E

EM.Picasso
Tutorial Lessons

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EM.Picasso Tutorial Lesson 7

Designing a Slot-Coupled Patch Antenna

Table of Contents

7.1 What You Will Learn

In this tutorial you will simulate multilayer planar structures that contain several metal and slot objects located on different trace planes. You will also learn how to set up a constrained parametric sweep that ties up different object parameters.

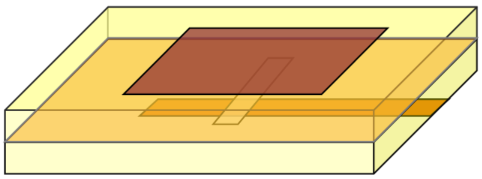


Figure 1. *The substrate layer configuration of the slot-coupled patch antenna.*

EM.Picasso Manual:

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

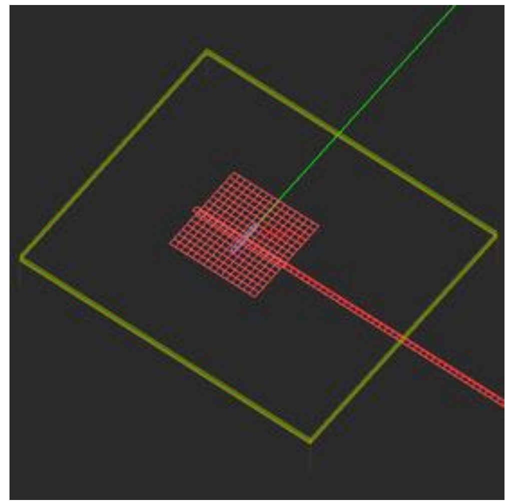
EM.Picasso Tutorial Gateway:

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

Download projects related to this tutorial lesson:

http://www.emagtech.com/downloads/ProjectRepo/EMPicasso_Lesson7.zip

Tutorial Project: Designing A Slot-Coupled Patch Antenna



Objective: In this project, you will build a multilayer slot-coupled patch antenna and investigate its near-field and far-field characteristics.

Concepts/Features:

- CubeCAD
- Stack-up Manager
- PEC Trace
- Slot Trace
- Electric Surface Current Distribution
- Magnetic Surface Current Distribution
- S-Parameters
- Variables
- Parametric Sweep

Minimum Version Required: All versions

7.2 Getting Started

Start a new project with the following parameters:

Starting Parameters	
Name	EMPicasso_Lesson7
Length Units	Millimeters
Frequency Units	GHz
Center Frequency	2.4GHz
Bandwidth	1GHz

Substrate Configuration	
Number of Finite Layers	2
Top Half-Space	Vacuum
Top Layer	ROGER RO 4003C: $\varepsilon_r = 3.38, \mu_r = 1, \sigma = \sigma_m = 0$, Thickness = 2mm
Bottom Half-Space	ROGER RO 4003C: $\varepsilon_r = 3.38, \mu_r = 1, \sigma = \sigma_m = 0$, Thickness = 0.787mm
Bottom Half-Space	Vacuum

7.3 Creating the Slot-Coupled Patch Antenna Geometry

Click on the **Slot-Coupled Patch Wizard**  button of the **Wizard Toolbar** (Figure 2) or select the menu item **Tools** → **Antenna Wizards** → **Slot-Coupled Patch Antenna**.

Figure 2. *EM.Picasso's Wizard Toolbar.*

The wizard creates the geometry of the patch antenna in the project workspace (Figure 3).

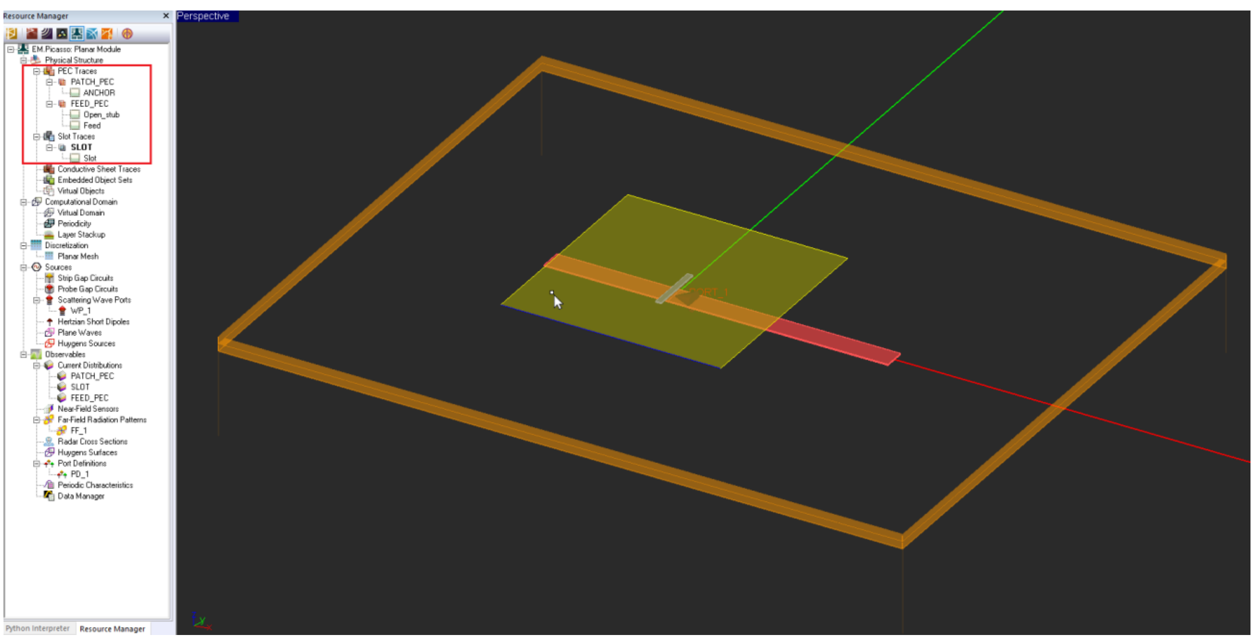
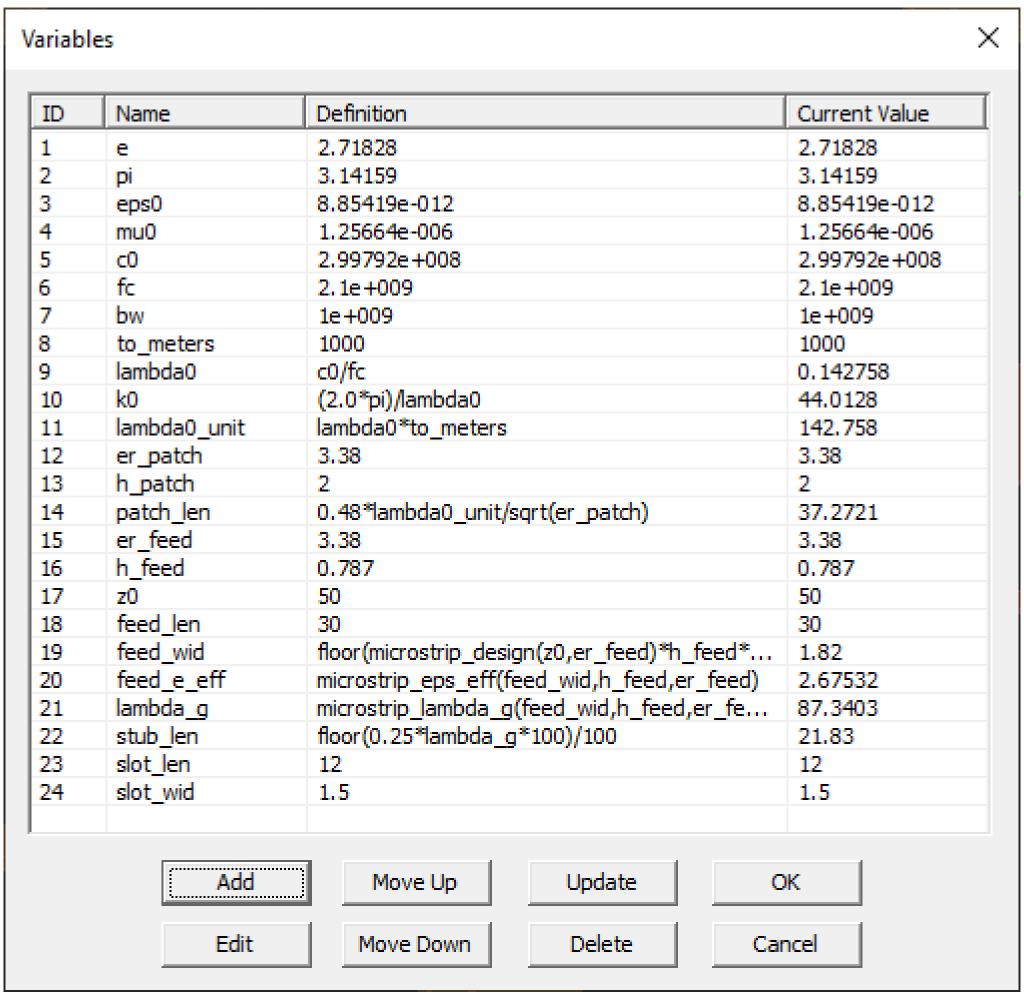


Figure 3. *The geometry of the slot-coupled patch antenna created by the wizard in the project workspace. The top patch object is shown in a mouse-over state.*

Open the Variables dialog and change the definition of the following variables:

Variable Name	Original Definition	New Definition
er_patch	2.2	3.38
h_patch	0.0015*to_meters	2
er_feed	2.2	3.38
h_feed	0.0015*to_meters	0.787
feed_len	1*patch_len	30
slot_len	0.25*patch_len	12
slot_wid	0.025*patch_len	1.5

The variables list now looks like Figure 4 as shown below:



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	2.1e+009	2.1e+009
7	bw	1e+009	1e+009
8	to_meters	1000	1000
9	lambda0	c0/fc	0.142758
10	k0	(2.0*pi)/lambda0	44.0128
11	lambda0_unit	lambda0*to_meters	142.758
12	er_patch	3.38	3.38
13	h_patch	2	2
14	patch_len	0.48*lambda0_unit/sqrt(er_patch)	37.2721
15	er_feed	3.38	3.38
16	h_feed	0.787	0.787
17	z0	50	50
18	feed_len	30	30
19	feed_wid	floor(microstrip_design(z0,er_feed)*h_feed*...	1.82
20	feed_e_eff	microstrip_eps_eff(feed_wid,h_feed,er_feed)	2.67532
21	lambda_g	microstrip_lambda_g(feed_wid,h_feed,er_fe...	87.3403
22	stub_len	floor(0.25*lambda_g*100)/100	21.83
23	slot_len	12	12
24	slot_wid	1.5	1.5

Figure 4. *The Variables dialog showing the new values of some variables.*

The wizard created three trace planes according to the table below:

Trace Label	Trace Type	Function	Trace Location
PATCH_PEC	PEC Trace	Patch Plane	Between Top Substrate Layer and Top Half-Space
SLOT	Slot Trace	Coupling Slot Plane	Between Top Substrate Layer and Bottom Substrate Layer
FEED_PEC	PEC Trace	Microstrip Feed Plane	Between Bottom Substrate Layer and Bottom Half-Space

7.4 Examining the Multilayer Substrate's Layer Hierarchy

Open EM.Picasso's Stackup Settings dialog and inspect the hierarchy of the substrate layers and interspersed trace planes (Figure 5). You can assign different colors to different substrate layers. In the Stackup Settings dialog, select and highlight the dielectric layer called "Patch Substrate" and click the **Edit** button of the dialog to open the substrate layer dialog.

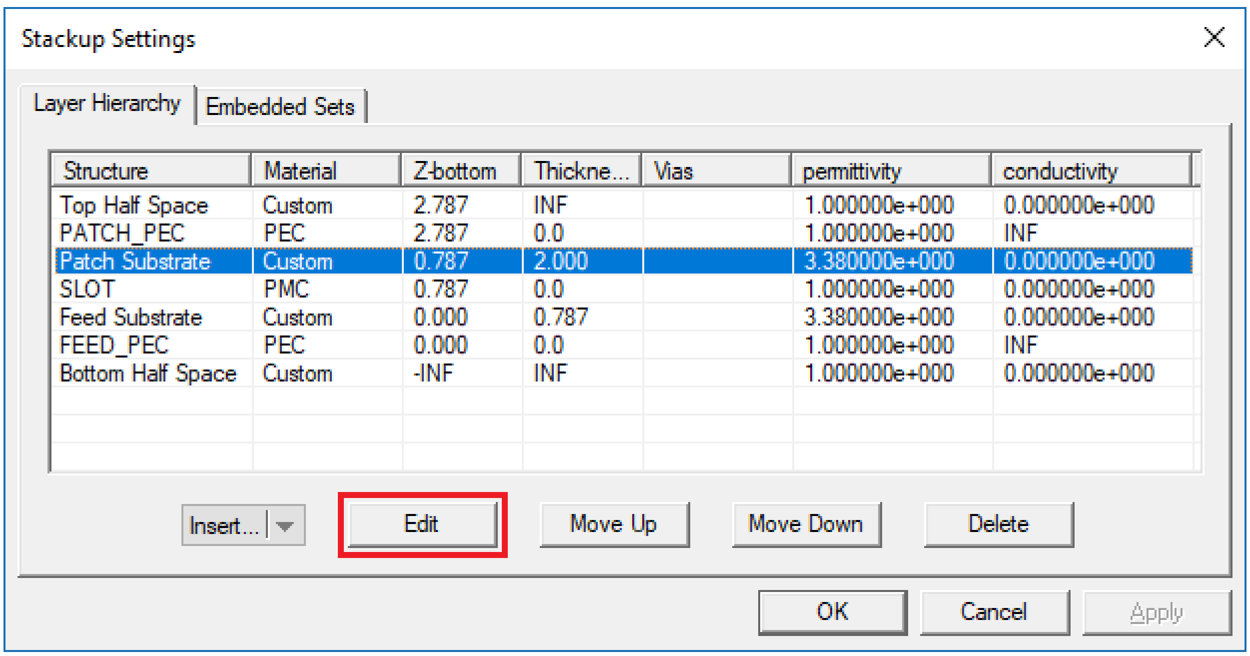


Figure 5. *The Stackup Settings dialog showing the substrate configuration of the slot-coupled patch antenna.*

Click on the **Color** button in the substrate layer dialog to open Windows' standard color palette and choose green for the color of this layer (Figure 6).

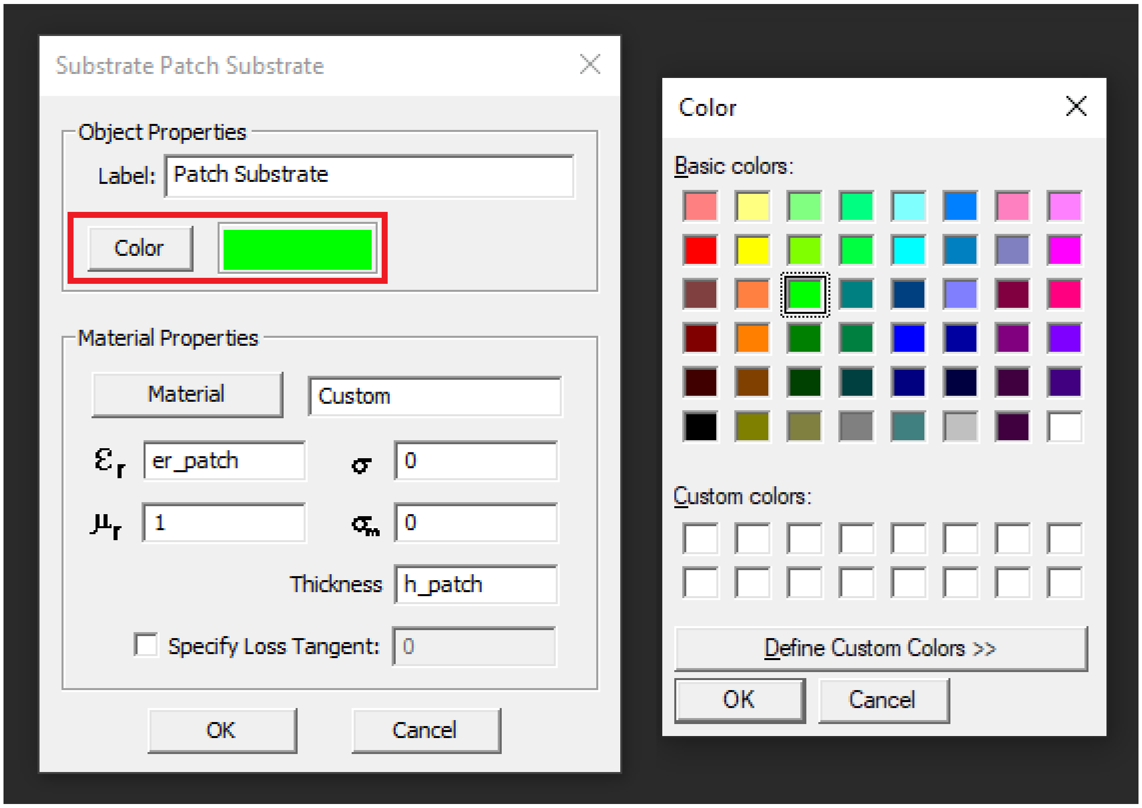


Figure 6. *Changing the layer color in the substrate layer dialog.*

Once you return to the project workspace, your physical structure will look like this:

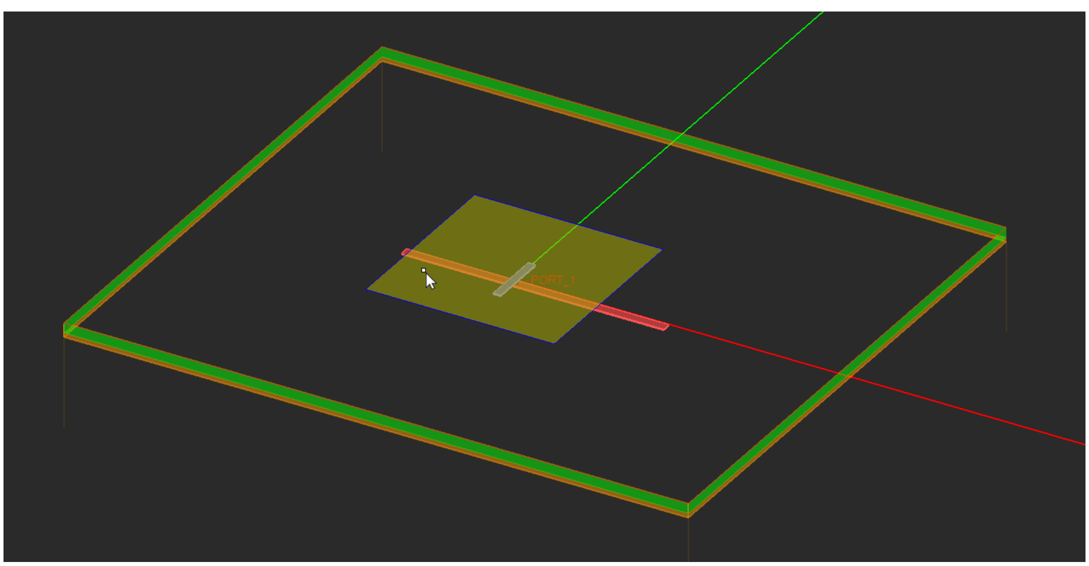


Figure 7. *The geometry of the slot-coupled patch antenna with the virtual domain box showing substrate layers of different colors. The top patch object is shown in a mouse-over state.*

The wizard created the following set of geometric objects, which together constitute your slot-coupled patch antenna structure:

Label	Object Type	Trace Group	Length	Width
ANCHOR	Rectangle Strip	PATCH_PEC	patch_len	patch_len
slot	Rectangle Strip	SLOT	slot_wid	slot_len
Open_stub	Rectangle Strip	FEED_PEC	stub_len	feed_wid
Feed	Rectangle Strip	FEED_PEC	feed_len	feed_wid

7.5 Running a PMOM Analysis of the Multilayer Antenna

The wizard already defined a Scattering Wave Port called "WP_1" and associated it with the "Feed" object. It also initiated a default far-field radiation pattern observable as well as three current distribution observables, one for each trace group (Figure 8).

In EM.Picasso, each individual trace plane requires its own current distribution observable. PEC traces have electric surface current distribution plots in A/m, while slot traces have magnetic surface current distribution plots in V/m.

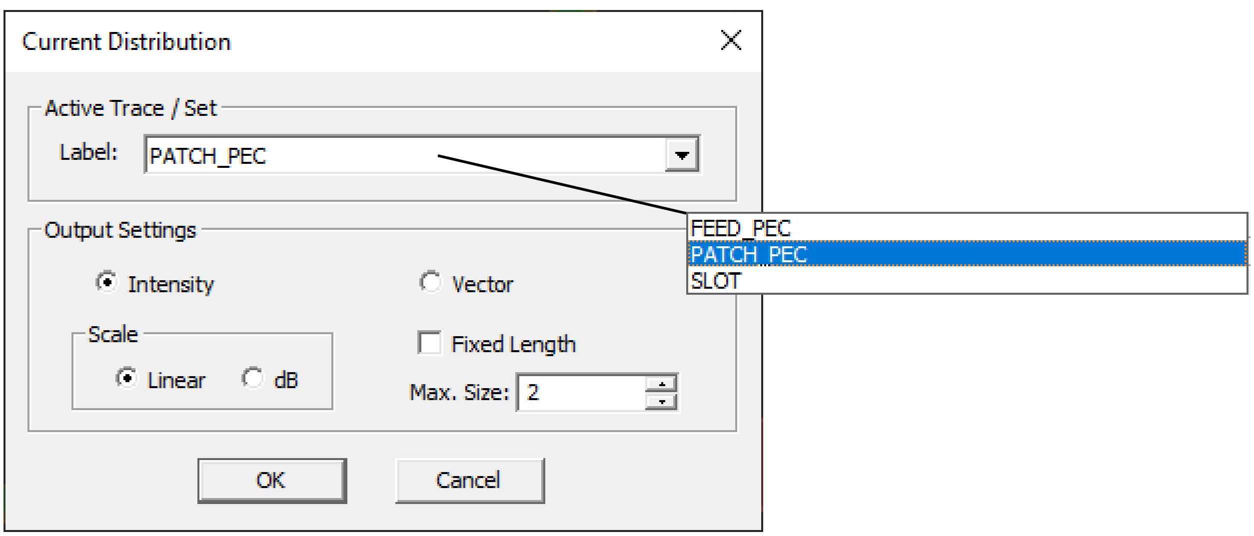


Figure 8. *EM.Picasso's Current Distribution dialog.*

The wizard also set the mesh density of the antenna structure to 30 cells/λ_{eff} as shown in Figure 9 shown as below:

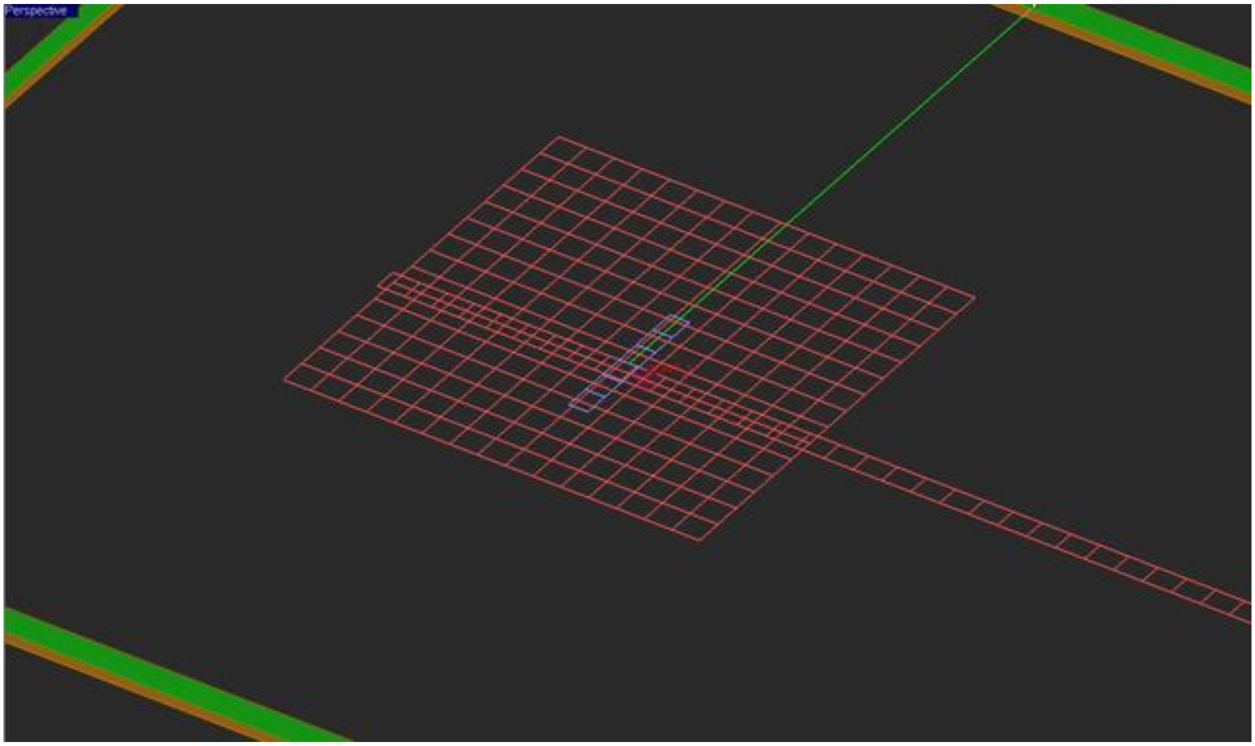


Figure 9. *The planar mesh of the multilayer slot-coupled patch antenna structure.*

Run a quick single-frequency PMOM analysis of your multilayer planar structure. At the end of the simulation, the following port characteristic values are reported in the output message window:

S11: -0.684217 +0.056196j

S11(dB): -3.266925

Z11: 9.308750 +1.978907j

Y11: 0.102781 -0.021850j

Visualize all the three current distributions on the patch, slot and feed planes (Figures 10-12). You need to freeze the “ANCHOR” object to be able to see the current distributions on the slot. Notice the standing wave pattern on the microstrip feed line.

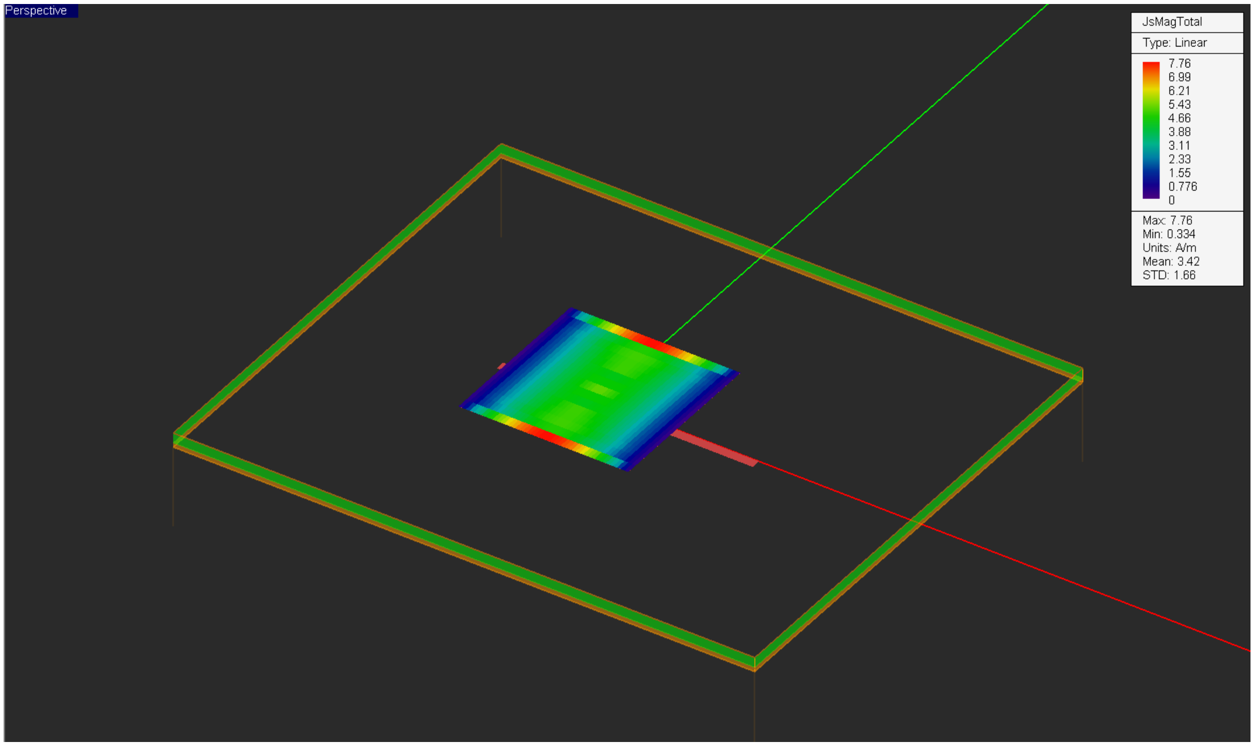


Figure 10. *The electric surface current distribution on the top patch.*

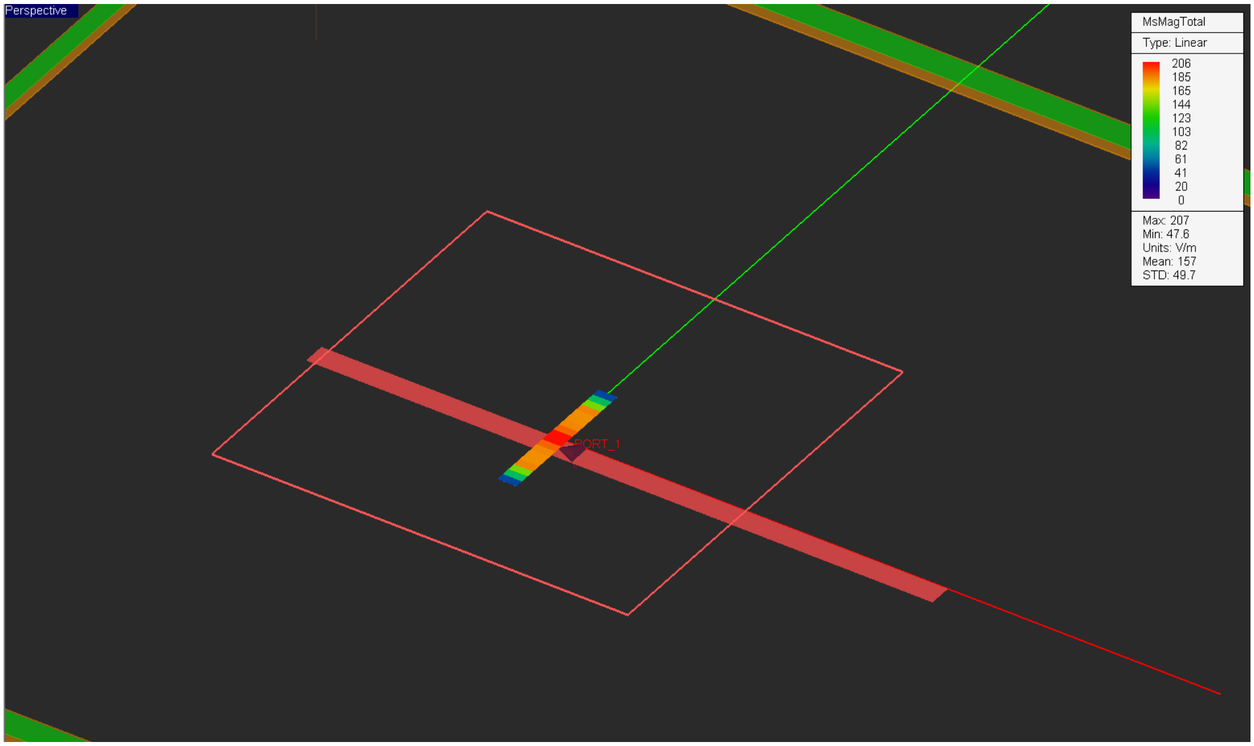


Figure 11. *The magnetic surface current distribution on the coupling slot.*

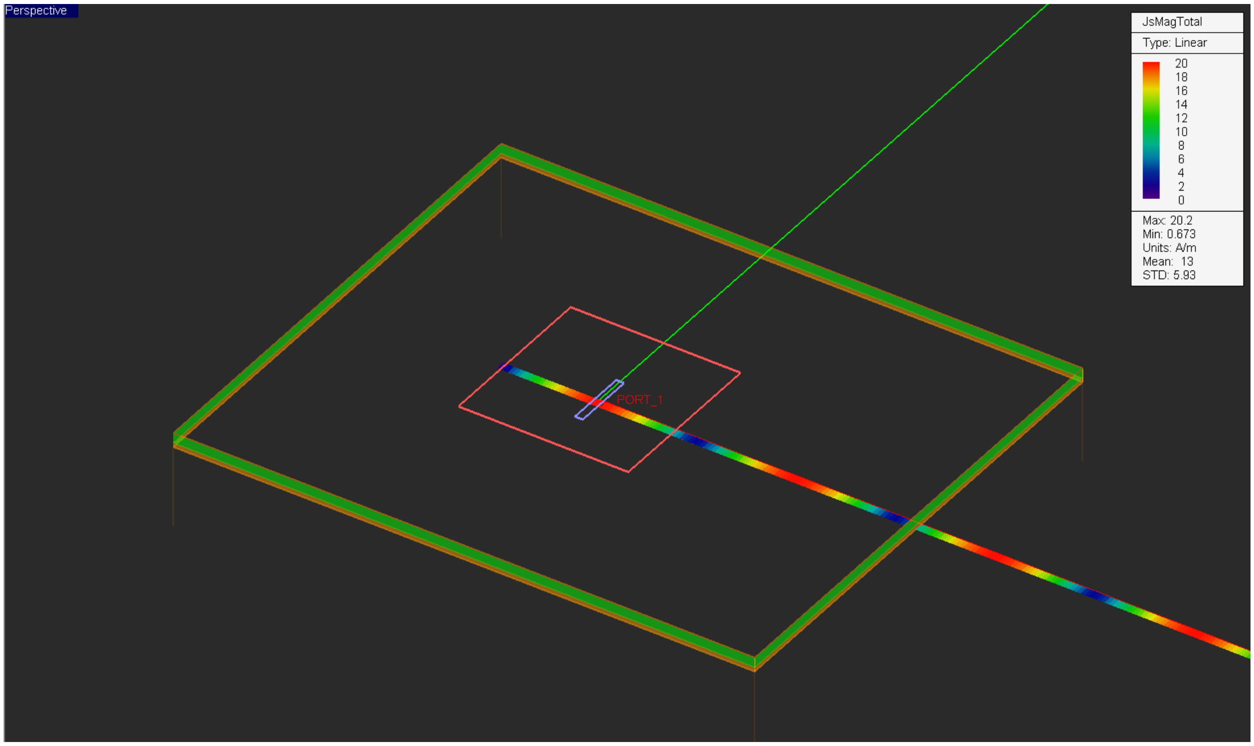


Figure 12. *The electric surface current distribution on the feed line and open stub.*

Visualize the 3D radiation pattern of your antenna. Note the portion of the radiation pattern in the lower half-space (90° $\leq \theta \leq$ 180°).

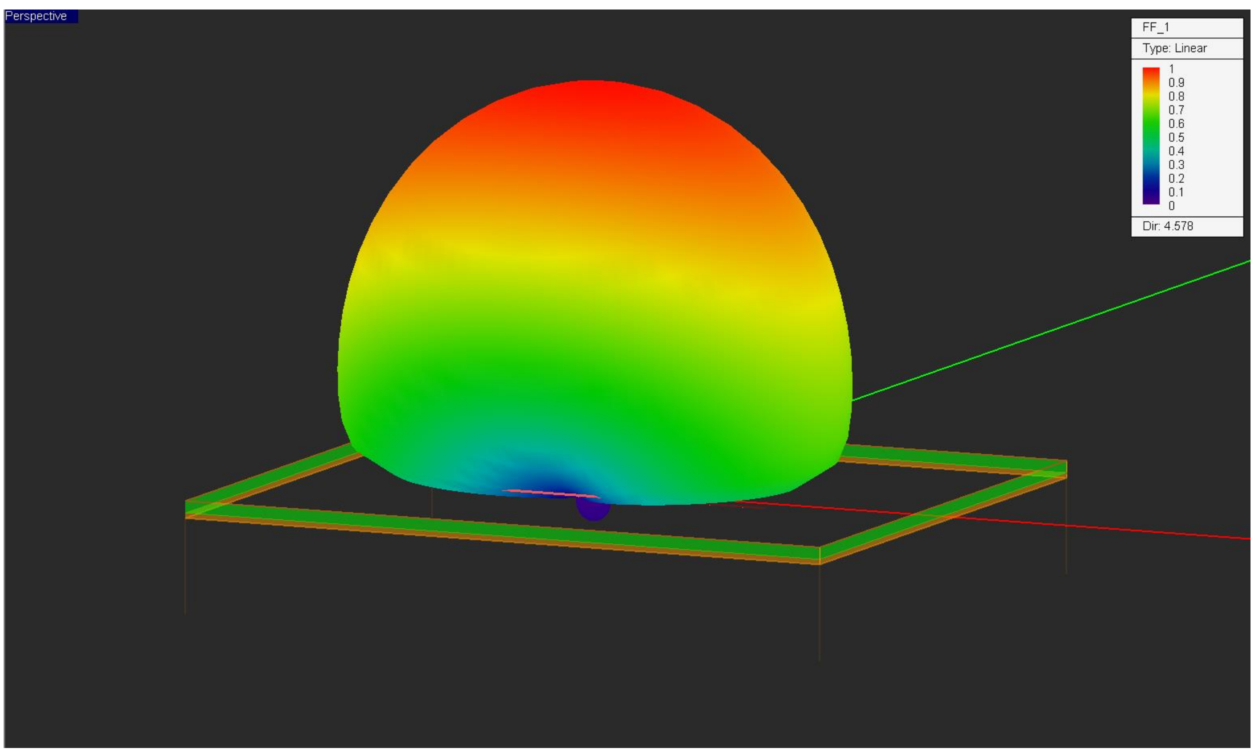
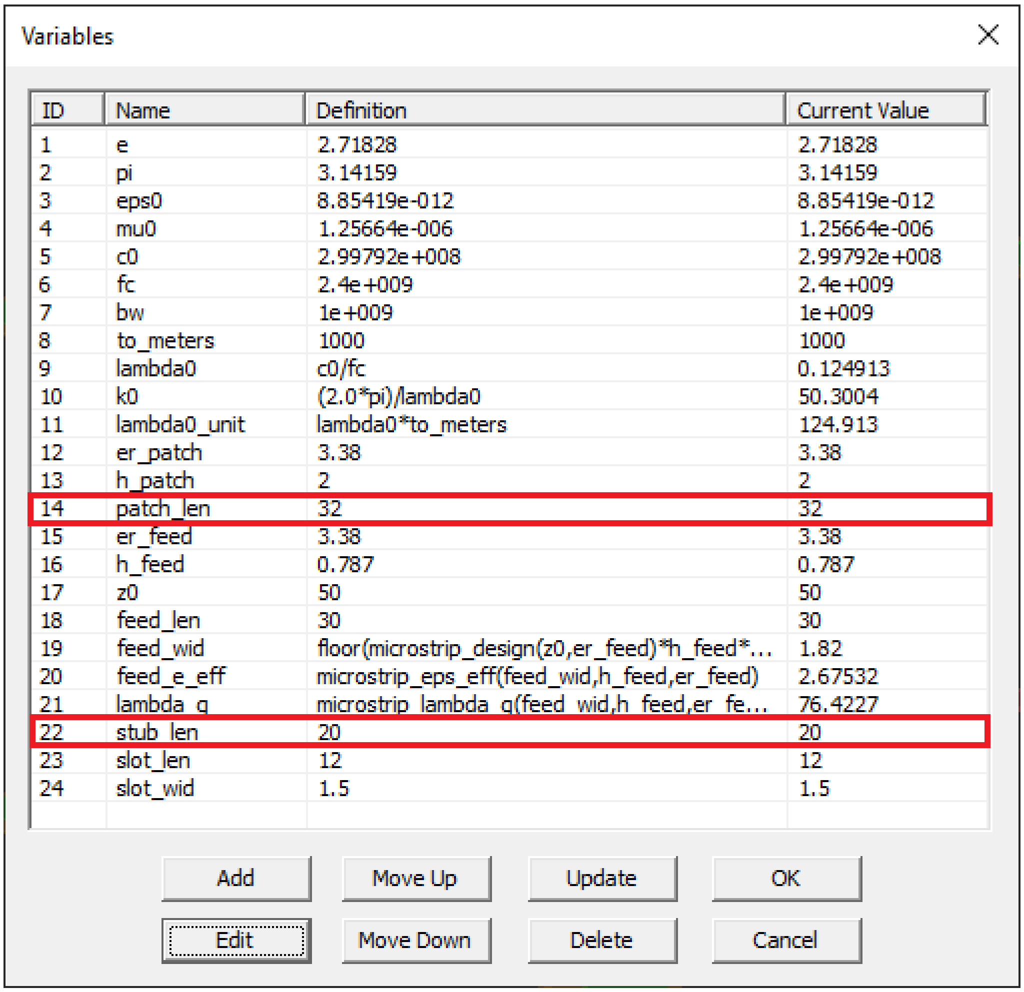


Figure 13. *The 3D radiation pattern of the slot-coupled patch antenna.*

7.6 Tuning the Patch's Resonant Length

In this part of the tutorial lesson, you will vary the size of the top patch to find the resonant length. Open the Variables dialog and change the definition of two variables: "patch_len" and "stub_len" to numeric values of 32 and 20, respectively (Figure 14). This change turns both of them into independent variables that can be designated as sweep variables.



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	2.4e+009	2.4e+009
7	bw	1e+009	1e+009
8	to_meters	1000	1000
9	lambda0	c0/fc	0.124913
10	k0	(2.0*pi)/lambda0	50.3004
11	lambda0_unit	lambda0*to_meters	124.913
12	er_patch	3.38	3.38
13	h_patch	2	2
14	patch_len	32	32
15	er_feed	3.38	3.38
16	h_feed	0.787	0.787
17	z0	50	50
18	feed_len	30	30
19	feed_wid	floor(microstrip_design(z0,er_feed)*h_feed*…	1.82
20	feed_e_eff	microstrip_eps_eff(feed_wid,h_feed,er_feed)	2.67532
21	lambda_g	microstrip_lambda_g(feed_wid,h_feed,er_fe…	76.4227
22	stub_len	20	20
23	slot_len	12	12
24	slot_wid	1.5	1.5

Figure 14. *The Variables dialog showing the modified definition of several variables.*

Now run a parametric sweep of the variable "patch_len" according to the table below:

Sweep Variable Name	patch_len
Sweep Variable Type	Uniform
Start Value	31mm
Stop Value	33mm
Step Value	0.2mm

Plot the data file "S11_Sweep.CPX" (Figure 15). You can see that the return loss is minimized for a value of patch_len between 31.6mm and 31.8mm.

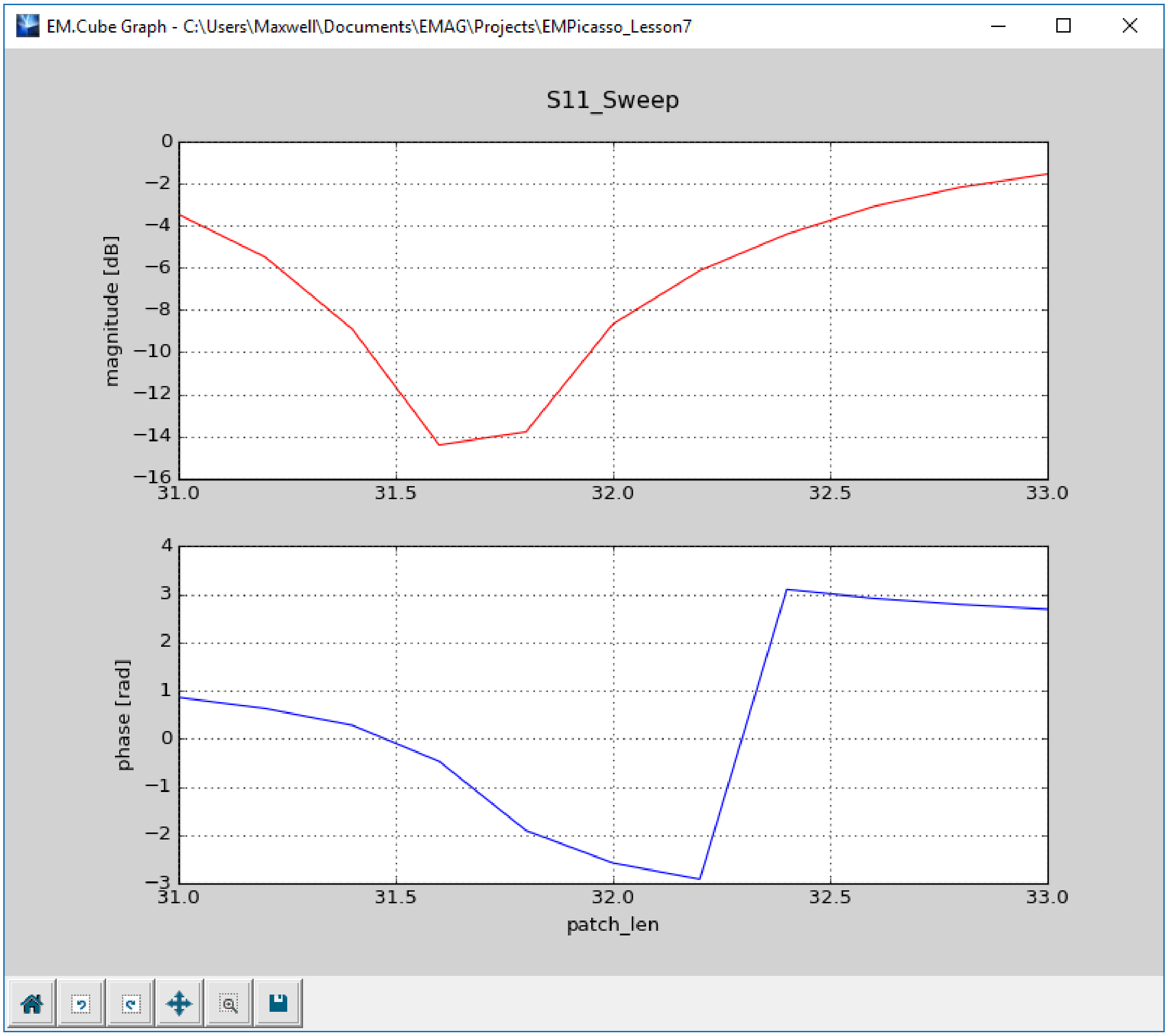


Figure 15. *The graph of return loss S_{11} as a function of the variable "patch_len".*

Open the variables dialog and set the value of "patch_len" equal to 31.7mm for the next part of the lesson.

7.7 Tuning the Length of the Open Microstrip Stub

The length of the open stub is usually set to extend $\lambda g/4$ beyond the location of the coupling slot, where λg is the guide wavelength of the microstrip line. In this part of the tutorial lesson, you will perform a parametric sweep of the variable "sub_length". Note that you already fixed the value of "patch_len" at its optimal value of 31.7mm. Use the following parameters for the sweep variable "stub_len":

Sweep Variable Name	stub_len
Sweep Variable Type	Uniform
Start Value	20mm
Stop Value	24mm
Step Value	0.25mm

Plot the data file "S11_Sweep.CPX" (Figure 16). You will find that the return loss is minimized for a value pf "stub_len" around 23.5mm. Open the variables dialog and set the value of "stub_len" equal to 23.5mm for the next part of the lesson.

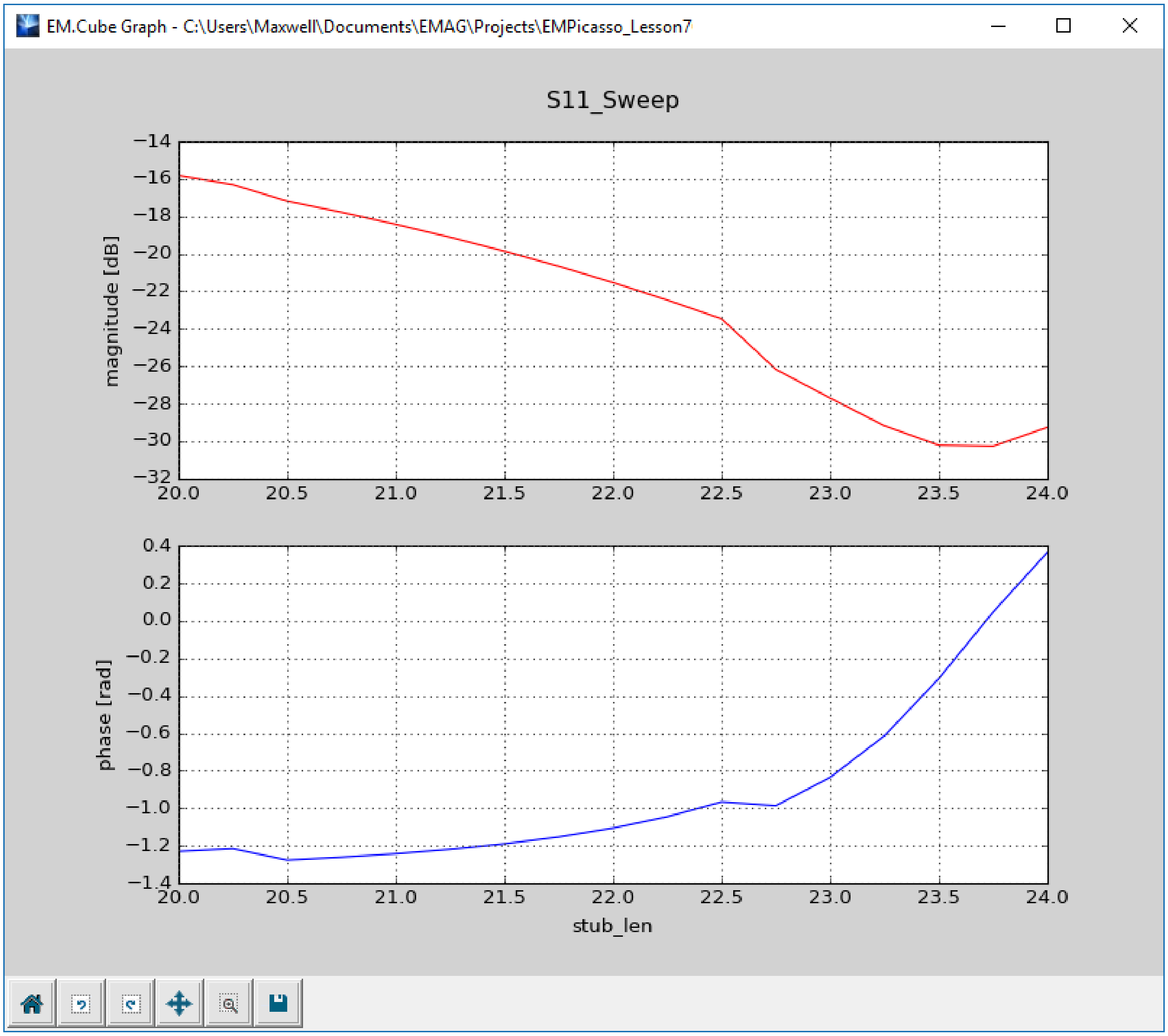
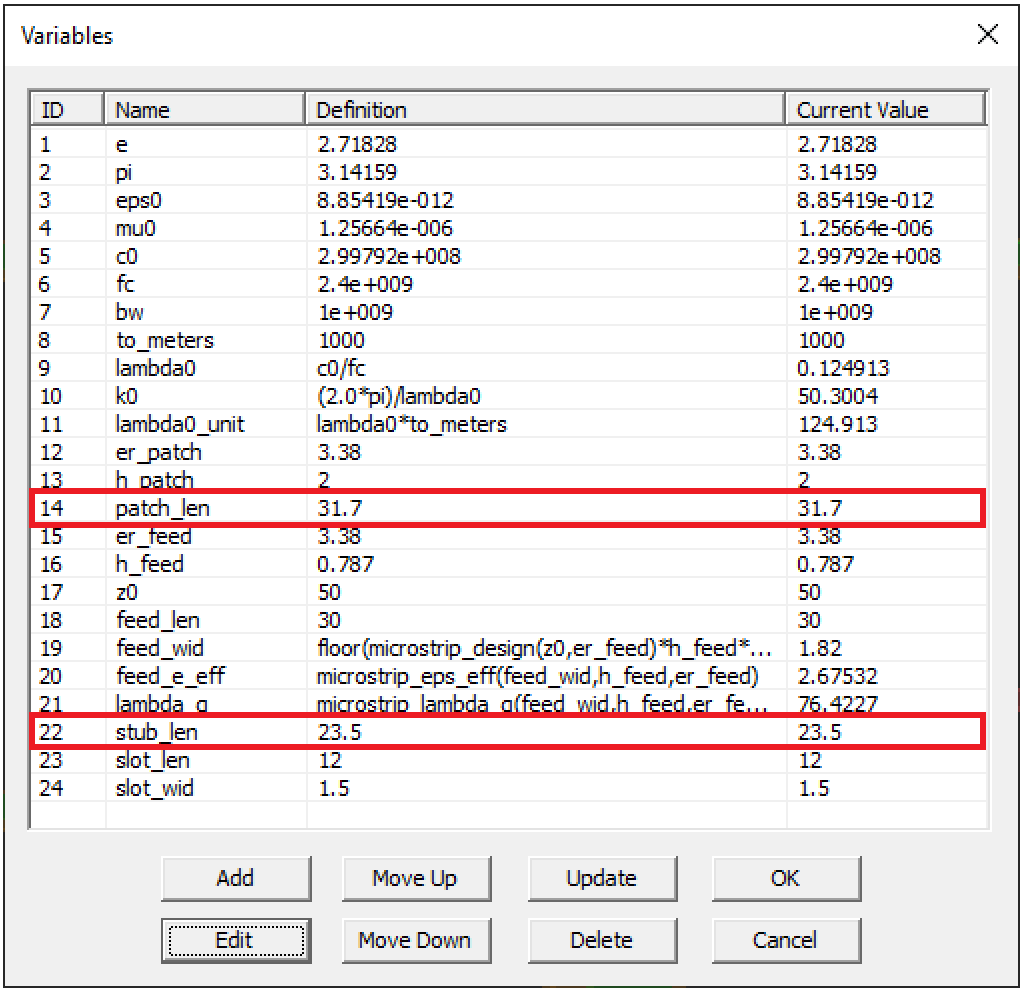


Figure 16. *The graph of return loss S_{11} as a function of the variable "stub_len".*

7.8 Verifying Your Optimized Slot-Coupled Patch Antenna

At this point, your slot-coupled patch antenna structure must have all the optimal values of the design variables as shown in Figure 17.



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	2.4e+009	2.4e+009
7	bw	1e+009	1e+009
8	to_meters	1000	1000
9	lambda0	c0/fc	0.124913
10	k0	(2.0*pi)/lambda0	50.3004
11	lambda0_unit	lambda0*to_meters	124.913
12	er_patch	3.38	3.38
13	h_patch	2	2
14	patch_len	31.7	31.7
15	er_feed	3.38	3.38
16	h_feed	0.787	0.787
17	z0	50	50
18	feed_len	30	30
19	feed_wid	floor(microstrip_design(z0,er_feed)*h_feed*...	1.82
20	feed_e_eff	microstrip_eps_eff(feed_wid,h_feed,er_feed)	2.67532
21	lambda_g	microstrip_lambda_g(feed_wid,h_feed,er_fe...	76.4227
22	stub_len	23.5	23.5
23	slot_len	12	12
24	slot_wid	1.5	1.5

Figure 17. *The Variables dialog showing the optimal values of the design variables.*

Run a single-frequency analysis of your antenna to verify its return loss and the quality of the current distribution maps. At the end of the simulation, the following port characteristic values are reported in the output message window:

S11: 0.029379 -0.009350j

S11(dB): -30.220259

Z11: 53.017276 -0.992318j

Y11: 0.018855 +0.000353j

Visualize the current distributions on the patch, slot and feed planes (see Figures 18-20). You can see from the current distribution on the microstrip feed line that the standing wave pattern you saw earlier is gone. A more uniform current distribution on the feed line is now observed, which is an indication of a good impedance match.

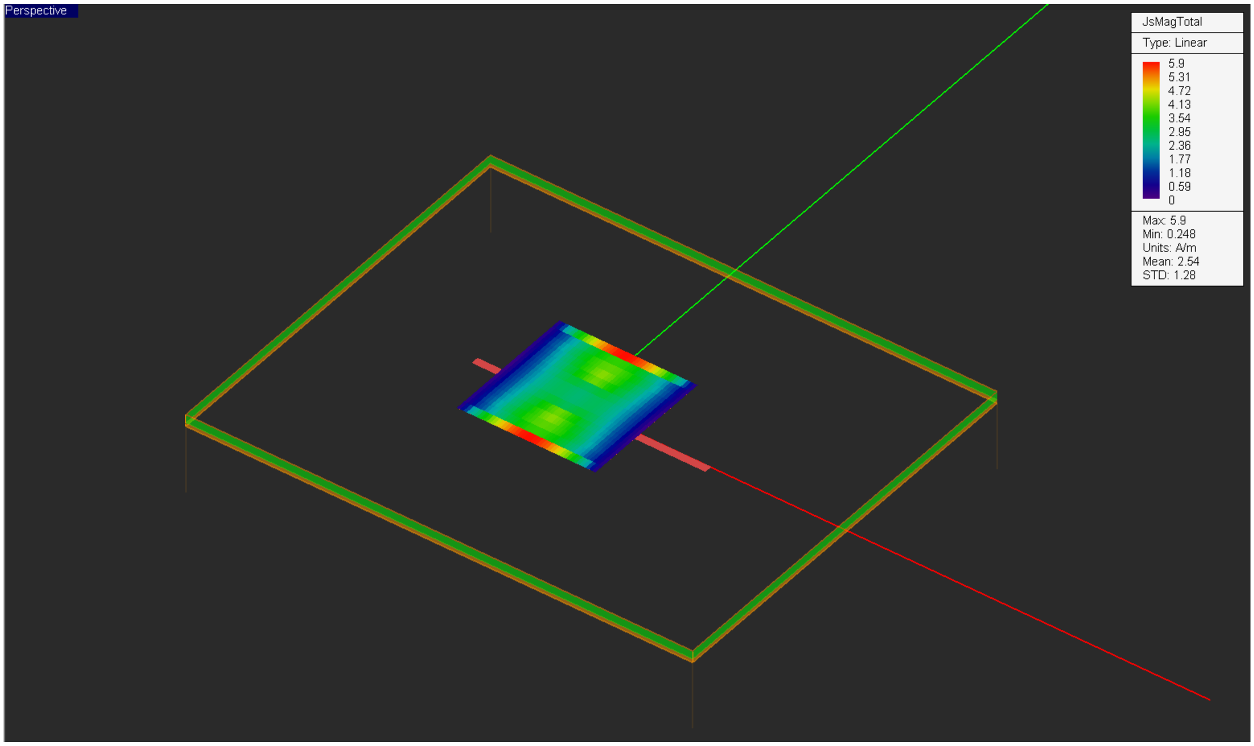


Figure 18. *The electric surface current distribution on the top patch in the optimized design.*

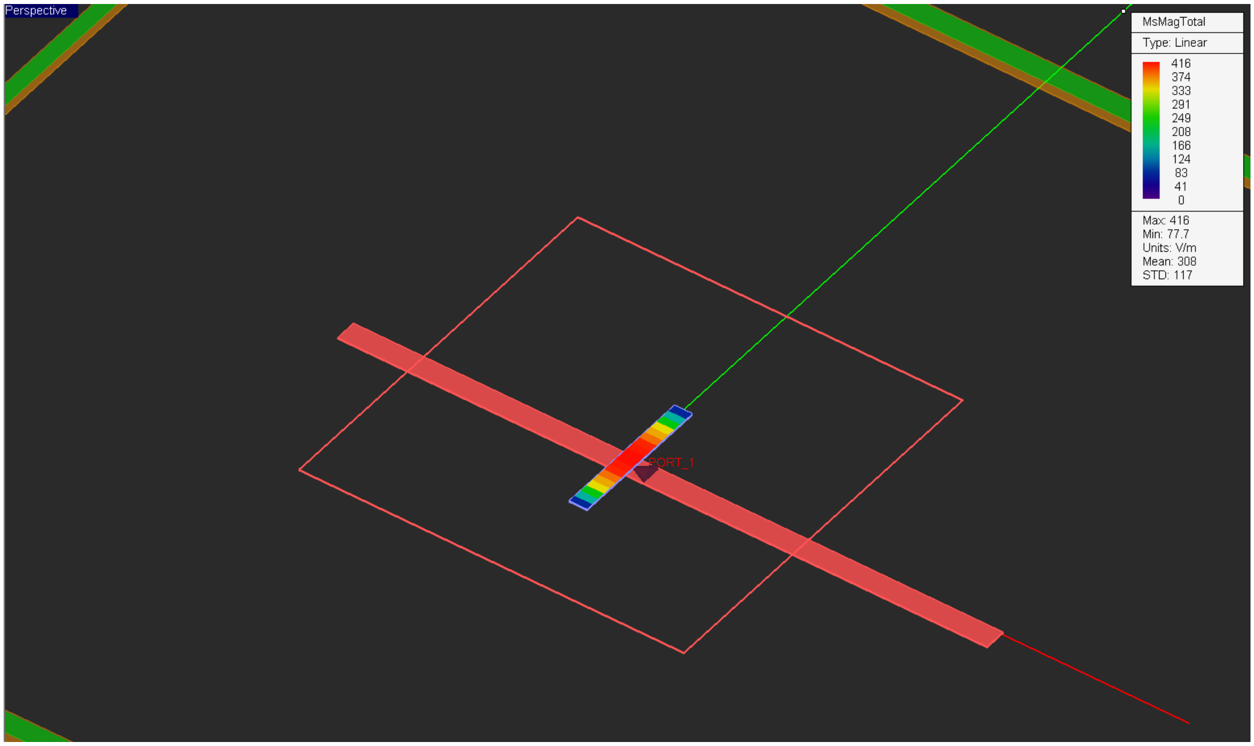


Figure 19. *The magnetic surface current distribution on the coupling slot in the optimized design.*

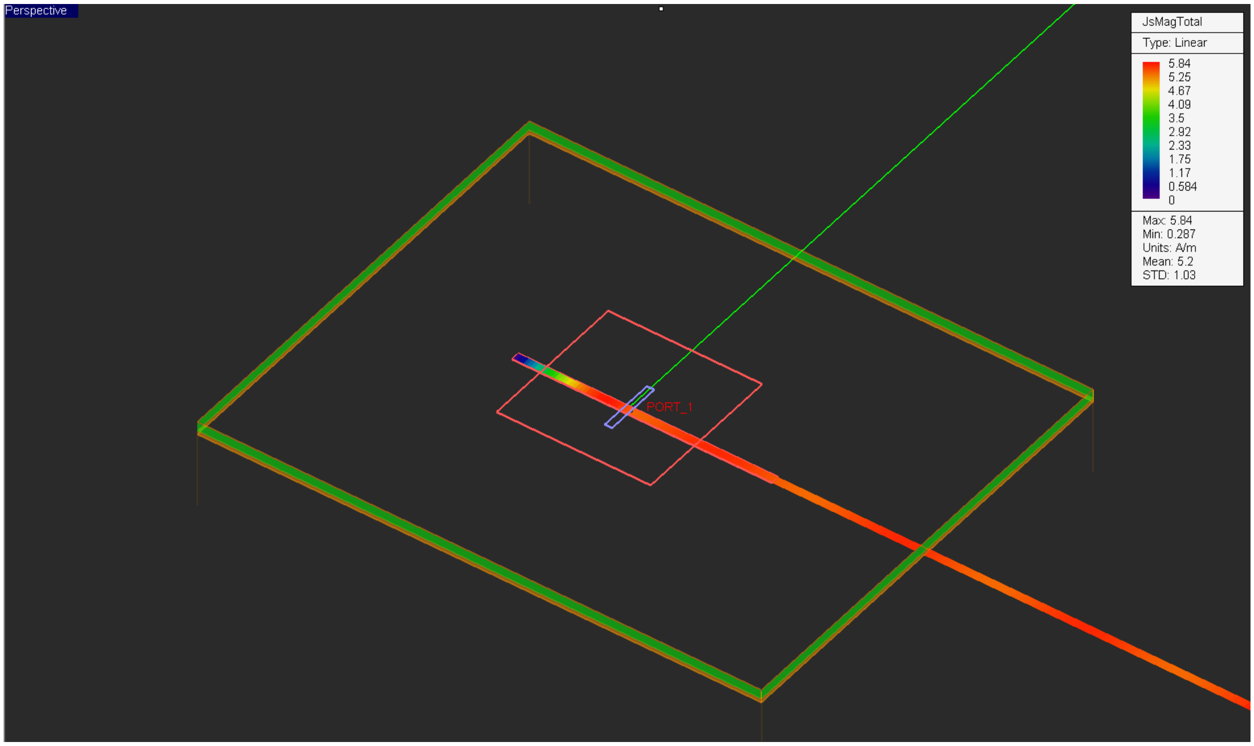


Figure 20. *The electric surface current distribution on the feed line and open stub in the optimized design.*

7.9 Running a Frequency Sweep of the Optimized Slot-Coupled Patch Antenna

To examine the resonant behavior and bandwidth of your slot-coupled patch antenna, run a frequency sweep with the following parameters:

Start Frequency	2GHz
End Frequency	3GHz
No. Samples	11
Fix Mesh at Center Frequency	

After the completion of the sweep simulation, open the Data Manager and perform a Smart Fit interpolation of the data files "S11_Sweep_.CPX" with **Interpolant Order** of 4 and visualize the rational-fitted data files "S11_Sweep_RationalFit.CPX" (Figures 21). The return loss (|S_{11}|) graph has a minimum of about -34dB at 2.4GHz with a 10-dB bandwidth of about 35MHz.

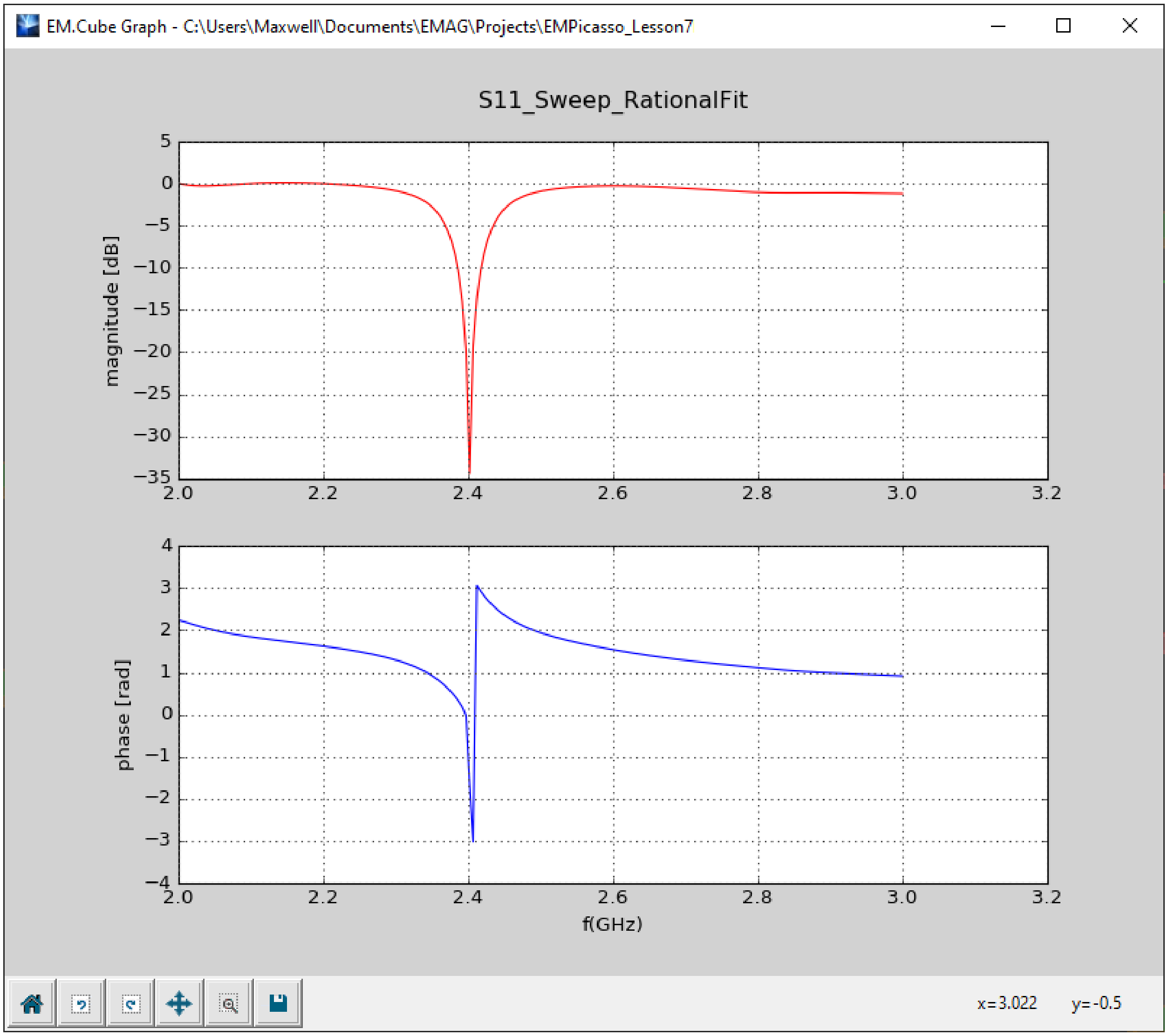


Figure 21. *The plot of the magnitude and phase of the S_{11} parameter of the optimized slot-coupled patch antenna.*