A

EM.Tempo

Tutorial Lessons

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EM.Tempo Tutorial Lesson 5

Analyzing A Planar Microstrip Band-Stop Filter

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5.1 What You Will Learn

In this tutorial you will model a two-port planar filter that is excited by two independent sources. You will first use a wizard to create a basic two-port microstrip through line. Then, you will add additional microstrip segments to complete your filter construction.

EM.Tempo Manual:

http://www.emagtech.com/wiki/index.php/EM.Tempo

EM. Tempo Tutorial Gateway:

http://www.emagtech.com/wiki/index.php/EM.Cube#EM.Tempo_Documentation

Download projects related to this tutorial lesson:

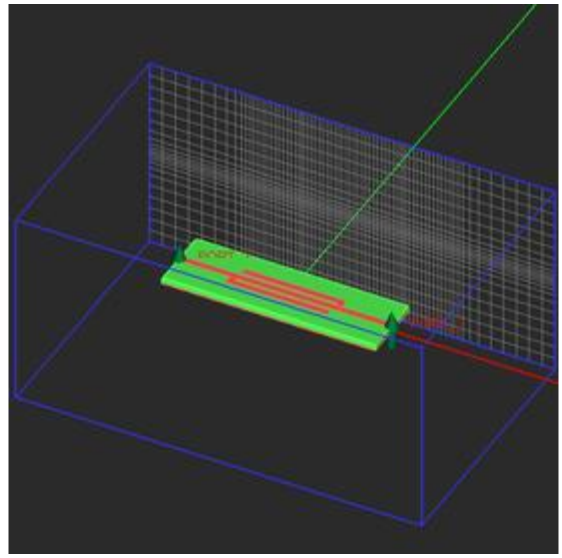
http://www.emagtech.com/downloads/ProjectRepo/EMTempo_Lesson5.zip

5.2 Getting Started

Open the EM.Cube application and switch to EM.Tempo. Start a new project with the following parameters:

Starting Parameters	
Name	EMTempo_Lesson5
Length Units	Mils
Frequency Units	GHz
Center Frequency	13GHz
Bandwidth	25GHz

Tutorial Project: Analyzing A Planar Microstrip Band-Stop Filter



Objective: In this project, a planar microwave circuit made of microstrip line segments is modeled and its frequency response is analyzed in EM.Tempo.

Concepts/Features:

- Computational Domain
- Boundary Conditions
- Microstrip Port Source
- Port Definition
- S-Parameters

Minimum Version Required: All versions

Make sure to set the Length Units to Mils (see Figures 1 and 2). Figure 3 shows the geometry of the planar filter and its microstrip line segments:

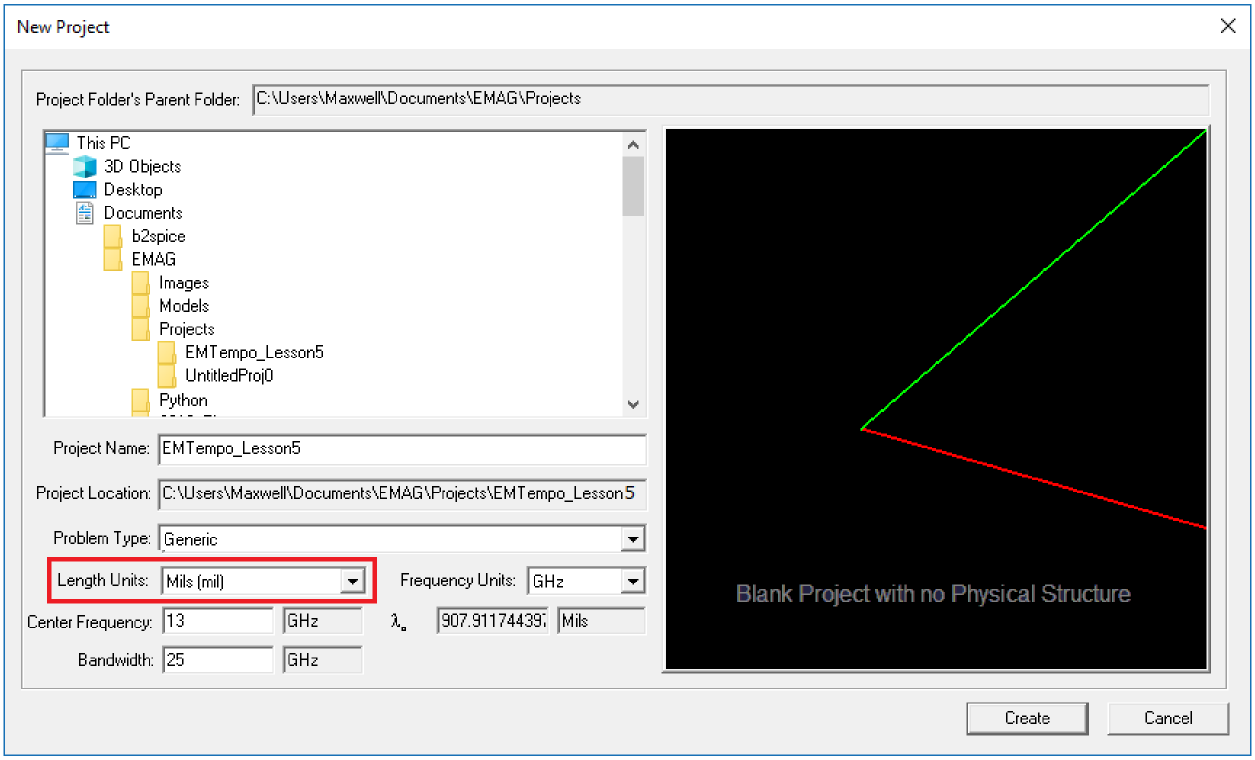


Figure 1. *The New Project dialog.*

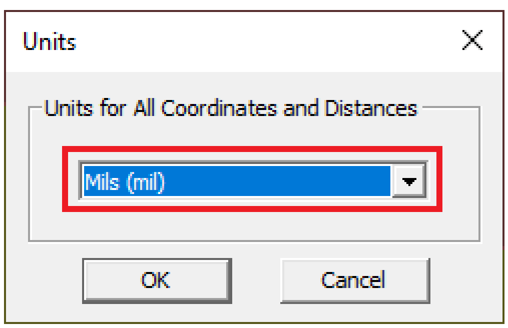


Figure 2. *The Unit dialog.*

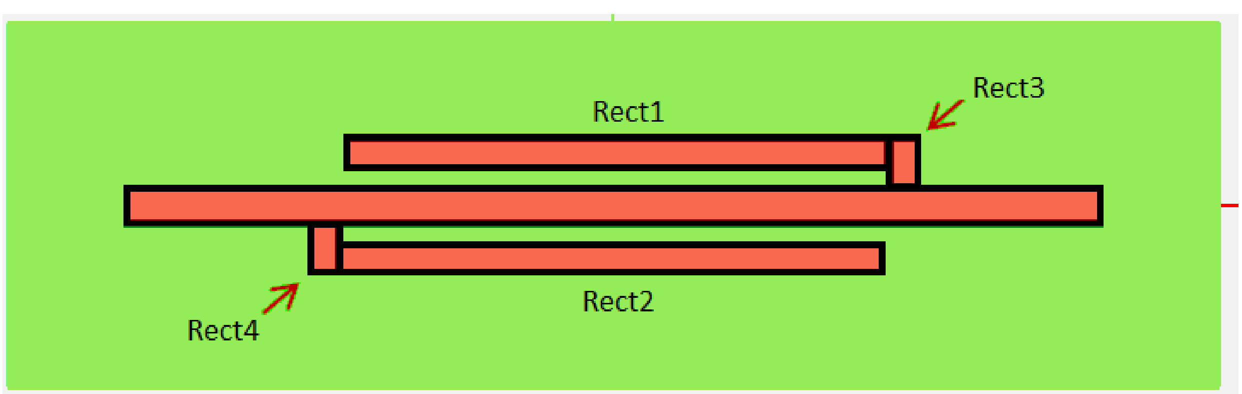


Figure 3. *The geometry of the planar filter and position of the microstrip components.*

5.3 Constructing the Base Geometry of a Two-Port Microstrip Line

Make sure you have changed the project **Length Units** to "Mils". Click on the **Two-Port Microstrip Wizard**  button of the **Wizard Toolbar** or select the menu item **Tools** → **Transmission Line Wizards** → **Two-Port Microstrip Line** (Figure 4).

Figure 4. *EM.Tempo's wizard toolbar.*

A default two-port microstrip line structure appears in the project workspace. You may zoom to fit your structure into the screen using the keyboard shortcut **Ctrl+E** or by clicking the **Zoom Extents**  button of the **View Toolbar** (Figure 5). The microstrip line extends across the whole length of the dielectric substrate (Figure 6). Two microstrip port sources are used to excite the microstrip through line from its two ends. These are indeed special distributed sources that are placed between PEC lines and a ground plane and are used to compute the scattering parameters.

Figure 5. *EM.Tempo's View Toolbar.*

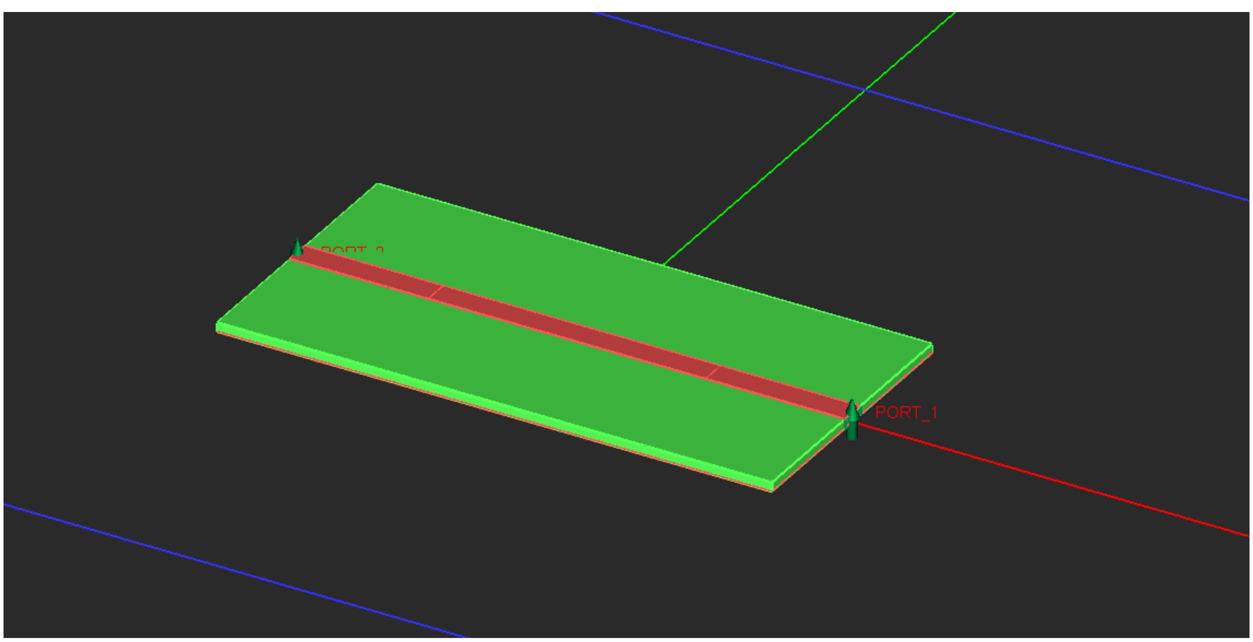


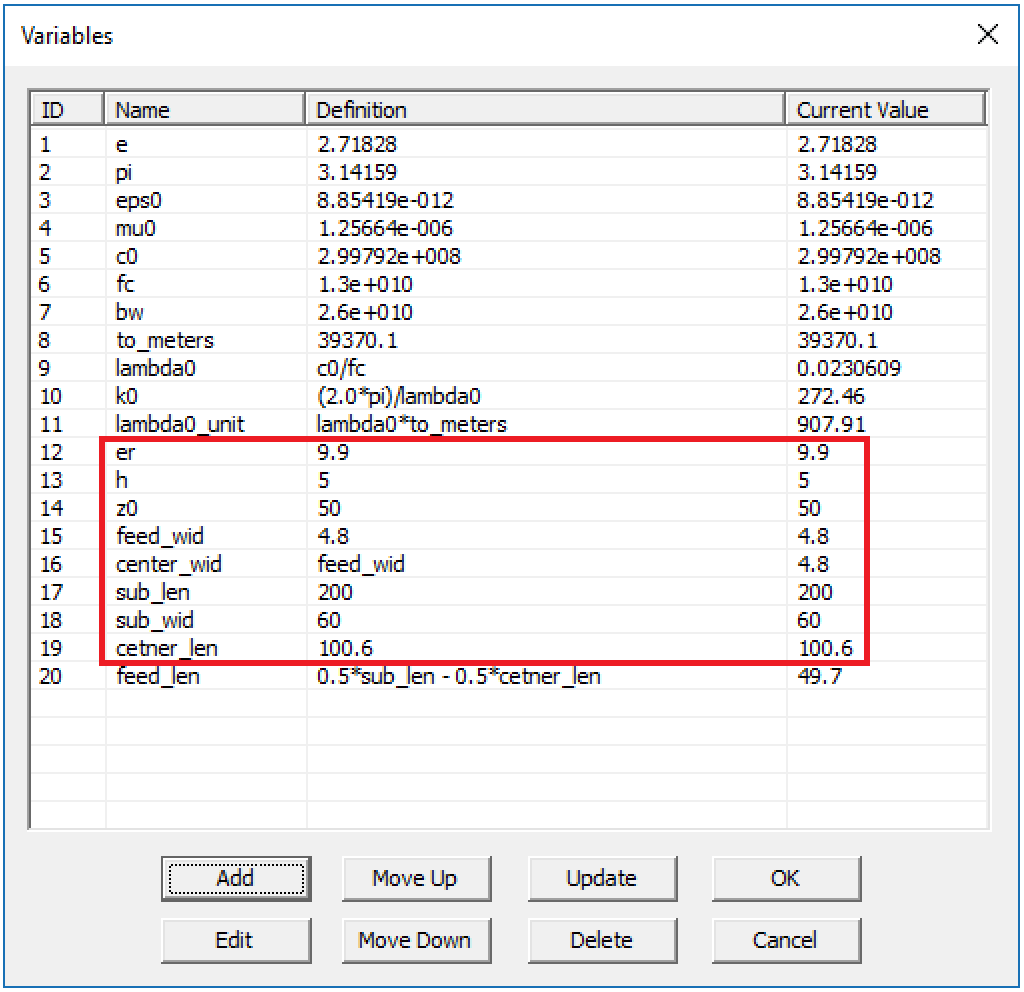
Figure 6. *The initially created two-port microstrip geometry.*

At this point, you are going to change the parameters of microstrip geometry the wizard created for you including the dielectric substrate properties. Open the Variables dialog and change the definition of the following variables (see Figure 7):

Variable Name	Original Definition	New Definition
er	2.2	9.9
h	0.0015*to_meters	5
sub_len	0.1*to_meters	200
sub_wid	0.05*to_meters	60
center_len	0.05*to_meters	100.6
feed_wid	microstrip_design(z0,er)*h	4.8

Some of the above length variables have original definitions that convert default meter-scaled values to the project units of your current project. This is done using the system variable "to_meters". You can simply replace this kind of variables with numeric values expressed in the current project units. Also, note that on a 5-mil substrate with ε_r = 9.9, a 50Ω microstrip line has a width of 4.815 mils. Here you change the width of the micostrip to a rounded value of 4.8 mils.

Zoom again to fit your structure into the screen. Figure 8 shows the geometry of the microstrip through line after affecting all the above changes.



ID	Name	Definition	Current Value
1	e	2.71828	2.71828
2	pi	3.14159	3.14159
3	eps0	8.85419e-012	8.85419e-012
4	mu0	1.25664e-006	1.25664e-006
5	c0	2.99792e+008	2.99792e+008
6	fc	1.3e+010	1.3e+010
7	bw	2.6e+010	2.6e+010
8	to_meters	39370.1	39370.1
9	lambda0	c0/fc	0.0230609
10	k0	(2.0*pi)/lambda0	272.46
11	lambda0_unit	lambda0*to_meters	907.91
12	er	9.9	9.9
13	h	5	5
14	z0	50	50
15	feed_wid	4.8	4.8
16	center_wid	feed_wid	4.8
17	sub_len	200	200
18	sub_wid	60	60
19	cetner_len	100.6	100.6
20	feed_len	0.5*sub_len - 0.5*cetner_len	49.7

Figure 7. *The variables dialog showing all the modified variables.*

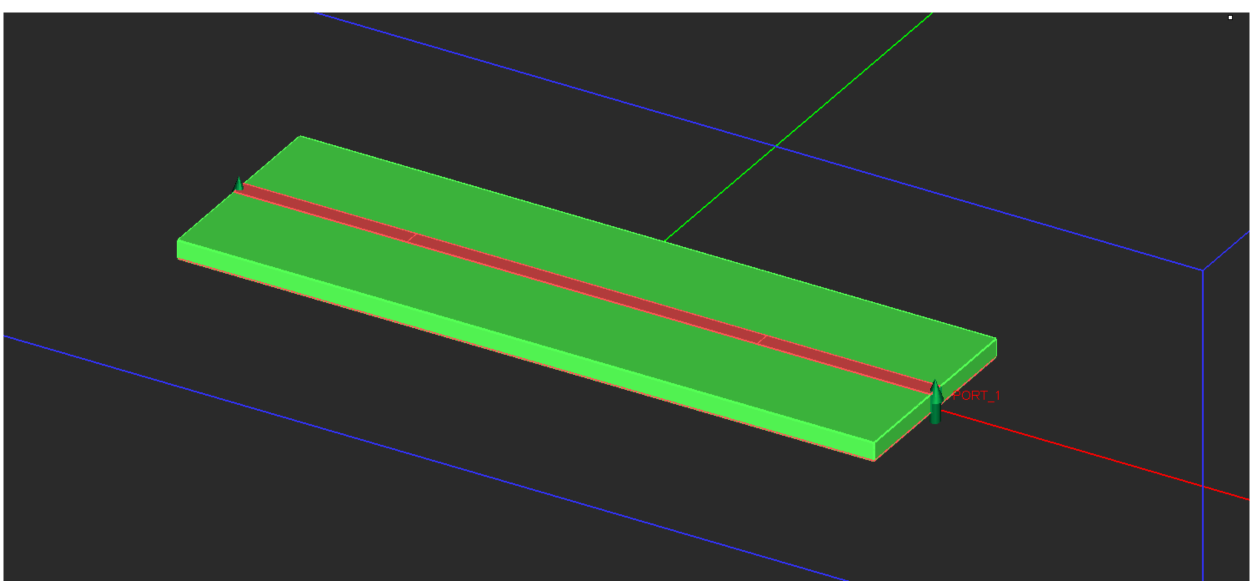


Figure 8. *The modified two-port microstrip geometry.*

5.4 Drawing the Additional Microstrip Components

The next step is adding four additional microstrip segments to turn the microstrip through line into a planar filter. But first you have to make sure that the objects you are going to draw will belong to the right material group. To do so, select the item "CONDUCTOR" under **PEC Objects** in the navigation tree, right-click on it and select **Activate** from the contextual menu (see Figure 9). This makes the PEC group called "CONDUCTOR" the active material group of the project for drawing and adding new objects.

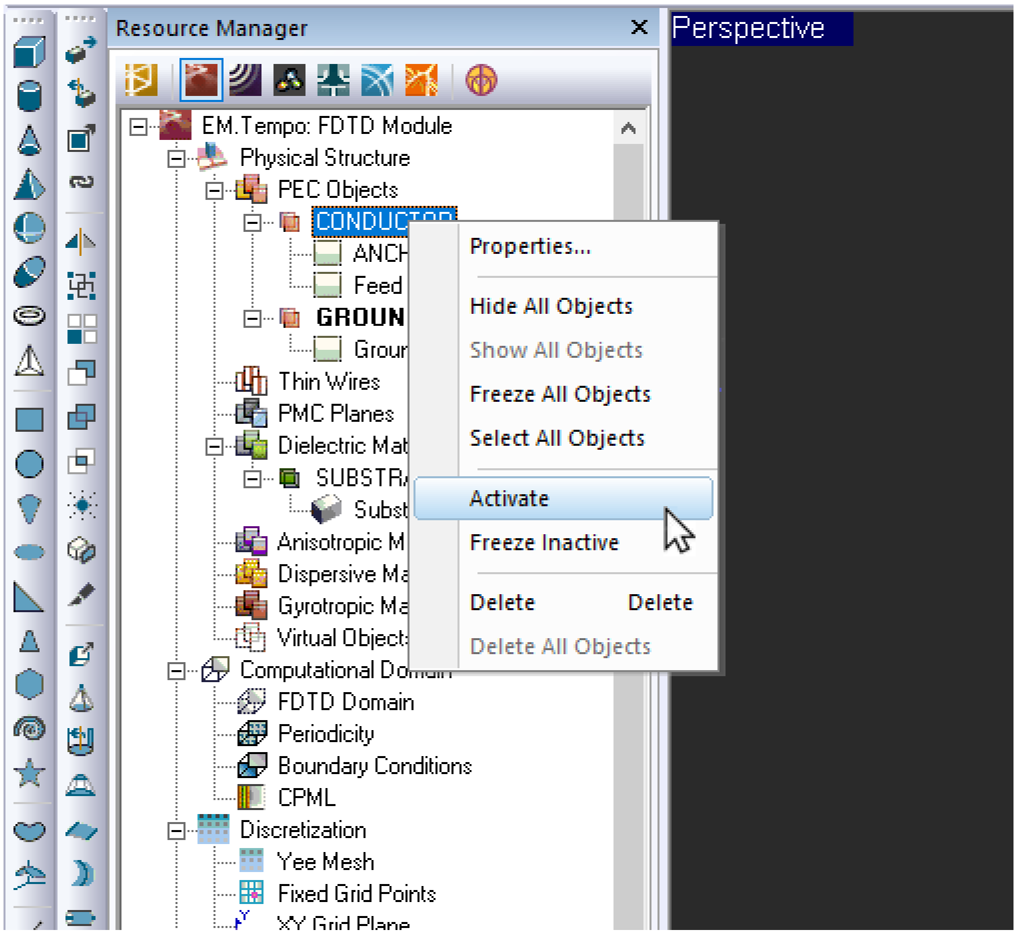


Figure 9. *Making a material group active in the navigation tree.*

Below is a list of the rectangle strip objects you need to draw in the project workspace:

Part	Object Type	Coordinates	Dimensions
Rect1	Rectangle Strip	(0.5mils, 8.8mils, 5mils)	90mils × 4.8mils
Rect2	Rectangle Strip	(-0.5mils, -8.8mils, 5mils)	90mils × 4.8mils
Rect3	Rectangle Strip	(47.9mils, 6.8mils, 5mils)	4.8mils × 8.8mils
Rect4	Rectangle Strip	(-47.9mils, -6.8mils, 5mils)	4.8mils × 8.8mils

There are many different ways of drawing, moving and manipulating objects in EM.Cube. As you learn more about EM.Cube's CAD tools and become more skilled in using them, you will find a number of facilitating shortcuts that take advantage of object snap points. But for now, you can simply draw the objects below on a blank space in the project workspace and then place them in the right locations by changing their coordinated according to the above table.

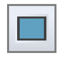
To draw a rectangle, click the **Rect Strip** tool  button of the **Object Toolbar** (Figure 10) or select the menu item **Object** → **Surface** → **Rectangle Strip** or use the keyboard shortcut **Alt+R**.

Figure 10. *Selecting the Rectangle Strip tool in the object toolbar.*

With the rectangle strip tool selected, click on a blank space in the project workspace and drag the mouse to draw the planar rectangle object. A property dialog opens up at the lower right corner of your screen (Figure 11). As you drag the mouse, you will see that the X-dimension and Y-dimension of your new object continuously change. When the base reaches the desired size or something close to that, click the mouse. You can always fine-tune the size of your object by entering exact numeric values for its dimensions. You will notice four small red balls on the four sides (edges) of the rectangle strip object. These are called edit handles and can be used to change the dimensions of the object. Or you can simply type in any value for the X- and Y-dimensions of your rectangle. Next, you have to position your rectangle strip in the right location by entering the given values for the coordinates of the center of the local coordinate system (LCS).

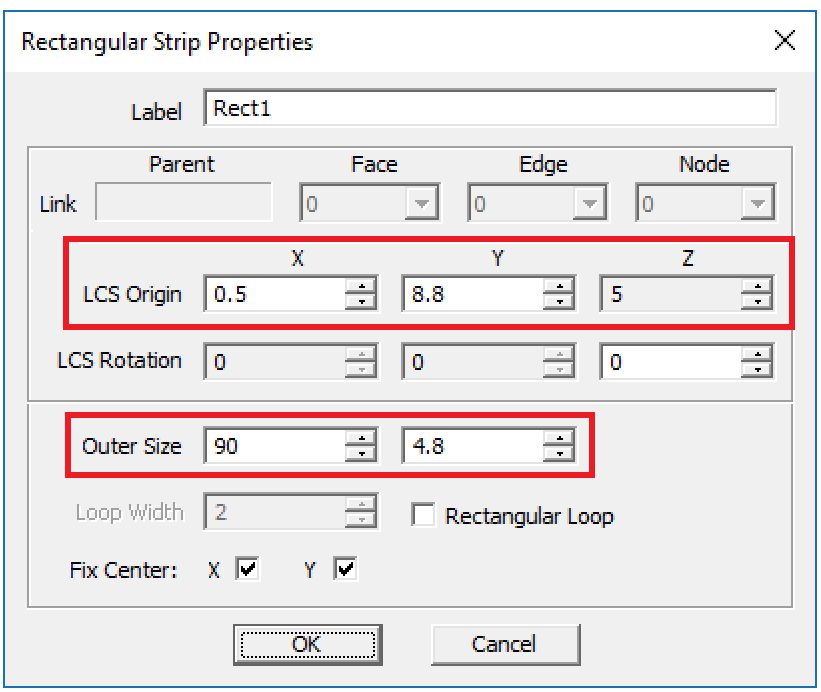


Figure 11. *The property dialog of the rectangle strip object.*

After drawing and positioning all the four rectangle strips, your filter geometry will look like Figure 12 as shown below.

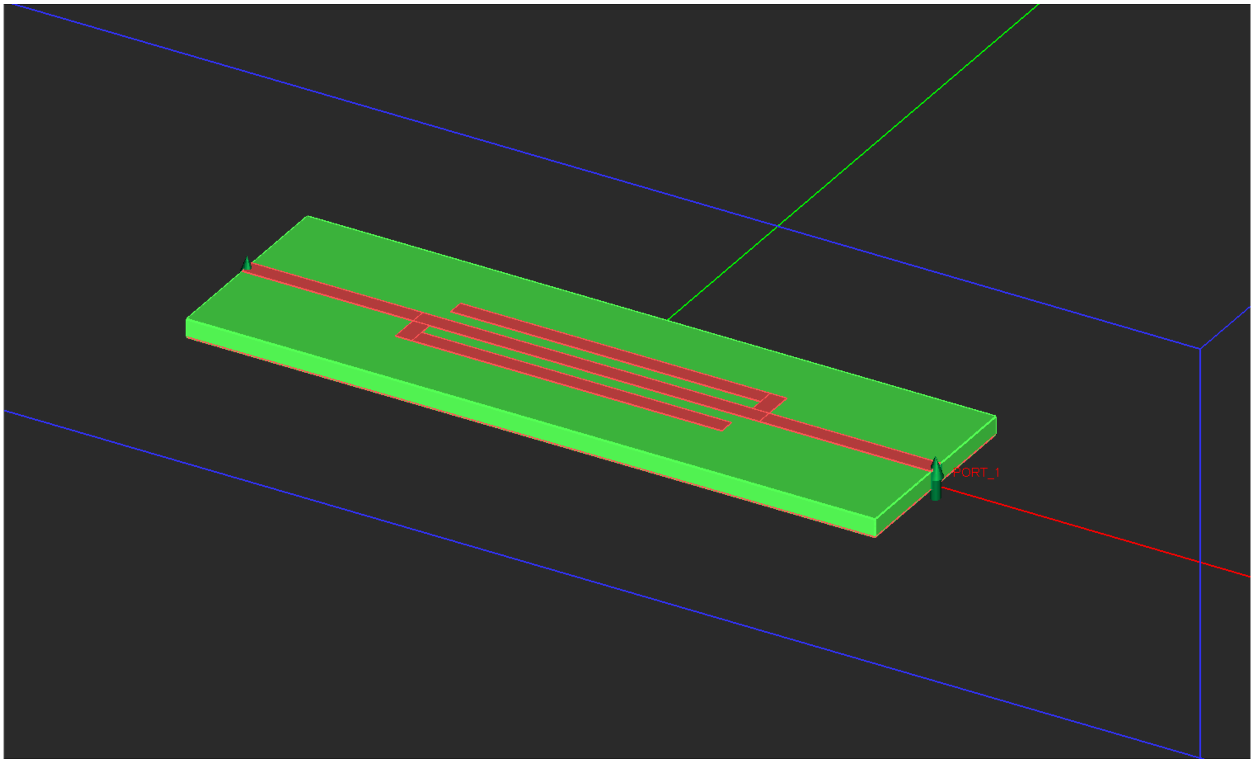


Figure 12. *The completed two-port microstrip filter geometry.*

5.5 Examining the Sources & Ports

The wizard automatically initiated two microstrip port sources and associated them with the two feed strips objects at the two edges of the substrate. Two port observables were also defined and associated with the sources. In other words, the wizard already took care of the excitation and observables for your project. A microstrip port/source is associated with a narrow long rectangle strip object. It is a special distributed source that is placed underneath the strip object having the same width as the strip plus an additional **height** parameter, which represents that height of thickness of the substrate. You can open the property dialog of the two microstrip source and examine their parameters (Figure 13).

Also, open the port definition dialog and see how the two ports have defined and associated with the two sources (Figure 14).

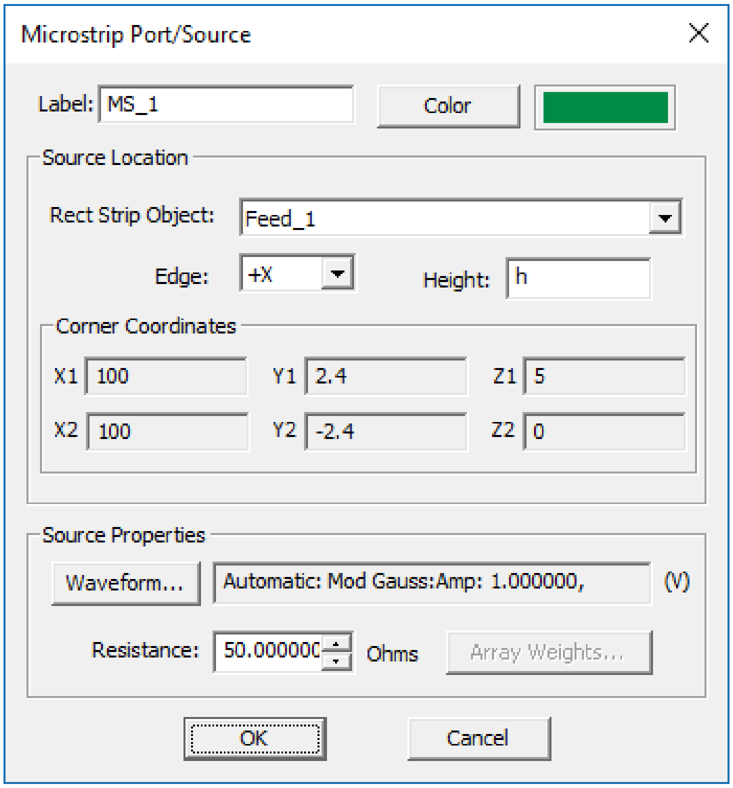


***Figure 13**. The microstrip port dialog.*

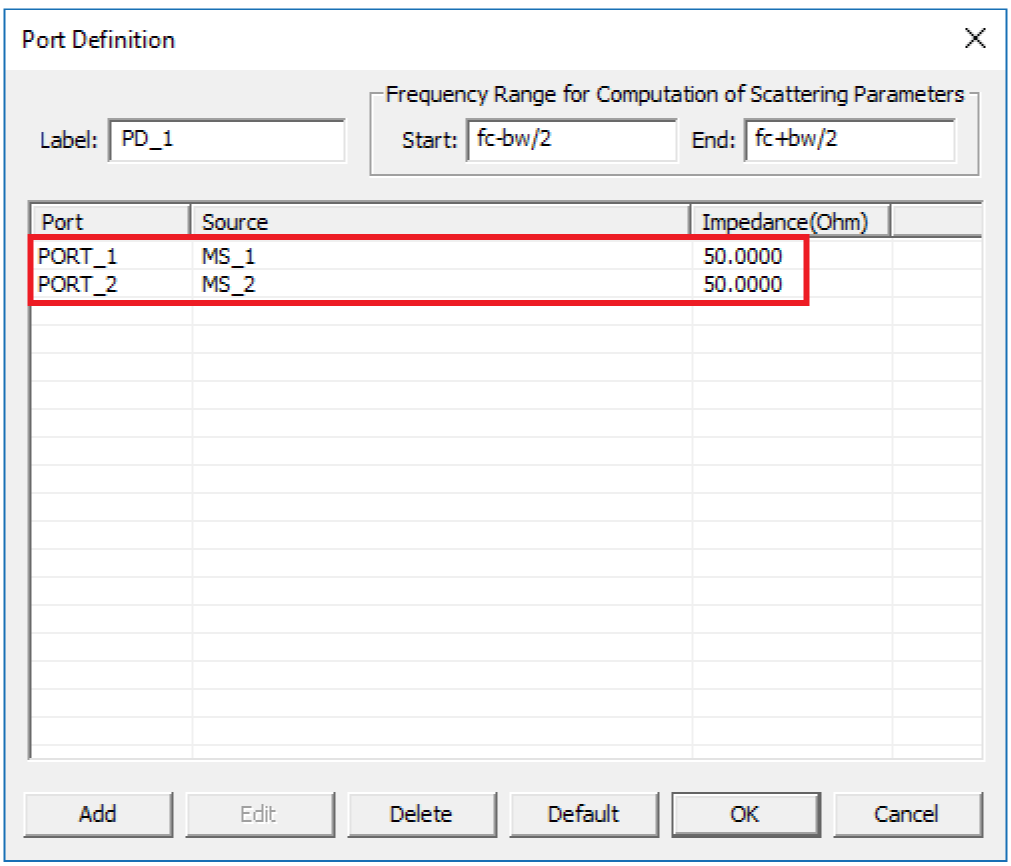


***Figure 14**. The port definition dialog showing the two ports associated with the two sources.*

Both ports have reference impedance of 50Ω. These are the port characteristics impedances that are used to define and compute the scattering parameters in the FDTD method:

$$S_{ij} = \sqrt{\frac{Re(Z_i)}{Re(Z_j)}} \cdot \frac{V_j - Z_j^* I_j}{V_i + Z_i I_i}$$

In the above equation, V_i and V_j are the voltages across ports i and j, respectively, and I_i and I_j are the currents that flow through those ports. During the FDTD simulation of a two-port structure like your planar filter, a "port sweep" takes place behind the scenes. First, the source MS_1 is turned on with a voltage of 1V and source MS_2 is turned off (shorted). The voltage and currents at the locations of these distributed sources are measured after a complete FDTD time marching loop. Next, the source MS_2 is turned on with a voltage of 1V and source MS_1 is turned off (shorted).

Calculation of the port characteristics of an N-port structure in EM.Tempo requires a port sweep that generates N binary excitations of all the ports and requires N separate FDTD time marching loops.

5.6 Setting the Computational Domain

EM.Tempo automatically places a domain box around your physical structure. The default box is positioned a quarter free-space wavelength away from the largest bounding box of your structure. You can change the values of the **Domain Offset** parameters individually at all the six faces of the domain box. To do so, open the Domain Settings dialog by clicking the **Domain** button of the **Simulate Toolbar** or selecting the menu item **Simulate → Computational Domain → Domain Settings...** or use the keyboard shortcut **Ctrl+A** (Figure 15).

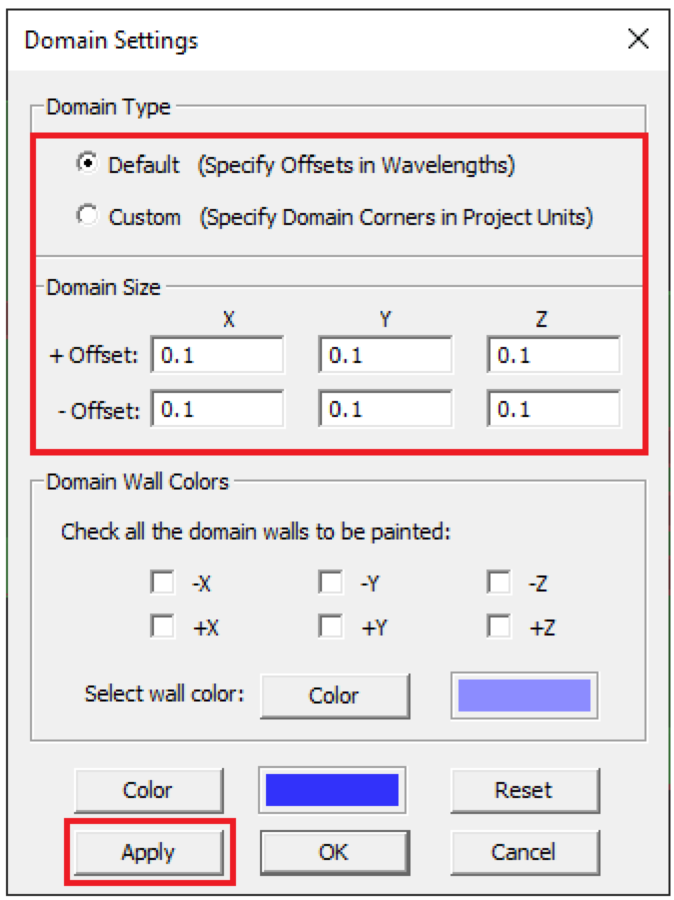


***Figure 15.** EM.Tempo's Domain Settings dialog.*

Note that the six walls of the domain box represent perfectly matched layer (PML) boundary conditions by default. They are liked to model an open-boundary problem. A filter structure does not radiate. Therefore, you can afford placing the domain walls much closer to your physical structure. In the Domain Settings dialog, change the default domain offset values in wavelengths from 0.25 to 0.1 along all the six ±x, ±y and ±z directions.

5.7 Analyzing the Planar Filter

At this point, your filter is ready for simulation. Before starting the simulation, try to mesh your physical structure. The wizard set the mesh density to 40 cells/λ_{eff}. It would be interesting to examine the mesh grid planes and see how EM.Tempo's adaptive mesh generator discretizes the substrate layer and the microstrip discontinuity regions. The figures 16 and 17 show the XY and ZX grid planes of your microstrip filter structure.

In the Engine Settings dialog, set the value of **Power Threshold** to -40dB and increase **No. Time Steps** to 20,000. Run a **Wideband Analysis** (see Figure 18). In this case, the port sweep process involves two binary excitations.

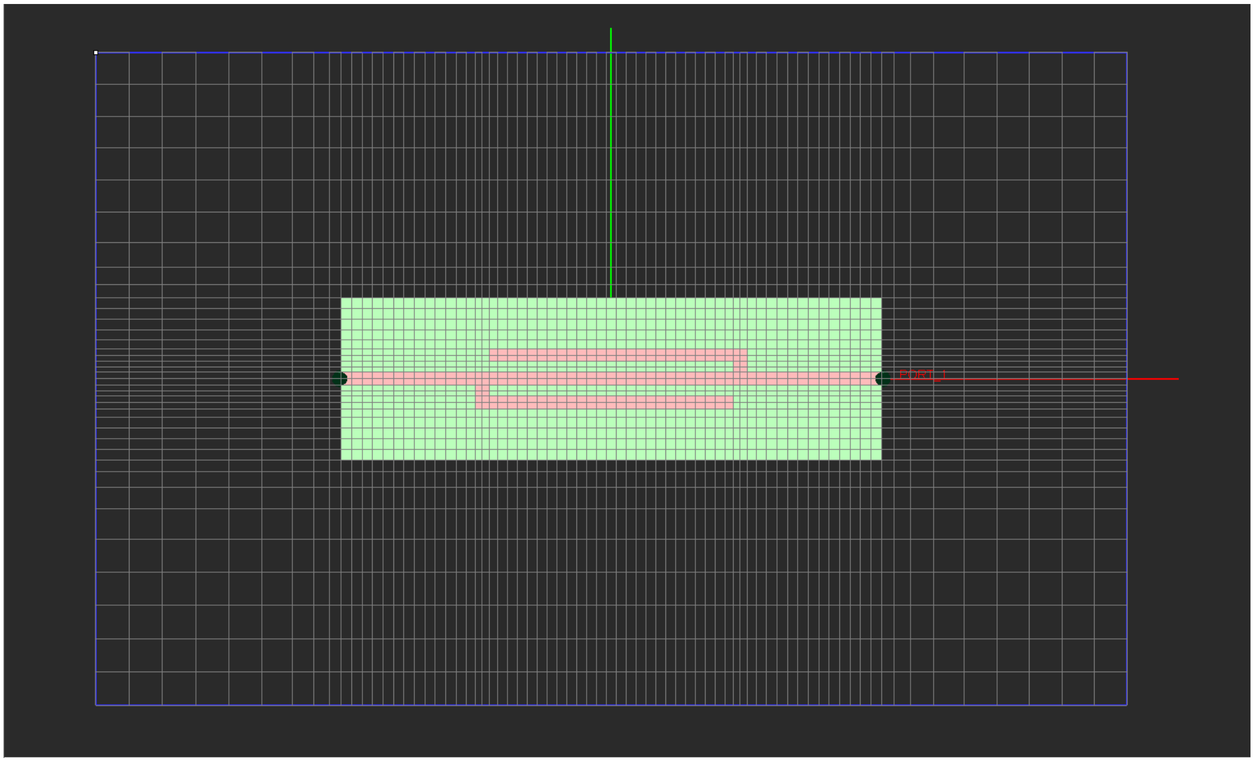


Figure 16. *The top view of EM.Tempo's XY grid plane.*

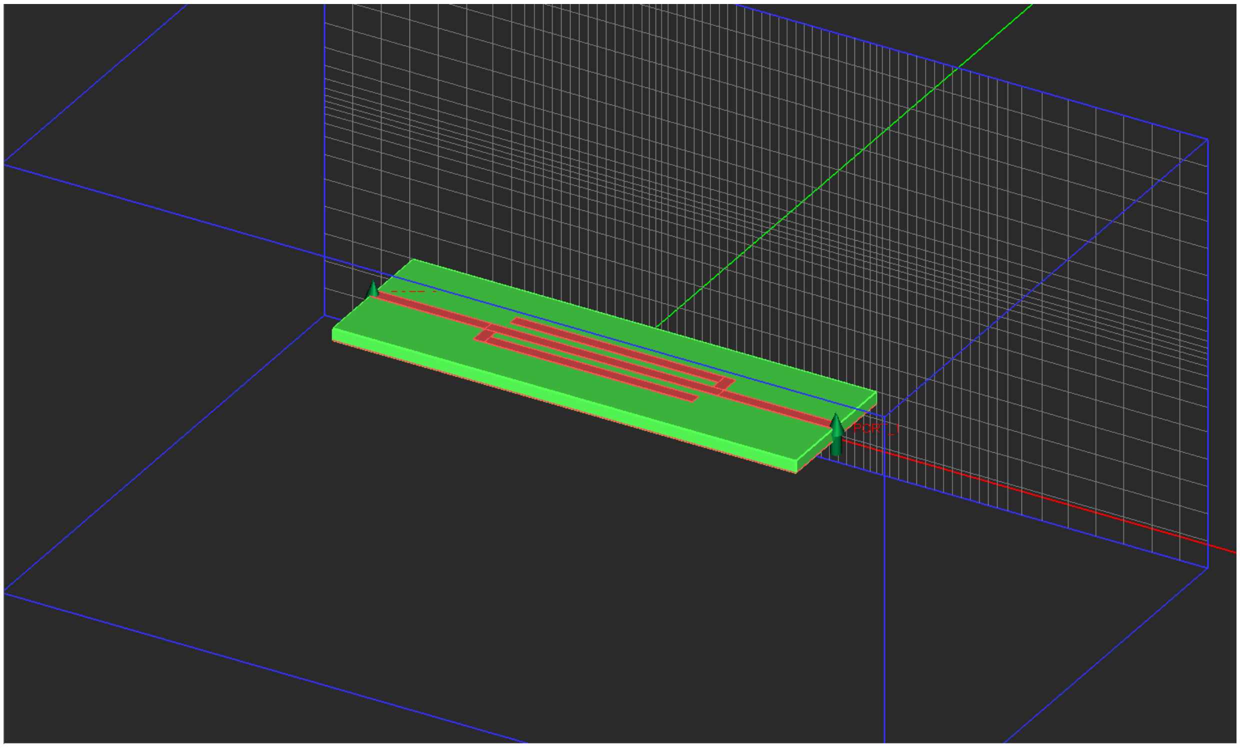


Figure 17. *The perspective view of EM.Tempo's ZX grid plane.*

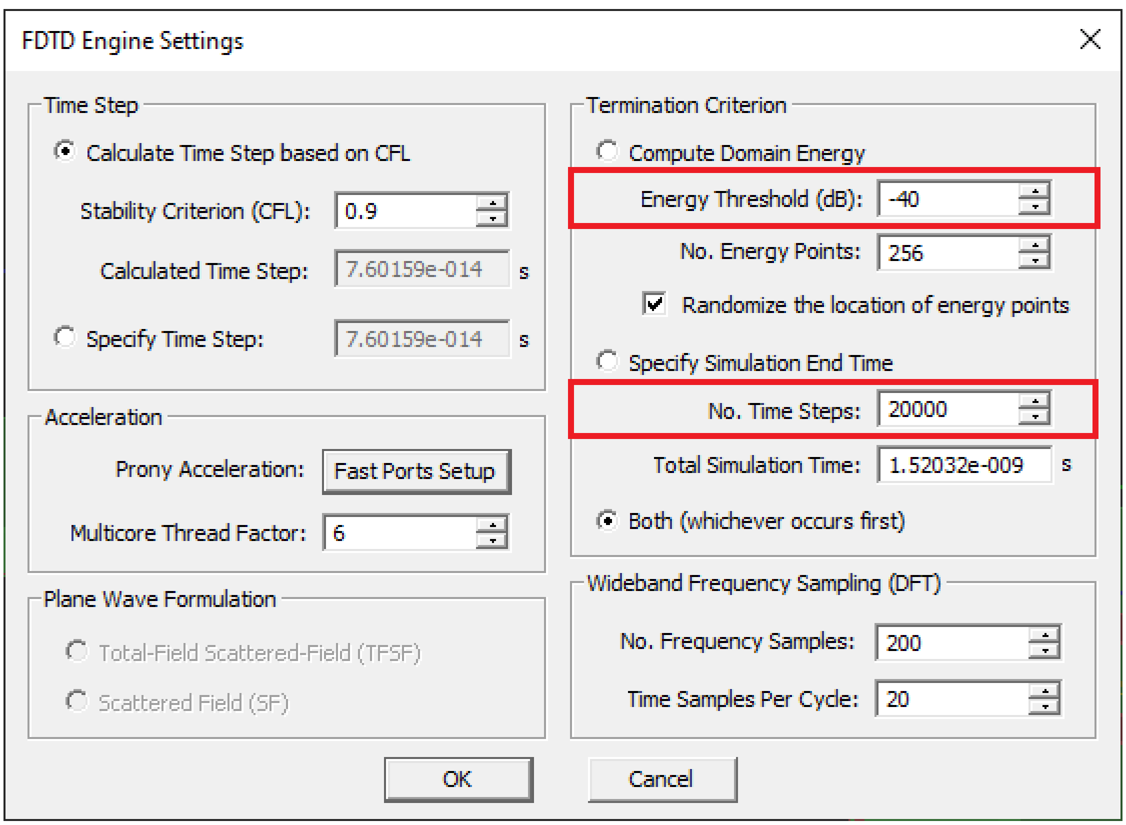


Figure 18. *EM.Tempo's Simulation Engine Settings dialog.*

5.8 Plotting the Frequency Response of the Filter

Once the two-port FDTD simulation is finished, a number of output data files appear in the Data Manager. These include $N^2 = 4$ scattering parameter files with names like “DP_Sij.CPX”, N^2 impedance parameter files with names like “DP_Zij.CPX”, N^2 admittance parameter files with names like “DP_Yij.CPX”. Figure 19 and 20 show the return loss (S_{11}) and insertion loss (S_{21}) of the band-stop filter. The filter features a 4.5GHz stop band over the frequency range [10GHz - 14.5GHz].

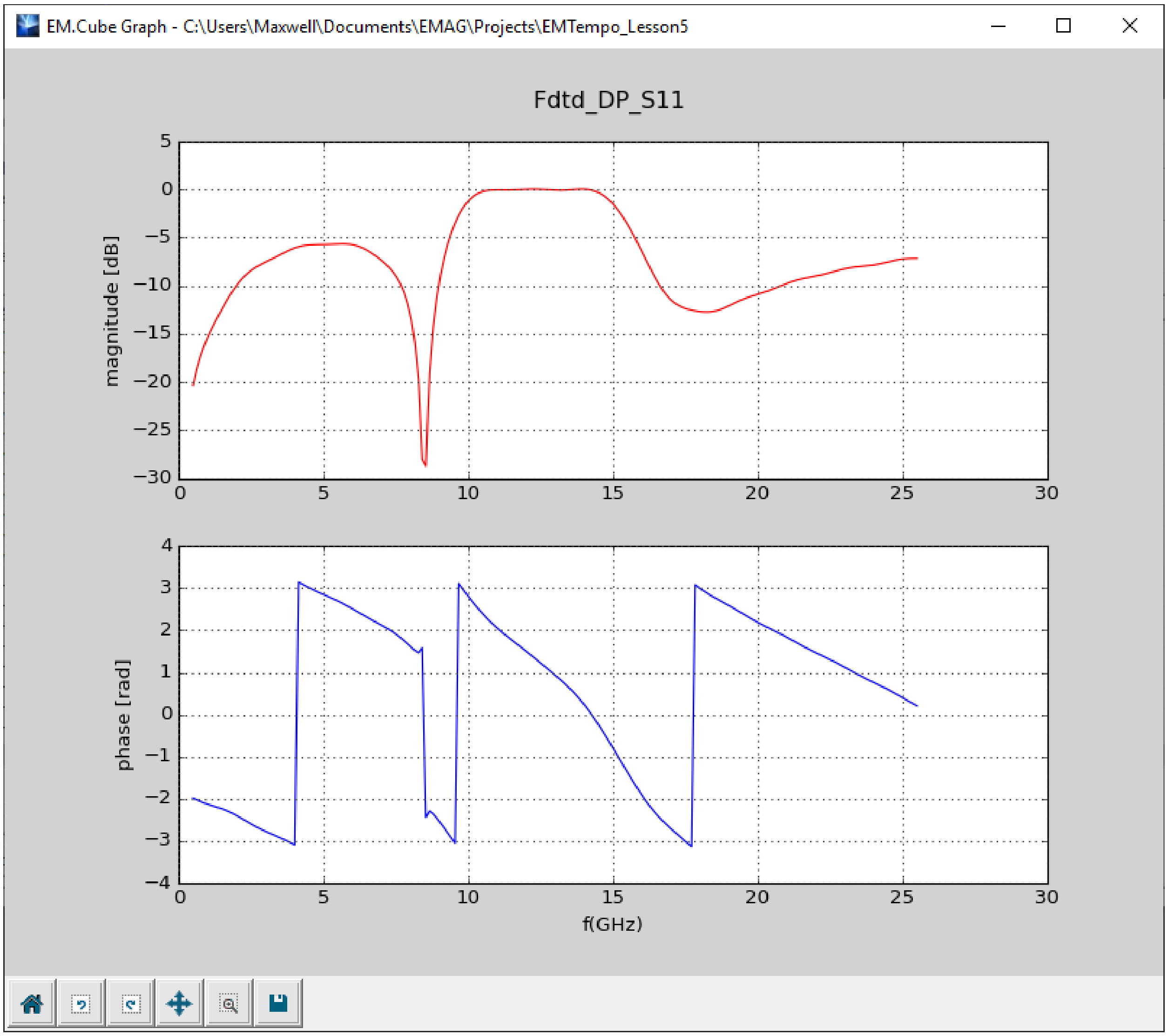


Figure 19. *The plot of S11 parameter of the microstrip filter structure.*

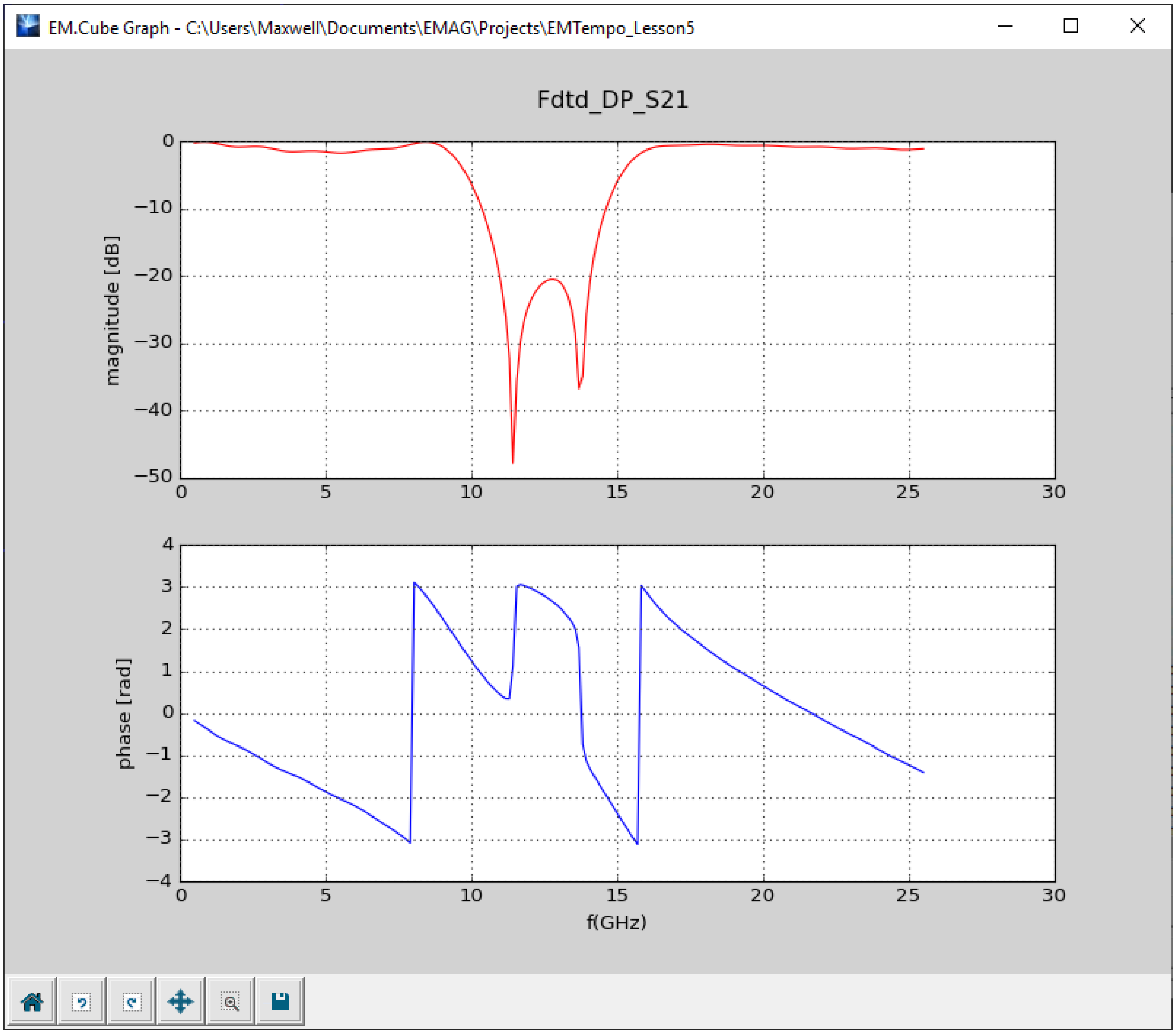


Figure 20. *The plot of S21 parameter of the microstrip filter structure.*