Modeling Microwave Waveguide Components: The Tuned Stub

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Abstract: 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 the active circuit at one end only. This paper 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 case, three (3) stubs have been added along the length of the waveguide to optimize the tuning performance.

Keywords: waveguide, microwave, tuned-stub, VSWR, power-transfer.

1. Introduction

Microwave signals need to be clear and undistorted to ensure accurate information transfer. The primary function of many waveguide systems is to convey a complex, broad power range, wave-based, electromagnetic signal from the generating or receiving source to the consuming or input load with a minimum of signal dissipation and/or distortion. Since waveguides have 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 paper, the COMSOL Multiphysics RF Module software (version 4.3) 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.

One of the primary advantages of using COMSOL Multiphysics software is the inherent capability of 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, it was necessary to add the equation for the calculation of the Voltage Standing Wave Ratio (VSWR). The VSWR is a measure of the power transfer match and indirectly of the potential signal dispersion and/or distortion.

2. Designing the Three-Stub Tuner Model

A stub {1} 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.
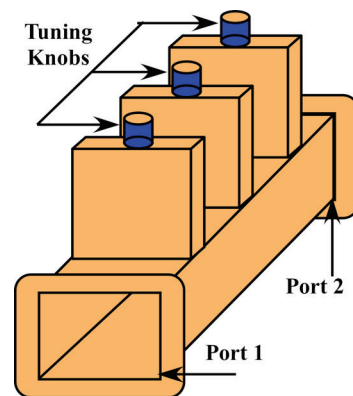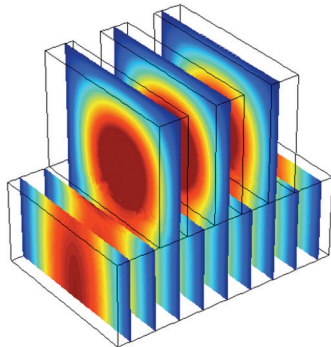

Figure 1. Three Stub Tuner.

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 paper. 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 electro-magnetically couple the stubs to the main waveguide cavity.

The stubs are short-circuited at the unconnected end and open-circuited at the waveguide-connected end. Rotating the blue 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.).

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 paper.

3. Modeling Using the RF Module in COMSOL Multiphysics 4

In this paper, the RF Module of the COMSOL Multiphysics software (version 4.3) 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 {2, 3} is one of a number of different complex methodologies that can be used to analyze the properties of circuits at RF and microwave frequencies. The S-parameter methodology employs matched-load terminations, rather than short-circuit or open-circuit terminations. The use of S-parameter methodology {4} 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.
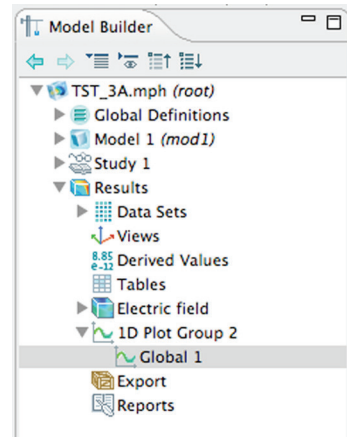
Figure 3. Three Stub Tuner Model Builder Tree.

### 3.1 Building the Three Stub Tuner Model

You can start building the Three Stub Tuner Model on the COMSOL Multiphysics Desktop in Model Builder by selecting 3D > Next > Radio Frequency > Electromagnetic Waves, Frequency Domain (emw) > Add Physics > Next > Custom Studies > Empty Study > Finish. Figure 4 shows the initial Model Builder Tree.
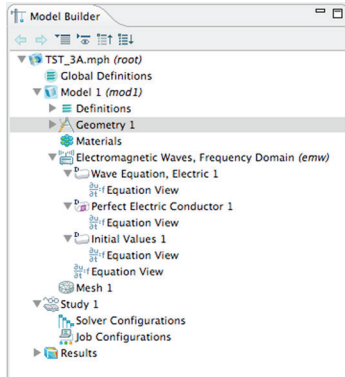
Figure 4. Three Stub Tuner Initial Model Builder Tree

In the next set of steps, the 3D Three Stub Tuner model is configured to use Boundary Mode Analysis {5}. The Boundary Mode Analysis sets up the parametric configuration for the creation and analysis of Port 1 and Port 2.

Right-Click on Study 1 in Model Builder and select Study Steps > Boundary Mode Analysis. Configure the Step 1: Boundary Analysis Settings as shown in the Appendix in Table 1. Figure 5 shows the Settings for Step 1 in place. Create and configure Step 2: Boundary Mode Analysis using the same methodology. Configure the Settings for Step 2, as shown in Table 1.
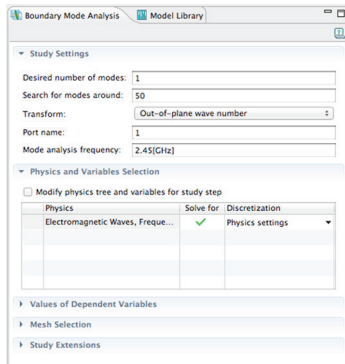
Figure 5. Boundary Mode Analysis Settings for Step 1

Right-Click on Study 1 in Model Builder and select Study Steps > Frequency Domain to add Step 3. The Frequency Domain Settings are as shown in the Appendix in Table 2. First,

Click on Step 3: Frequency Domain, then go to the Frequency Domain settings window and Click on the Range Settings button. Enter the parameters shown in Table 2.
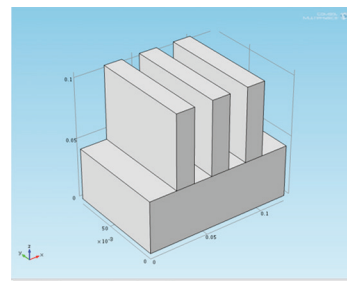
3.2 The Three Stub Tuner Model Geometry

The Three Stub Tuner geometry comprises the union of 4 rectangular prisms. The configuration data, as defined in the Appendix in Table 3, should be entered in the model, as follows: Right-Click Global Definitions > select Parameters and enter the data in the Parameters edit window.

Build the Three Stub Tuner geometry as follows: Right-Click on Geometry 1 and 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. Once entered, Click > Build Selected. Create each additional Block using the same methodology with the next new set of six (6) global data parameters.

Once all four (4) blocks have been created, then you can Right-Click Geometry 1 and select Boolean Operations > Union. Click Zoom Extents in the Graphics Toolbar. Then, Select all four (4) of the domains and add them to the Union Selection window. Uncheck the Keep interior boundaries checkbox. Click Build All.

The final configuration of the Three Stub Tuner Model is as shown in Figure 6.

Figure 6. Three Stub Tuner Model Geometry

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.

3.3 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 on Model Builder > Model 1 > Materials and then Select Material from the pop-up window. Right-Click on Material 1 > Select > Rename. Enter Vacuum as the name of the material and 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.

Right-Click on Model Builder > Model 1 > Materials and then Select Material from the pop-up window. Right-Click on Material 2 > Select > Rename. Enter Lossy Wall Material as the name of the material and Click OK.

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

In the Material > Material Properties > Basic Properties list, select and add the Basic Properties shown in Table 5. In the In the Material > Material Contents edit window, Enter the parameter values for each property as shown in Table 5.

3.4 The Three Stub Tuner Model Electromagnetic Waves, Frequency Domain Configuration

To configure the Electromagnetic Waves, Frequency Domain (emw) Module, Right-Click on the Electromagnetic Waves, Frequency Domain (emw) Module and Select Impedance Boundary Condition from the pop-up window.

Click on Impedance Boundary Condition 1. In the Graphics window, Select boundaries 2-23 and add them to the Selection edit window in the Impedance Boundary Condition Settings page.

Next, Right-Click on the Electromagnetic Waves, Frequency Domain (emw) Module and Select Port from the pop-up window. Click on Port 1.

Select Boundary 1 in the Graphics window. Add Boundary 1 to the Port Selection window in the Settings Page. In Port > Port Properties, Set the Type of port to Numeric and the Wave excitation at this port to On.

Now, Right-Click on the Electromagnetic Waves, Frequency Domain (emw) Module and Select Port from the pop-up window. Click on Port 2.

Select Boundary 24 in the Graphics window. Add Boundary 24 to the Port Selection window in the Settings Page. In Port > Port Properties, Set the Port name to 2, the Type of port to Numeric and the Wave excitation at this port to Off.

3.4 The Three Stub Tuner Model Mesh Configuration

Right-Click Model Builder Mesh, Select Free Tetrahedral from the pop-up list. Click on Mesh 1 > Size. On the Size Settings page, in the Element Size Parameters > Maximum element size edit window, Enter 0.006.
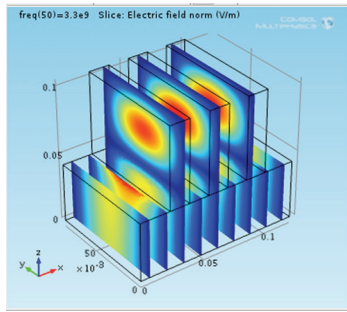

3.4 The Three Stub Tuner Model Computation

Right-Click on Study 1, Select Compute.

4. The Three Stub Tuner Results

The default plot is a Multislice plot with one plot plane in each of the primary directions (x, y, z). To create the plot shown in Figure 2, Right-Click on the Results > Electric field > Multislice icon and Select Delete.

Next, Right-Click on the Results > Electric field and Select Slice. Click on Slice 1. Go to the Slice Settings page and enter 9 in the Slice > Plot > Plane Data > Planes edit window. Click Plot in the toolbar. The resultant plot is shown in Figure 7.

Figure 7. Three Stub Tuner Model
Electric Field Result

4.1 The Three Stub Tuner Model VSWR Calculation

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

$$1. \qquad VSWR = \frac{1+|S_{11}|}{1-|S_{11}|}$$

Where S_{11} is the Port 1 scattering coefficient and is calculated by the RF Module.
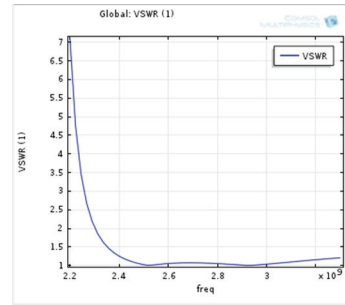
To plot the VSWR, Right-Click on Model Builder > Results, Select 1D Plot Group from the pop-up list. Next, Right-Click on 1D Plot Group 2, Select Global from the pop-up list. Click on Global.

Enter, as the y-axis data Expression:

$$2. \quad (1 + abs(emw.S11)) / (1 - abs(emw.S11))$$

Click > Plot in the Toolbar.

The VSWR plot is shown in Figure 8.

Figure 8. Three Stub Tuner Model
VSWR Plot

5. Conclusions

A new model has been developed and presented for the Three Stub Tuner, a critical microwave component. This model shows the electric field distribution and the VSWR. This model demonstrates that the RF Module of COMSOL Multiphysics software can be easily employed, when properly configured, to calculate microwave component power distribution and reflection analysis problems.

6. References

1. http://en.wikipedia.org/wiki/
      Stub_(electronics)
2. http://en.wikipedia.org/wiki/Scattering_
      parameters
3. COMSOL RF Module Users Guide, pp 42-48
4. COMSOL RF Module Users Guide, pp 43,
waveguide_adapter model.
5. COMSOL RF Module Users Guide, pp 135-136
6. COMSOL Multiphysics Users Guide, pp 78
7. COMSOL Multiphysics Users Guide, pp 580

7. Appendix

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}

Table 2: Frequency Domain Settings

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

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

parameter	value	description
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 cond.

Table 4: Three Stub Tuner Material: Vacuum

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

Table 5: Three Stub Tuner Material: Lossy Wall Material

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