-08
Solution  L1 Objective=1.19209e-08
```

Displaying the Optimized Responses

Choose "Xsweep" from the "Display" menu. In the "Xsweep Display Options" dialog box, click on "OK" or press <Enter> to accept the default setting. As shown in Fig. 7.6, the specification is met.

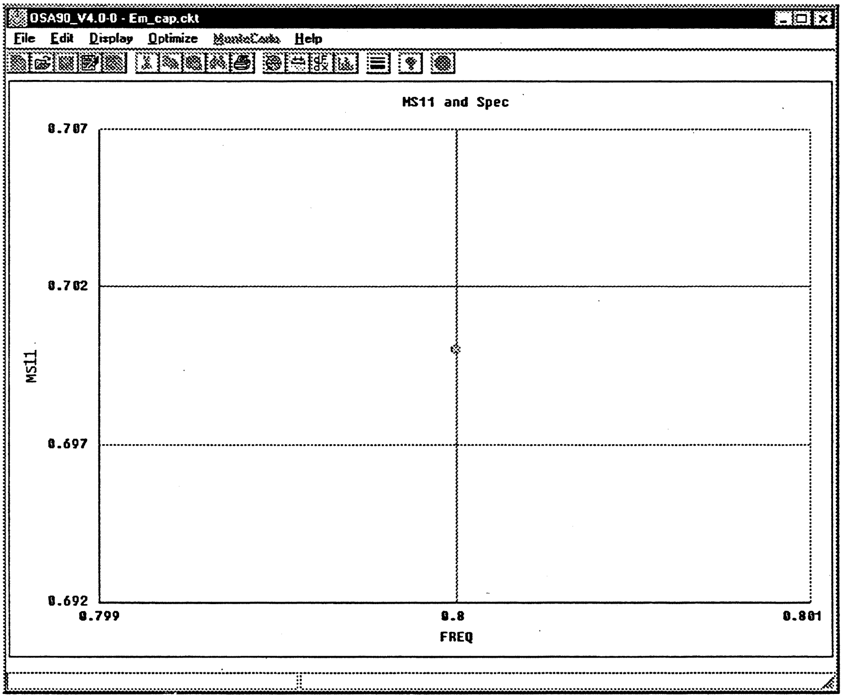


Fig. 7.6 MS11 meets specification after optimization.

7.4 Formulating User-Defined Responses

This section illustrates the feature of user-defined responses. Using the capacitor example, instead of showing the *S* parameters, we calculate and display the capacitance versus parameter sweeps of the dielectric constant EPSR and the dielectric layer thickness T.

Select "Edit Input File" from the "File" menu.

The Empipe element is defined in the Model block:

```
Model
#include "em_cap.inc";

   EM_CAP_EPSR: 6.8;
   EM_CAP_T: ?0.157435?;

   EM_CAP  1 2 0
      EPSR=EM_CAP_EPSR  T=(EM_CAP_T * 1um);

   PORTS 1 0 2 0;

   CIRCUIT;

   MS_DB[2,2] = if (MS > 0) (20 * log10(MS)) else (NAN);
end
```

The labels "EM_CAP_EPSR" and "EM_CAP_T" represent the two parameters of the Empipe element "EM_CAP". The pair of question marks following the label "EM_CAP_T" indicates that the "T" parameter is defined as an optimization variable.

Redefining the Ports

The Model block contains this statement:

```
PORTS 1 0 2 0;
```

It reflects the fact that in the ".geo" file the capacitor is defined as a two-port, as depicted in Fig. 7.7, where nodes 1 and 2 represent the two electrodes and node 0 represents the substrate.

It will be more convenient to analyze the characteristics of the capacitor if we redefine the circuit as a one-port, as shown in Fig. 7.8.

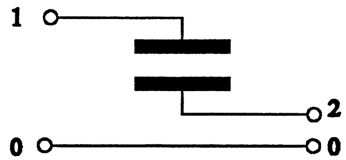


Fig. 7.7 The em port configuration for the capacitor.

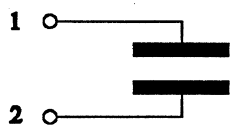


Fig. 7.8 The capacitor redefined as a one-port.

We can redefine the ports by editing the Model block. Change this statement

```
PORTS 1 0 2 0;
```

to

```
PORT 1 2;
```

OSA90 will automatically convert the two-port data produced by *em* to the appropriate one-port data.

We also need to modify another statement in the Model block:

```
MS_DB[2,2] = if (MS > 0) (20 * log10(MS)) else (NAN);
```

This formula for the two-port *S* parameters in dB is no longer applicable to the redefined one-port circuit.

Comment out the statement by inserting an exclamation mark at the beginning of the line, as

```
! MS_DB[2,2] = if (MS > 0) (20 * log10(MS)) else (NAN);
```

OSA90 treats any text following an exclamation mark as a comment (until the end of line).

Formulating Capacitance as User-Defined Response

Insert the following statement into the Model block just before the "end" line:

```
Capacitance = IY11 / (2 * PI * FREQ) * 1000;
```

The label IY11 represents the imaginary part of Y_{11}. OSA90 provides built-in labels for identifying the Y parameters: RY for the real parts and IY for the imaginary parts.

PI and FREQ are also built-in labels of OSA90, representing the constant π and the analysis frequency, respectively.

The default unit of FREQ is GHz. The multiplication by 1000 in the above formula converts the unit of Capacitance to pF.

OSA90 provides a comprehensive set of algebraic operations and mathematical functions to facilitate preprocessing of variables and postprocessing of responses. For further details please consult the *OSA90/hope User's Manual.*

The Modified Model Block

The Model block after the modifications should be as the following.

```
Model
#include "em_cap.inc";

   EM_CAP_EPSR: 6.8;
   EM_CAP_T: ?0.157435?;

   EM_CAP  1 2 0
      EPSR=EM_CAP_EPSR  T=(EM_CAP_T * 1um);

   PORT 1 2;

   CIRCUIT;

!   MS_DB[2,2] = if (MS > 0) (20 * log10(MS)) else (NAN);

   Capacitance = IY11 / (2 * PI * FREQ) * 1000;
end
```

Parameter Sweeps of EPSR and T

In order to display the user-defined response Capacitance, we need to include it in the Sweep block (which controls the simulation ranges and outputs). We also wish to examine the effect of varying the dielectric parameters on the capacitance. To do that we need to define parameter sweeps of EPSR and T. (You should follow the tutorial in Chapter 6, where we discussed parameter sweeps, if you have not already done so.)

The original Sweep block contains

```
Sweep
   AC: FREQ: 800MHz
       MS MS_DB PS
      {XSWEEP Title="MS11 and Spec"
       Y=MS11
       XMIN=799MHz XMAX=801MHz NXTICKS=2 X_title=FREQ
       SPEC=(at 800MHz, = 0.7)};
end
```

where the labels "MS", "MS_DB" and "PS" represent the *S*-parameter responses.

Modify the Sweep block as follows.

```
Sweep
   AC: FREQ: 800MHz
       EM_CAP_EPSR: 6 6.8 7.6
       EM_CAP_T: 0.1 0.2 0.3 0.4
       Capacitance;
end
```

The label EM_CAP_EPSR represents the parameter EPSR of the element EM_CAP and the label EM_CAP_T represents the parameter T. The user-defined response Capacitance is specified as the output.

Simulation and Display

Select "Compile Input File" from the "File" menu or press <F7>. Choose "Xsweep" from the "Display" menu. In the "Xsweep Display Options" dialog box, click on the line "EM_CAP_EPSR". From the list of available choices, click on "All Values"and press <Enter> or click on "OK" to continue.

The graphical display is shown in Fig. 7.9.

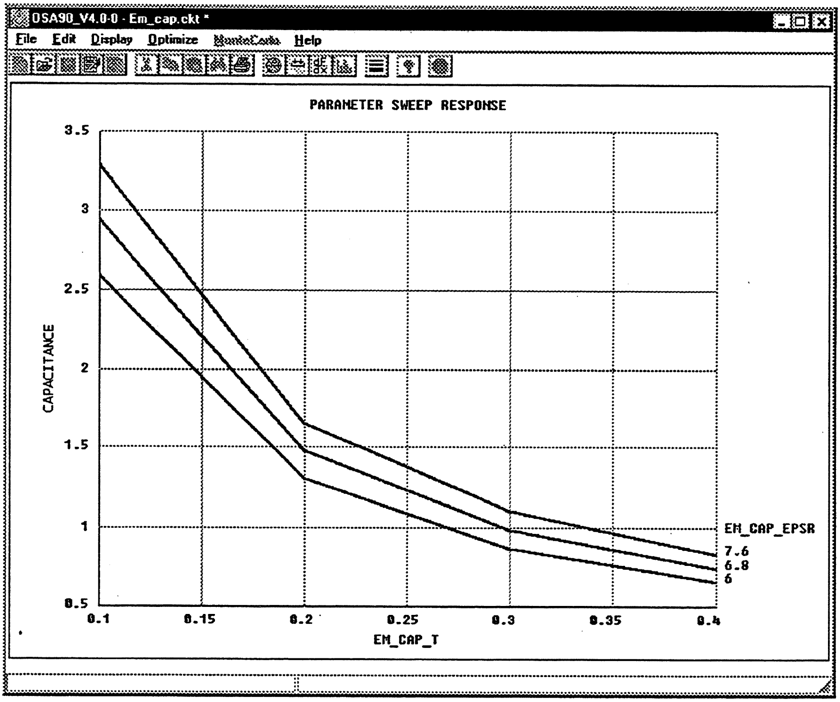


Fig. 7.9 Capacitance versus the dielectric layer thickness.

Capacitance Versus the Dielectric Constant

Choose "Xsweep" from the "Display" menu. In the "Xsweep Display Options" dialog box, click on the box "X-axis". From the list of choices, select "EM_CAP_EPSR". Click on the box "EM_CAP_T" and from the list of available choices click on "All Values". Press <Enter> or click on "OK" to continue..

The graphical display is shown in Fig. 7.10.

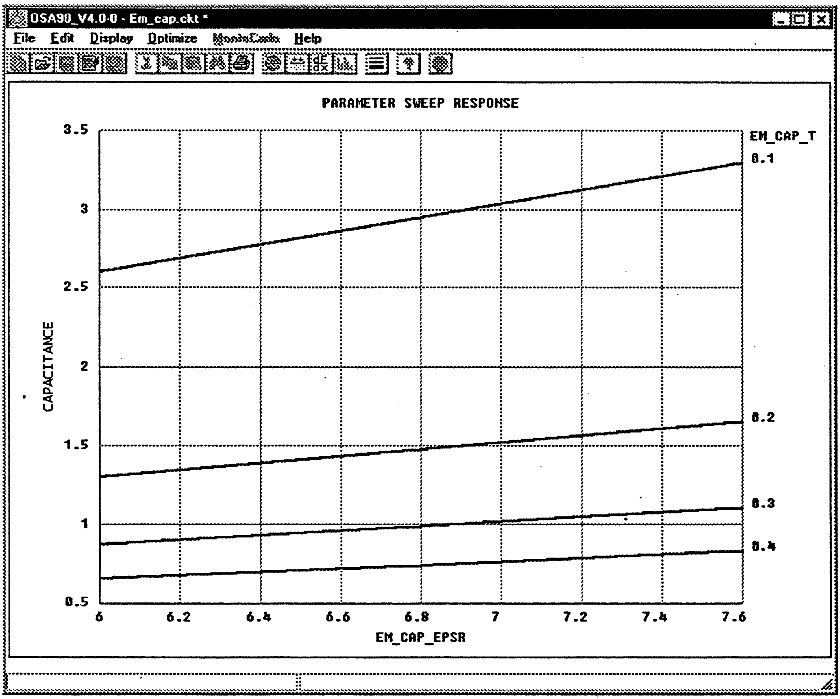


Fig. 7.10 Capacitance versus the dielectric constant.

7.5 Parametric Plots

The capacitance of an MIM capacitor is given by

$$C = A \epsilon / t$$

where A is the area of the metal (electrodes), ϵ is the dielectric constant (of the center layer) and t is the dielectric layer thickness. The results shown in Figs. 7.9 and 7.10 are consistent with this formula.

We can also use OSA90 to plot the capacitance versus $1/t$ instead of t. We can accomplish this using the parametric plot feature of OSA90. A parametric plot involves two responses, both of which are functions of the same sweep parameter. Instead of plotting a response versus the sweep parameter, we plot one response versus the other response.

For the example on hand, we will define $1/t$ as a user-defined response and then plot the capacitance (one response) versus $1/t$ (the other response), with t as the sweep parameter.

Editing the Input File

Select "Edit Input File" from the "File" menu.

In the Model block, the parameter t is represented by the label EM_CAP_T. Add to the Model block (just before the "end" line) this statement:

```
One_Over_T = 1 / EM_CAP_T;
```

The Model block after the modifications should contain the following.

```
Model
    ...
    ...

    Capacitance = IY11 / (2 * PI * FREQ) * 1000;
    One_Over_T = 1 / EM_CAP_T;
end
```

Then, include the label One_Over_T in the Sweep block as an additional response for the second sweep set, as

```
Sweep
   AC: FREQ: 800MHz
       EM_CAP_EPSR: 6 6.8 7.6
       EM_CAP_T: 0.1 0.2 0.3 0.4
       Capacitance One_Over_T;
end
```

Select "Compile Input File" from the "File" menu or press <F7>. Select "Parametric" from the "Display" menu. Press <Enter> or click on "OK".

The parametric plot of CAPACITANCE versus ONE_OVER_T is shown in Fig. 7.11. It clearly illustrates the linear dependence of the capacitance on $1/t$.

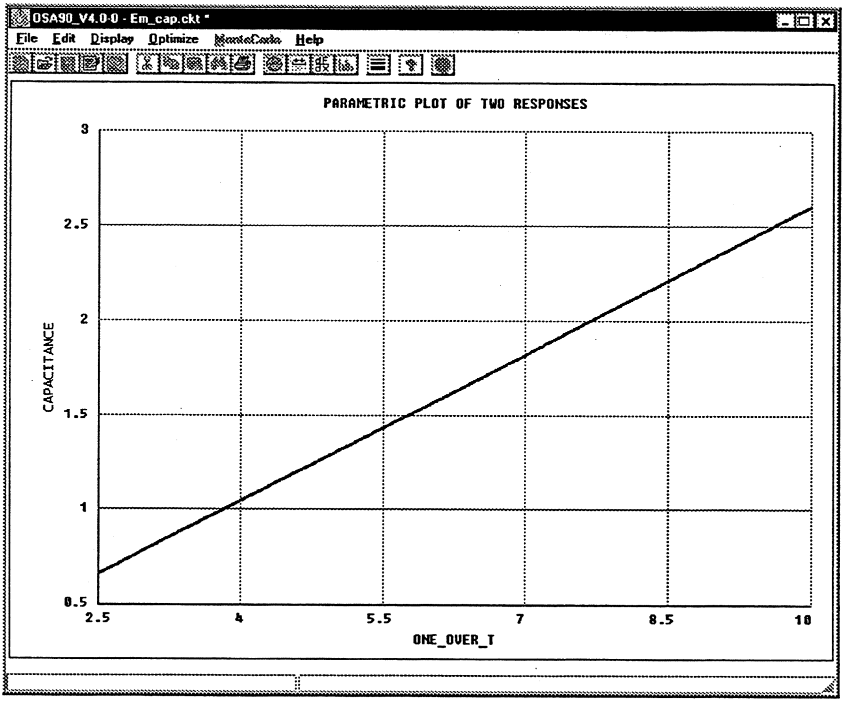


Fig. 7.11 Parametric plot of capacitance versus 1/t.

Concluding the Tutorial

Click on the "Cancel" button in the "Select Variables" window. This brings you back to the main window of Empipe. Click on the "Quit" button. You will be prompted whether you wish to save the project file. Click "No".

8

Empipe Geometry Capture

8

Empipe Geometry Capture

8.1 Introduction

We hope that the series of tutorials in Chapters 3 to 7 has acquainted you with the features and operations of Empipe.

The steps of using Empipe for EM optimization can be summarized as follows.

1 Start with a ".geo" file which represents the nominal structure.

2 Generate a set of ".geo" files which logically describes how the structure will evolve in relation to incremental changes in the designable parameters.

3 Invoke Empipe to process the set of ".geo" files by Geometry Capture.

4 Define optimization variables and specifications.

5 Perform simulation and optimization within the OSA90 environment.

6 Save the optimized geometry.

This chapter provides a formal description of the Geometry Capture procedure, focusing on steps 1 to 4.

8.2 Describing the Nominal Structure

The first step is to describe the nominal structure. You do this by creating a ".geo" file which contains, in accordance with the syntax specified by Sonnet Software, geometrical coordinates, substrate data, port definitions, etc.

Sonnet Software provides the *xgeom* program as the primary tool for manipulating ".geo" files. It also supply a utility program to convert GDSII files to ".geo" files.

Typically, the nominal geometry represents an initial design. It may be the result of a synthesis procedure, or an optimization using a circuit simulator, or an empirical design based on past experiences. As far as Empipe is concerned, it simply serves as a reference point.

em Analysis Control File

You also need an *em* analysis control file which defines the frequency points according to the syntax specified by Sonnet Software. By default, *em* analysis control files are given the extension ".an".

Testing the Files Before Using Empipe

We strongly recommend that you test the nominal ".geo" file and the analysis control file to make sure that they are acceptable to *em*. Empipe assumes that the ".geo" files provided to it are already validated. It does not perform a full-scale independent verification on the ".geo" file syntax.

Empipe Element Name

Each structure you wish to optimize using Empipe should be given a name. This name is also incorporated into the names of all the related files, serving as a common thread.

For example, the structure we considered in the tutorial of Chapter 4 is named "dfstub" (for double folded stub). The nominal ".geo" file is named dfstub0.geo, and the incremental ".geo" files are named dfstub1.geo, dfstub2.geo and dfstub3.geo. The *em* analysis control file is named dfstub.an. The Empipe element definition file is named dfstub.inc, the OSA90 input file is named dfstub.ckt, and the database file is named dfstub_1.dbs.

8.3 Creating Incremental Geo Files

You need to define a set of designable parameters. Typically they represent geometrical dimensions, but you can also include material parameters for the dielectric and metallization layers.

We use the terms "designable parameters" and "optimization variables" as two related but separate concepts. The designable parameters are candidates for optimization variables, but not all the designable parameters are necessarily optimized at the same time. Before an optimization starts, Empipe lets you choose which designable parameters are going to be optimization variables.

Empipe lets you define the designable parameters using the concept of Geometry Capture. It is general enough to accommodate arbitrary geometries and yet simple to understand and use.

Consider the example shown in Fig. 8.1. It has two designable parameters: W and L.

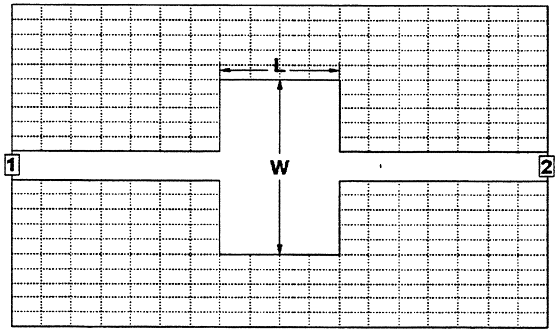


Fig. 8.1 A structure with two designable parameters.

Representing a Parameter by an Incremental Change

For each designable parameter, you need to create an additional ".geo" file. You make an incremental change in one of the designable parameters and show the corresponding change in the geometry with respect to the nominal structure.

Consider the example shown in Fig. 8.1. The incremental changes in the two designable parameters are illustrated in Fig. 8.2.

By comparing the nominal and incremental ".geo" files, Empipe automatically extracts the information necessary for translating a given set of parameter values to the corresponding geometrical coordinates.

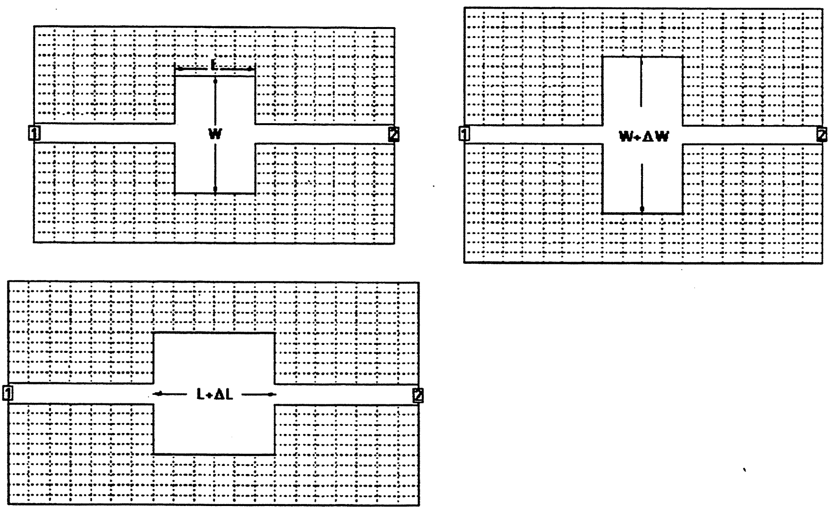


Fig. 8.2 Incremental changes in the parameters W and L.

Implicit Constraints On the Geometry

Geometry Capture allows you to express graphically subtle constraints on the geometry which are otherwise difficult to define.

For instance, the difference between Fig. 8.1 and Fig. 8.2 implies that the geometry remains symmetrical after changes in the parameter W. If we use Fig. 8.3 instead of Fig. 8.2 to represent an incremental change in the parameter W, then Empipe will interpret this as to imply that the parameter W has a one-sided effect on the geometry.

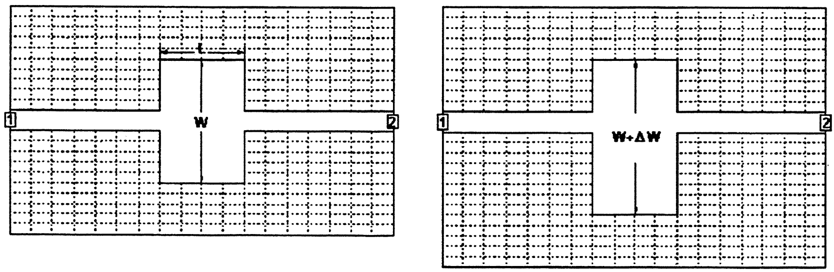


Fig. 8.3 One-sided incremental change in the parameter W.

Also, according to Fig. 8.2, the size of the substrate box varies with the parameter W to keep a constant margin between the metal and the substrate edges. If Fig. 8.4 is used instead of Fig. 8.2, then the substrate box size remains independent of the parameter W. (This would require, however, that the parameter W be bounded so that, as W may be increased during optimization, the metal will not grow beyond the substrate box. See the tutorial in Chapter 4 for an example on specifying bounds on variables.)

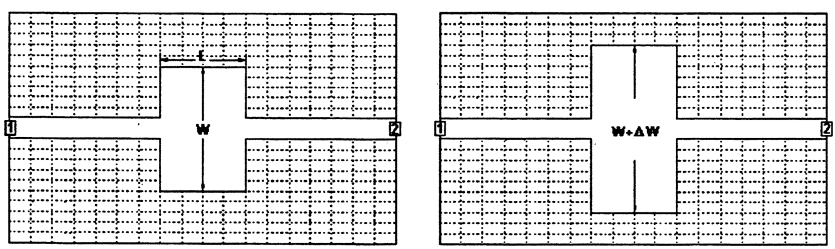


Fig. 8.4 The substrate box size is independent of the parameter W.

As another example, if Fig. 8.5 is used to represent an incremental change in the parameter L, the implication is that when L changes, the overall length of the structure remains the same. As the parameter L increases, the center polygon becomes longer and the feed lines become shorter, and vice versa.

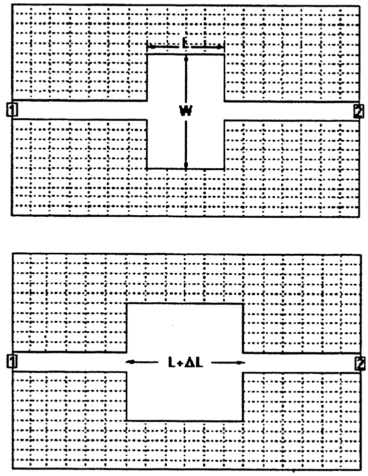


Fig. 8.5 A different definition of the parameter L.

Defining a Scaling Parameter

You can define parameters which scale the whole or part of the structure. For example, Fig. 8.6 represents an incremental change in a parameter which scales the center polygon in both the X- and Y-dimensions.

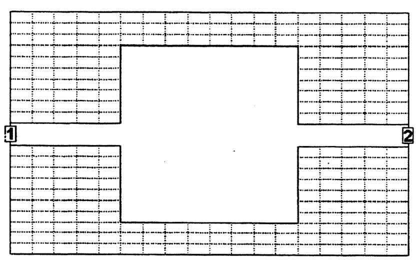


Fig. 8.6 Incremental change in a scaling parameter.

Rules for Creating Incremental Geo Files

The Cell Size Must Remain the Same

The *em* cell size in the incremental ".geo" files must remain exactly the same as that of the nominal ".geo" file. Parameter-dependent cell size is not permitted.

Be careful if you need to change the substrate box size. Be sure to choose the option of keeping the cell size constant when prompted by *xgeom*.

The Geometry Must Remain On-Grid

The nominal and incremental geometries must be on-grid. It means that the geometrical increments must be a multiple of the cell size.

You Cannot Add or Delete Polygons

The total number of polygons in the incremental ".geo" files must be identical to that of the nominal ".geo" file. Furthermore, the order in which the polygons appear in the ".geo" file must remain the same. When you need to stretch or shrink a polygon, utilize *xgeom*'s ability to move the individual vertices of the polygon. Sometimes you may think that instead of manipulating the vertices, it is easier just to delete the existing polygon and draw a new one. Do not do this, for *xgeom* may reshuffle the order of appearance of the polygons. This would confuse Empipe when it attempts to compare the ".geo" files.

You Cannot Change the Basic Shape of a Polygon

The basic shapes of the polygons in the incremental ".geo" files must remain the same as those of the nominal ".geo" file. For instance, you cannot change a polygon from a rectangle to a triangle.

8.4 Processing Geo Files by Empipe

Starting Empipe

To start Empipe, click on the "Empipe" icon located in the "Osa" program group.

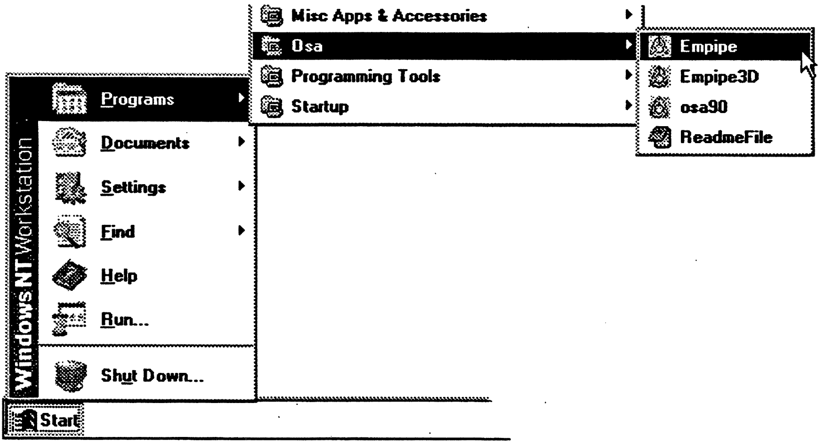


Fig. 8.7 Location of Empipe on the Start Menu

Empipe first looks for the file *name*.inc in the current directory as an indication of whether or not the structure has been processed before. If the file exists, Empipe will retrieve the data from the file. If the file does not exist, then Empipe assumes that *name* represents a new element to be defined. In this case, the Empipe main window will be mostly blank, as depicted in Fig. 8.8.

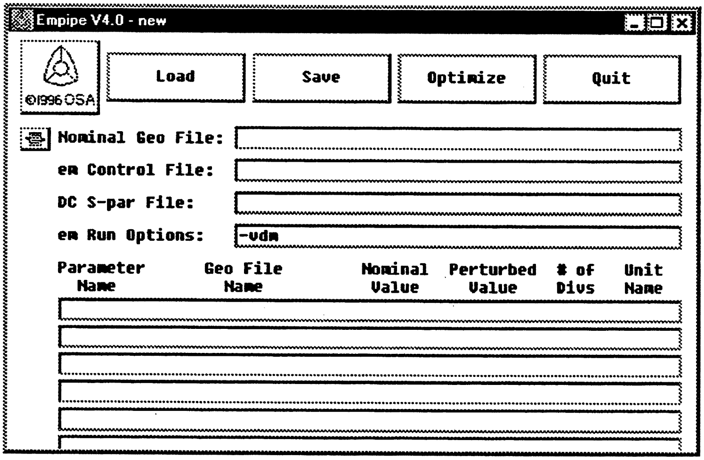


Fig. 8.8 Empipe Geometry Capture form editor.

Nominal Geo File

This entry identifies the nominal ".geo" file.

To change any entry in the form editor, click the left-hand mouse button on the box, and then type in the appropriate entry.


This button appears adjacent to the entry box. If you click on it, ***xgeom*** will be invoked to display the nominal ".geo" file.

em Control File

This entry identifies the ***em*** analysis control file. An analysis control file is required by ***em***. It defines the frequencies for the ***em*** analysis.

DC S-par File

This is an optional entry. You can specify a file which contains the *S* parameters of the structure at DC. This is needed only if you wish to involve the Empipe element in DC or harmonic balance simulation (available through the OSA90/hope program).

The ***em*** analysis produces *S* parameters for AC only. The DC *S* parameters have to be obtained by other means (using a circuit simulator, for instance).

In the DC *S*-parameter file, if given, the data must be arranged in the following order:

```
S11   S12   ...   S1n
S21   S22   ...   S2n

...

Sn1   Sn2   ...   Snn
```

where *n* is the number of ports and `S11 ... Snn` are real numbers (DC *S* parameters cannot have nonzero imaginary parts).

If DC *S* parameters are needed during a nonlinear circuit simulation but are not supplied, they will be extrapolated from the AC *S* parameters computed by ***em***. The impact on the accuracy of the results is unpredictable.

em Run Options

This entry allows you to specify the run-time options for ***em***. For a complete list of the available options, please check the ***em*** User's Manual from Sonnet Software. The default options are -vdm (verbose, automatic de-embedding and memory saver).

Empipe operates on the *S* parameters calculated by ***em***. The ***em*** run-time options "y" and "z" are incompatible with this requirement and therefore cannot be used.

Parameter Definition Data

The incremental changes for the designable parameters are described on the lines under the heading

```
Parameter   Geo File   Nominal   Perturbed   # of   Unit
  Name        Name      Value      Value     Divs   Name
```

Each line corresponds to one parameter. We will discuss the individual fields (columns) in the following.

Parameter Name

This can be an arbitrary ASCII string of no more than 32 characters, such as "W", "Width", "L1", "EPSR" or "Dielectric_Constant".

Geo File Name

This entry identifies the ".geo" file which describes the geometry of the structure after an incremental change in the parameter value is made.

 Click on this button to invoke *xgeom* to view the ".geo" file.

Nominal Value

This refers to the value of the parameter represented by the nominal ".geo" file. It should be entered as a plain number, for the physical unit, if any, is entered as a separate item.

Perturbed Value

This refers to the parameter value after the incremental change.

Number of Divs

This entry measures the incremental change in terms of the *em* grid size. It is obtained by dividing the difference between the nominal value and the perturbed value by the *em* cell size along the appropriate dimension.

For example, suppose that the parameter is changed from 100 to 110 (we leave out the physical unit, whatever it may be). The incremental change is 10. If the geometrical change is along the X dimension of the layout and the grid size for the X dimension is 5, then the number of divisions is 2.

However, sometimes in order to preserve the geometrical symmetry, you may need to make symmetrical perturbations with respect to the plane of symmetry. In this case, the "grid" for the Empipe Geometry Capture may be different from the *em* grid. Typically, the smallest symmetrical perturbation is two times the *em* cell size, and hence the correct entry for "# of Divs" is half the number of *em* cells covered by the perturbation. The tutorial example in Chapter 5 illustrates this concept in detail.

Unit Name

This entry identifies the physical unit of the parameter. Permissible unit names include IN (inch), MIL (milli-inch), M (meter), CM (centimeter), MM (millimeter), UM (micron) and NONE (without unit).

Defining Dielectric and Metallization Parameters

In addition to geometrical dimensions, you can also define designable parameters for the dielectric and metallization layers of the structure.

In a ".geo" file, each dielectric layer has five parameters, namely thickness of the layer, relative dielectric constant, dielectric loss tangent, relative permeability and magnetic loss tangent. Each type of metallization has three parameters, namely DC resistivity, skin effect coefficient and surface reactance.

You can select any of these parameters for optimization by providing Empipe with an incremental ".geo" file in which the dielectric or metallization parameter value of interest is different from that of the nominal ".geo" file.

em does not impose a grid on dielectric and metallization parameters, i.e., ***em*** can analyze structures with arbitrary dielectric and metallization parameter values. However, if we define a designable dielectric or metallization parameter without discretization, then during optimization whenever there is a change in that parameter value, no matter how small, ***em*** will have to be invoked to re-analyze the structure.

We can reduce the number of ***em*** simulations by imposing a discretization grid on each designable dielectric or metallization parameter. ***em*** will be invoked only if the parameter value has changed by more than one grid. For variations of the parameter value within one grid, Empipe will utilize interpolation to obtain simulation results. So long as we choose a grid that is reasonably small, this scheme will improve the efficiency without excessive loss of accuracy.

From the information you entered into the form editor, Empipe determines the size of the interpolation interval by dividing the difference between the nominal parameter value and the perturbed value by the number of divisions.

The tutorials in Chapters 6 and 7 demonstrate in detail the parameterization of dielectric and metallization layers.

Menu Buttons in the Empipe Main Window

`Load`

Click on this button to load a different Empipe element definition into the Empipe window. You be presented with the "Empipe Open File" dialog box. This box is the standard Windows "File Open" dialog box. Empipe element files end in ".inc".

Empipe then looks for the file *name*.inc. If it is found, the data contained in the file will be retrieved and displayed in the window. Otherwise, Empipe will assume that *name* identifies a new structure to be created. In either case, the data previously contained in the window is overwritten.

`Save`

Click on this button to save the current data in the Empipe window to a disk file. You be presented with the "Empipe Save File" dialog box. This box is the standard Windows "File Save" dialog box. The file will be saved with the extension ".inc".

The current name is offered as the default, but you have the opportunity to change it to a new name. Utilizing this feature, you can load an existing structure, make some modifications and then save it under a new name.

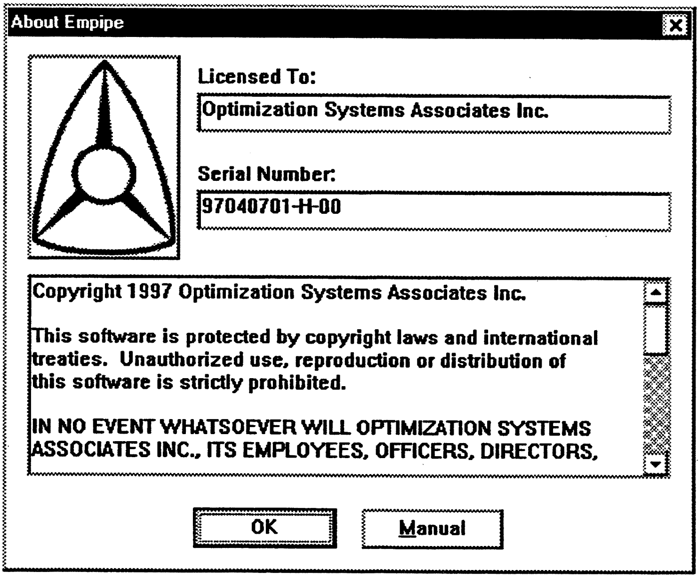
`Optimize`

Click on this button to start simulation and optimization. It leads to separate Empipe windows for selecting optimization variables and formulating design specifications, which is the subject of the following section (Section 8.5).

`Quit`

Click on this button to exit from Empipe.

This button provides information about your installation of Empipe. Clicking on this button will cause the "About Empipe" dialog box to appear. Contained in this dialog box is information regarding the licence. It also contains a "Manual" button for accessing the on-line version of the Empipe User's Manual.



8.5 Optimization Variables and Specifications

To initiate simulation and optimization, click on this button in the Empipe form editor:

`Optimize`

Two new windows entitled "Empipe Select Variables" and "Empipe Specifications" will appear, as depicted in Fig. 8.9.

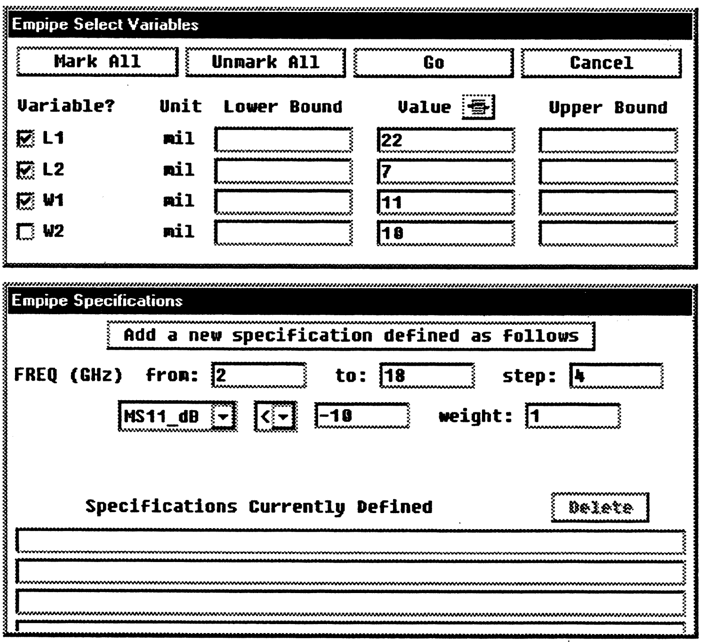


Fig. 8.9 The "Select Variables" and "Specifications" windows.

All the parameters are listed as candidates for optimization variables. For each parameter, there is a check box under the heading "Variable?" and adjacent to the parameter name. If you click on this box, a check mark will appear in the box to indicate that the associated parameter is selected as an optimization variable. If you click on the box a second time, the check mark will disappear. In other words, the check box acts as a toggle switch, turning on and off the status of selection.

Alternatively, you can click on the <Mark All> button to select all the parameters or the <Unmark All> button to undo the selection of all the parameters.

The <Go> and <Cancel> buttons apply to both the "Empipe Select Variables" and "Empipe Specifications" windows. Click on the <Go> button only after you have completed both windows. The <Cancel> button cancels both windows.

Value

The starting point (initial value) for each optimizable parameter is shown under the heading "Value". By default, it is set to the parameter's nominal value. If you wish to choose a different starting point, click on the entry box under "Value" and enter the desired value.

After Simulation and Optimization, the Optimized Solution is displayed under "Value".

You can click on the button to view the geometry of the starting point. This feature can also be used to generate new projects for arbitrary parameter values, as demonstrated in the tutorials of Chapters 4 and 5.

Upper and Lower Bounds

You can impose bounds on the optimization variables using the entry boxes under the headings "Lower Bound" and "Upper Bound".

During optimization, the parameter values are constrained within the lower and upper bounds if they are specified.

If the bounds are not given explicitly, they will be assigned automatically. Suppose that the starting point of a variable is x.

If the lower bound is not given explicitly, it is set to 0 if $x \geq 0$, or $-\infty$ if $x < 0$.

If the upper bound is not given explicitly, it is set to $+\infty$ if $x \geq 0$, or 0 if $x < 0$.

Specifications for Optimization

In general, the definition of a specification involves the following steps:

1. Select a frequency range.
2. Select an *S*-parameter response.
3. Select a specification type (upper, lower or equality specification).
4. Enter a numerical value as the goal.
5. Optionally, enter a weighting factor.

Selecting a Frequency Range

The frequency range definition line appears as

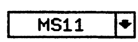
```
FREQ (GHz)   from: ...   to: ...   step: ...
```

The frequency range defined in the ***em*** analysis control file is offered as the default (if the analysis control file contains more than one frequency range, the first one is used).

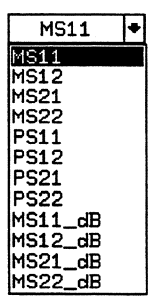
You can modify the frequency range as needed.

Selecting an S-Parameter Response

This is the entry box for selecting an *S*-parameter response:



To select a different *S*-parameter response, click on the arrow adjacent to the box. A list of available responses is displayed, similar to this one:



The label MSij represents the magnitude of S_{ij}, PSij represents the phase of S_{ij} in degrees, and MSij_dB represents the magnitude of S_{ij} in decibels.

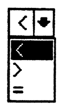
If the number of ports is more than 2, then the list will not show all the available responses at the same time due to the limited display area. A scroll bar will appear alongside the list to enable you to browse through different subsets of the available responses.

To select a response from the list, simply click on it. If you wish to cancel the list while it is shown, click the mouse button outside the list window.

Selecting the Type of Specification

The entry box for selecting the type of specification appears as

Click on the arrow and you will see the list of available choices:



The symbols "<", ">" and "=" represent upper, lower and equality specifications, respectively. To select a specification type, click on the appropriate symbol.

Entering a Numerical Value as the Goal

The third field on the specification line represents the numerical goal. To enter the goal, first click on the box and then type in the appropriate number. You may use the cursor keys, the <Back Space> key and the <Delete> key for editing, if necessary.

Optional Weighting Factor

You can enter an optional weighting factor. The default value is 1. To enter the weighting factor, first click on the box and then type in the appropriate number (the weighting factor must be a positive number). You may use the cursor keys, the <Back Space> key and the <Delete> key for editing, if necessary.

Completing the Definition of a Specification

Once you have selected the frequency range, the *S*-parameter response, the specification type, the numerical goal and, optionally, the weighting factor, click on the button

`Add a new specification defined as follows`

The specification you have just defined is added to the next available line under the heading "Specifications Currently Defined".

You can define up to 16 specifications with different frequency ranges, responses or goals.

Deleting a Specification

If you wish to change a specification which is already defined, you will have to delete the existing specification line and redefine it.

To delete a specification, click on the appropriate line under the heading "Specifications Currently Defined". You will see the button labelled "Delete", which was dimmed, changes to the normal color. Click on this "Delete" button to delete the selected specification line.

9

OSA90 Environment

9

OSA90 Environment

9.1 Introduction

OSA90 is a general-purpose simulation and optimization environment. It is included in the Empipe package to serve as the optimization engine. OSA90 is also marketed separately as a linear and nonlinear circuit CAD system.

OSA90 offers an impressive collection of state-of-the-art optimizers, including minimax, ℓ_1, ℓ_2 (least squares), quasi-Newton, conjugate gradient, Huber, simplex, random, simulated annealing and yield optimization algorithms.

OSA90 also offers a comprehensive set of algebraic operators and mathematical functions to facilitate user-defined pre- and post-processing of variables and responses. You can define labels, equations, conditional expressions (if and else), vectors and matrices. You can utilize built-in functions for matrix algebra, LU factorization, eigenvalues, eigenvectors, discrete Fourier transform, piece-wise linear and cubic spline interpolations, and so on.

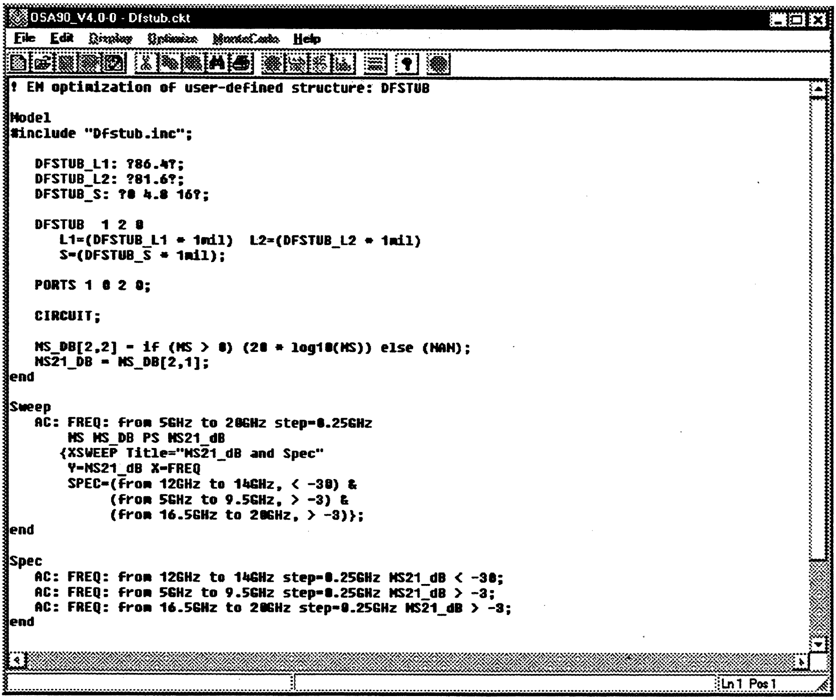
You can plot responses and functions in a variety of formats: parameter sweeps, parametric plots, Smith chart and polar plots, even 3D visualization and contours.

Tools for statistical analysis are also at your finger tip: uniform, normal, exponential, lognormal and sample distributions, absolute and relative tolerances, correlation matrices, Monte Carlo analysis, histograms, run charts and scattering diagrams.

You can also license the OSA90/hope option, which offers additional circuit simulation and optimization capabilities, including nonlinear DC, small-signal AC and nonlinear large-signal harmonic balance analyses, comprehensive libraries of nonlinear active device and linear passive element models, user-definable linear subcircuits, user-definable nonlinear device models. You can simulate, display and optimize DC and AC voltages, currents, *S*, *Y* and *Z* parameters, insertion loss, stability factor, group delay, large-signal harmonic distortion, compression, intermodulation products, intercept points, and more. You can optimize designs of small-signal amplifiers, power amplifiers, filters, mixers, frequency multipliers and oscillators. You can take advantage of the unique Datapipe technology to connect external software for functionally integrated simulation and optimization.

The wealth of features of OSA90 is covered in detail in a separate *OSA90/hope User's Manual.* In this chapter, we provide a summary of the input file structure and menu hierarchy, confined to the scope of Empipe applications.

9.2 OSA90 Window




```
! EM optimization of user-defined structure: DFSTUB

Model
#include "Dfstub.inc";

   DFSTUB_L1: ?86.4?;
   DFSTUB_L2: ?81.6?;
   DFSTUB_S: ?0 4.0 16?;

   DFSTUB  1 2 0
      L1=(DFSTUB_L1 * 1mil)  L2=(DFSTUB_L2 * 1mil)
      S=(DFSTUB_S * 1mil);

   PORTS 1 0 2 0;

   CIRCUIT;

   MS_DB[2,2] = if (MS > 0) (20 * log10(MS)) else (NAN);
   MS21_DB = MS_DB[2,1];
end

Sweep
   AC: FREQ: from 5GHz to 20GHz step=0.25GHz
        MS MS_DB PS MS21_dB
      {XSWEEP Title="MS21_dB and Spec"
       Y=MS21_dB X=FREQ
       SPEC=(from 12GHz to 14GHz, < -30) &
            (from 5GHz to 9.5GHz, > -3) &
            (from 16.5GHz to 20GHz, > -3)};
end

Spec
   AC: FREQ: from 12GHz to 14GHz step=0.25GHz MS21_dB < -30;
   AC: FREQ: from 5GHz to 9.5GHz step=0.25GHz MS21_dB > -3;
   AC: FREQ: from 16.5GHz to 20GHz step=0.25GHz MS21_dB > -3;
end
```

Fig. 9.1 OSA90 window.

The top of the window contains the menu bar and toolbar, the middle portion window is the input file (netlist) and located at the bottom of the window is the status bar.

9.3 OSA90 Input File

An OSA90 input file is like a netlist. It is an ASCII text file with the extension ".ckt". The input file contains definitions of parameters, variables, labels, models, responses, equations, frequency ranges, parameter sweeps, simulation outputs, optimization specifications, operation control options, statistical tolerances and distributions, etc.

The contents of an input file are divided into sections called file blocks. Each file block is designated to supply a particular type of information. Table 9.1 lists the input blocks that are relevant in the context of Empipe. More details are available in the *OSA90/hope User's Manual*.

TABLE 9.1 INPUT FILE BLOCKS

Block Name	Contents
MODEL	variables, labels, equations, models
SWEEP	simulation types, ranges, outputs
SPECIFICATION	optimization specifications
CONTROL	operation control options
MONTECARLO	statistical analysis ranges, outputs
STATISTICS	statistical correlation matrices
TRACE	record of optimization variables

Each input file block begins with a block name and ends with the keyword "end". Block names and keywords are case insensitive. For example, MODEL, Model and model are all treated as identical.

Contained within an input file block are statements. A statement consists of one or more lines of text and must always be terminated by a semicolon.

Example:

```
DFSTUB_L1: 86.4;
```

Here is an example of a multi-line statement:

```
DFSTUB  1 2 0
   L1=(DFSTUB_L1 * 1mil)  L2=(DFSTUB_L2 * 1mil)
   S=(DFSTUB_S * 1mil);
```

Example of OSA90 Input File: bend1.ckt

The following is the OSA90 input file for the double folded stub filter example used in the tutorial of Chapter 4. The file name is “dfstub.ckt”. We will dissect this file to illustrate the structure and syntax of the OSA90 input files.

```
! EM optimization of user-defined structure: DFSTUB

Model
#include "dfstub.inc";

   DFSTUB_L1: ?86.4?;
   DFSTUB_L2: ?81.6?;
   DFSTUB_S: ?0 4.8 16?;

   DFSTUB  1 2 0
      L1=(DFSTUB_L1 * 1mil)  L2=(DFSTUB_L2 * 1mil)
      S=(DFSTUB_S * 1mil);

   PORTS 1 0 2 0;

   CIRCUIT;

   MS_DB[2,2] = if (MS > 0) (20 * log10(MS)) else (NAN);
   MS21_DB = MS_DB[2,1];
end

Sweep
   AC: FREQ: from 5GHz to 20GHz step=0.25GHz
        MS MS_DB PS MS21_dB
       {XSWEEP Title="MS21_dB and Spec"
        Y=MS21_dB X=FREQ
        SPEC=(from 12GHz to 14GHz, < -30) &
             (from 5GHz to 9.5GHz, > -3) &
             (from 16.5GHz to 20GHz, > -3)};
end

Spec
   AC: FREQ: from 12GHz to 14GHz step=0.25GHz MS21_dB < -30;
   AC: FREQ: from 5GHz to 9.5GHz step=0.25GHz MS21_dB > -3;
   AC: FREQ: from 16.5GHz to 20GHz step=0.25GHz MS21_dB > -3;
end

Control
   Perturbation_Scale=1.0e-4;
   Optimizer=Minimax;
end
```

Comments

The first line of "dfstub.ckt" is a comment:

```
! EM optimization of user-defined structure: DFSTUB
```

OSA90 treats any text following an exclamation mark until the end of line as a comment.

Include Files

The first statement following the Model block header is

```
#include "dfstub.inc";
```

It instructs OSA90 to merge the contents of the file "dfstub.inc" into the body of the input file at the location where the #include directive appears.

The file "dfstub.inc" is generated by Empipe. It contains the parameterization data and ".geo" file for the double stub filter. The use of include files is an efficient and convenient way of merging information stored in separate files.

Labels and Optimization Variables

The next three statements in the Model block are

```
DFSTUB_L1: ?86.4?;
DFSTUB_L2: ?81.6?;
DFSTUB_S: ?0 4.8 16?;
```

These statements define labels representing optimization varibales.

In the OSA90 input file, optimization variables are delimited by a pair of question marks.

If there is only one number between the question marks, as

label: ?*x*?;

then x represents the starting point of the variable. The lower bound is implicitly set to 0 if $x \geq 0$, or $-\infty$ if $x < 0$. The upper bound is set to $+\infty$ if $x \geq 0$, or 0 if $x < 0$.

If there are three numbers between the question marks, then they represent the lower bound, the starting point and the upper bound of the variable, respectively.

You can also define labels to represent numerical constants, vectors, matrices and formulas. For details see *OSA90/hope User's Manual*.

Element Model

The next statement in the Model block is

```
DFSTUB  1 2 0
   L1=(DFSTUB_L1 * 1mil)  L2=(DFSTUB_L2 * 1mil)
   S=(DFSTUB_S * 1mil);
```

It refers to the Empipe element named DFSTUB. Following the element name are three integers representing the connection nodes. Following the nodes are the parameters of the element. In this case the parameter values are assigned through the use of labels. You can also assign parameter values directly using numerical constants, optimization variables and formulas (expressions).

Example:

```
DFSTUB  1 2 0
   L1=86.4mil  L2=?81.6mil?
   S=(3 * 1.6mil);
```

If you have licensed the OSA90/hope option then you can use the circuit model libraries, including nonlinear active device models and a large selections of linear elements.

Port Definition

Ports of the circuit are defined by this statement in the Model block:

```
PORTS 1 0 2 0;
```

The double folded stub filter is defined as a two-port. In general, for an *n*-port, the keyword PORTS is followed *n* pair of nodes, each pair (two consecutive nodes) defines one of the ports.

A related keyword PORT can be used to define a single port, followed by a pair of nodes.

The CIRCUIT Statement

The statement

```
CIRCUIT;
```

indicates the completion of the circuit definition. When the file parser encounters this statement, it checks the connections of the whole circuit and, if no error is found, generates the circuit response labels.

Defining Responses

OSA90 has a set of predefined circuit response labels, such as those listed in Table 9.2.

TABLE 9.2 RESPONSE LABELS

Label	Response
MS*ij*	magnitude of S_{ij}
PS*ij*	phase of S_{ij}
RS*ij*	real part of S_{ij}
IS*ij*	imaginary part of S_{ij}
RY*ij*	real part of Y_{ij}
IY*ij*	imaginary part of Y_{ij}
RZ*ij*	real part of Z_{ij}
IZ*ij*	imaginary part of Z_{ij}
GD*ij*	group delay

In addition to the scalar labels listed in Table 9.2, you can also use matrix labels by omitting the indices. For instance, MS represents the matrix of all MS*ij*, i.e., the magnitude of all S parameters. The dimension of such matrices is $n \times n$, where n is the number of ports.

From these predefined labels, other responses can be derived using expressions. For instance, the last two statements in the Model block of the file "bend1.ckt" define the S-parameter responses in dB:

```
MS_DB[2,2] = if (MS > 0) (20 * log10(MS)) else (NAN);
MS11_DB = MS_DB[1,1];
```

The first statement defines a 2 by 2 matrix MS_DB to be calculated from the built-in response label MS. The second statement establishes an alias for the matrix element MS_DB[1,1].

These statements are generated by Empipe according to the responses involved in the specifications you have defined for optimization.

Sweep Block

The Sweep block defines frequency range and simulation outputs. In the file "dfstub.ckt", the Sweep block contains

```
AC: FREQ: from 5GHz to 20GHz step=0.25GHz
    MS MS_DB PS MS21_dB
   {XSWEEP Title="MS21_dB and Spec"
    Y=MS21_dB X=FREQ
    SPEC=(from 12GHz to 14GHz, < -30) &
         (from 5GHz to 9.5GHz, > -3) &
         (from 16.5GHz to 20GHz, > -3)};
```

The leading keyword AC indicates the simulation type as small-signal AC (the OSA90/hope option, if licensed, supports two additional types of simulation: DC and harmonic balance).

Following the keyword AC is the frequency range definition. After that is the list of response labels. The next five lines define a graphical view, which is used to tailor the format of the graphical display.

In generating the OSA90 input file, Empipe automatically selects the response(s) of interest (primarily the ones for which specifications are given) to be included in the Sweep block. For the double folded stub filter, the specifications are imposed on the response MS21_dB, therefore MS21_dB is included in the response labels. The specifications on MS21_dB are included in the graphical view definition, so that they will be superimposed on the plot.

Specification Block

The statements in the Spec block represent the specifications you have defined in Empipe. The syntax of these statements are quite self-explanatory. The Spec block in the file "dfstub.ckt" contains

```
AC: FREQ: from 12GHz to 14GHz step=0.25GHz MS21_dB < -30;
AC: FREQ: from 5GHz to 9.5GHz step=0.25GHz MS21_dB > -3;
AC: FREQ: from 16.5GHz to 20GHz step=0.25GHz MS21_dB > -3;
```

Control Block

The Control block allows you to modify the default setting of a number of options of OSA90. The Control block in the file "dfstub.ckt" contains

```
Perturbation_Scale=1.0e-4;
Optimizer=Minimax;
```

It defines the perturbation scale for estimating gradients. This particular value is found to be a good choice for Empipe applications. It also selects the minimax optimizer according to the type of specifications involved.

9.4 OSA90 Menus

Near the top of the OSA90 window is the menu area, where the menu options are presented.

You can use the mouse to highlight the different menu options. As you do so, the status bar displays a brief comment on the function of the highlighted option.

To select a menu option, you can click the left-hand mouse button on the desired option.

The OSA90 menu is summarized in Table 9.3.

TABLE 9.3 OSA90 MENU OPTIONS

Menu Option	Brief Description
File	reads, edits, parses and saves files
Edit	provides access to cut, copy and paste
Display	calculates and displays responses and functions
Optimize	initiates optimization
MonteCarlo	performs statistical (Monte Carlo) analysis
Help	where to go when you need help

On-Line Help

OSA90 comes complete with an on-line copy of its users manual. Should you need help on any features in OSA90, you can press <F1>.

9.5 OSA90 File Editor

OSA90 has a built-in full screen ASCII text file editor. Primarily, it allows you to create, retrieve, modify and save input files for OSA90.

File and Edit Menus

The screen editor features search and replace, cut and paste, undo, printing, and more. The editor is integrated with the file parser to make syntax error detection and correction convenient and friendly.

The various editor options, hot keys and toolbar buttons are listed in Table 9.4 and their functions listed in Table 9.5.

TABLE 9.4 FILE AND EDIT MENUS

Menu Option	Hot Key	Toolbar Button
File	**Alt + F**	
➥Open	Ctrl + O	
➥Save	Ctrl + S	
➥Save As		
➥New	Ctrl + N	
➥Edit Input File	Ctrl + E	
➥Compile Input File	F7	
➥Print	Ctrl + P	
➥Online Manual	F1	
➥Exit	Alt + F4	
Edit	**Alt + E**	
➥Undo	Ctrl + Z	
➥Cut	Ctrl + X	
➥Copy	Ctrl + C	
➥Paste	Ctrl + V	
➥Select All	Ctrl + A	
➥Find	Ctrl + F	
➥Replace	Ctrl + R	

TABLE 9.5 FILE AND EDIT MENU FUNCTIONS

Option	Brief Description
Open	opens an existing file
Save	saves the current input file
Save As	saves the current input file under a different name
New	creates a new input file
Edit Input File	returns to editing mode
Compile Input File	compiles the input file and checks for syntax errors
Print	prints the current contents of the OSA90 main window
Online Manual	displays the online manual.
Exit	exits OSA90
Undo	undoes the last edit or change to the input file
Cut	deletes selected text and places it on the clipboard
Copy	copies selected text to the clipboard
Paste	places the contents of the clipboard at the current cursor location
Select All	selects the text of the entire file
Find	searches the file for the specified text
Replace	replaces specified text with alternate text

9.6 OSA90 Display

The OSA90 "Display" menu options allow you to view the responses calculated by *em* in a variety of formats. The "Display" menu options are listed in Table 9.6.

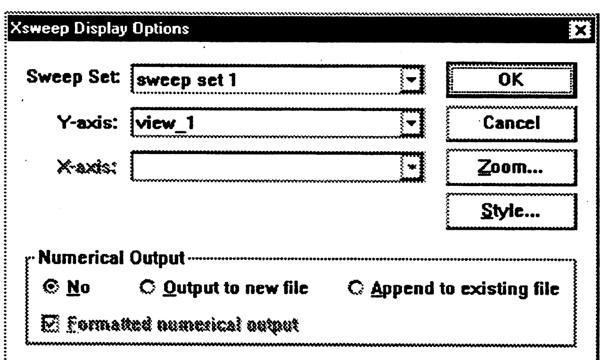
TABLE 9.6 DISPLAY FORMATS

Option	Brief Description
Xsweep	displays one or more responses versus frequency or a parameter
Parametric	displays one or more responses versus another response
Array	displays elements of an array
Waveform	displays time-domain waveforms (for the OSA90/hope option)
Smith	displays Smith charts and polar plots
Visual	displays 3D visualization and contours

Xsweep Display

The "Xsweep" option under the "Display" menu provides the most typical format of presentation:

a rectangular plot of one or more response labels versus the frequency or another parameter. When you select Xsweep, a dialog box will appear.



Defining a Parameter Sweep

A very useful feature is to display responses versus model parameters. For instance, you may ask OSA90 to sweep the miter parameter "*d*" of the waveguide bend and then display the *S*-parameter responses versus the parameter "*d*".

First, you have to define the parameter sweep in the Sweep block of the OSA90 input file. For example:

```
Sweep
   AC:   FREW: 2GHz;
         EM_RES_RDC: 150 200 250
         MS11;
end
```

The parameter label ("EM_RES_RDC" in the example) must be followed by a colon ":".

You can assign a set of discrete values for the sweep parameter, as shown in the above example. You can also assign a set of uniformly spaced points with an interval:

```
EM_RES_RDC: from 100 to 300 step=50
```

This translates into a set of values for EM_RES_RDC as 100, 150, ..., 300.

You can also specify the number of divisions within the sweep interval:

```
EM_RES_RDC: from 100 to 300 N=4
```

This translates into a step size of (300 - 100) / 4 = 50. Consequently, the parameter EM_RES_RDC will be swept for these values: 100, 150, ..., 300.

Parameter sweeps with exponential step size are also possible. See the *OSA90/hope User's Manual* for detail.

Selecting a Sweep Parameter for the X-axis

If you have defined a parameter sweep in addition to a frequency sweep, then you can select to display the response(s) versus either the frequency or the sweep parameter.

In the dialog box for the Xsweep display, click on the "X-axis:" option. The available choices are presented from which you can make a selection.

Selecting Response Labels for the Y-axis

For sweep sets which contain multiple response labels, you can choose to display one of the responses or all of the responses. In the dialog box for the Xsweep display, click on the "Y-axis:" option. The available choices are presented from which you can make a selection.

9.7 OSA90 Optimization

The choices available for the "Optimize" menu option are listed in Table 9.7. By default, Empipe selects a suitable optimizer based on the type of specifications you have defined.

TABLE 9.7 OPTIMIZERS AND OBJECTIVE FUNCTIONS

Optimizer	Gradient-Based	Objective Function
L1	Yes	L1
L2	Yes	L2
Minimax	Yes	Minimax
Quasi-Newton	Yes	Generalized L2, L2, Sum of Errors
Conjugate Gradient	Yes	Generalized L2, L2, Sum of Errors
Huber	Yes	Huber, Huber+
One-Sided L1	Yes	One-Sided L1
Random	No	Generalized L2, L1, L2, Minimax, Sum of Errors
Simplex	No	Generalized L2, L1, L2, Minimax, Sum of Errors
Simulated Annealing	No	Generalized L2, L1, L2, Minimax, Sum of Errors

Number of Iterations

This option in the dialog box allows you to limit the maximum number of iterations. The optimizer will stop once this limit is reached even if a solution within the desired accuracy has not been found. If this happens, the best set of values of the variables (in terms of minimizing the objective function) is presented as the solution.

Accuracy of Solution

This option allows you to specify the desired accuracy of the solution. The optimization will stop when the step size separating the current step and the next step is smaller than the specified accuracy. The step size is relative to the norm of the variable vector.

Show Downhill Iterations Only

During optimization, OSA90 displays the iteration count and current value of the objective function on the screen. By default, this information is displayed at every iteration.

For example:

```
Iteration   1/30 Max Error=8.14511
Iteration   2/30 Max Error=6.34936
Iteration   3/30 Max Error=1.53442
Iteration   4/30 Max Error=0.553539
Iteration   5/30 Max Error=-0.19606
Iteration   6/30 Max Error=-0.213403
Iteration   7/30 Max Error=-0.213773
Solution  Max Error=-0.213773
```

Of the iteration count, the first number is the current iteration and the second one is the maximum number of iterations specified. For example, 3/30 means that the current iteration is the 3rd out of a maximum of 30.

Sometimes it is possible to observe the value of the objective function getting larger than that of a previous iteration. In the example, the 6th iteration produces a higher objective function value than that of the 5th iteration. This is not unusual. It is a part of the optimization algorithm.

You can instruct the program to display only those iterations that lead to a better (smaller) objective function value than the previous ones. You can do so by checking the "show downhill iterations only" box in the optimization dialog box. You may find this especially desirable for the random optimizer, since it usually requires a large number of random explorations which result in fluctuating objective function values.

10

Empipe Database

10

Empipe Database

10.1 Database Index

Empipe employs a database system to avoid duplicate ***em*** analyses. Every time Empipe invokes ***em***, the simulation results are stored in a database, together with the corresponding parameter values. Subsequently, when ***em*** analysis results are needed, Empipe checks the database first.

Empipe database file names have the form of

*element*_*i*.dbs

where *element* identifies the Empipe element and *i* is an integer index. For example, the database file name for the double folded stub filter tutorial in Chapter 4 is dfstub_1.dbs.

The database index is used to distinguish different versions of the same structure. The default index is 1.

Normally, there are few reasons to create a new database index. One reason may be to compare the results of different versions of ***em*** by storing them in separate database files.

The only way to change the database index is to modify the OSA90 input file. Locate within the input file the Empipe element reference and add the INDEX parameter.

Example:

```
DFSTUB  1 2 0
   INDEX=2
   ...
```

The database created after this modification will be named dfstub_2.dbs.

Note, however, that dfstub_2.dbs will start out as an empty file. It will not contain the data stored in dfstub_1.dbs, which means that all the ***em*** simulations saved in dfstub_1.dbs will have to be repeated when they are needed.

You can disable the database mechanism entirely by assigning INDEX = 0. This instructs Empipe to ignore the database and always invoke ***em*** for EM simulation. Furthermore, the EM simulation results will not be saved in any database files. We did this in Chapter 4 intentionally in order to track the ***em*** simulation in real time.

10.2 Converting Database to ASCII Data File

As part of the Empipe package, a utility program called **dbs2dat** is provided to facilitate converting Empipe database files to ASCII data files.

Usage:

```
dbs2dat database datafile
```

where *database* denotes the name of an existing Empipe database file and *datafile* is the name of the output file which will contain the converted data.

Example:

```
dbs2dat tpad_1.dbs tpad.dat
```

where **tpad_1.dbs** is the database for the distributed attenuator example used in Chapter 5. The converted data written to **tpad.dat** is partially shown as follows.

```
Data From File tpad_1.dbs (Last Modified on  Aug  8 18:46:35 1995)

N_PARS 4
N_FREQS 5
N_PORTS 2

 22 7 11 10
   2 0.232043 -9.294 0.254789 -8.861 0.254789 -8.861 0.219005 -8.365
   6 0.228578 -26.21 0.250072 -25.69 0.250072 -25.69 0.219694 -24.25
   10 0.23058 -41.3 0.246908 -41.57 0.246908 -41.57 0.225596 -39.17
   14 0.240537 -55.55 0.247087 -57.32 0.247087 -57.32 0.238017 -53.63
   18 0.257626 -69.58 0.250045 -73.42 0.250045 -73.42 0.256298 -67.93

 24 7 11 10
   2 0.260873 -8.773 0.237937 -8.83 0.237937 -8.83 0.24862 -8.102
   6 0.25735 -25.16 0.233402 -25.62 0.233402 -25.62 0.249128 -23.54
   10 0.259171 -39.97 0.230408 -41.43 0.230408 -41.43 0.254695 -38.2
   14 0.268684 -54.11 0.230634 -57.1 0.230634 -57.1 0.266466 -52.52
   18 0.284987 -68.12 0.233517 -73.13 0.233517 -73.13 0.283883 -66.78

  ......
  ......

 12 6 9 10
   2 0.076526 -15.09 0.33132 -8.934 0.33132 -8.934 0.053164 -11.27
   6 0.07177 -39.58 0.324903 -25.96 0.324903 -25.96 0.054182 -30.2
   10 0.071289 -54.6 0.320292 -41.99 0.320292 -41.99 0.061107 -43.4
   14 0.079908 -64 0.319902 -57.81 0.319902 -57.81 0.075948 -54.69
   18 0.098237 -72.76 0.322978 -73.92 0.322978 -73.92 0.098448 -66.38
```

In the data file, a header line identifies the source database, followed by three lines listing the number of parameters, the number of frequencies and the number of ports, respectively.

The data is divided into data sets, separated by a blank line. Each data set begins with a list of parameter values, followed by the *S* parameters. For example, the first data set in tpad.dat is

```
22 7 11 10
  2 0.232043 -9.294 0.254789 -8.861 0.254789 -8.861 0.219005 -8.365
  6 0.228578 -26.21 0.250072 -25.69 0.250072 -25.69 0.219694 -24.25
  10 0.23058 -41.3 0.246908 -41.57 0.246908 -41.57 0.225596 -39.17
  14 0.240537 -55.55 0.247087 -57.32 0.247087 -57.32 0.238017 -53.63
  18 0.257626 -69.58 0.250045 -73.42 0.250045 -73.42 0.256298 -67.93
```

The first line shows the values of the four parameters, in the same order as they appear in the Empipe form editor (in this case they are L1, L2, W1 and W2, see Chapter 5).

The next five lines correspond to the five frequencies. The data on each line represents

```
FREQ MS11 PS11 MS21 PS21 MS12 PS12 MS22 PS22
```

where FREQ denotes the frequency (in GHz), MS*ij* denotes the magnitude of S_{ij} and PS*ij* denotes the phase of S_{ij} (in degrees).

Database Files from Earlier Versions of Empipe

The conversion of a database created by Empipe Version 3.1 (or later) to an ASCII data file is fully automated.

The utility can also be applied to database files created by earlier versions of Empipe. If such a database represents an Empipe library element (see Chapter 12), then the process is also fully automated. If the database represents an arbitrary structure defined by Geometry Capture, then you will be prompted to specify the number of parameters, the number of frequencies and the number of ports, for this information was not stored in the earlier versions of Empipe database.

Note that the Empipe program itself has no problem reading database files of an earlier version, because it already has all the necessary information.

10.3 Creating Database from Data File

A utility program called dat2dbs is included in the Empipe package. It can be used to create an Empipe database file from an ASCII data file.

Usage:

```
dat2dbs datafile database
```

where *datafile* denotes the name of an existing ASCII data and *database* is the name of the database file to be created.

Example:

```
dat2dbs tpad.dat tpad_2.dbs
```

where tpad.dat is produced by dbs2dat from tpad_1.dbs, as described in Section 10.2. The resulting database tpad_2.dbs should contain the same data as in tpad_1.dbs.

In general, the data file must contain a header like this

```
N_PARS  n1
N_FREQS n2
N_PORTS n3
```

where *n1*, *n2* and *n3* denote the number of parameters, the number of frequencies and the number of ports, respectively.

Editing Empipe Database

By combining the two utility programs dbs2dat and dat2dbs, you will be able to edit the contents of an Empipe database in three steps.

1. Use dbs2dat to convert an existing database to a data file.

2. Edit the data file using a text editor. You can delete unwanted data sets to trim down an oversized database. You can manually expand the database by adding new sets of *S* parameters produced by ***em*** (the ***em*** outputs can be included directly without editing). You can even modify the numbers, but that is cheating.

3. Use dat2dbs to convert the edited data file to a new database, perhaps using an index different from the original database.

11

Response Interpolation

11

Response Interpolation

11.1 Linear and Quadratic Interpolations

Empipe utilizes response interpolation in order to accommodate parameter values which do not exactly fall on the predefined discretization grid required by ***em***.

The type of interpolation is user-selectable by means of the Empipe element parameter MODEL. For example:

```
DFSTUB  1 2 0
   MODEL=2
   ...
```

Possible values for MODEL are listed in Table 11.1.

TABLE 11.1 MODEL CHOICES

Value	Description
0.	interpolation disabled
1	linear interpolation (this is the default value)
2	quadratic interpolation
3	linear interpolation based on S parameters, magnitude and phase
4	quadratic interpolation based on S parameters, magnitude and phase
5	linear interpolation based on Y parameters, real and imaginary parts
6	quadratic interpolation based on Y parameters, real and imaginary parts
7	linear interpolation based on S parameters, real and imaginary parts
8	quadratic interpolation based on S parameters, real and imaginary parts
9	linear interpolation based on Z parameters, real and imaginary parts
10	quadratic interpolation based on Z parameters, real and imaginary parts

The choices 1 and 2 represent the default schemes for linear and quadratic interpolations, respectively. Currently, the choices 1 and 2 are mapped to 3 and 4, respectively. This may be replaced in future releases by more sophisticated schemes.

Disabling Response Interpolation

The response interpolation feature can be entirely disabled by setting MODEL=0. In this case, any off-grid parameters are simply snapped to the nearest on-grid values, as illustrated in Fig. 11.1.

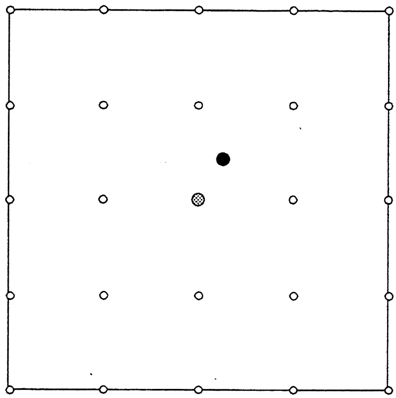


Fig. 11.1 *Interpolation disabled: the off-grid point (solid) is snapped to the nearest on-grid point (shaded).*

Linear Interpolation

Linear interpolation of an off-grid point requires ***em*** analyses at $n + 1$ base points, where n is the number of parameters whose values are off-grid. The placement of the base points is illustrated in Fig. 11.2.

Linear interpolation is adequate when the grid size is sufficiently small that the variation of the response of interest within one cell can be approximated with reasonable accuracy by a linear function.

Quadratic Interpolation

Quadratic interpolation generally provides more accurate results than linear interpolation, at the expense of increased computational effort. Quadratic interpolation of an off-grid point requires ***em*** analyses at $2 \times n + 1$ base points, where n is the number of parameters whose values are off-grid. The placement of the base points for quadratic interpolation is illustrated in Fig. 11.3.

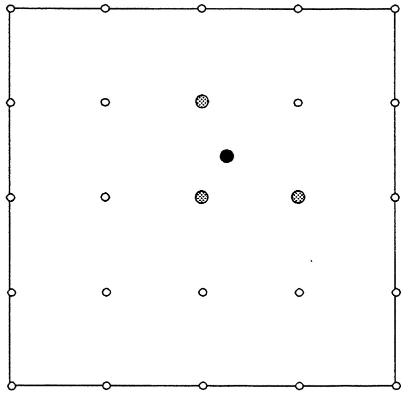


Fig. 11.2 The base points (shaded) needed for linear interpolation of an off-grid point (solid).

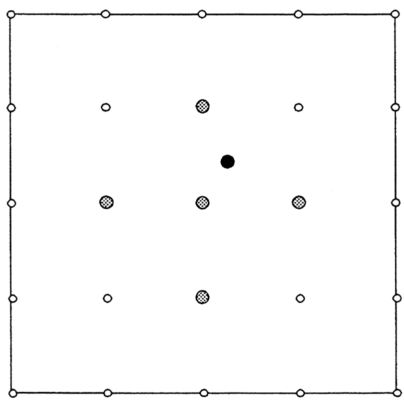


Fig. 11.3 The base points (shaded) needed for quadratic interpolation of an off-grid point (solid).

11.2 Choosing S, Y or Z Parameters

In using interpolation, a problem may arise when the response function to be interpolated has a local minimum or maximum with respect to the frequency and its location on the frequency axis shifts significantly between two base points.

Consider the illustration in Fig. 11.4. The two solid lines represent the response MS11 at two base points. The response has a local minimum with respect to the frequency and its location changes from 8.53 GHz for one base point to 8.72 GHz for the other base point. A linear interpolation applied to these two base points leads to the erroneous result depicted by the dashed line in Fig. 11.4.

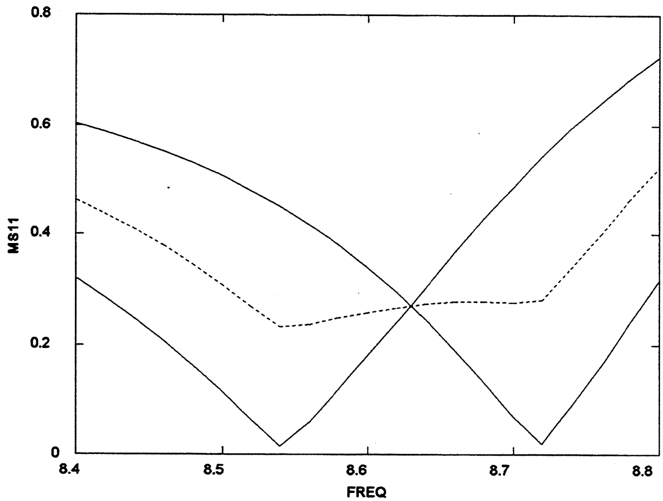


Fig. 11.4 A problem with interpolation.

If you encounter this problem, you can reduce its severity by using a finer grid or a set of more densely spaced frequencies. Unfortunately, this means you will have to repeat the ***em*** simulation.

A more efficient remedy is to choose the *Y* or *Z* parameters instead of the *S* parameters as the response functions used in the interpolation. This can solve the problem if the *Y* or *Z* parameters do not contain any shifting minima or maxima. The most significant advantage of this solution is that it does not require any new ***em*** simulation. Empipe first converts the *S* parameters to the *Y* or *Z* parameters, performs the interpolation and then converts the results back to *S* parameters.

Currently, you have to choose the *Y* or *Z* parameters manually on a trial and error basis. An automated scheme is under development.

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