Tutorial: Patch Antenna

Design and Simulation using ADS

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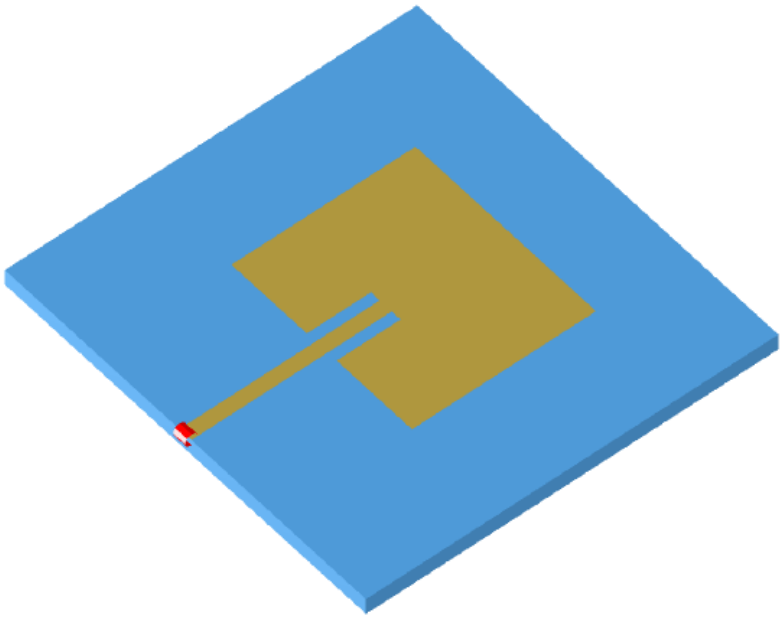
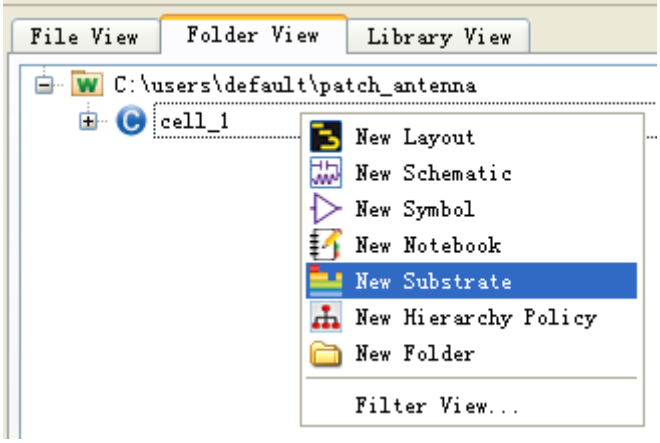
If you have any questions, please contact me (kzeng2@buffalo.edu)

1. Open ADS, create a workspace for this design.
2. Now we want to design a patch antenna like this:



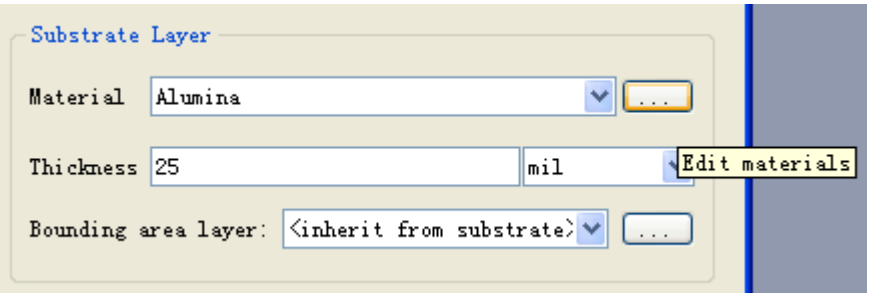
Generally, patch antenna has a shape of rectangle, and it can be feed with copper cable or microstrip line in our case. In the drawing above, blue area is the substrate and brown area represents the top conducting layer which is half of the antenna. There is another bottom layer underneath blue area covering the whole area that is the ground conducting layer- the other half of the antenna. The short length of gap between feed line and the top layer antenna is for impedance match. For detailed explanation, please visit reference 1.

3. To specify the property of blue area substrate, right click on cell_1 or whatever name you set for your cell, choose 'New Substrate'. Press OK to create a new substrate.

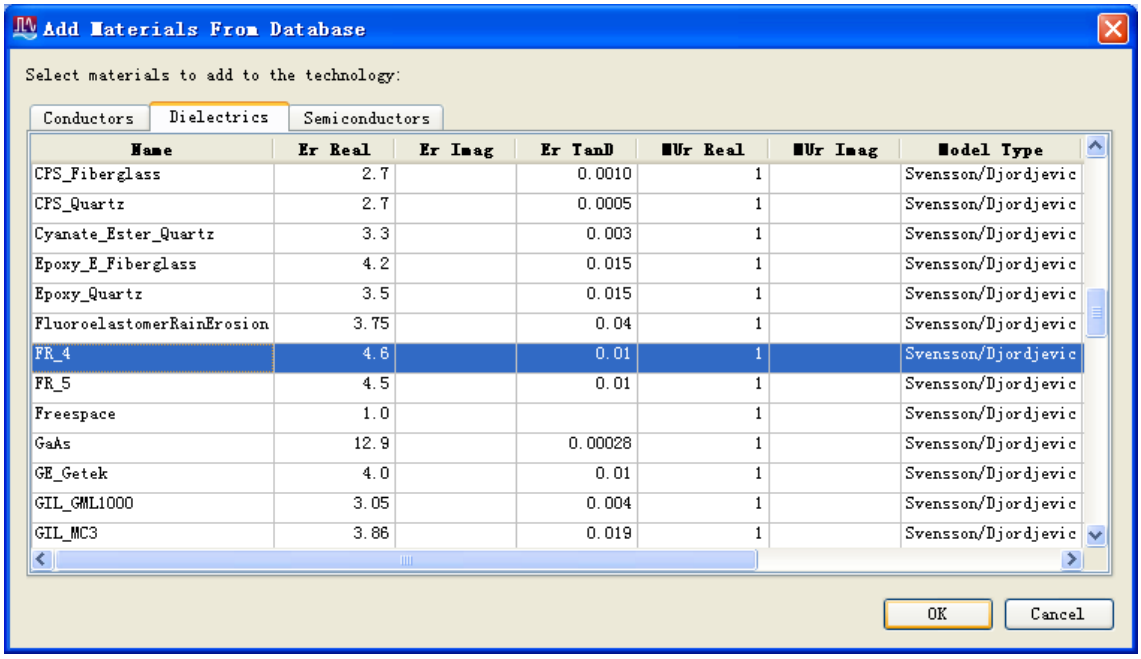


4. In substrate window, we can see a view of all the layers of our design. Click on them, you can see the material and thickness of each layer on the right panel. From top to

bottom, we have air, top interface-conductor layer, substrate and bottom interface layer. All conducting layer looks yellow and substrate in between them is light blue in color. Now choose the substrate layer in the middle, click the button on the right of material to edit its material.



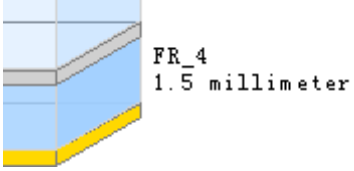
5. We suppose our design is fabricated on PCB, the most common kind of substrate for PCB is FR-4. Under the dielectrics tab, press 'Remove Dielectric' to remove the default one, then press 'Add From Database' find FR-4 then press OK to add it.



Name	Er Real	Er Imag	Er TanD	MUr Real	MUr Imag	Model Type
CPS_Fiberglass	2.7		0.0010	1		Svensson/Djordjevic
CPS_Quartz	2.7		0.0005	1		Svensson/Djordjevic
Cyanate_Ester_Quartz	3.3		0.003	1		Svensson/Djordjevic
Epoxy_E_Fiberglass	4.2		0.015	1		Svensson/Djordjevic
Epoxy_Quartz	3.5		0.015	1		Svensson/Djordjevic
FluoroelastomerRainErosion	3.75		0.04	1		Svensson/Djordjevic
FR_4	4.6		0.01	1		Svensson/Djordjevic
FR_5	4.5		0.01	1		Svensson/Djordjevic
Freespace	1.0			1		Svensson/Djordjevic
GaAs	12.9		0.00028	1		Svensson/Djordjevic
GE_Getek	4.0		0.01	1		Svensson/Djordjevic
GIL_GML1000	3.05		0.004	1		Svensson/Djordjevic
GIL_MC3	3.86		0.019	1		Svensson/Djordjevic

Now we should see the dielectric material only have one kind that is FR-4. Press OK to confirm and go back to the layer view. Then choose FR-4 in the drop-down box of material.

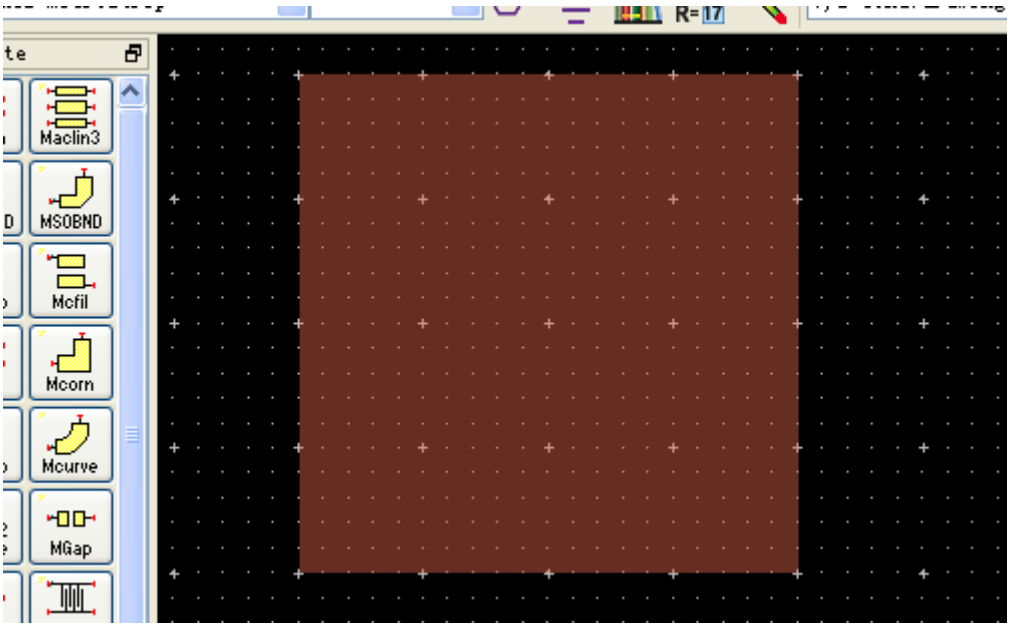
6. Set the thickness of substrate FR-4, see the image in step 4, second row to set the value. Note the thickness of substrate will affect the performance of antenna. Generally, it should not be smaller than 0.05 of a wavelength (Reference 1). For our operation wavelength at 10GHz, 0.05 of a wavelength is 1.5mm. So we might as well set it to 1.5mm. After this we should see:



7. Same idea, to set the thickness and material of bottom and top conducting layer. Click on the bottom layer (yellow), we can use perfect conductor as material so that doesn't need to change. Set thickness of it to 1.37 mil, this is a common value for PCB. Also, set the thickness of top conducting layer to 1.37 mil. Now we've finished material and

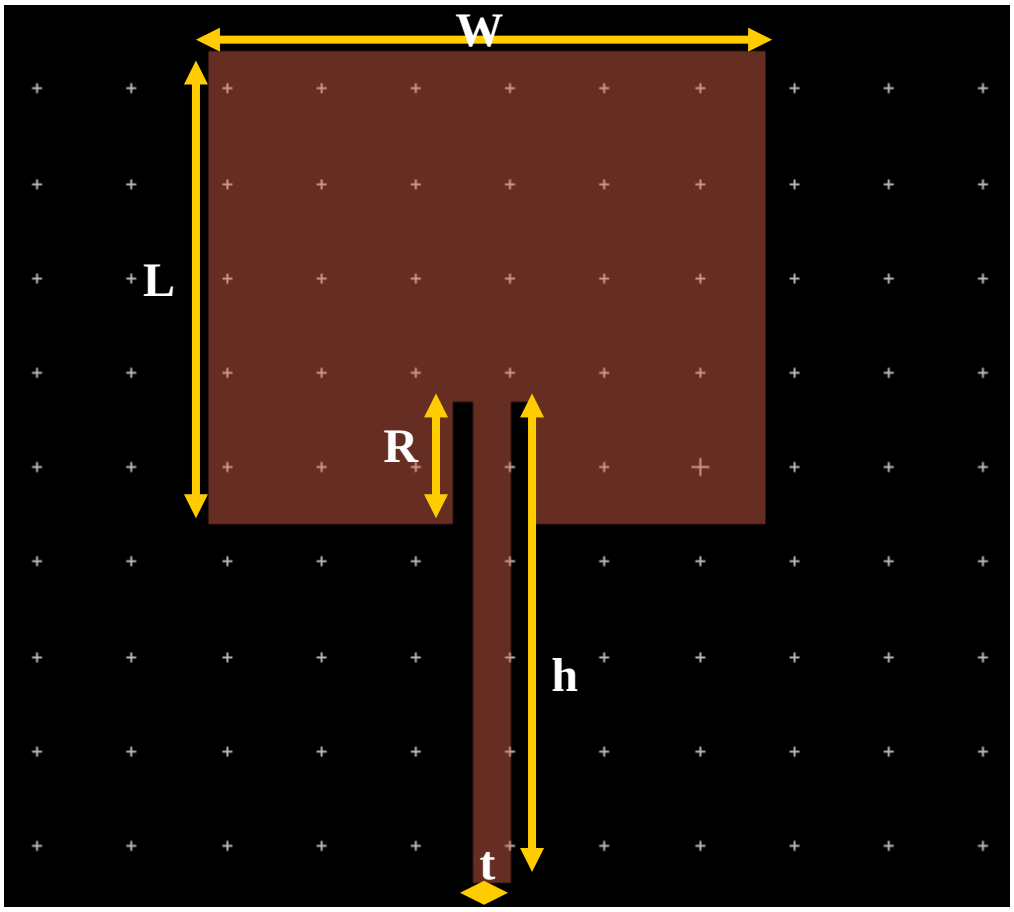
substrate setup, save it and close the window.

8. New a layout window in the workspace. (See the image at step 3, First option.) You should see a black background space with dots in it, it is the place for physical drawing and layout of your antenna. Menu bar, click 'Insert' and choose 'Rectangle', draw a square in layout window.



What you have drawn is the top conducting layer, and we want to create the shape like the figure in step 2. Do whatever you need to do to create a shape like that, you can also find a very nice layout guide at reference 5.

9. After the layout, you should have a shape like so:



This is a complete design of patch antenna. However, there are many parameters you need to adjust and take care of. Especially, when you are designing the antenna, bear in mind the dimensions of it. Length of the rectangle 'L' is used to tune the signal, it should be half-wavelength namely λ/2 if dielectric constant is 1; Width of the rectangle 'W' can affact the impedance looking from the end of feed line, here we just use a square shape where W=L since the impedance has already been reduced by recessed feed line; 'R' is the measure of how much the feed line has recessed into antenna, it affacts input impedance directly; 't' and 'h' are the width and length of feed line respectively, they determine the characteristic impedance of the line.

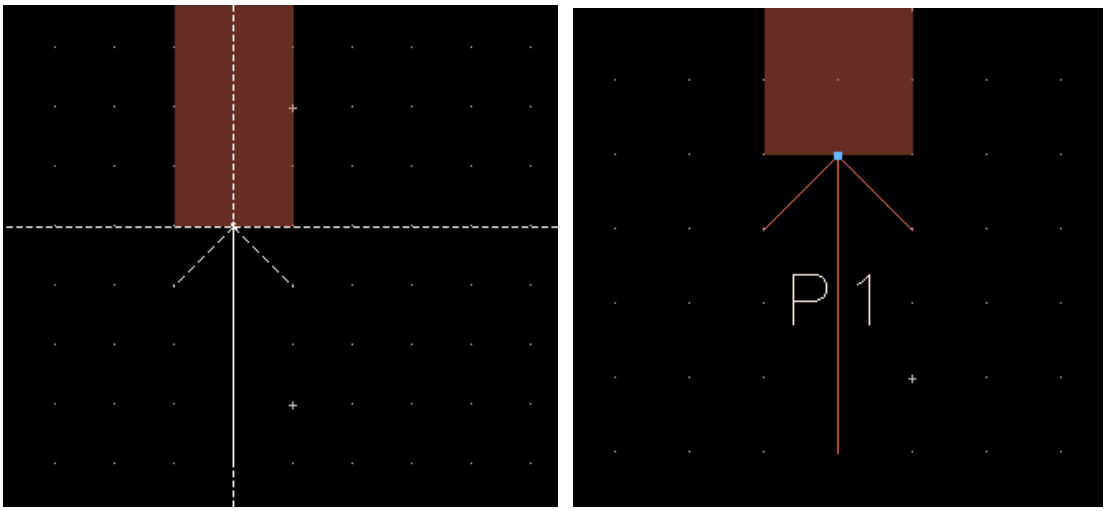
The parameters of substrate along with all these dimensions together determine the final performance and radiation pattern of patch antenna. For design details and trade off between parameters, please visit reference 1. To measure the dimensions, click 'Insert' and choose 'Measure'.

Now for design frequency of 10GHz, use this equation(reference 1)

$$f_c \approx \frac{c}{2L\sqrt{\varepsilon_r}} = \frac{1}{2L\sqrt{\varepsilon_0 \varepsilon_r \mu_0}}$$

We get value of L equals 275.18mil, however the fringing effect makes L seems longer so we use L= 250mil ; W= 250mil; R= 65 mil=L/4, to reduce a half of the original input impedance; h= 255mil, this feed line length is equivalent as Electrical length= λ/2, so the feed line has no effect on the measurement, t can be any value, here we choose t= 10mil.

10. Design is complete. For Electric-Magnetic field simulation, we need to have a signal input port. Click 'Insert' on menu bar, choose 'Pin', and then put the pin at the end of feed line. The arrow should be pointing up, meaning the signal is going up.



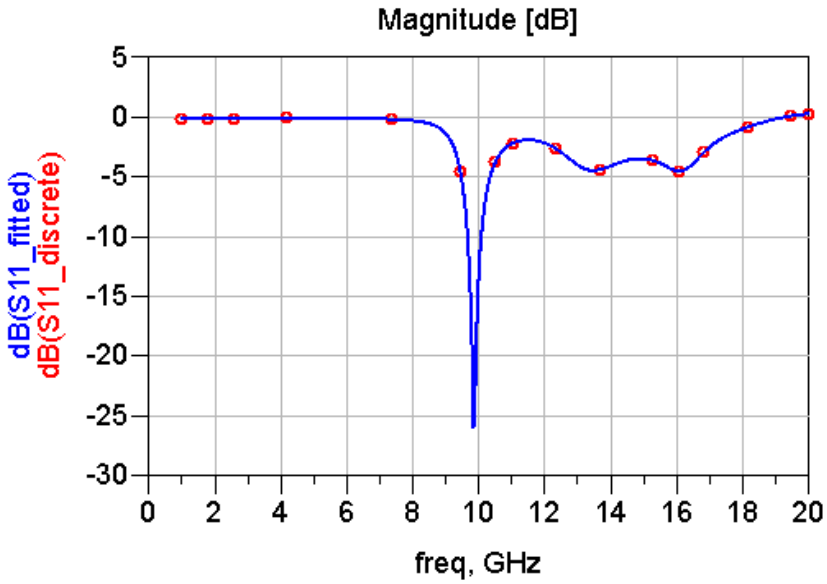
11. Click 'EM' on menu bar, choose 'Simulation Setup'. In the setup window, we need to specify all the simulation conditions. First, click 'Mom uW', choose 'Momentum Microwave' simulator. Then 'Frequency plan', since our operation frequency is around 10GHz, we can sweep from 1 to 20GHz, like so:

Frequency Plan

	Type	Fstart	Fstop	Npts	Step	Enabled
1	Adaptive	1 GHz	20 GHz	50 (max)	-	☑

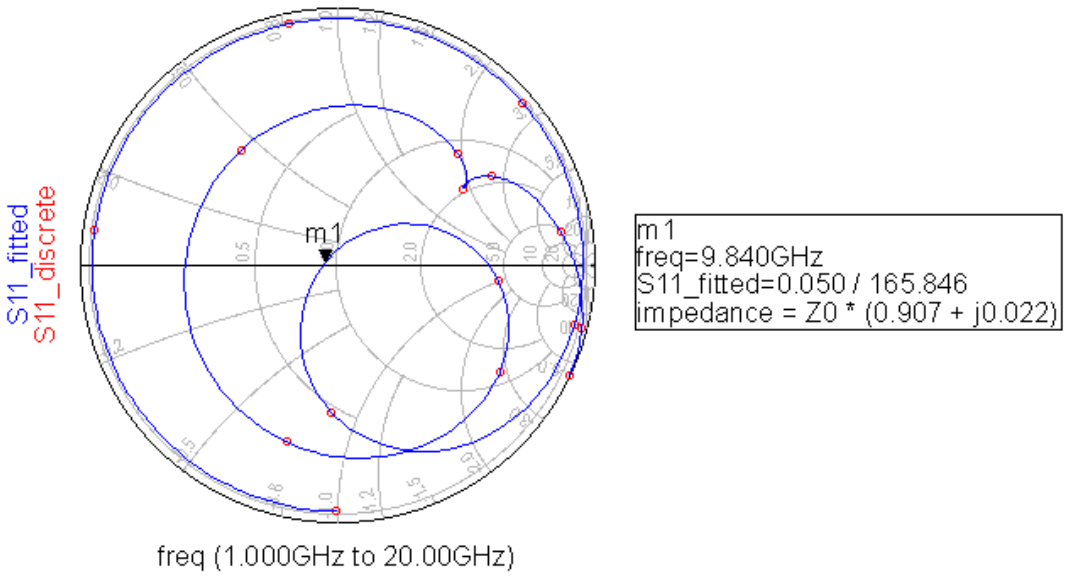
Now, in the right bottom corner, choose generate 'S-Parameters' and press 'Simulate' to start simulation. After this, a few windows will pop up, wait until simulation is finished.

12. After the simulation is finished, a result window will pop up showing you the plot of S11 vs. frequency:

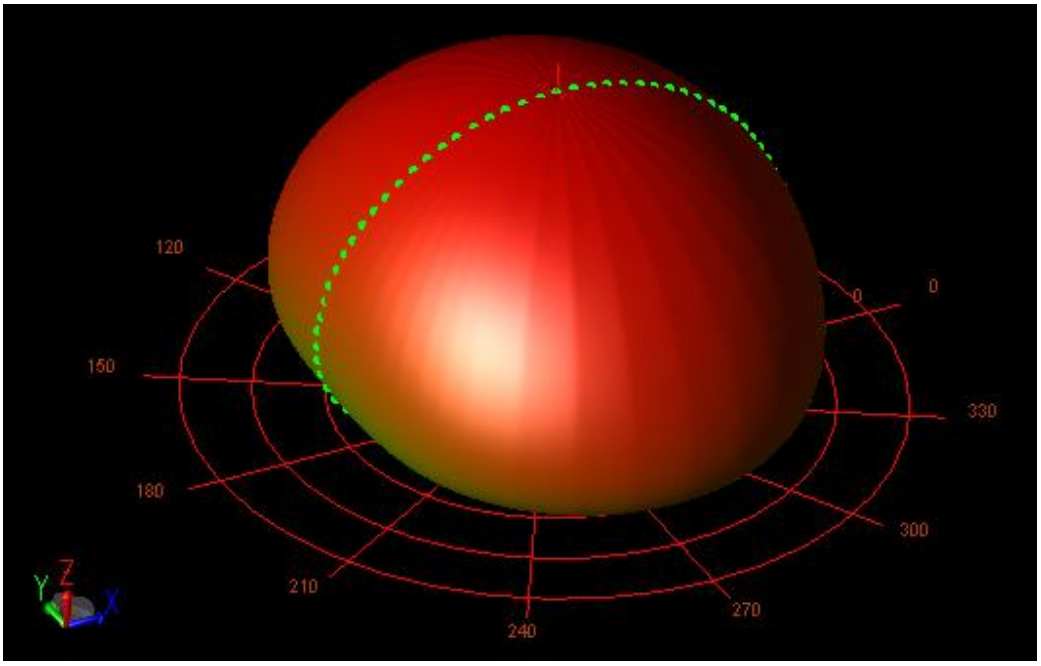


In the plot, we can see that frequency around 10GHz is all radiated out so its reflection is very small. At other frequencies, the S11 value are almost 0 namely S11=1, which means they are all reflected.

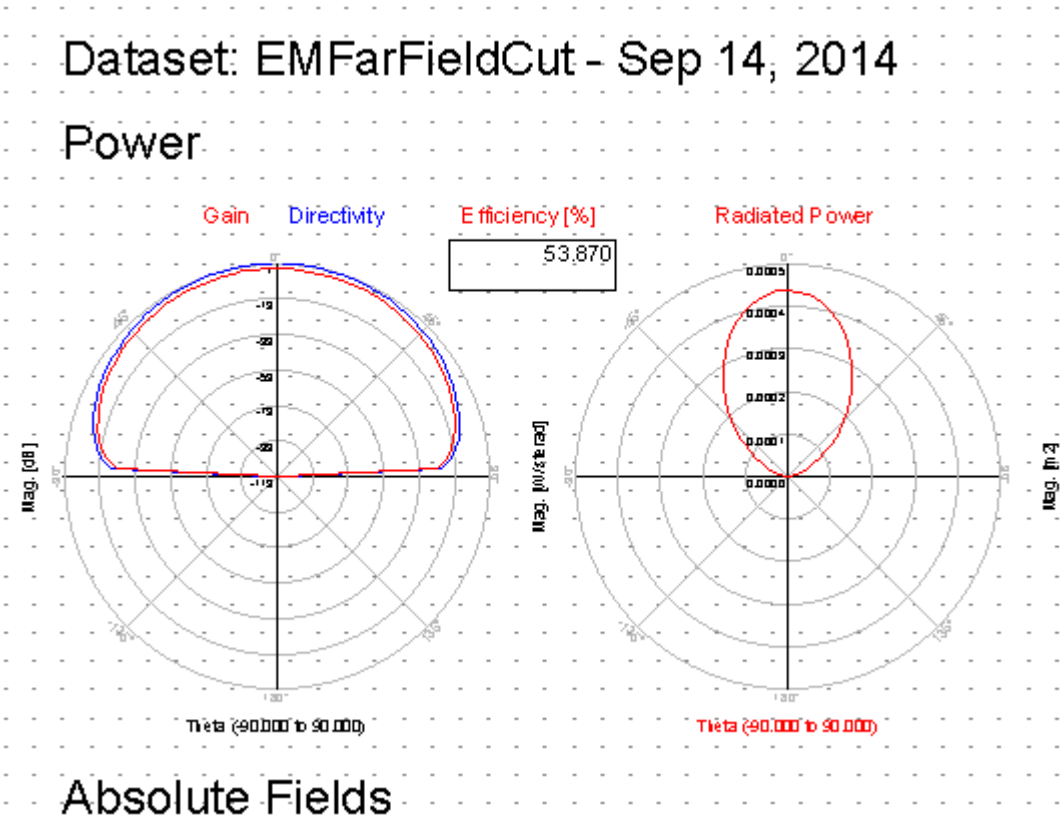
Also, in the Smith Chart below, we can see at frequency 9.840GHz antenna is almost perfectly matched to the signal source, no imaginary part for the impedance. Therefore, all signals at 9.840GHz are transmitted.



12. To view the far field antenna radiation pattern, Click 'EM' on menu bar, choose 'Post-Processing' then 'Far Field'. Select frequency around 10GHz, then press 'Compute'. After waiting, a 3D radiation pattern window will show up. Use mouse drag around it to see the pattern from different angles.

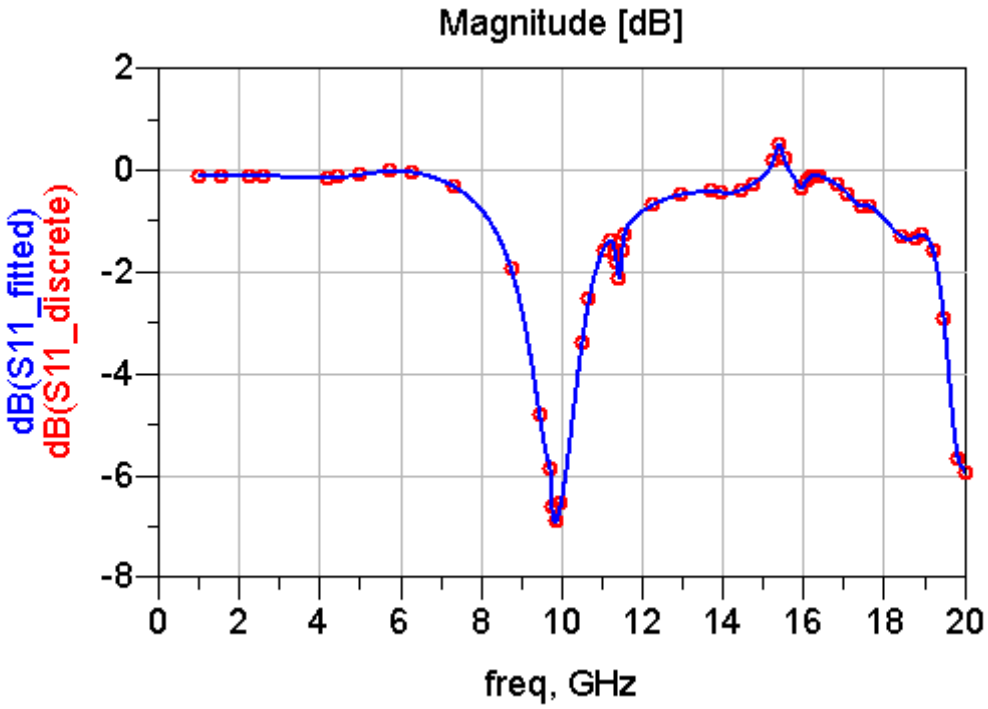


Now you can choose 'Plot Properties' tab at left bottom side, choose 'Far Field Cut' tab above, click 'Enable'. Adjust θ and φ values to choose your cut, then press 'Display Cut in Data Display' to see the profile of that cut.



13. Now the whole design and simulation process is completed. You can do more simulation as you change the substrate, all the designing parameters or even the shape

of the antenna. For example, in this tutorial, we used recessed feed line which gives us a good match at 10GHz, S11=-25dB.
If we do not have the recessed structure, namely R= 0mil. The S11 plot result is this:



Here, we only have S11=-7dB compared to -25dB when feed line is recessed. This shows that a recessed feed line indeed decreased the input impedance so that antenna can be matched way better at 10GHz with much smaller reflection.

Reference:

1. Patch antenna theory, http://www.antenna-theory.com/antennas/patches/antenna.php
2. Momentum EM simulation visualization operation, http://edadocs.software.keysight.com/display/ads2011/Visualizing+Momentum+Simulations
3. Radiation patterns for different kinds of antennas, http://www.cisco.com/c/en/us/products/collateral/wireless/aironet-antennas-accessories/prod_white_paper0900aecd806a1a3e.html
4. Wavelength- frequency conversion, https://www2.chemistry.msu.edu/faculty/reusch/virttxtjml/cnvcalc.htm
5. ADS layout toolbox user guide, http://cp.literature.agilent.com/litweb/pdf/ads2008/usrguide/ads2008/Editing_a_Layout.html#EditingaLayout-EditingaLayout