RF Module

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RF Module

The Three Stub Tuner

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PREFACE

This book is one of the books in the *Multiphysics Modeling Series*. Each book in the series is designed to model an important Multiphysics problem or process in a highly focused manner. In the case of this book, the problem chosen is that of modeling a component that is widely used in a diverse number of industrial applications. The modeling software employed is COMSOL Multiphysics (version 4.3a) and this model employs the RF Module. The specific model built is upwardly compatible with later versions of the COMSOL Multiphysics software through the import function.

The waveguide device modeled here specifically demonstrates the exploration of a small, but very important, subset of components of the family of microwave hardware devices designed to facilitate the optimized transfer of power from the generating source to the consuming load. Each of those components is called, in electronics terminology, a Tuned Stub.

A stub is a length of transmission line or waveguide that is connected to an active circuit at one end only. This book models a rectangular waveguide with three adjustable stubs distributed along the upper surface of the waveguide. The waveguide stubs are hollow, as is the waveguide, and they are each electromagnetically connected to the inner cavity, at right angles to the central axis of the waveguide via an aperture in the wall of the waveguide. In this model, three (3) stubs have been added, at appropriate locations along the length of the waveguide, to optimize the tuning performance.

The first portion of this book builds the Three Stub Tuner Model using a step-by-step process to ensure that the model is easily and correctly built. The second portion of this book explores the consequences of changing the length of different individual Stubs through Variations on the Three Stub Tuner Model.

INTRODUCTION

Microwave signals need to be clear and undistorted to ensure accurate information transfer. The primary function of many waveguide systems is to convey complex, broad power range, wave-based, electromagnetic signals from the generating or receiving source to the consuming or input load with a minimum of signal dissipation and/or distortion. Because waveguides are of great technological importance and application diversity, they are designed and manufactured in a large range of wave-length-specific, application-dictated, shapes, sizes, and configurations.

In this book, the COMSOL Multiphysics RF Module software (version 4.3a) is employed to perform a two-port S-parameter analysis of a Three Stub Tuner in the range of 2.2 to 3.3 GHz.

The primary advantage of using COMSOL Multiphysics software is the breadth of built-in functions available in the diverse collection of Multiphysics modules. Additionally, when the need arises, another advantage afforded by using the COMSOL Multiphysics software is the inherent capability of the software to allow the modeler to modify or create, as needed, suitable equations for insertion into the model for the calculation of the model parameters or for the incorporation of data into visualization plots.

In the case of this 3D model, the equation for the calculation of the Voltage Standing Wave Ratio (VSWR) was added to those equations normally incorporated into the COMSOL Multiphysics software. The quantity VSWR is a measure of the power transfer match and also, indirectly of the potential signal dispersion and/or distortion.

CHAPTER 1

MODELING METHODOLOGY USING COMSOL 4.X

1.1 COMPUTATIONAL HARDWARE CONSIDERATIONS

There are two fundamental rules for choosing the platform that will support successful modeling with COMSOL 4.x. The first rule is to be sure to determine the minimum system requirements that the employed version of 4.x requires before choosing the computer to run your new modeling software. The model developed in this book uses COMSOL Multiphysics 4.3a. The model in this book can be built using COMSOL Multiphysics software Version 4.3a or later. The modeling software needs to be installed in either a Microsoft Windows® or a Macintosh OS X® operating systems environment.

COMSOL Multiphysics 4.3a software supports shared memory parallelism under both the Microsoft Windows and the Macintosh OS X operating systems. Distributed memory parallelism is supported on a Microsoft Windows Cluster, using a COMSOL Floating Network

License. Neither distributed memory nor cluster computing will be covered in this book.

The second rule of successful modeling is that the modeler should run 4.3a on the platform with the highest processor speed and the most memory obtainable. It is, in general, the rule that the model processing speed increases in proportion to instruction size (32 bit, 64 bit), the core speed, the number of platform cores, and to the amount of usable available memory.

The platforms that this author uses are an Apple Mac Pro®, and a MacBook Pro® running Mac OS X version 10.7.x. Those platforms have four (4) 3 GHz cores and 16 GB of RAM. Both platforms are configured for 64-bit processing and run at the 64-bit rate when using 4.3a.

1.2 FIRST PRINCIPLES AS APPLIED TO MODEL DEFINITION

A First Principles Analysis is derived from the fundamental laws of nature. In the case of the model considered in this book or when developing additional models from any other source material, the reader needs to be able to show that the calculated results obtained from the model are consistent with the laws of physics and with the expected properties of materials employed in the building of the model. In the case of this Non-Relativistic (Classical) Physics Analysis, the physical laws of conservation require that what goes in (as mass, energy, charge, etc.) must come out (as mass, energy, charge, etc.) or must accumulate within the boundaries of the model. To do otherwise violates fundamental physics principles.

The reader must be able to determine by inspection of the model that the appropriate factors for the material properties of each domain and for the boundary conditions have been considered in the development of the specifications for the particular geometry. He must also be knowledgeable of the implicit assumptions and default specifications that are normally incorporated into the COMSOL Multiphysics software model. Failure to consider the results of incorporation of the default specifications can lead to errors and to subsequent failure of the model.

1.3 SOME COMMON SOURCES OF MODELING ERRORS

There are four primary sources of common modeling errors: insufficient initial analysis, insufficient concern for critical details, lack of a proper understanding of the basic principles required for the creation of an adequate model, and an insufficient understanding of the basic defining details needed to yield an adequate model to yield correct answers to the fundamental questions required to fulfill the needs of the modeling goals.

Primarily, the most frequent modeling errors are those that result from the model builder exercising insufficient attention to either the development of the details of the model or the incorporation into the model of conceptual errors and/or the generation of keying errors during data/parameter/formula entry.

One major source of errors occurs during the process of naming variables. The model builder should be careful to never give the same name to his variables as COMSOL gives to the default variables {1, 2, 3}. COMSOL Multiphysics software seeks a value for the designated variable everywhere within its operating domain. When two or more variables have the same name, an error is created.

Human errors can best be avoided by using uniquely distinguishable characters in variable names. For example, if at all possible, never use a lower case L, a number 1, and/or an upper case I, which in some fonts are relatively indistinguishable. Similarly, do not use an upper case O and/or the number 0. Give your variables meaningful names (T_input, T_output, T_high, etc.). Also, variable names are case-sensitive, i.e., T_input is not the same as T_INPUT.

The first rule in model development is to clearly understand the exact problem you plan to solve and then specify in detail what aspects of the problem you plan to address in the model that you build. The specifications of the modeling problem to be solved should include a list of the magnitudes and of the relative contribution provided by the particular physical properties of the materials employed in the model that are vital to the functioning of the anticipated model. Also, you need to determine the relative degree of interaction between the employed materials.

Always build your initial model to solve for the minimum necessary information. It will converge more rapidly. A more comprehensive model can always be developed at some time in the future.

You should carefully investigate the problem that you wish to understand. Then build your model carefully. Typical physical properties that are probably coupled in any developed model are heat and geometrical expansion/contraction (liquid, gas, solid), current flow and heat generation/reduction, phase change and geometrical expansion/contraction (liquid, gas, solid) and/or heat generation/reduction, and chemical reactions. There may also be others.

Having done the initial model evaluation analysis and written a hierarchical list, you should then estimate the best physical, least coupled, lowest dimensionality model building approach to achieve the most meaningful First Approximation Model.

CHAPTER 2

APPLICABLE RF THEORY

2.1 ELECTRICAL IMPEDANCE THEORY

The concept of electrical impedance, as used in Alternating Current (AC) theory, is an expansion on the basic concept of resistance as illustrated by Ohm's Law, in Direct Current (DC) theory. Ohm's Law was discovered by Georg Ohm and as published in 1827 {4}, is:

$$I = \frac{V}{R} \tag{2.1}$$

Where: I = Current in Amperes [A]

V = Voltage (Electromotive Force) in Volts [V]

R = Resistance in Ohms [ohm].

In AC theory, both voltage (V) and current (I) alternate periodically as a function of time. Typically, the alternating behavior (frequency (f)) of the voltage and current are separately represented as either a single sinusoidal wave or as a sum of several sinusoidal waves. The analysis of complex waveforms is typically handled by Fourier {5} Analysis.

In this case, however, for clarity, the exploration of the concept of impedance will be confined to single frequency analysis. The concept of impedance was developed and named by Oliver Heaviside {6} in 1886. Arthur E. Kennelly {7} reformulated impedance in the currently used complex number formulation in 1893.

The first factor that needs to be considered when expanding modeling calculations from the DC realm (frequency equals zero ($f=0$)) to the AC realm (frequency greater than zero ($f>0$)) is that the resistance (R) maps into the impedance (Z), as follows {8}:

$$Z = R + j\left(\omega L - \frac{1}{\omega C}\right) = R + jX = \left(R^2 + X^2\right)^{1/2} e^{j\tan^{-1}(X/R)} \quad (2.2)$$

Where: Z = Complex Impedance [ohm]

R = Resistance in Ohms [ohm]

$j = (-1)^{1/2}$ (imaginary unit)

$\omega = 2\pi f$ = Angular Frequency

X = Reactance [ohm]

L = Inductance [henry]

C = Capacitance [farad].

A second factor that needs to be considered by the modeler when modeling in the AC realm is the skin depth (δ) {9}. In any material, as a function of the complex permittivity {10}, electromagnetic waves (AC) will be attenuated (dissipated, turned into heat, etc.) and shifted in phase as a function of the distance (depth) traveled in that material.

Consider, for example, for a transverse electromagnetic wave propagating in the Z direction, the voltage relationship would be expressed as follows:

$$E_x = E_0 * e^{-kz} = E_0 * e^{-\alpha z} * e^{-j*\beta z} \quad (2.3)$$

Where: E_x = Transverse Electromagnetic wave propagating in the Z direction

E_0 = Scalar Voltage Amplitude

k = Complex Propagation constant

$j = (-1)^{1/2}$

e = Base of Natural Logarithms

a = Attenuation Constant

β = Wave Solution Constant

And where a is:

$$a = \omega * \left(\frac{\mu\varepsilon}{2} \left(1 + \left(1 + \left(\frac{\sigma}{\omega\varepsilon} \right)^2 \right)^{\frac{1}{2}} \right) \right)^{\frac{1}{2}} \tag{2.4}$$

And where:

ε = permittivity

μ = permeability

ω = angular frequency

σ = conductivity.

For a good conductor, where $1 << \sigma/\omega\varepsilon$, the 1's in the above equation can be ignored and then a becomes:

$$a = \sqrt{\frac{\omega\mu\sigma}{2}}. \tag{2.5}$$

The skin depth (δ) is the point at which the amplitude of the signal of interest decreases to $E_0{}^*e^{-1}$.

Therefore, δ is:

$$\delta = \frac{1}{a}. \tag{2.6}$$

CHAPTER 3

DESIGNING THE THREE STUB TUNER MODEL

A stub {11} is a length of transmission line or waveguide that is connected to the active circuit at one end only. The stub can be either open-circuited or short-circuited at the unconnected end. In this case, the stubs are short-circuited at the unconnected end and there are three stubs distributed along the length of the waveguide segment. See Figure 1.

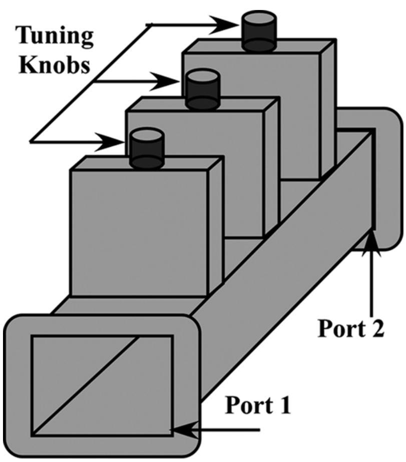


FIGURE 1. Three Stub Tuner.

Figure 1 shows a diagram of a section of rectangular waveguide with three adjustable stubs distributed along the upper surface of the waveguide. The Figure 1 configuration is the basis of the model in this book. Each of the waveguide stubs is a hollow rectangular cavity in a similar manner to the primary waveguide.

Each stub is orthogonally mechanically coupled, as shown in Figure 1, to the primary inner waveguide cavity, via an aperture in the top-wall of the waveguide. These stub-connected apertures in the top-wall electromagnetically couple the stubs to the main waveguide cavity {12}.

The stubs are short-circuited at the unconnected end and open-circuited at the waveguide-connected end. Rotating each knob shown in Figure 1, at the top of each stub, varies the electrical and the mechanical length of each stub. Stub tuners may be designed to have any number of stubs (1, 2, 3, etc.). However, consideration must be given to such factors as ease of tuning and cost of fabrication. See Figure 2.

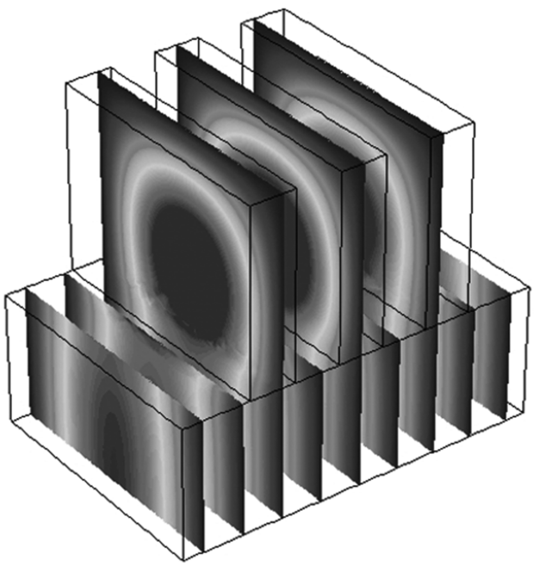


FIGURE 2. Three Stub Tuner Calculated Field-Distribution Solution.

As can be seen in the calculated field-distribution solution displayed in Figure 2, three (3) stubs have been appended along the length of the waveguide to strive for an optimized performance of the final tuner design. The construction details of this model are presented and discussed in the body of this book.

CHAPTER 4

BUILDING THE THREE STUB TUNER MODEL USING THE RF MODULE IN COMSOL MULTIPHYSICS 4.X

In this book, the RF Module of the COMSOL Multiphysics software (version 4.3a) is employed to perform a two-port S-parameter analysis of a three stub tuner in the range of 2.2 to 3.3 GHz, the electromagnetic field results of which are shown in Figure 2.

S-parameter analysis {13, 14} is one of a number of different methodologies that can be used to analyze the properties of circuits at RF and microwave frequencies. The S-parameter methodology employs matched-load terminations at each of the ends of the main waveguide, rather than using short-circuit or open-circuit terminations. The use of S-parameter methodology lends itself well for use in the processing of complex matrices and complex matrix calculations.

The Model Builder Tree of the completed COMSOL Multiphysics model is shown in Figure 3.

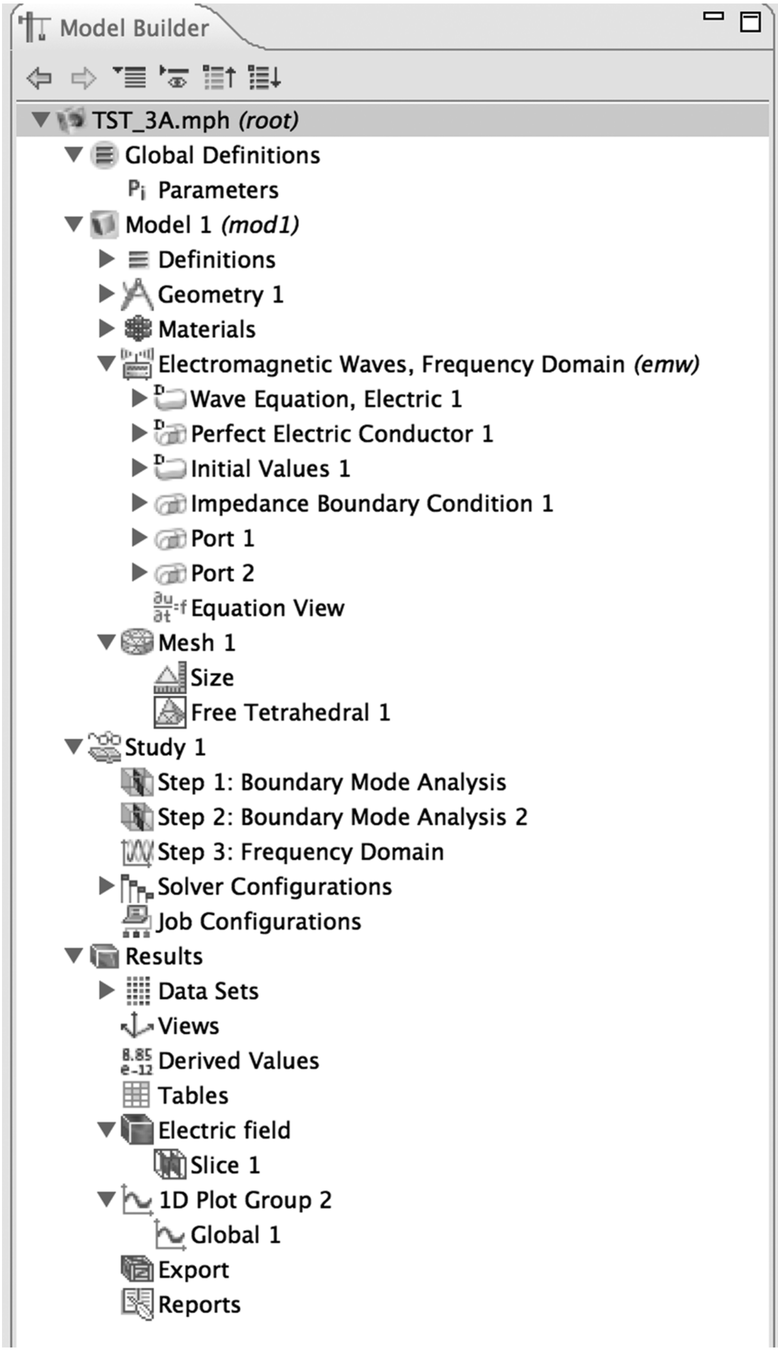


FIGURE 3. The Completed Three Stub Tuner Model Builder Tree.

4.1 BUILDING THE THREE STUB TUNER MODEL

You may start building the Three Stub Tuner Model on the COMSOL Multiphysics Desktop in Model Builder by:

Select > 3D

Click > Next

Select > Radio Frequency > Electromagnetic Waves, Frequency Domain (emw)

Click > Add Physics

Click > Next

Select > Custom Studies > Empty Study

Click > Finish (Flag)

Click Geometry 1

Select Length unit mm from the Pull-down bar in the Geometry window

Click Build All

Figure 4 shows the initial Model Builder Tree.

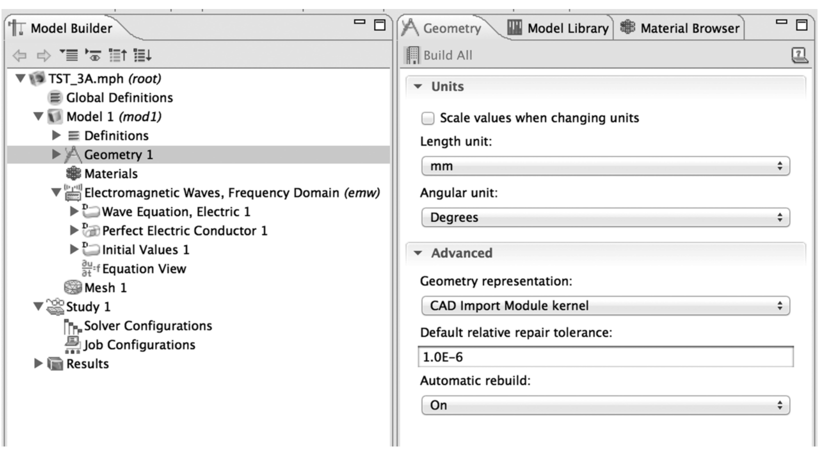


FIGURE 4. Initial Three Stub Tuner Model Builder Tree.

In the next set of steps, the 3D Three Stub Tuner Model is configured to use Boundary Mode Analysis {15, 16, 17}. Using Boundary Mode Analysis sets up the parametric configuration for the creation and analysis of the Three Stub Tuner Ports, Port 1 (Input) and Port 2 (Output).

Right-Click > Study 1 in the Model Builder

Select > Study Steps > Boundary Mode Analysis

See Figure 5.

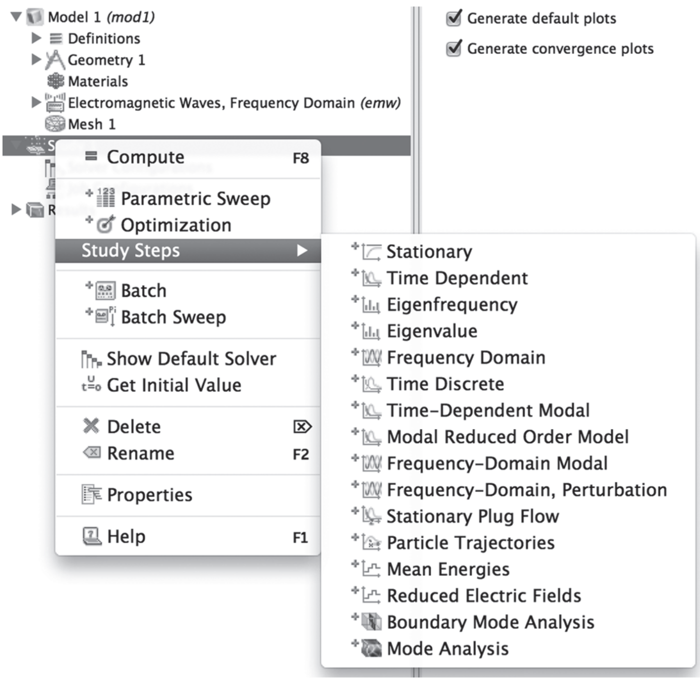


FIGURE 5. Boundary Mode Analysis Selection.

TABLE 1. Boundary Mode Analysis Step Settings

Parameter	**Step 1**	**Step 2**
# of modes	1	1
Search for modes	50	50
Transform	out of plane	out of plane
Port name	1	2
Analysis frequency	2.45[GHz]	2.45[GHz}

Configure Step 1: Boundary Mode Analysis Settings as shown in Table 1.

Figure 6 shows the Boundary Mode Study settings for Step 1 as configured.

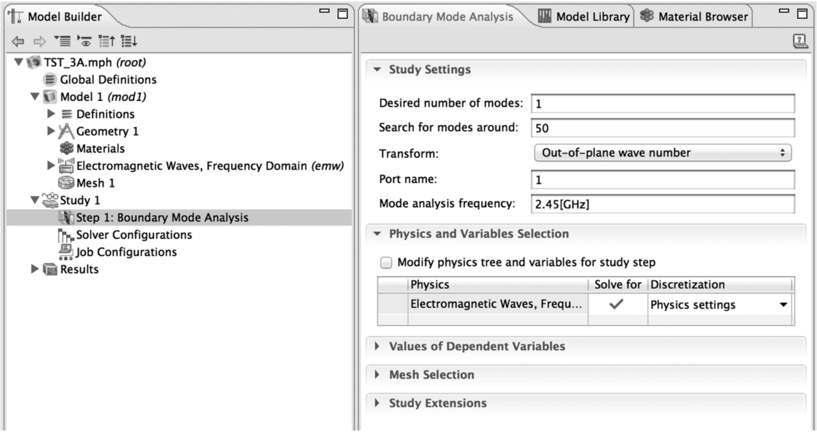


FIGURE 6. Boundary Mode Analysis Study Settings, Port 1.

Configure Step 2: Boundary Mode Analysis Settings as shown in Table 1.

Figure 7 shows the Boundary Mode Study Settings for Step 2 as configured.

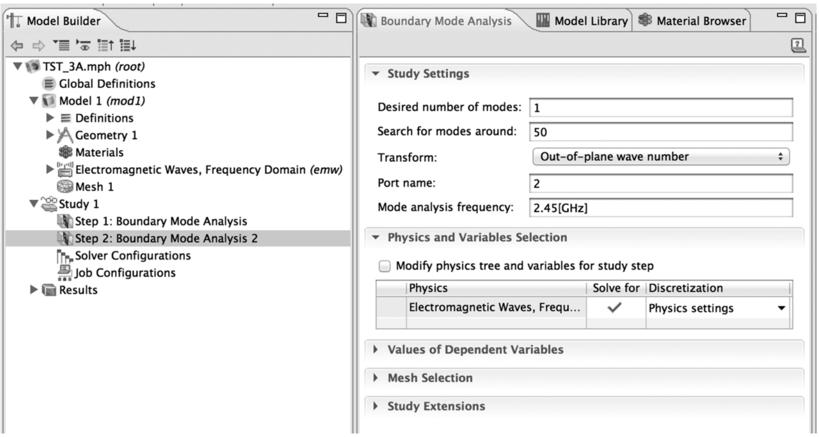


FIGURE 7. Boundary Mode Analysis Study Settings, Port 2.

TABLE 2. Frequency Domain Settings

Step	Value
Start	2.2e9
Step	1.1e9/49
Stop	3.3e9

Right-Click > Study 1 in Model Builder

Select > Study Steps > Frequency Domain, Step 3

Figure 8 shows Step 3 selection.

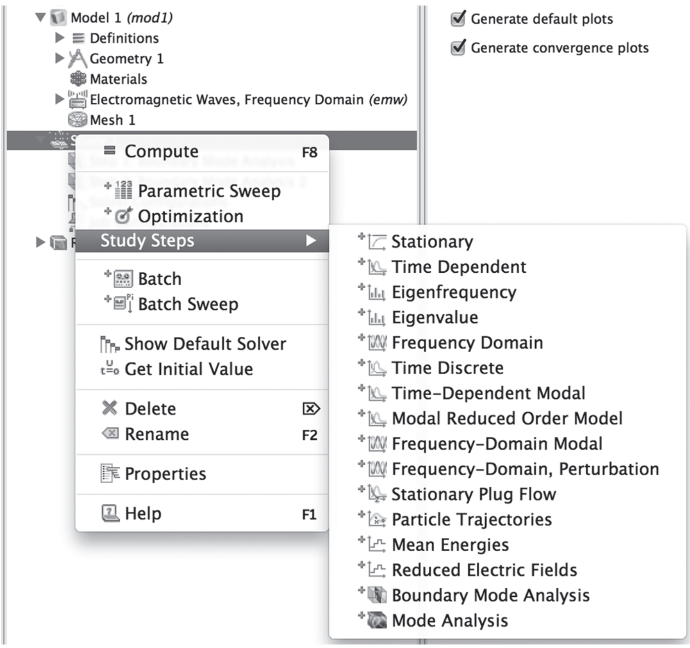


FIGURE 8. Frequency Domain, Step 3 Selection.

The Frequency Domain Settings are shown in Table 2.

Click > Step 3: Frequency Domain

Select > Frequency Domain settings window

Click > the Range Settings button

Enter the parameters shown in Table 2

See Figure 9.

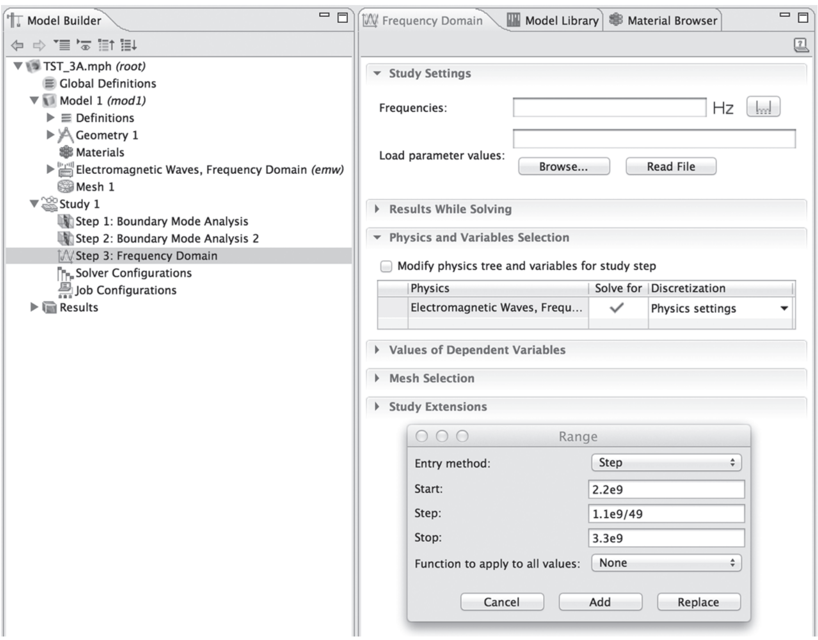


FIGURE 9. Frequency Domain, Step 3 Settings, as Configured.

4.2 THE THREE STUB TUNER MODEL GEOMETRY

The Three Stub Tuner geometry comprises the union of 4 rectangular prisms. The prism configuration data is defined in Table 3. In this model, the parameters are collected in one location so that they can be conveniently modified, if needed.

TABLE 3. Three Stub Tuner Geometry Parameters

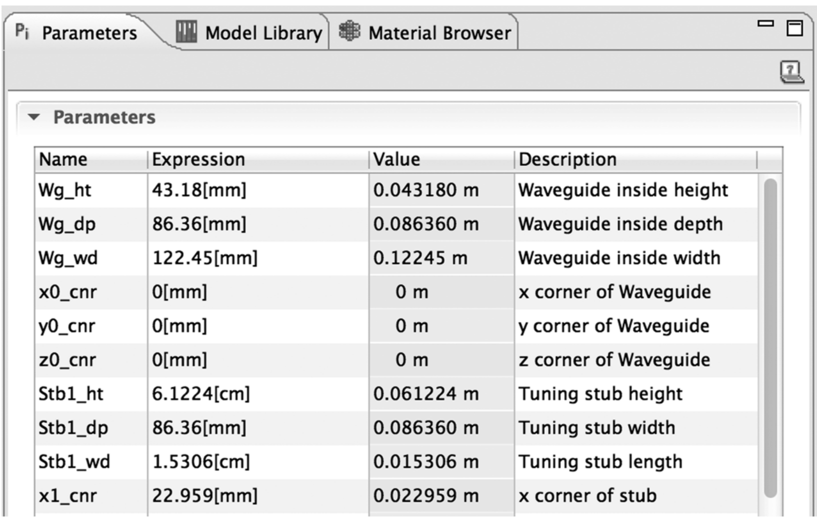
Parameter	Value	Description
Wg_ht	43.18[mm]	Waveguide inside height
Wg_dp	86.36[mm]	Waveguide inside depth
Wg_wd	122.45[mm]	Waveguide inside width
x0_cnr	0[mm]	x corner of Waveguide
y0_cnr	0[mm]	y corner of Waveguide
z0_cnr	0[mm]	z corner of Waveguide
Stb1_ht	6.1224[cm]	Tuning stub height
Stb1_dp	86.36[mm]	Tuning stub width
Stb1_wd	1.5306[cm]	Tuning stub length
x1_cnr	22.959[mm]	x corner of stub
y1_cnr	0[mm]	y corner of stub
z1_cnr	43.18[mm]	z corner of stub
Stb2_ht	6.1224[cm]	Tuning stub height
Stb2_dp	86.36[mm]	Tuning stub width
Stb2_wd	1.5306[cm]	Tuning stub length
x2_cnr	53.571[mm]	x corner of stub
y2_cnr	0[mm]	y corner of stub
z2_cnr	43.18[mm]	z corner of stub
Stb3_ht	6.1224[cm]	Tuning stub height
Stb3_dp	86.36[mm]	Tuning stub width
Stb3_wd	1.5306[cm]	Tuning stub length
x3_cnr	84.184[mm]	x corner of stub
y3_cnr	0[mm]	y corner of stub
z3_cnr	43.18[mm]	z corner of stub
sigma_wall	6.3e7[S/m]	Wall conductivity

The data from Table 3 should be entered in the model, as follows:

Right-Click > Global Definitions > Select Parameters

Enter the Table 3 data in the Parameters edit window

See Figure 10.



Name	Expression	Value	Description
Wg_ht	43.18[mm]	0.043180 m	Waveguide inside height
Wg_dp	86.36[mm]	0.086360 m	Waveguide inside depth
Wg_wd	122.45[mm]	0.12245 m	Waveguide inside width
x0_cnr	0[mm]	0 m	x corner of Waveguide
y0_cnr	0[mm]	0 m	y corner of Waveguide
z0_cnr	0[mm]	0 m	z corner of Waveguide
Stb1_ht	6.1224[cm]	0.061224 m	Tuning stub height
Stb1_dp	86.36[mm]	0.086360 m	Tuning stub width
Stb1_wd	1.5306[cm]	0.015306 m	Tuning stub length
x1_cnr	22.959[mm]	0.022959 m	x corner of stub

FIGURE 10. First Half of Global Parameter Data, as Configured.

See Figure 11.

Parameters | Model Library | Material Browser

Parameters

Name	Expression	Value	Description
y1_cnr	0[mm]	0 m	y corner of stub
z1_cnr	43.18[mm]	0.043180 m	z corner of stub
Stb2_ht	6.1224[cm]	0.061224 m	Tuning stub height
Stb2_dp	86.36[mm]	0.086360 m	Tuning stub width
Stb2_wd	1.5306[cm]	0.015306 m	Tuning stub length
x2_cnr	53.571[mm]	0.053571 m	x corner of stub
y2_cnr	0[mm]	0 m	y corner of stub
z2_cnr	43.18[mm]	0.043180 m	z corner of stub
Stb3_ht	6.1224[cm]	0.061224 m	Tuning stub height
Stb3_dp	86.36[mm]	0.086360 m	Tuning stub width
Stb3_wd	1.5306[cm]	0.015306 m	Tuning stub length
x3_cnr	84.184[mm]	0.084184 m	x corner of stub
y3_cnr	0[mm]	0 m	y corner of stub
z3_cnr	43.18[mm]	0.043180 m	z corner of stub
sigma_wall	6.3e7[S/m]	6.3000E7 S/m	Wall conductivity

FIGURE 11. Second Half of Global Parameter Data, as Configured.

Build the Three Stub Tuner geometry as follows:

Right-Click > Geometry 1

Select Block

Go to the Block 1 Settings window and enter the first six (6) parameters* in the Size and Shape and Position global data parameters edit windows.

*(Be sure to enter the appropriate Global Parameter name for each of the Size and Shape and Position edit fields, guided by the information in the Global Parameter Description field for each Global Parameter.)

Click > Build Selected

See Figure 12.

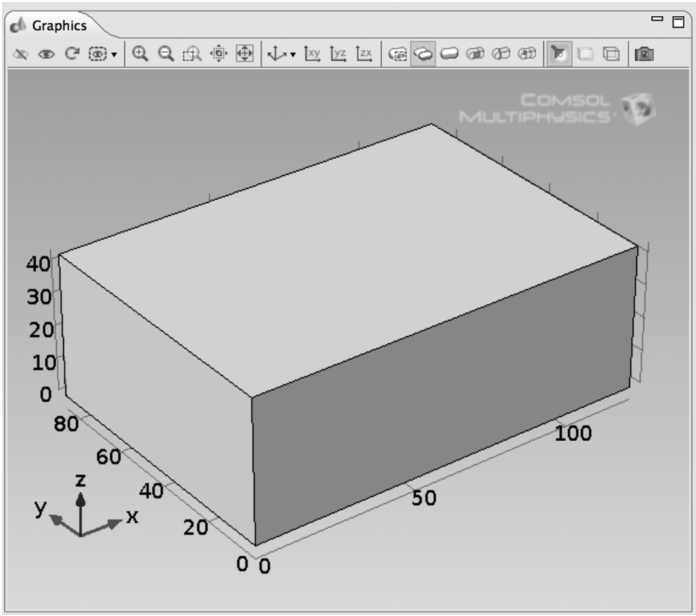


FIGURE 12. Block Parameters and Waveguide, without Stubs.

Create each of the additional Blocks (Tuned Stubs) using the same methodology. Use one set of six (6) global data parameters for each new block.

Right-Click Geometry 1

Select Block

Go to the Block 2 Settings window and enter the second group of six (6) parameters in the Size and Shape and Position global data parameters edit windows.

Click > Build Selected

See Figure 13.

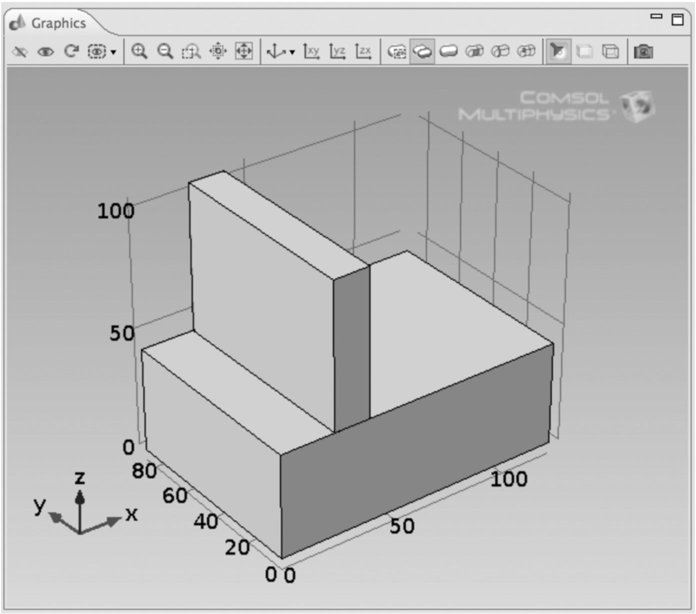


FIGURE 13. Block Parameters and Waveguide, with One Stub.

Right-Click > Geometry 1

Select Block

Go to the Block 3 Settings window and enter the third group of six (6) parameters in the Size and Shape and Position global data parameters edit windows.

Click > Build Selected

See Figure 14.

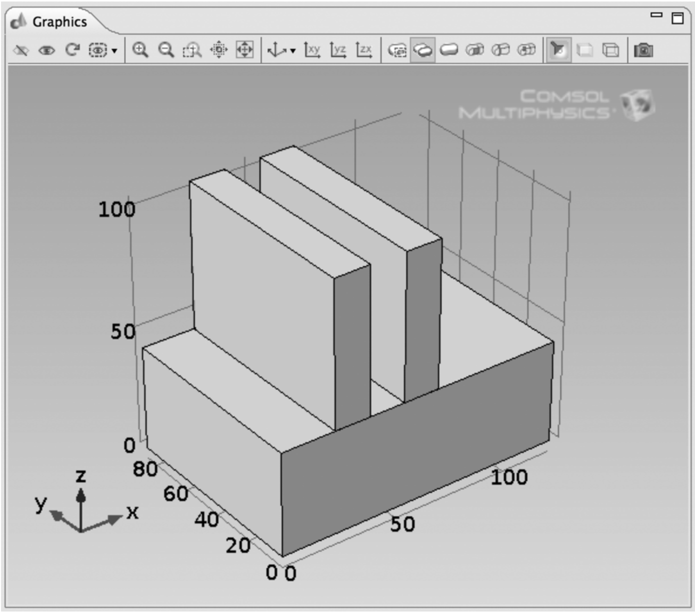


FIGURE 14. Block Parameters and Waveguide, with Two Stubs.

Right-Click > Geometry 1

Select Block

Go to the Block 4 Settings window and enter the fourth group of six (6) parameters in the Size and Shape and Position global data parameters edit windows.

Click > Build Selected

See Figure 15.

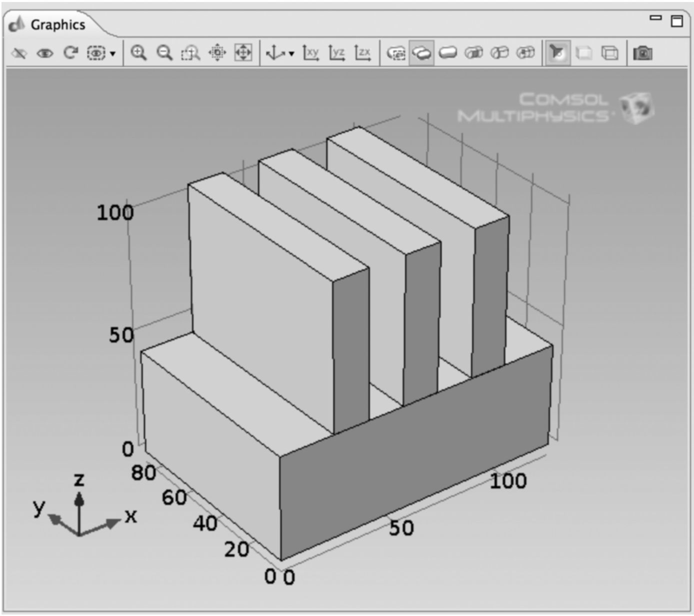


FIGURE 15. Block Parameters and Waveguide, with Three Stubs.

Once all four (4) blocks have been created, then:

Right-Click > Geometry 1

Select Boolean Operations > Union

Click > Zoom Extents in the Graphics Toolbar

Select all four (4) of the domains and add them to the Union Selection window

Uncheck the Keep interior boundaries checkbox

See Figure 16.

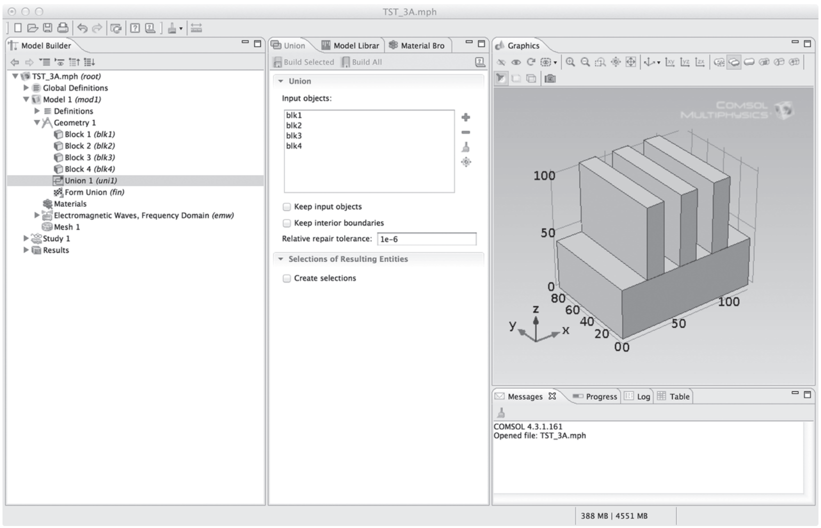


FIGURE 16. Union of the Waveguide and the Three Stubs.

Click Build All

The last parameter entry in Table 3 is the value of the wall conductivity, which will be used in defining the wall material of the Three Stub Tuner walls and is used in calculating the wall losses of the tuner.

4.3 THE THREE STUB TUNER MODEL MATERIALS

The Three Stub Tuner Model comprises two materials: the domain = vacuum and the (wall) boundaries = very thin conductive sheets (e.g., Silver).

Right-Click > Model Builder > Model 1 > Materials

Select Material from the pop-up window

Right-Click > Material 1

Select > Rename

Enter Vacuum as the name of the material

Click OK

In the Material Selection edit window, add Domain 1

In the Material > Material Contents edit window enter the values of the properties shown in Table 4

TABLE 4. Three Stub Tuner Material: Vacuum

Property	Name	Value	Unit
relative permittivity	epsilonr	1	1
relative permeability	mur	1	1
electrical conductivity	sigma	1.0e-9	S/m

See Figure 17.

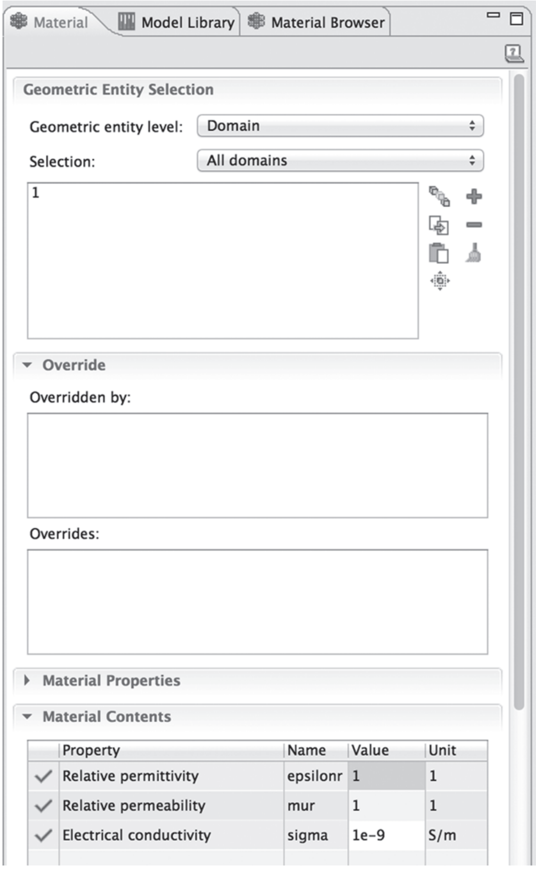


FIGURE 17. Materials Properties of Vacuum, as Configured.

Right-Click > Model Builder > Model 1 > Materials

Select Material from the pop-up window

Right-Click > Material 2 > Select > Rename

Enter Lossy Wall Material as the name of the material

Click OK

TABLE 5. Three Stub Tuner Material: Lossy Wall Material

Property	Name	Value	Unit
relative permittivity	epsilonr	1	1
relative permeability	mur	1	1
electrical conductivity	sigma	sigma_wall	S/m

In the Material Geometric Entity Selection edit window, Select Boundary from the pull-down list. Add Boundaries 2-23 to the Selection edit window.

See Figure 18.

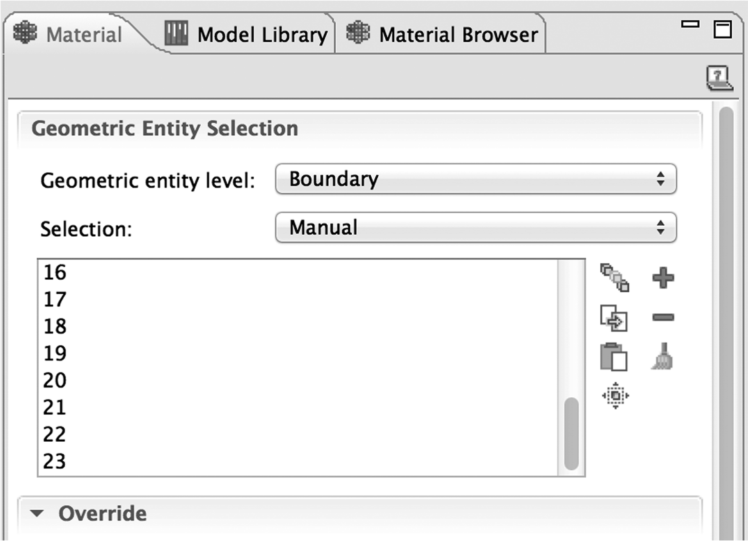


FIGURE 18. Domain Boundaries, as Configured.

In the Material > Material Properties > Basic Properties list:

Select and add the Basic Properties shown in Table 5

In the Material > Material Contents edit window:

Enter the parameter values for each property as shown in Table 5

See Figure 19.

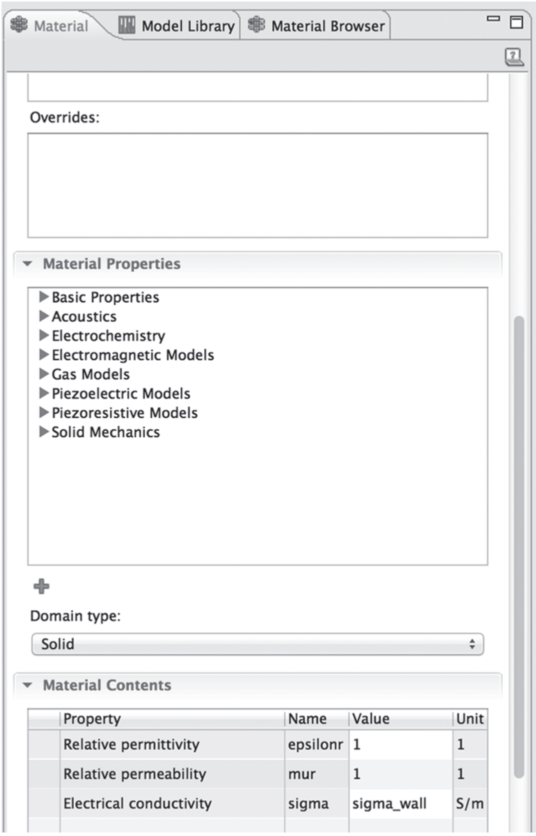


FIGURE 19. Lossy Wall Properties, as Configured.

4.4 THE THREE STUB TUNER MODEL ELECTROMAGNETIC WAVES, FREQUENCY DOMAIN CONFIGURATION

To configure the Electromagnetic Waves, Frequency Domain (emw) Module:

Right-Click > Electromagnetic Waves, Frequency Domain (emw) Module

Select Impedance Boundary Condition from the pop-up window

Click > Impedance Boundary Condition 1

In the Graphics window:

Select boundaries 2-23 (You may need to rotate the graphic to find all of the boundaries.)

Add them to the Selection edit window in the Impedance Boundary Condition Settings page

See Figure 20.

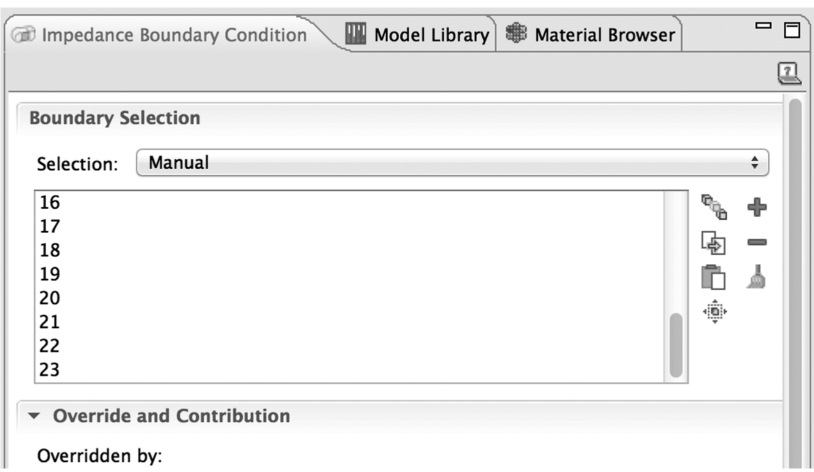


FIGURE 20. Impedance Boundary Condition, as Configured.

Right-Click > Electromagnetic Waves, Frequency Domain (emw) Module

Select > Port from the pop-up window

Click > Port 1

Select Boundary 1 in the Graphics window

Add Boundary 1 to the Port Selection window in the Port Page

See Figure 21.

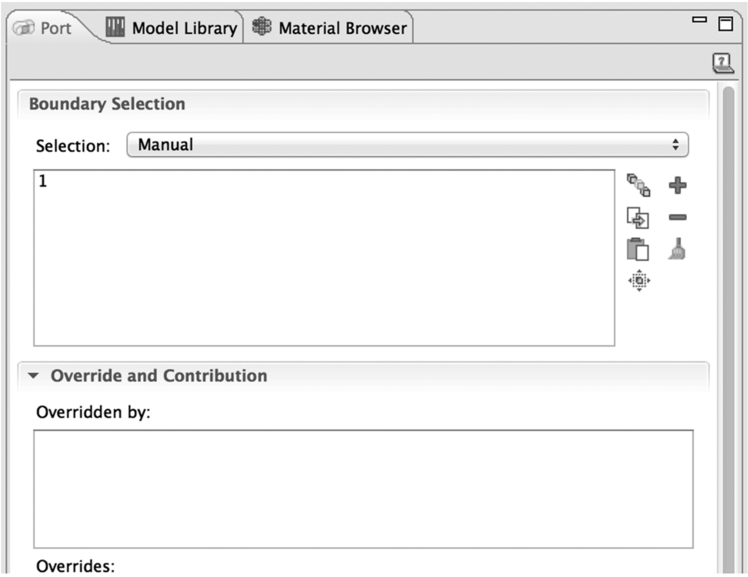


FIGURE 21. Port 1 Boundary Selection, as Configured.

In Port > Port Properties

Set > Type of Port to Numeric

Set > Wave excitation for Port 1 to On

See Figure 22.

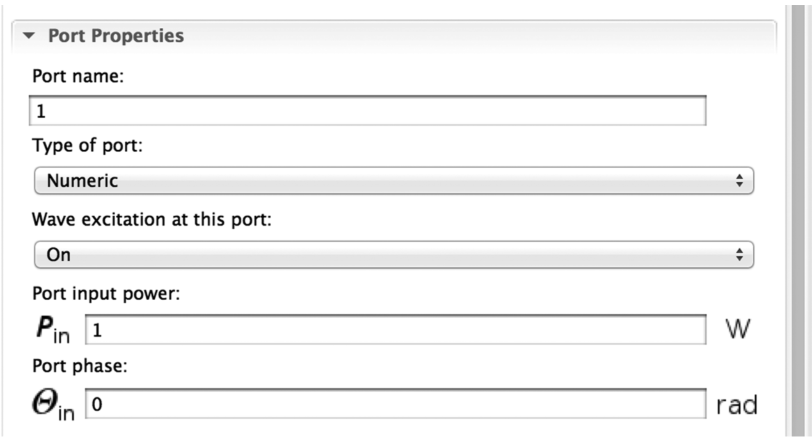


FIGURE 22. Port 1 Properties Settings, as Configured.

Right-Click > Electromagnetic Waves, Frequency Domain (emw) Module

Select Port from the pop-up window

Click > Port 2

Select Boundary 24 in the Graphics window

Add Boundary 24 to the Port Selection window in the Port Page

See Figure 23.

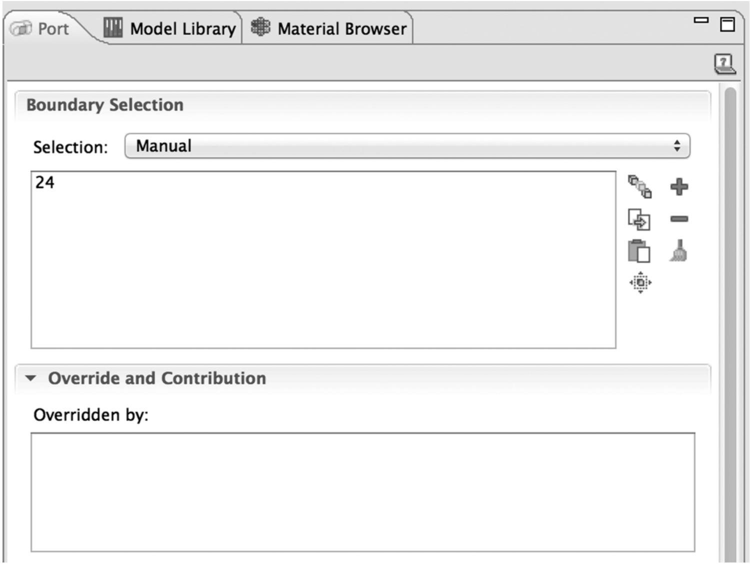


FIGURE 23. Port 2 Boundary Selection, as Configured.

In Port > Port Properties

Set the Port name to 2

Set Type of port to Numeric

Set Wave excitation at this Port 2 to Off

See Figure 24.

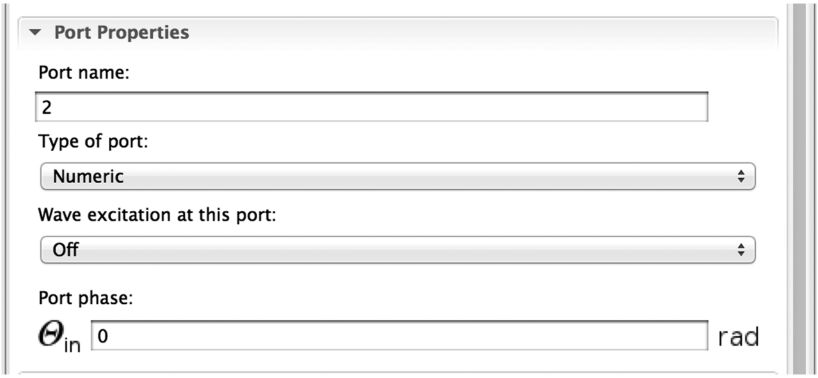


FIGURE 24. Port 2 Properties Settings, as Configured.

4.5 THE THREE STUB TUNER MODEL MESH CONFIGURATION

Right-Click > Model Builder > Model 1 > Mesh

Select Free Tetrahedral from the pop-up list

Click on Mesh 1 > Size

On the Size page, in the Element Size Parameters > Maximum element size edit window

Enter 6[mm] (This size is chosen to optimize the mesh element size.)

See Figure 25.

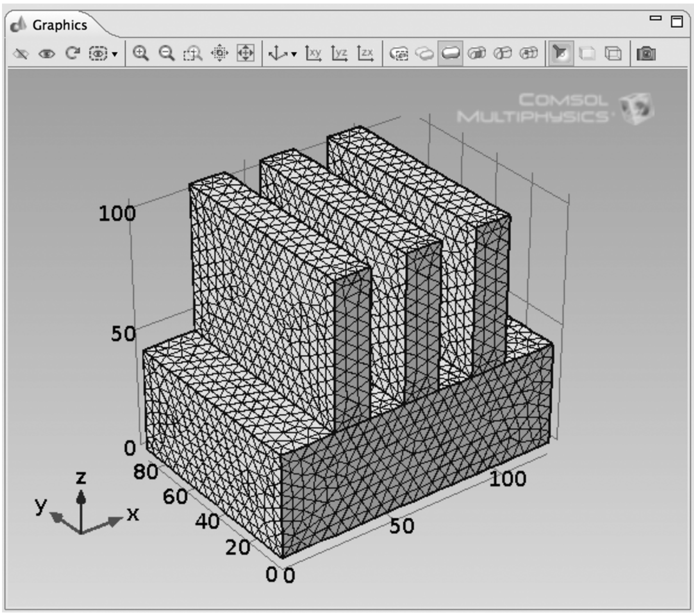


FIGURE 25. Meshed Model.

4.6 THE THREE STUB TUNER MODEL COMPUTATION

Right-Click on Study 1

Select Compute

See Figure 26.

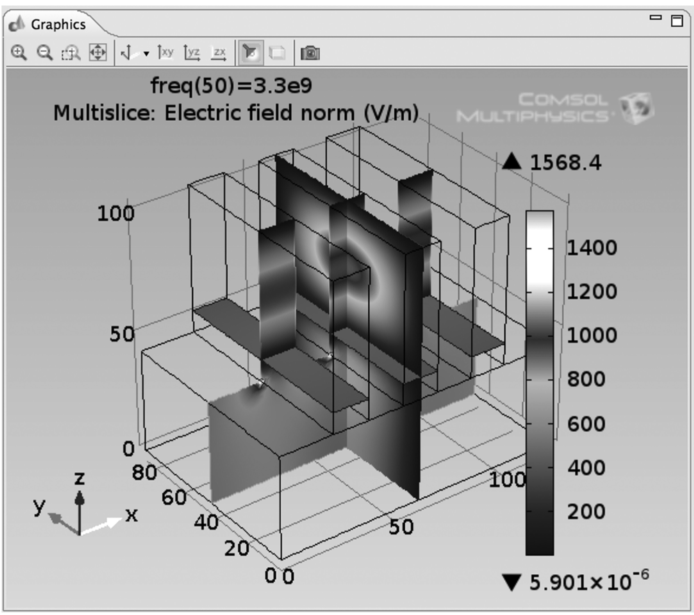


FIGURE 26. Calculated Three Stub Tuner Electric Field, Default Settings.

CHAPTER 5

THREE STUB TUNER MODEL RESULTS

The default plot is a Multislice plot with one plot plane in each of the primary directions (x, y, z).

To modify the plot so that it shows the electric field distribution in each of the Tuned-Stubs:

Right-Click > Results > Electric field > Multislice icon

Select Delete

Next:

Right-Click > Results > Electric field

Select > Slice

Click on Slice 1

On the Slice Settings page:

Enter 9 in the Slice > Plot > Plane Data > Planes edit window

Click Plot in the toolbar

To adjust the position of the Color Legend:

Click > Results > Electric field

Click > Color Legend Twistie on the 3D Plot Group page

Select > Left from the Pull-down menu

Click > Zoom Extents

The resultant plot is shown in Figure 27.

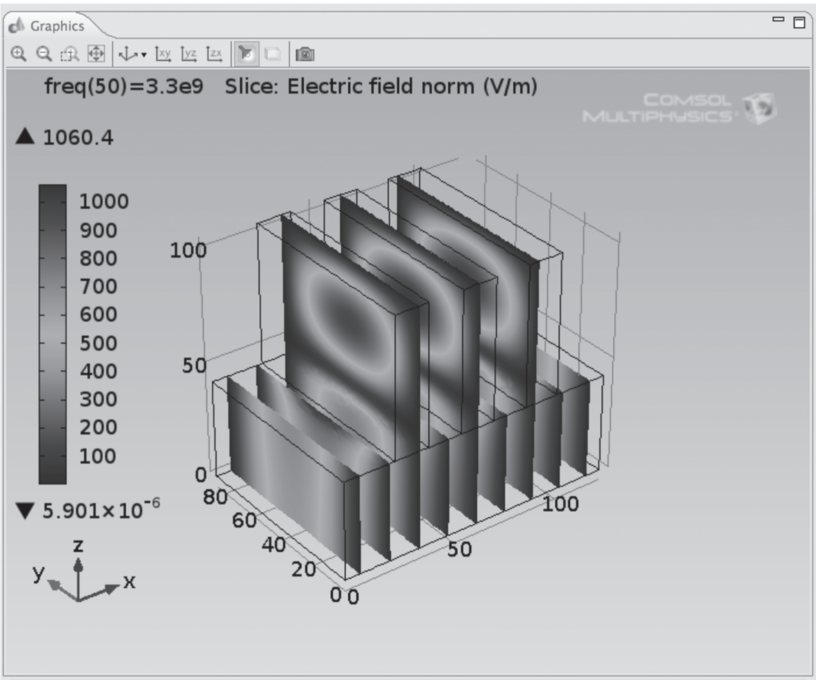


FIGURE 27. Calculated Three Stub Tuner Electric Field, Revised Settings.

CHAPTER 6

THREE STUB TUNER MODEL VSWR CALCULATIONS

The VSWR (Voltage Standing Wave Ratio) is defined mathematically as:

$$VSWR = \frac{1+|S_{11}|}{1-|S_{11}|} \tag{6.1}$$

Where S_{11} is the Port 1 scattering coefficient. The RF Module calculates S_{11}.

To plot the VSWR:

Right-Click on Model Builder > Results

Select 1D Plot Group from the pop-up list

Right-Click on 1D Plot Group 2

Select Global from the pop-up list

Click on Global

Enter, as the y-axis data Expression:

$$(1+abs(emw.S11))/(1-abs(emw.S11)). \tag{6.2}$$

Enter VSWR in the Description edit field

See Figure 28.

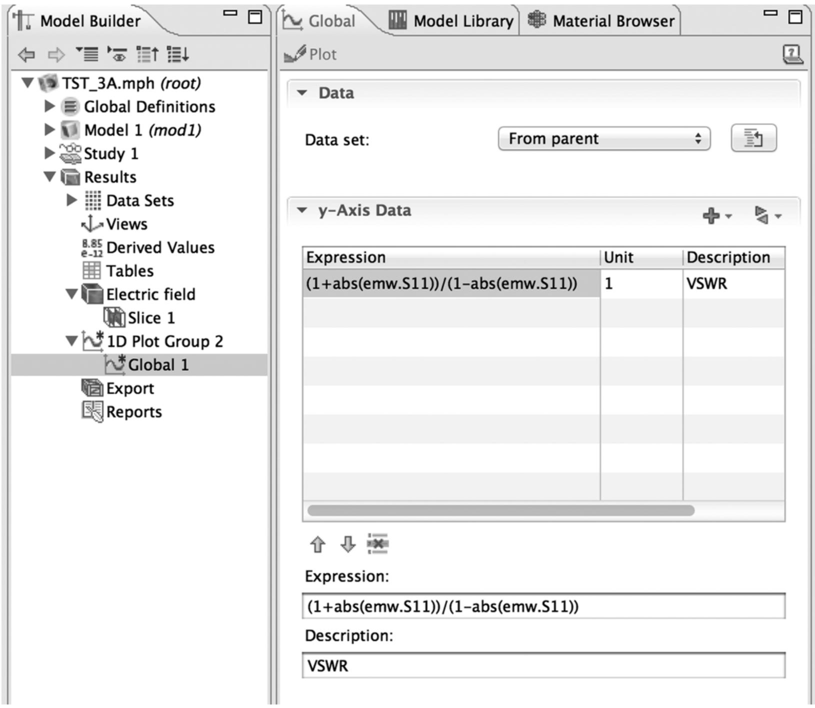


FIGURE 28. VSWR Calculation Settings.

Click > Plot in the Toolbar

The VSWR plot is shown in Figure 29.

See Figure 29.

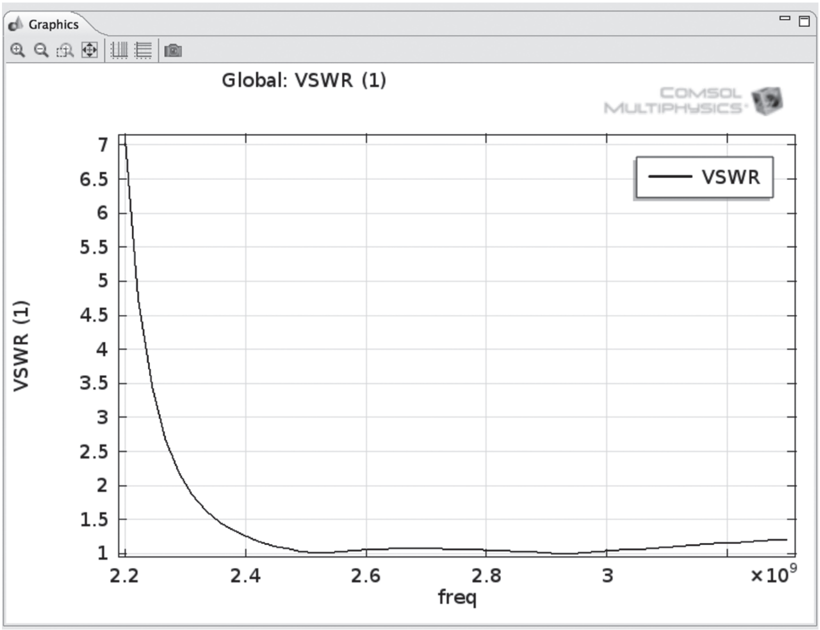


FIGURE 29. Three Stub Tuner Model VSWR Plot.

CHAPTER 7

CONCLUSIONS FROM THE THREE STUB TUNER MODEL

This book develops and presents a new model for the Three Stub Tuner, a critical microwave component. This Three Stub Tuner Model shows the electric field distribution and the VSWR. The VSWR graph shows that the Three Stub Tuner has almost no power reflection in the range from 2.4 GHz to 3.3 GHz.

This book demonstrates that the RF Module of COMSOL Multiphysics software can easily be employed to calculate power distribution and reflection analysis problems for microwave components. This model, in particular, is easily expanded to applications for rectangular waveguide components in both higher and lower frequency ranges.

For further guidance in COMSOL Multiphysics step-by-step modeling for RF and other areas of physics, see Reference {18}.

CHAPTER 8

FIRST VARIATION ON THE THREE STUB TUNER MODEL

In this variation, the height of the first stub will be increased. Open the Three Stub Tuner model TST_3A.mph in COMSOL Multiphysics. Once opened, the COMSOL Multiphysics Desktop should appear as shown in Figure 30.

See Figure 30.

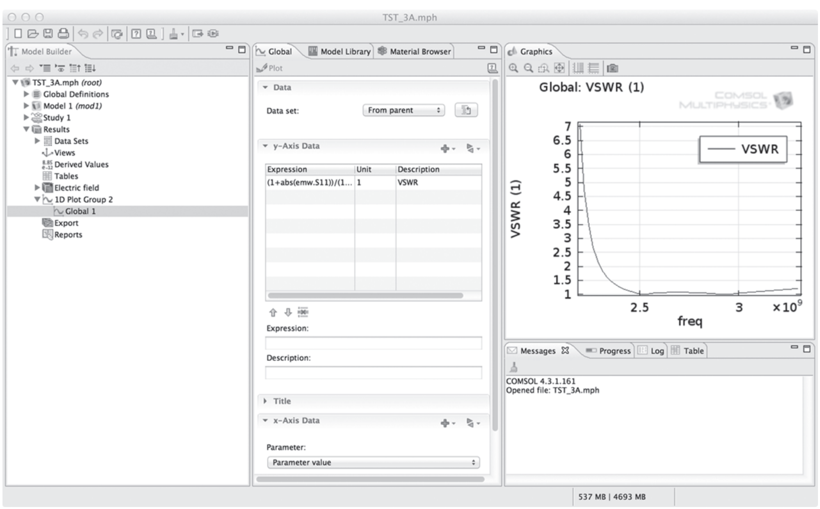


FIGURE 30. Three Stub Tuner Model TST_3A.mph on Desktop.

Save a copy of TST_3A.mph as TST_3AM1.mph. Open TST_3AM1.mph on the COMSOL Multiphysics Desktop.

See Figure 31.

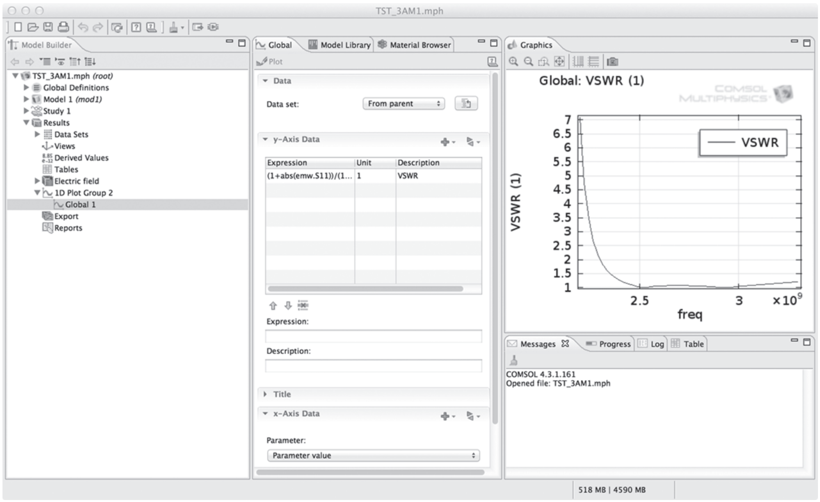


FIGURE 31. Three Stub Tuner Model TST_3AM1.mph on Desktop.

Click > Global Definitions Twistie

Click > Parameters

See Figure 32.

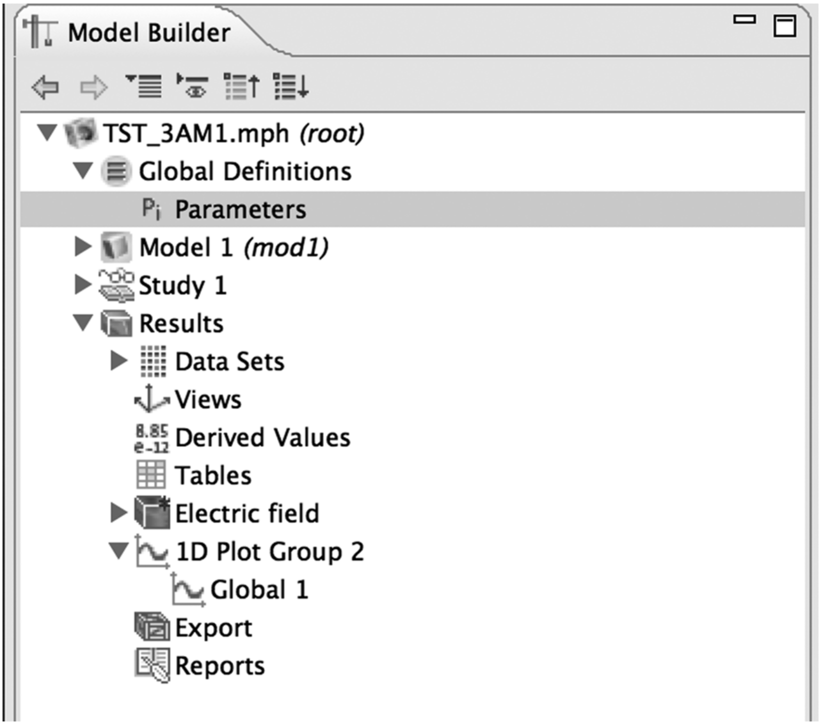
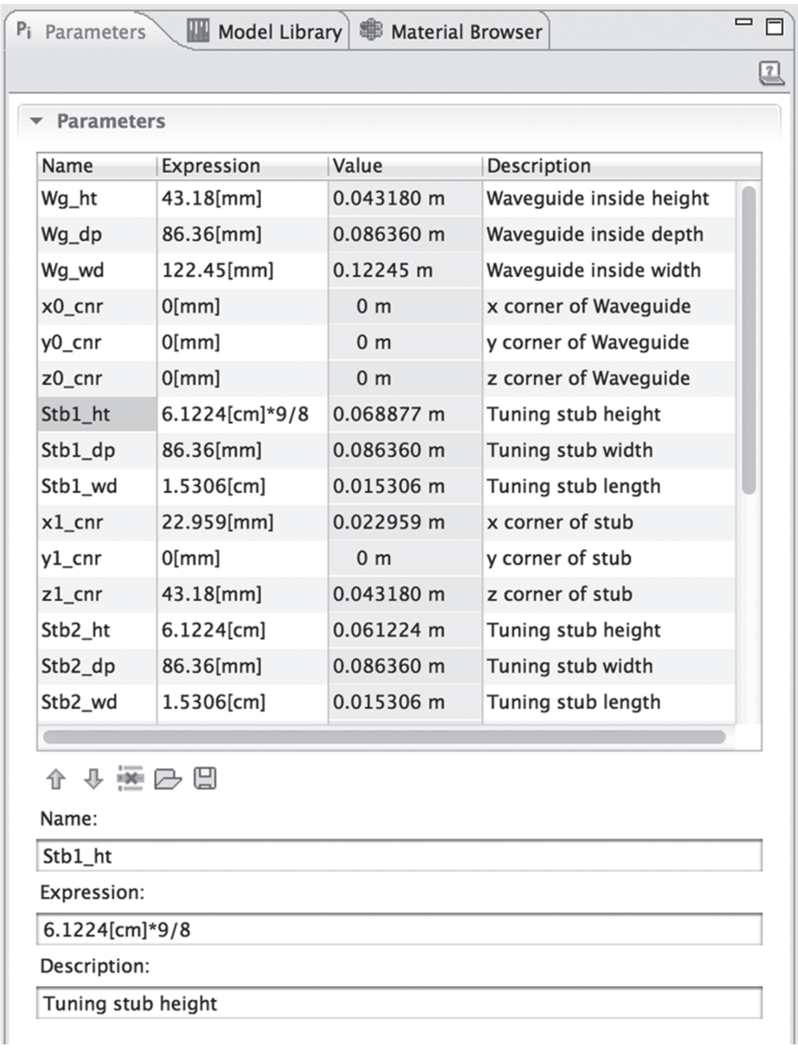


FIGURE 32. TST_3AM1.mph Model Builder Tree.

In the Parameters file edit window,

Enter > Stb1_ht = 6.1224[cm]*9/8 in the Stb1_ht Expressions edit window.

See Figure 33.



Name	Expression	Value	Description
Wg_ht	43.18[mm]	0.043180 m	Waveguide inside height
Wg_dp	86.36[mm]	0.086360 m	Waveguide inside depth
Wg_wd	122.45[mm]	0.12245 m	Waveguide inside width
x0_cnr	0[mm]	0 m	x corner of Waveguide
y0_cnr	0[mm]	0 m	y corner of Waveguide
z0_cnr	0[mm]	0 m	z corner of Waveguide
Stb1_ht	6.1224[cm]*9/8	0.068877 m	Tuning stub height
Stb1_dp	86.36[mm]	0.086360 m	Tuning stub width
Stb1_wd	1.5306[cm]	0.015306 m	Tuning stub length
x1_cnr	22.959[mm]	0.022959 m	x corner of stub
y1_cnr	0[mm]	0 m	y corner of stub
z1_cnr	43.18[mm]	0.043180 m	z corner of stub
Stb2_ht	6.1224[cm]	0.061224 m	Tuning stub height
Stb2_dp	86.36[mm]	0.086360 m	Tuning stub width
Stb2_wd	1.5306[cm]	0.015306 m	Tuning stub length

FIGURE 33. TST_3AM1.mph Parameters File Edit Window, Stb1_ht (Modified).

Click > Model 1 (mod1) Twistie

Click > Geometry 1

In the Geometry edit window,

Click > Build All

See Figure 34.

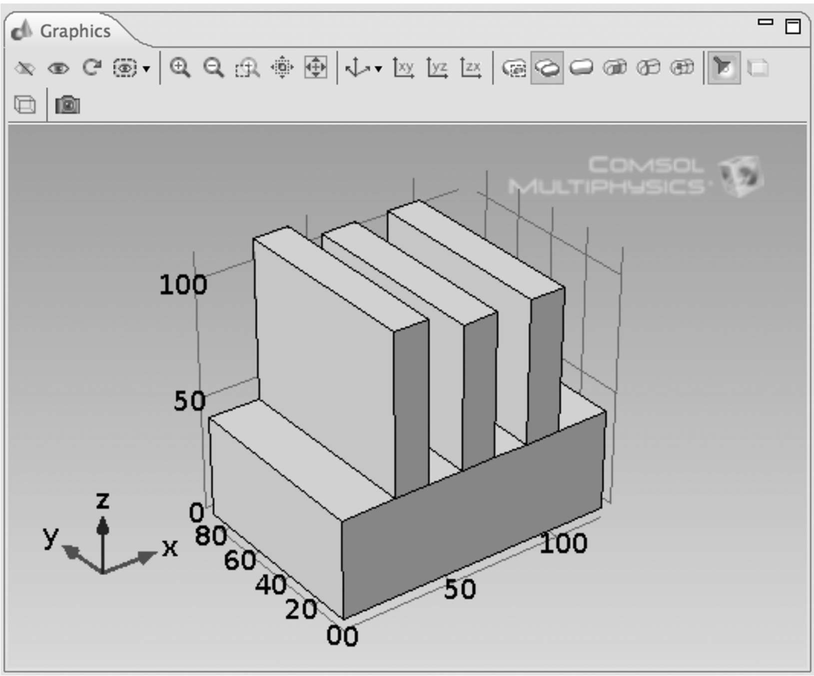


FIGURE 34. Three Stub Tuner Geometry (Modified).

You should now notice that the first stub (Stb1_ht) is slightly taller than the other two stubs.

Next, the model needs to be re-meshed.

Click > Mesh 1

Right-Click > Mesh 1

Select > Build All

See Figure 35.

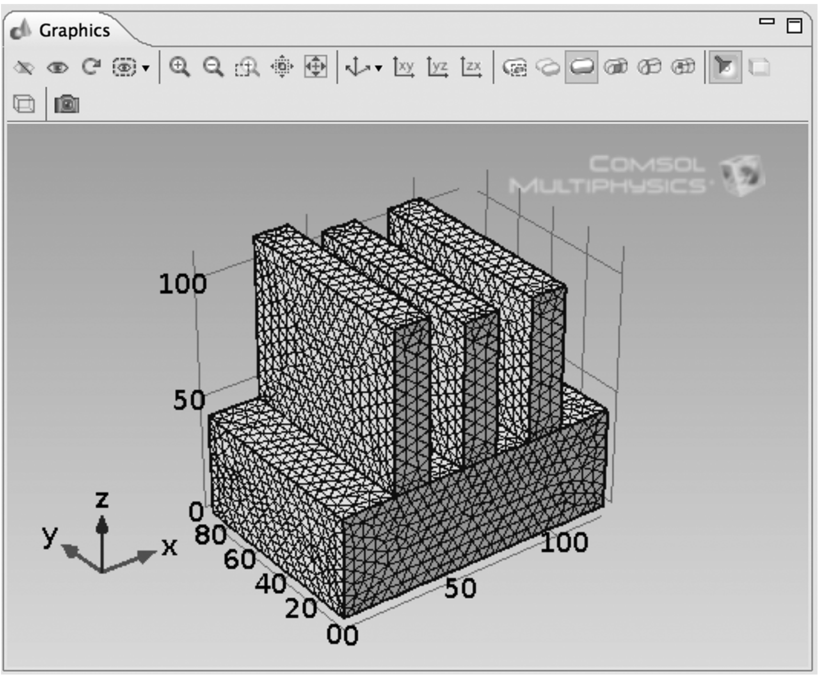


FIGURE 35. Three Stub Tuner Geometry (Modified) Meshed.

The number of mesh elements in this meshed model will be about 1.3% larger than that of the first model, due to the increased size of the first stub.

Having now meshed the model, the results of this change can now be computed.

Click > Study 1

Right-Click > Study 1

Select > Compute

See Figure 36.

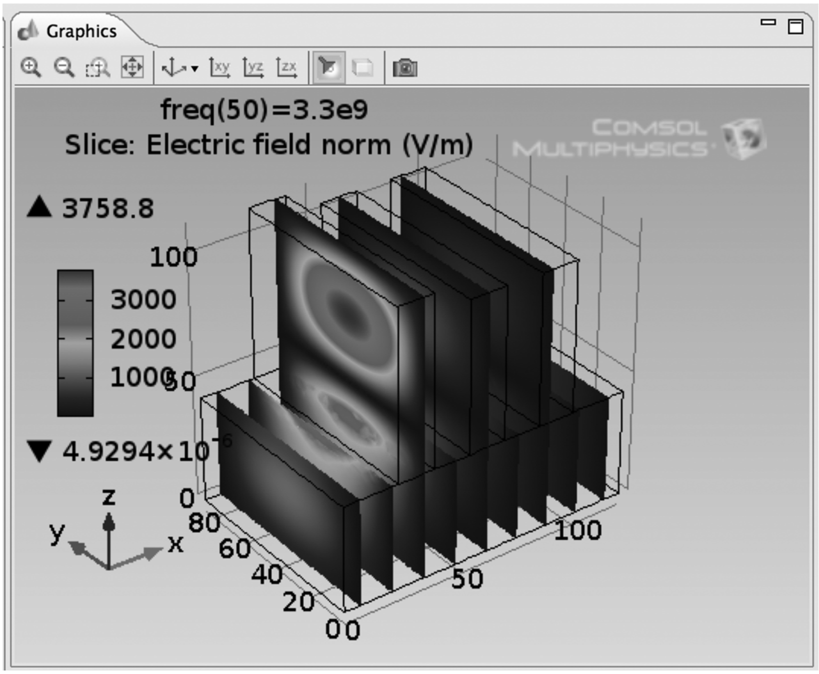


FIGURE 36. Three Stub Tuner (Modified) Electric Field Distribution.

Click > Results > 1D Plot Group 2 Twistie

Click > Global 1

See Figure 37.

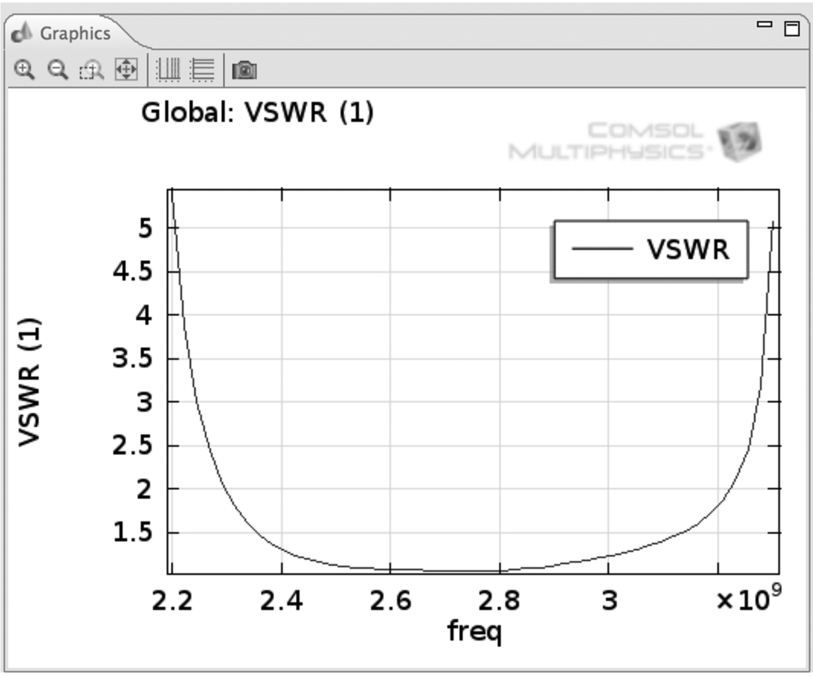


FIGURE 37. Three Stub Tuner (Modified) VSWR.

For comparison see Figure 38.

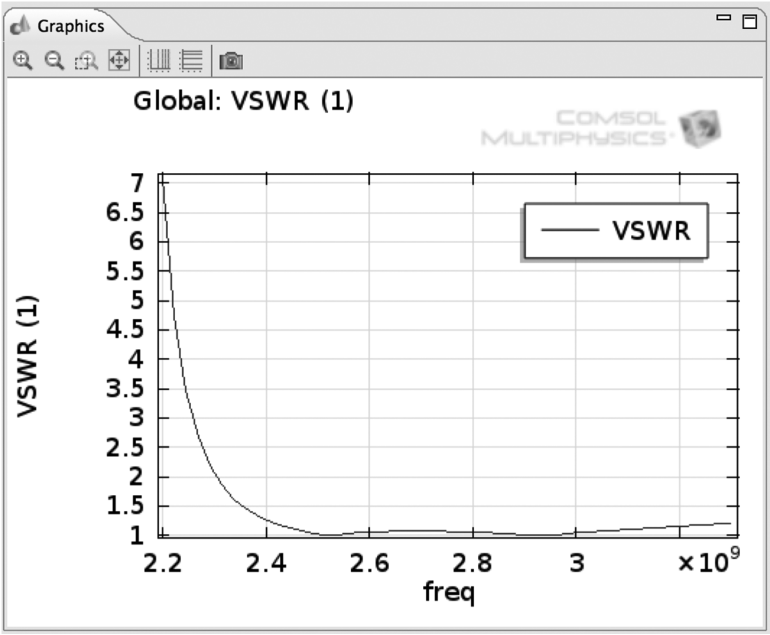


FIGURE 38. Three Stub Tuner VSWR.

By comparing Figure 37 to Figure 38, it can be seen that the slight elongation of the First Stub, by the 9/8 ratio, changes the Three Stub Tuner from a high-pass filter to a band-pass filter. The band-pass filter has optimum transmission in the 2.4 GHz to 3.0 GHz range.

CHAPTER 9

SECOND VARIATION ON THE THREE STUB TUNER MODEL

In this second variation, the height of the second stub will be increased. Open the Three Stub Tuner model TST_3A.mph in COMSOL Multiphysics. Once opened, the COMSOL Multiphysics Desktop should appear as shown in Figure 39.

See Figure 39.

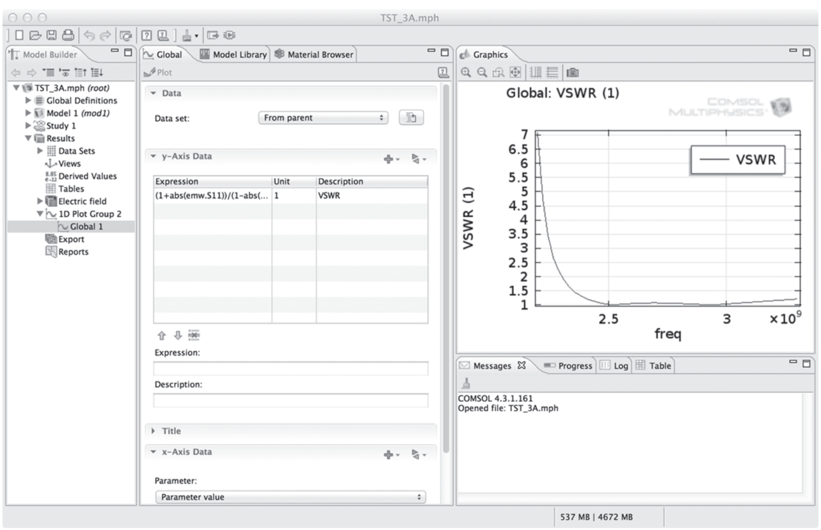


FIGURE 39. Three Stub Tuner Model TST_3A.mph on Desktop.

Save a copy of TST_3A.mph as TST_3AM2.mph. Open TST_3AM2.mph on the COMSOL Multiphysics Desktop.

See Figure 40.

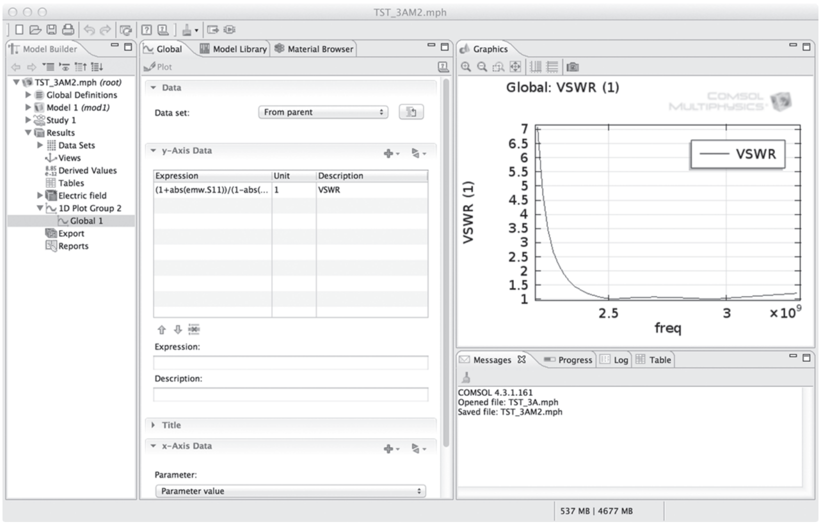


FIGURE 40. Three Stub Tuner Model TST_3AM2.mph on Desktop.

Click > Global Definitions Twistie

Click > Parameters

See Figure 41.

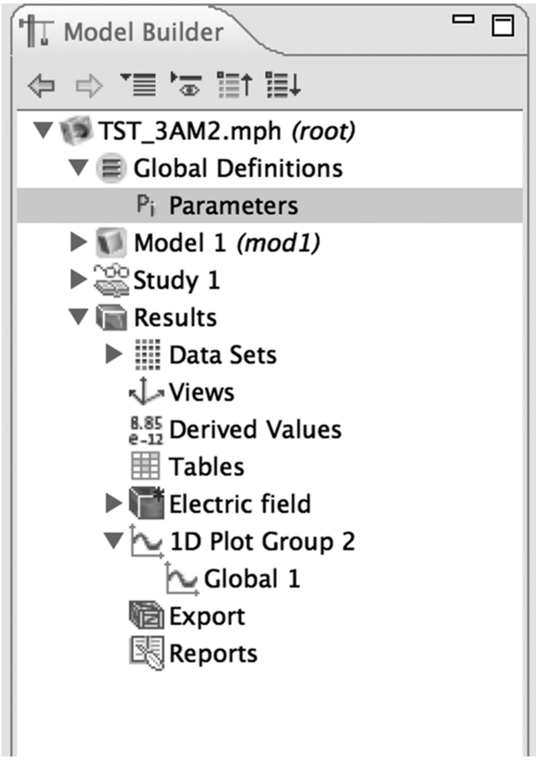
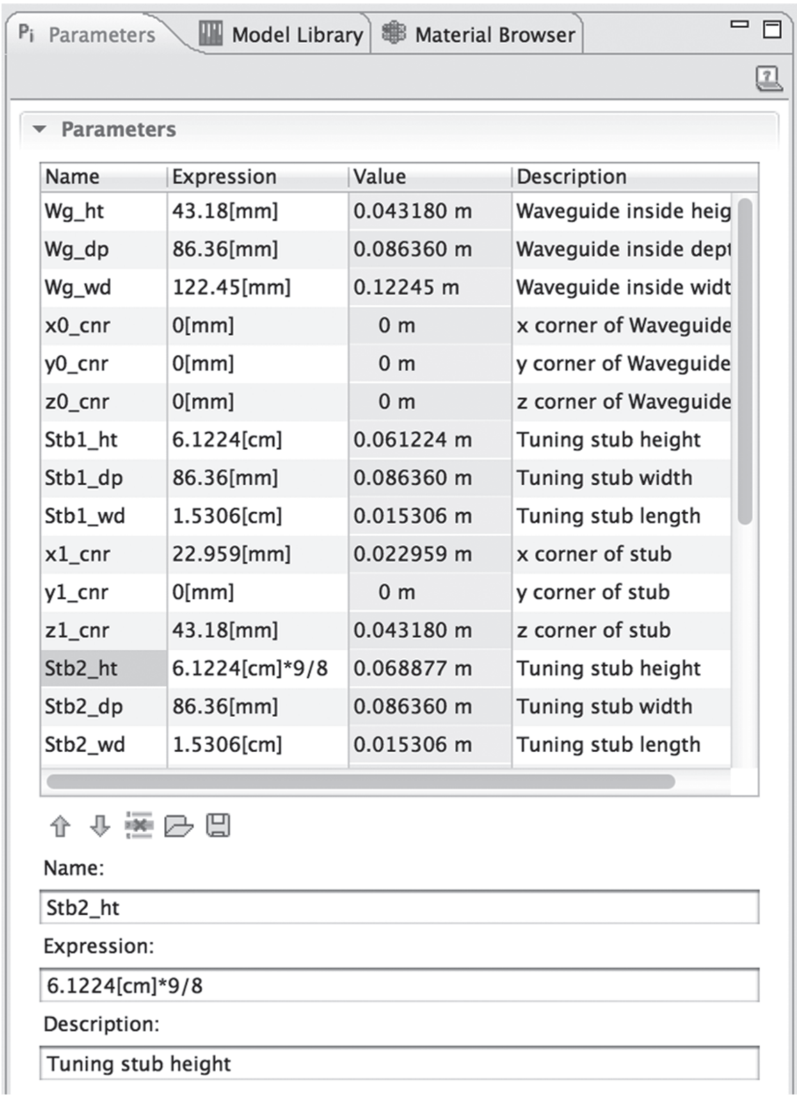


FIGURE 41. TST_3AM2.mph Model Builder Tree.

In the Parameters file edit window,

Enter > Stb2_ht = 6.1224[cm]*9/8 in the Stb2_ht Expressions edit window.

See Figure 42.



Name	Expression	Value	Description
Wg_ht	43.18[mm]	0.043180 m	Waveguide inside heig
Wg_dp	86.36[mm]	0.086360 m	Waveguide inside dept
Wg_wd	122.45[mm]	0.12245 m	Waveguide inside widt
x0_cnr	0[mm]	0 m	x corner of Waveguide
y0_cnr	0[mm]	0 m	y corner of Waveguide
z0_cnr	0[mm]	0 m	z corner of Waveguide
Stb1_ht	6.1224[cm]	0.061224 m	Tuning stub height
Stb1_dp	86.36[mm]	0.086360 m	Tuning stub width
Stb1_wd	1.5306[cm]	0.015306 m	Tuning stub length
x1_cnr	22.959[mm]	0.022959 m	x corner of stub
y1_cnr	0[mm]	0 m	y corner of stub
z1_cnr	43.18[mm]	0.043180 m	z corner of stub
Stb2_ht	6.1224[cm]*9/8	0.068877 m	Tuning stub height
Stb2_dp	86.36[mm]	0.086360 m	Tuning stub width
Stb2_wd	1.5306[cm]	0.015306 m	Tuning stub length

FIGURE 42. TST_3AM2.mph Parameters File Edit Window, Stb2_ht (Modified 2).

Click > Model 1 (mod1) Twistie

Click > Geometry 1

In the Geometry edit window,

Click > Build All

See Figure 43.

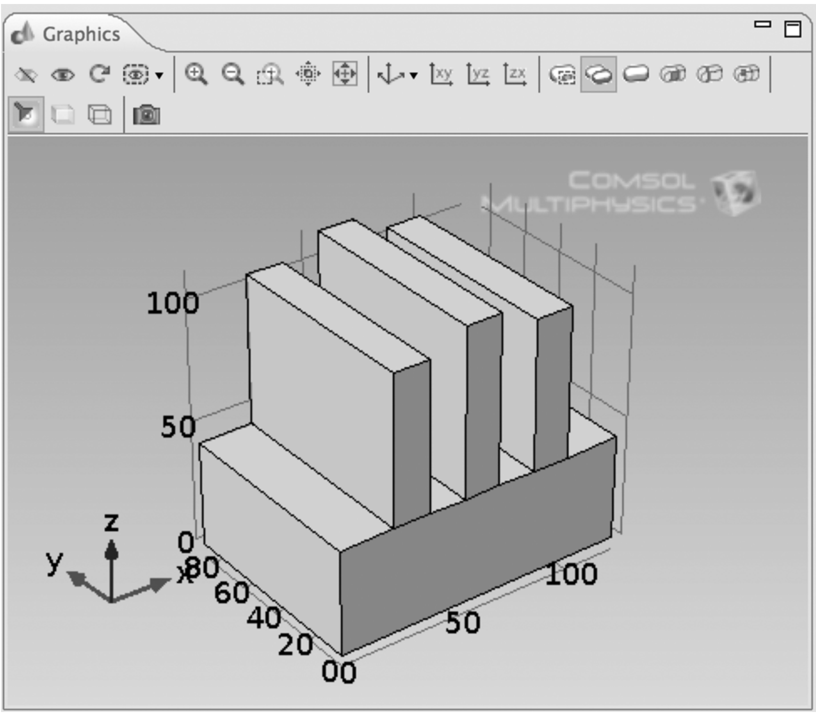


FIGURE 43. Three Stub Tuner Geometry (Modified 2).

You should now notice that the second stub (Stb2_ht) is slightly taller than the other two stubs.

Next, the model needs to be re-meshed.

Click > Mesh 1

Right-Click > Mesh 1

Select > Build All

See Figure 44.

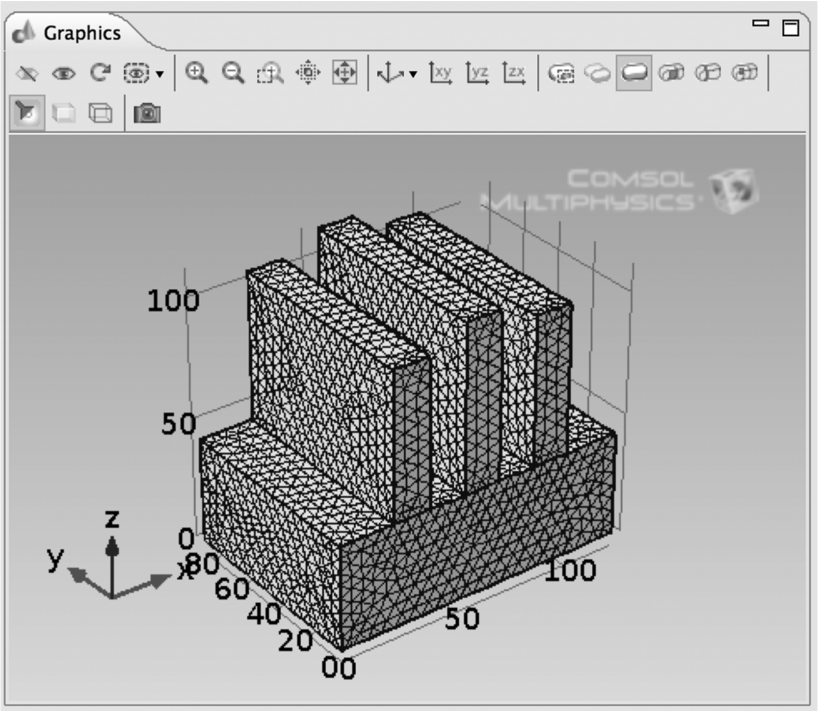


FIGURE 44. Three Stub Tuner Geometry (Modified 2) Meshed.

The number of mesh elements in this meshed model will be about 1.3% larger than that of the first model, due to the increased size of the second stub.

Having now meshed the model, the results of this change can now be computed.

Click > Study 1

Right-Click > Study 1

Select > Compute

See Figure 45.

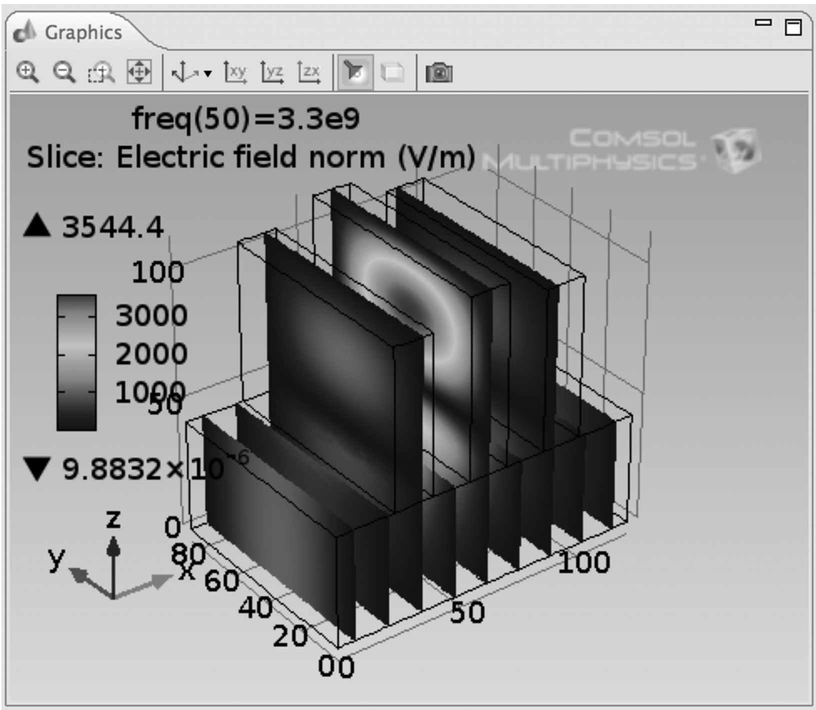


FIGURE 45. Three Stub Tuner (Modified 2) Electric Field Distribution.

Click > Results > 1D Plot Group 2 Twistie

Click > Global 1

See Figure 46.

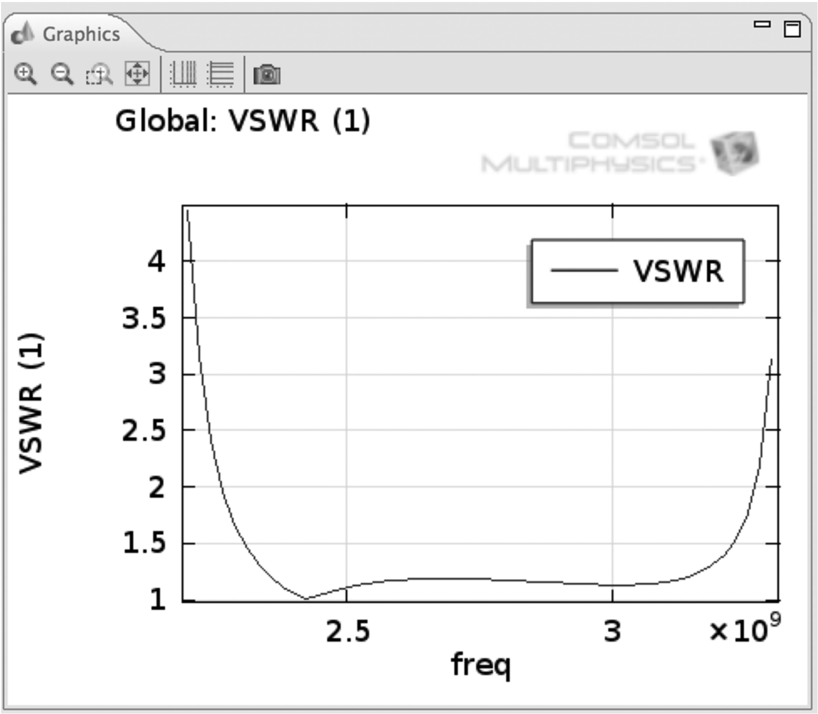


FIGURE 46. Three Stub Tuner (Modified 2) VSWR.

For comparison see Figure 47.

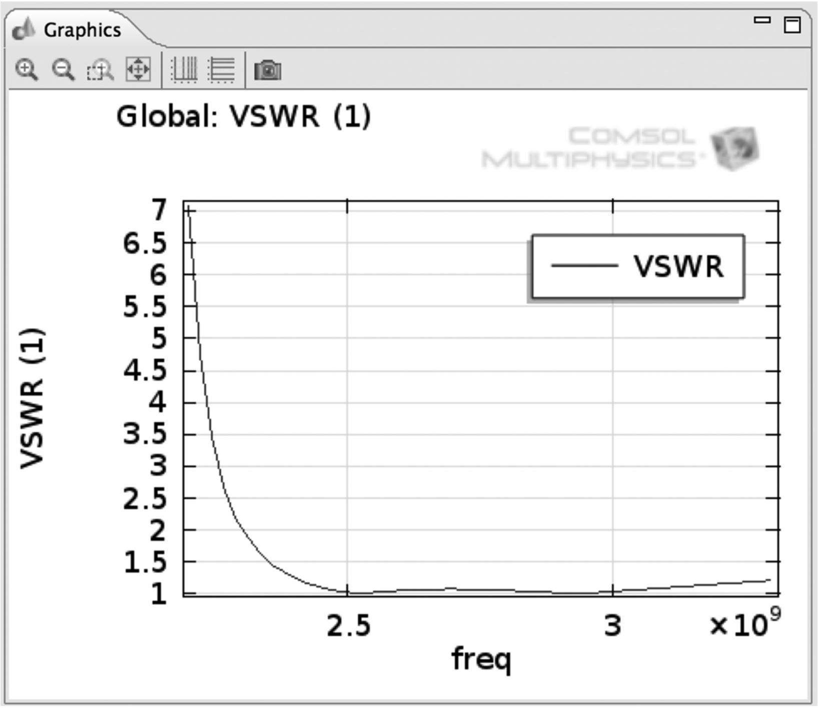


FIGURE 47. Three Stub Tuner VSWR.

By comparing Figure 46 to Figure 47, it can be seen that the slight elongation of the second stub, by the 9/8 ratio, changes the Three Stub Tuner from a high-pass filter to a band-pass filter. The band-pass filter has optimum transmission in the 2.3 GHz to 3.2 GHz range.

CHAPTER 10

THIRD VARIATION ON THE THREE STUB TUNER MODEL

In this third variation, the height of the third stub will be increased. Open the Three Stub Tuner model TST_3A.mph in COMSOL Multiphysics. Once opened, the COMSOL Multiphysics Desktop should appear as shown in Figure 48.

See Figure 48.

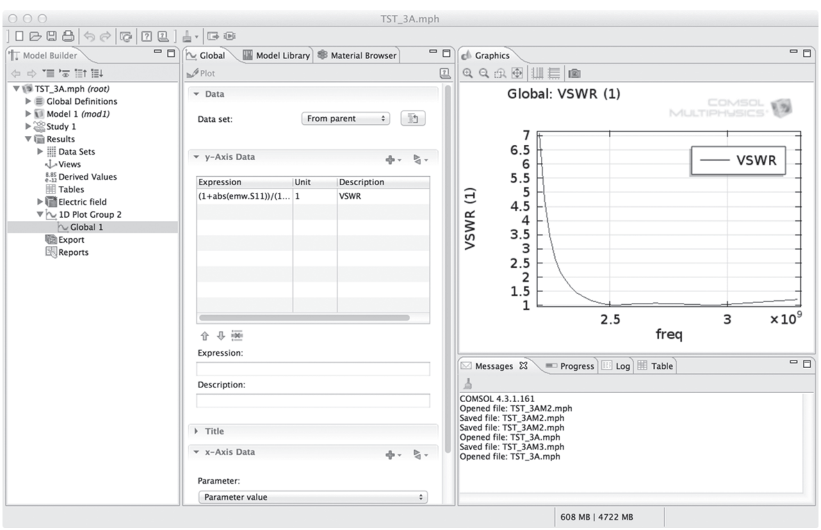


FIGURE 48. Three Stub Tuner Model TST_3A.mph on Desktop.

Save a copy of TST_3A.mph as TST_3AM3.mph. Open TST_3AM3.mph on the COMSOL Multiphysics Desktop.

See Figure 49.

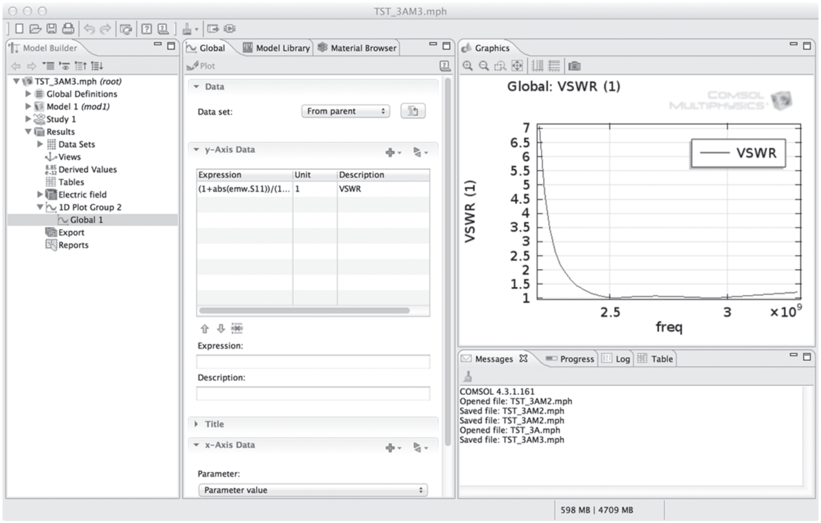


FIGURE 49. Three Stub Tuner Model TST_3AM3.mph on Desktop.

Click > Global Definitions Twistie

Click > Parameters

See Figure 50.

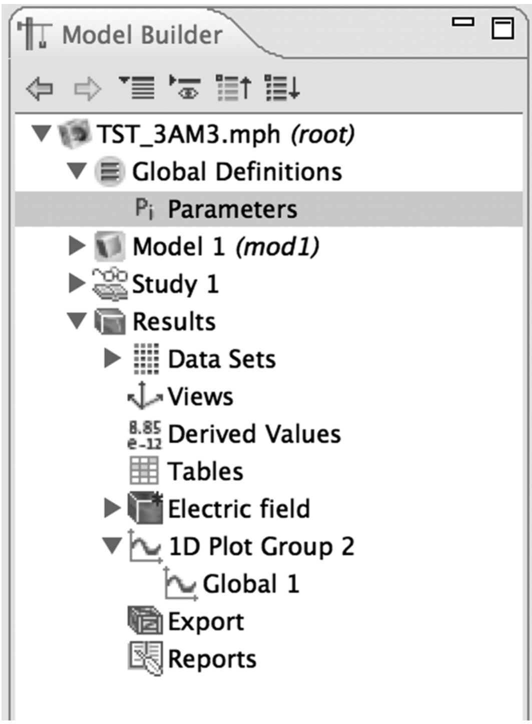


FIGURE 50. TST_3AM3.mph Model Builder Tree.

In the Parameters file edit window,

Enter > Stb3_ht = 6.1224[cm]*9/8 in the Stb3_ht Expressions edit window.

See Figure 51.

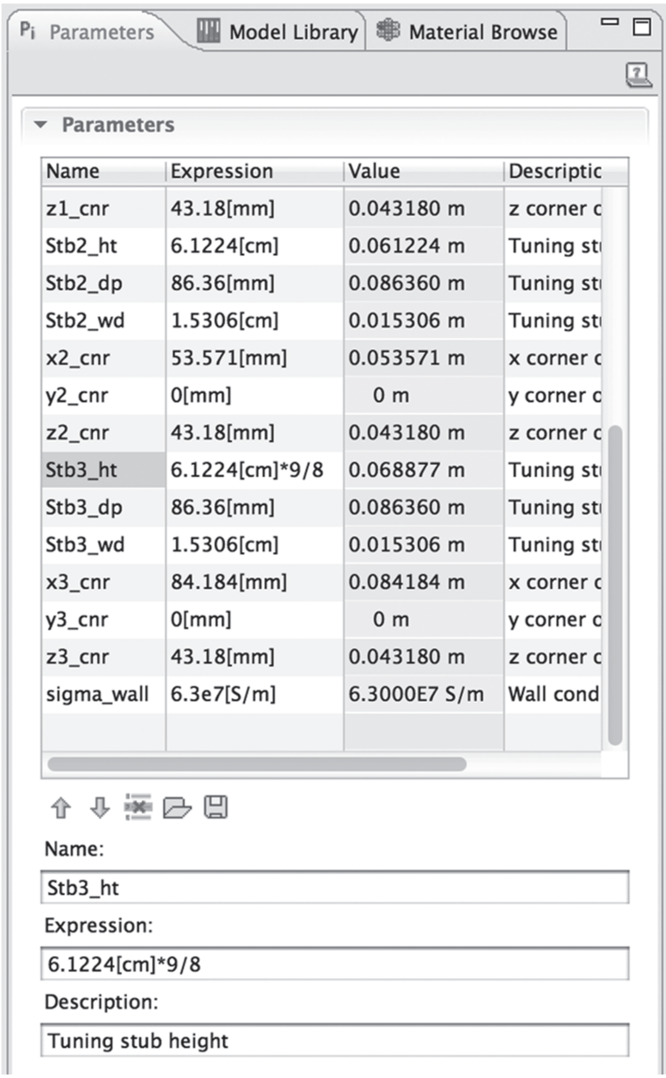


FIGURE 51. TST_3AM3.mph Parameters File Edit Window, Stb3_ht (Modified 3).

Click > Model 1 (mod1) Twistie

Click > Geometry 1

In the Geometry edit window,

Click > Build All

See Figure 52.

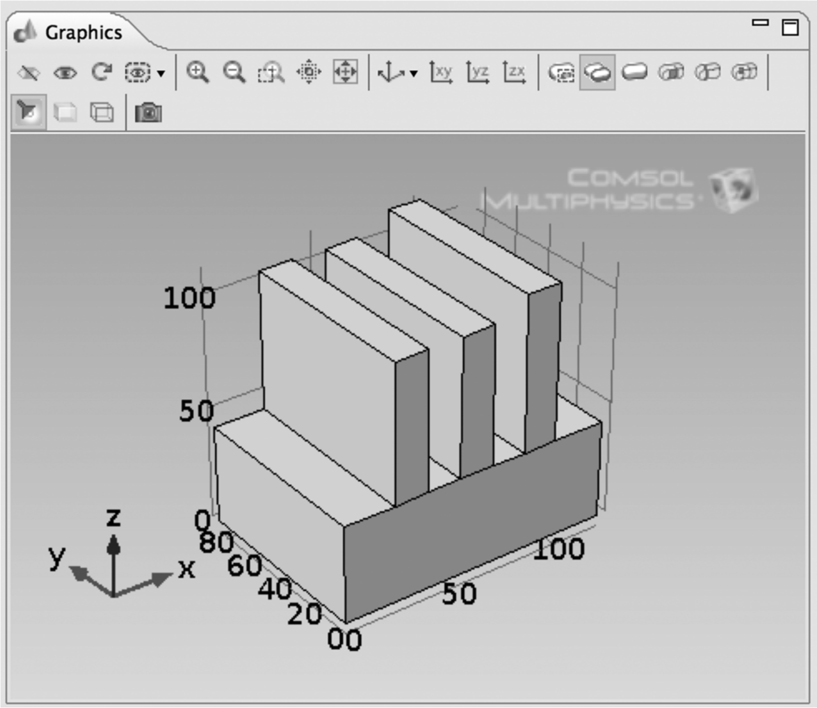


FIGURE 52. Three Stub Tuner Geometry (Modified 3).

You should now notice that the third stub (Stb3_ht) is slightly taller than the other two stubs.

Next, the model needs to be re-meshed.

Click > Mesh 1

Right-Click > Mesh 1

Select > Build All

See Figure 53.

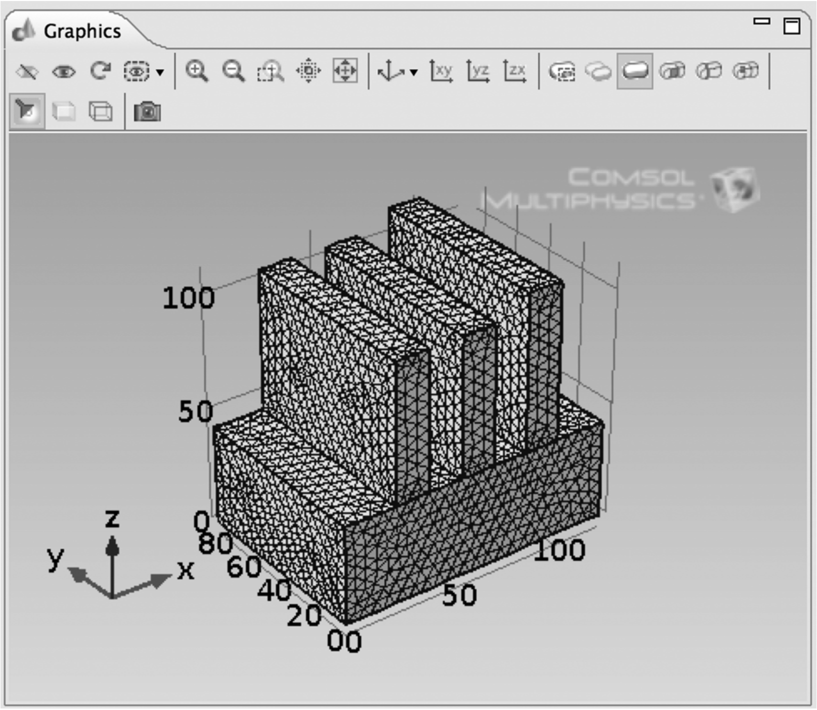


FIGURE 53. Three Stub Tuner Geometry (Modified 3) Meshed.

The number of mesh elements in this meshed model will be about 1.3% larger than that of the first model, due to the increased size of the third stub.

Having now meshed the model, the results of this change can now be computed.

Click > Study 1

Right-Click > Study 1

Select > Compute

See Figure 54.

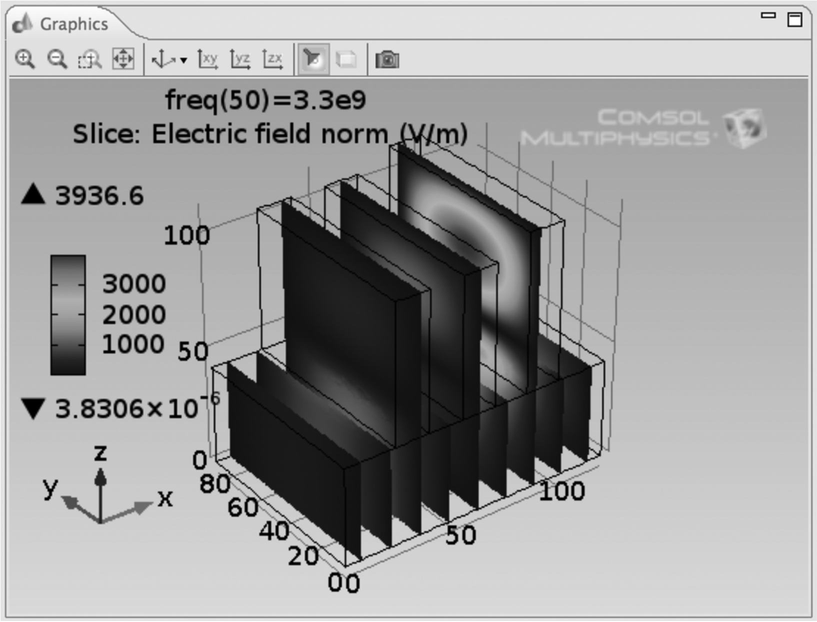


FIGURE 54. Three Stub Tuner (Modified 3) Electric Field Distribution.

Click > Results > 1D Plot Group 2 Twistie

Click > Global 1

See Figure 55.

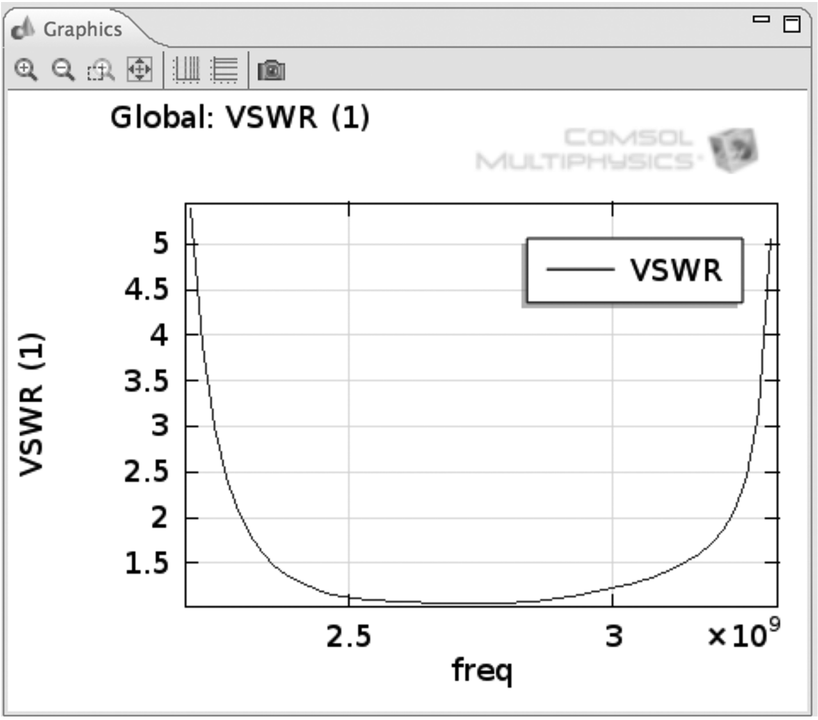


FIGURE 55. Three Stub Tuner (Modified 3) VSWR.

For comparison see Figure 56.

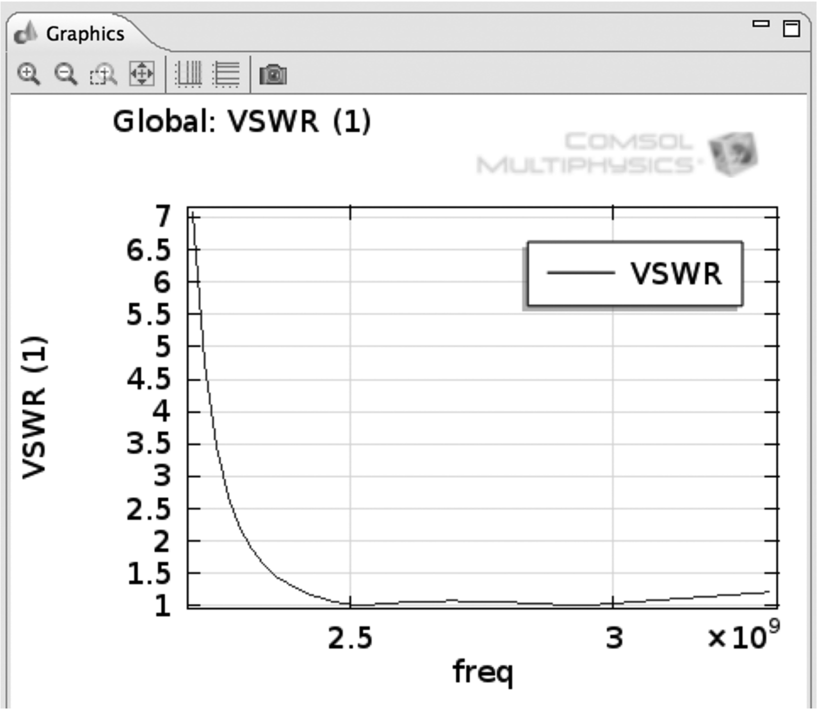


FIGURE 56. Three Stub Tuner VSWR.

By comparing Figure 55 to Figure 56, it can be seen that the slight elongation of the third stub, by the 9/8 ratio, changes the Three Stub Tuner from a high-pass filter to a band-pass filter. The band-pass filter has optimum transmission in the 2.35 GHz to 3.15 GHz range.

CHAPTER 11

CONCLUSIONS: THREE STUB TUNER MODEL PLUS VARIATIONS

The model variations in this book show that the Three Stub Tuner, a critical microwave component, is very sensitive to the length of each Stub. The relative lengths of the Stubs in this Three Stub Tuner model show the electric field distribution and the VSWR are readily manipulated to alter the band-pass of the system. The VSWR graphs show that the Three Stub Tuner can alter the power transmission in the range from 2.4 GHz to 3.3 GHz.

This book demonstrates that the RF Module of COMSOL Multiphysics software can easily be employed to calculate and tune the power distribution and to solve reflection analysis problems for microwave components. This model, in particular, is easily expanded to applications for rectangular waveguide components in both higher and lower frequency ranges.

For further guidance in COMSOL Multiphysics step-by-step modeling for RF and other areas of physics see Reference {18}.

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