Worcester Polytechnic Institute
Department of Electrical and Computer Engineering
ECE3311 Principles of Communication Systems /B05

Exercise#2
Radiating microstrip element (a microstrip patch antenna)

I. Introduction

1.1. Size of the patch element

Fig 1 show the radiating (i.e. the "thick") microstrip element - a simple **probe-fed** patch antenna on FR4 epoxy.

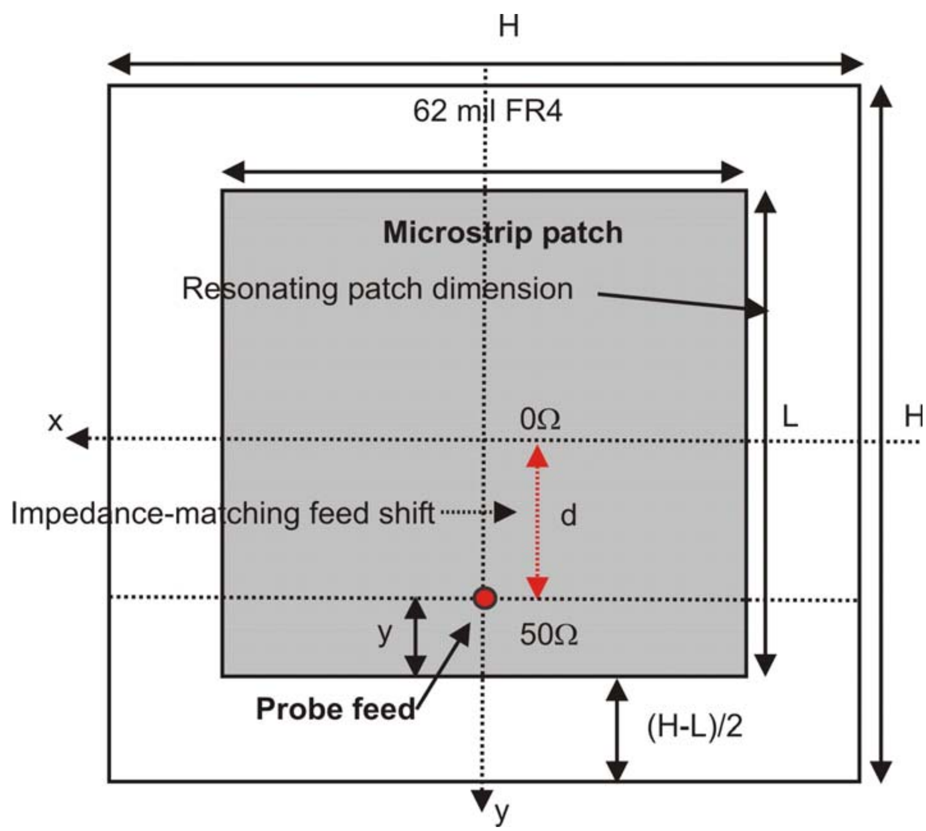


Fig. 1. Geometry of the probe-fed patch antenna on FR4.

The resonant frequency of the antenna is determined by the size, *L*, of the resonant dimension of the patch according to

$$f_{res} \approx \frac{c_0}{2L\sqrt{\varepsilon_r}} \qquad (1)$$

At the resonant frequency, the imaginary part of the input impedance Z=R+jX of the antenna – the reactance X– becomes exactly zero. The condition X=0 is the definition of the antenna system resonance(s).

One notes that Eq.(1) is the simple but **not** necessarily a very accurate result since it does not take into account the fringing effects close to the patch edges. However, for thin microstrip patches like the present one, the fringing is not very significant.

We are interested in the resonant frequency of 920 MHz. For FR4 with $\varepsilon_r = 4.4$, this would give according to Eq. (1)

$$L \approx 78\text{mm} \qquad (2)$$

We will use a slightly lower value, $L = 76.5\text{mm}$ as a starting guess, keeping in mind that this is not necessarily the exact result.

1.2. Resonant dimension of the patch element

The patch in Fig. 1 can resonate either along the x-axis or along the y-axis. How to select the right resonant dimension and make sure there is no resonance in the other dimension?

The resonant dimension of the patch is actually selected by the feed position: in Fig. 1 it will be the vertical direction of length L because the feed is asymmetric with regard to the vertical axis (the y-axis). Because the feed is symmetric with regard to the horizontal axis (the x-axis), it will not excite the horizontal mode – the corresponding impedance would be exactly zero for this mode – see lecture#6.

1.3. Two resonant dimensions

Sometimes one excites both resonant dimensions/modes simultaneously by putting the feed on the diagonal of the square patch. Why do we need it? The answer is simple – to create a **circular** polarization. By the way, any GPS antenna is circularly polarized. We will not study the circular polarization in this exercise.

1.4. The feed position

If we put the feed exactly on the edge of the patch, i.e. assume that

$$d = L/2 \tag{3}$$

in Fig. 1, then the impedance (strictly speaking, the resistance R since the reactance X is zero at the resonance) of the patch usually appears to be somewhat large – on the order of 100 Ω or even higher depending on the patch dimensions (cf. lecture#6 and Ref. [1]). We, however, need to have exactly 50 Ω at the resonance. What do we need to do? Just shift the feed position toward the center of the patch as shown in Fig. 1 [1-3]. This shift decreases (tunes) the resistance so that it finally might become exactly zero when the feed reaches the patch center.

Ref. [1] gives the analytical formula for tuning the antenna resistance R (at the resonance) to 50 Ω with the shifted feed:

$$R(d) \approx R(d = L/2) \cdot \cos^2\left(\frac{\pi(L/2 - d)}{L}\right) \tag{4}$$

where $R(d = L/2)$ is the resistance when the feed is located directly on the edge of the patch.

In this class exercise we will NOT tune the feed position. We will put the feed exactly on the edge of the patch. The feed position is tuned using the so-called parametric sweep in Ansoft HFSS and would require a separate lab exercise.

1.5. The feed position and resonant frequency

The feed position slightly tunes the resonant frequency as well – usually makes it slightly smaller when the feed is moved closer to the antenna center. This effect is minor though.

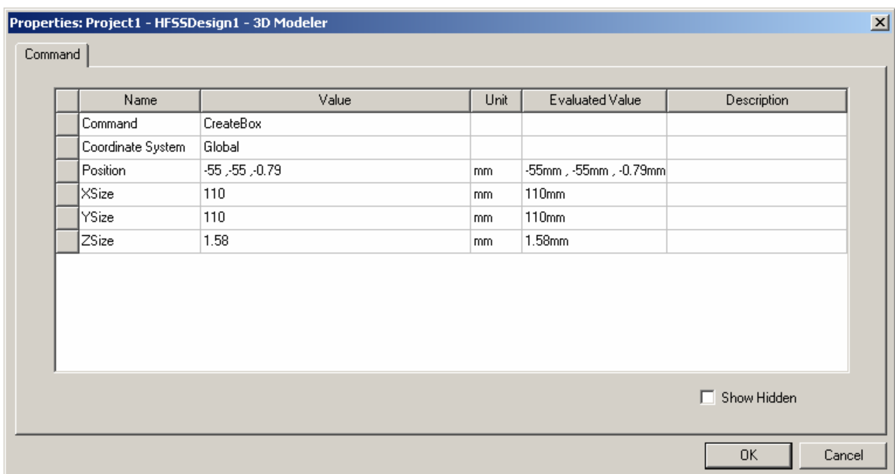
II. Experiment #1 – simple resonant solution; no optimization/tuning

2.1. Antenna geometry

The patch is to be considered at the center frequency of 920 MHz. The material is FR4 epoxy with the relative dielectric constant of $\varepsilon_r = 4.4$ and the loss tangent $\tan\delta = 0.02$. The FR4 thickness is 62 mil.

1. Open Ansoft HFSS. Change both Project directory and Temporary directory to C:\temp (if necessary). Save the (empty) Ansoft project as Project2.

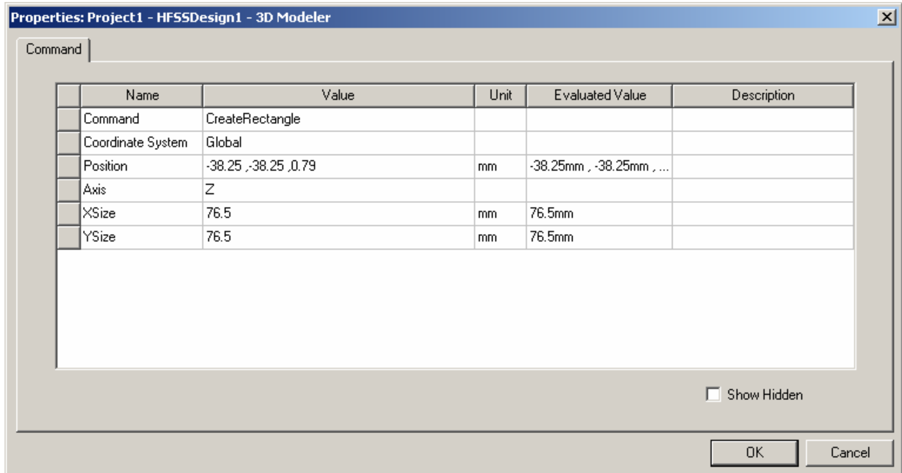
2. Introduce the dielectric substrate by drawing the box  with the size 110x110x1.58 mm. Center the box about the origin as shown in the dialog window below.



3. Open the material selection list (by using the right mouse click on the selected object). Assign FR4 material to that box.

4. Create a rectangle corresponding to the patch on the top of FR4 as shown in the dialog window below. Note that, instead of $L \approx 78\text{mm}$ predicted by Eq. (2), we will use a slightly smaller patch size:

$$L \approx 76.5\text{mm} \tag{5}$$



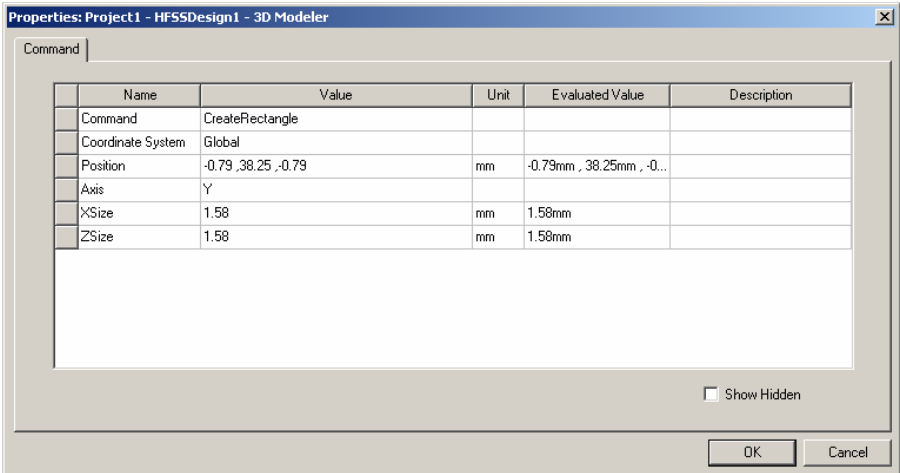
5. Select the patch rectangle and assign the PEC (perfect electric conductor) boundary to it (menu that appears after the right mouse click).

6. Create a rectangle corresponding to the ground plane (ground of the FR4 substrate) and also assign the PEC (perfect electric conductor) boundary to it (menu that appears after the right mouse click).

7. The vertical SMA connector (the so-called probe feed) for the microstrip patch is modeled as the lumped port, with the 50 Ω port impedance. First, we will locate the feed exactly on the patch edge. In order to assign the lumped port:

8. Draw a rectangle connecting the patch and the ground plane as shown in the figure below. Use XZ Grid Plane to draw the rectangle.

9. Select this small connecting rectangle and assign the lumped port (again after the right mouse click) to it as shown below. The integration line (along which the electric field, or the voltage test source, or the load, or etc. are given) should go vertically, from bottom to top. The right positions of the line ends will correspond to the mouse pointer in the form of a ***triangle***.



Properties: Project1 - HFSSDesign1 - 3D Modeler

Command

Name	Value	Unit	Evaluated Value	Description
Command	CreateRectangle			
Coordinate System	Global			
Position	-0.79 ,38.25 ,-0.79	mm	-0.79mm , 38.25mm , -0...	
Axis	Y			
XSize	1.58	mm	1.58mm	
ZSize	1.58	mm	1.58mm	

Show Hidden

OK Cancel

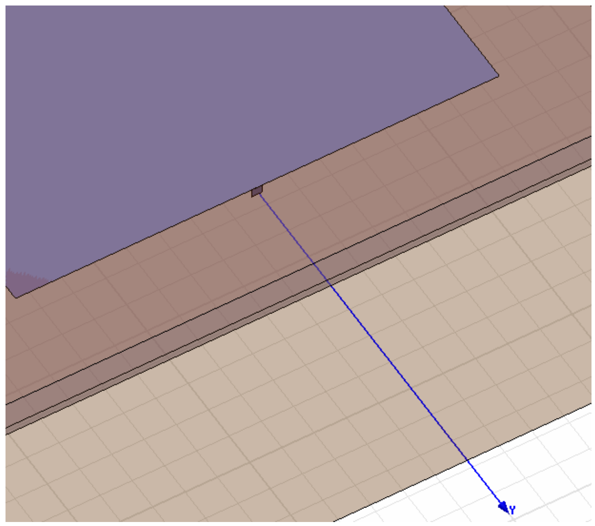


Fig. 2. Top – feed rectangle on the border of the patch corresponding to the lumped port plane; bottom – feed assemby.

10. Draw a larger box around the entire structure as shown below and assign (right mouse click) the radiation boundary to it. We remember that assigning the closing boundary is necessary for any of the finite-element (FEM) simulations.

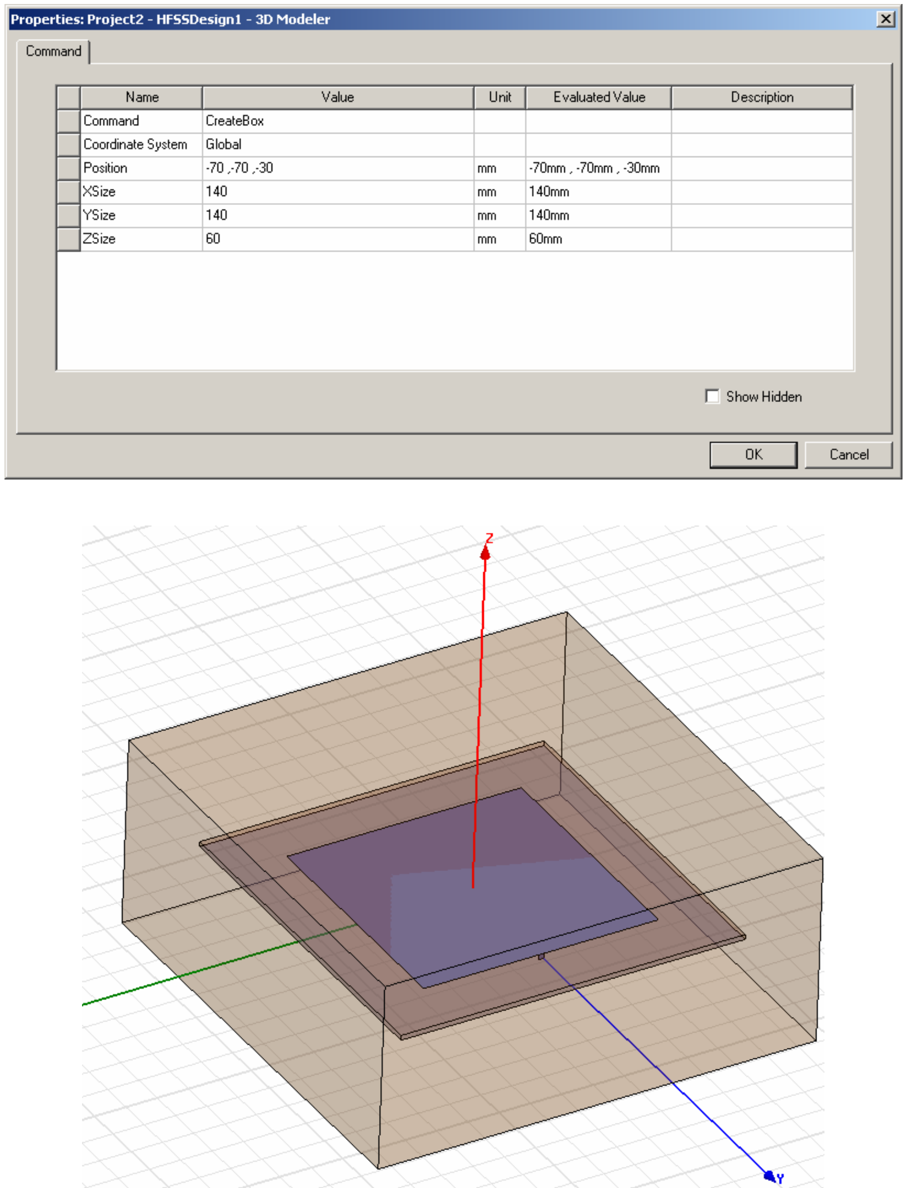


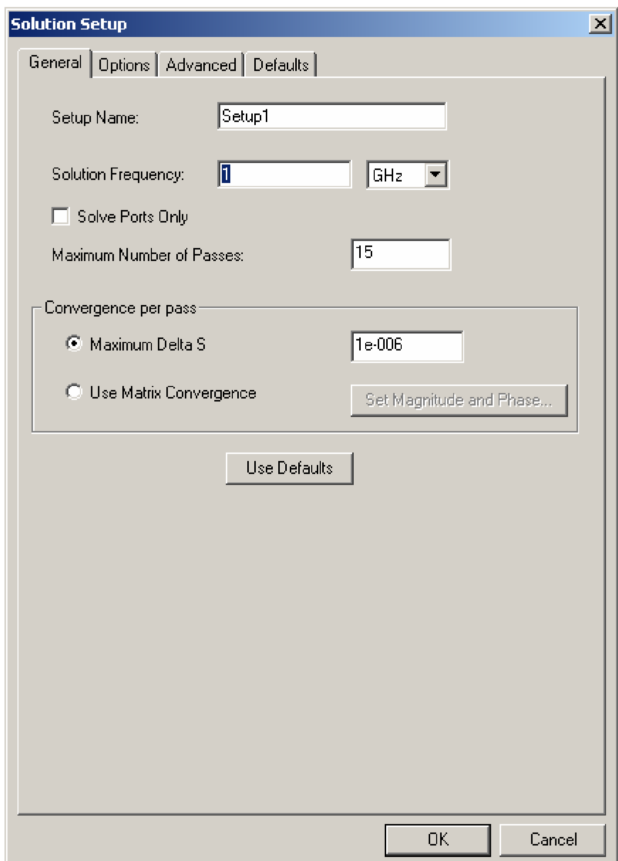
Fig. 3. A boundary box to which the radiation boundary condition is assigned.

11. The antenna structure is complete. The feed position is exactly on the patch edge.

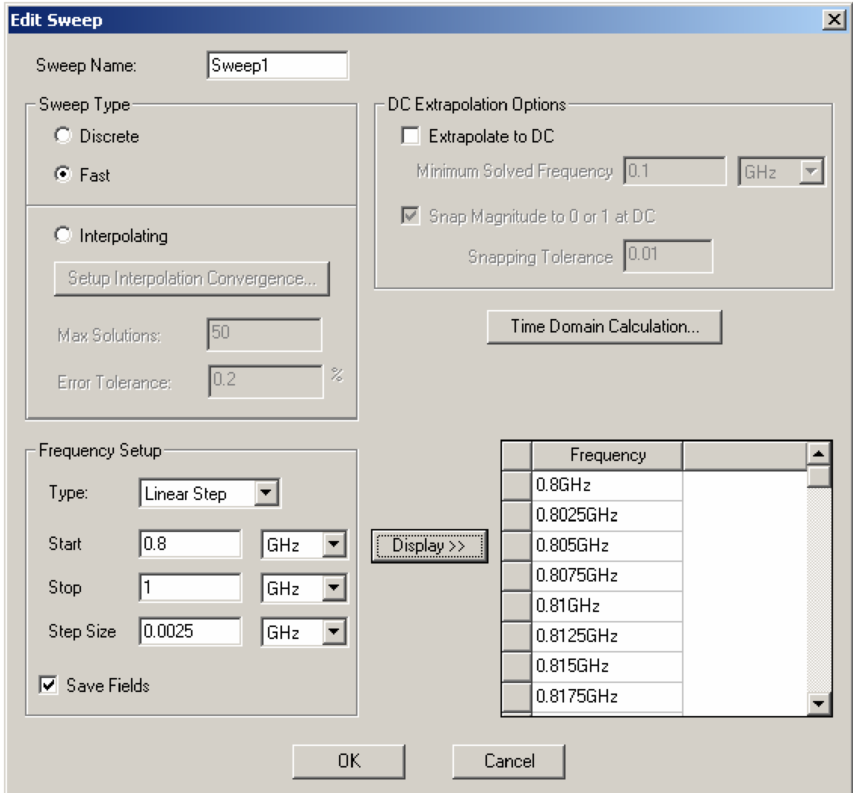
2.2. Simulation setup

We already know that the FEM method adaptively refines the mesh: the more passes we have the more accurate solution is expected. It's user's choice either to solve the problem fast or use more CPU time for a more accurate solution. Here, we will involve 15 passes.

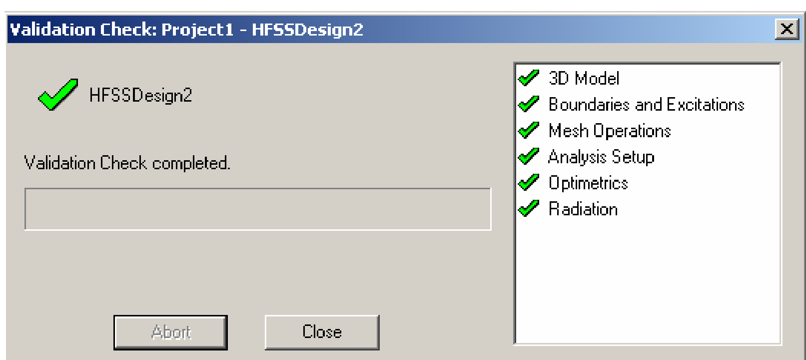
1. To setup the solution, go to Analysis setup as shown below and add a solution setup with right mouse click. Change the default parameters to the values shown in the figure that follows.



2. After the solution setup (Setup1) is all set, right click on Setup1 to add the frequency sweep. Use the following values for the frequency sweep:



Finally, check your model (run validation check) and then start the simulations – use button .



2.3. Impedance results

After the simulations are done go to Results/CreateReport and create a report for the antenna input impedance (not S_{11}!) including both real and imaginary parts. A figure shown below should appear.

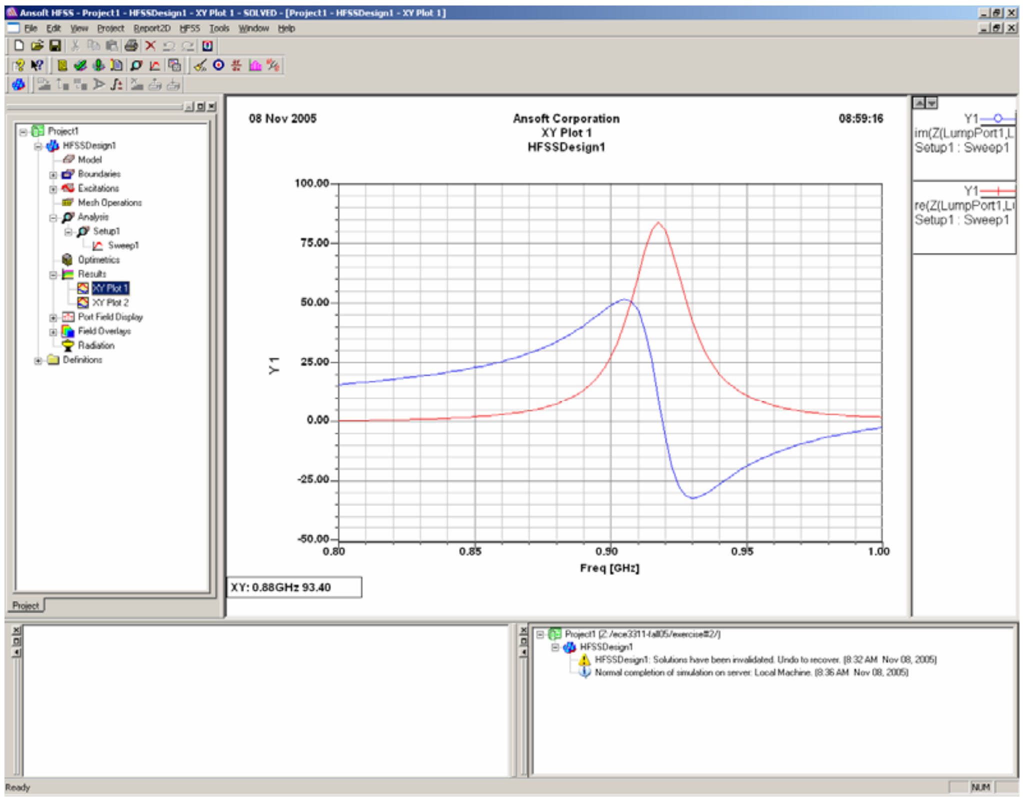


Fig. 4. Input impedance of the patch antenna with 15 passes.

Based on the impedance data please answer two questions:

1. What is exactly antenna's resonant frequency?
2. What is exactly antenna's resistance at the resonance?

Since the resistance is in fact higher than 50 Ohm (since the feed is located on the edge of the patch) the return loss never goes really low. Finer feed tuning would be necessary for this purpose. Please, create the report for return loss (magnitude of the reflection coefficient S_{11} in dB). Your result should look like Fig. 5 that is shown below.

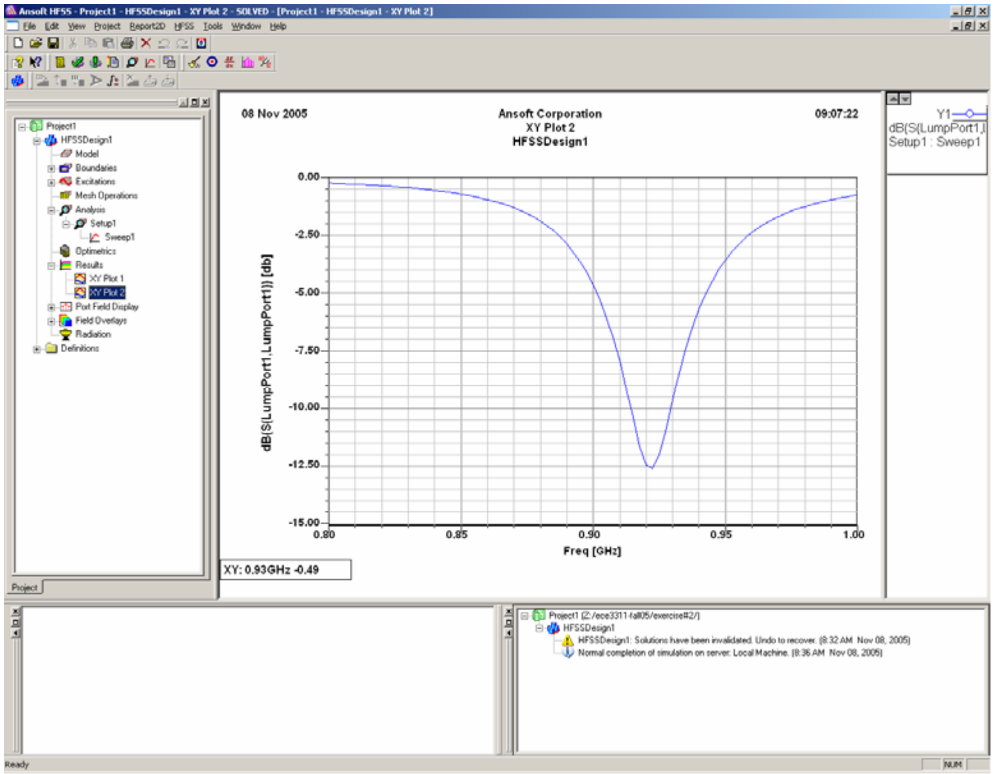


Fig. 5. Return loss of the patch antenna.

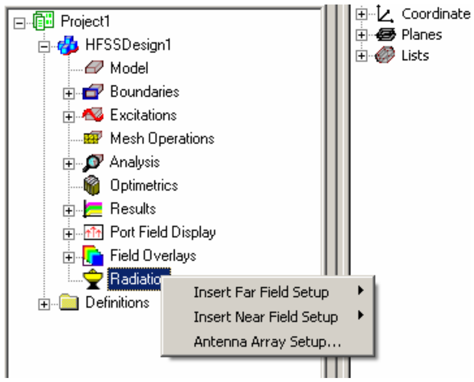
Using the results for the return loss estimate the ***antenna bandwidth***. The antenna bandwidth B is commonly defined as the (normalized) frequency interval where return loss goes below – 10dB, i.e. the bandwidth percentage is given by

$$B = \frac{\Delta f\,(\text{Return Loss} < \text{-10 dB})}{f_C} \times 100\% \qquad (6)$$

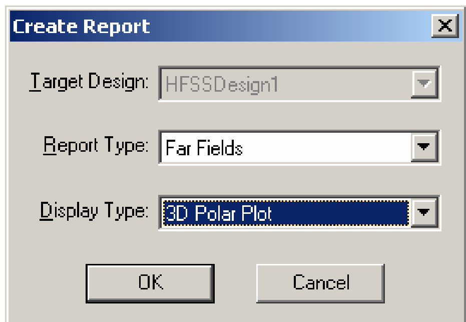
Note that Eq. (6) actually defines the ***impedance*** bandwidth of the antenna, which assures a proper impedance matching to 50 Ohm. Other bandwidth definitions are sometimes introduced, with regard to the polarization, scanning, etc.

2.4. Radiation results

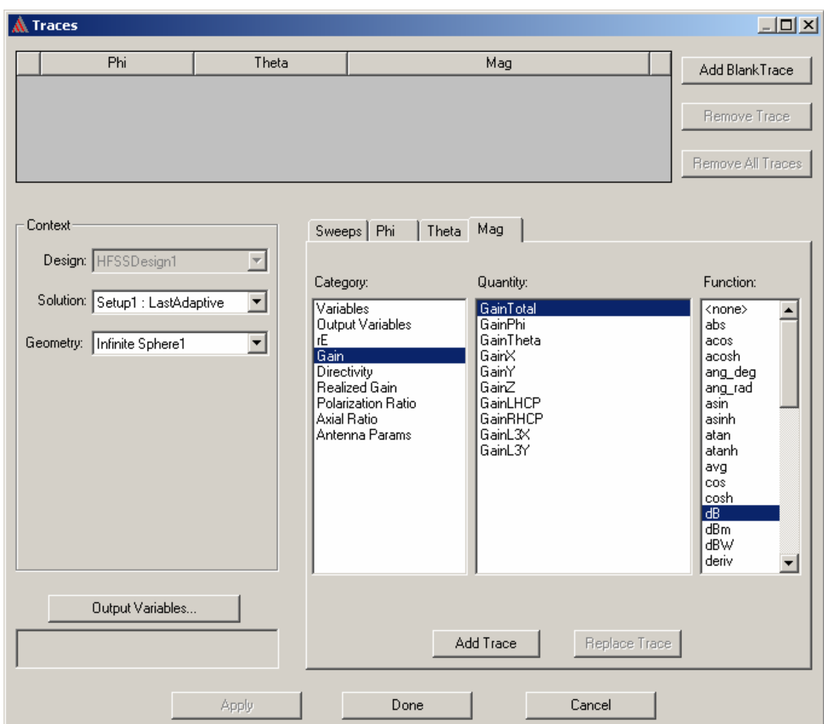
Now it's time to examine the radiation pattern of the patch antenna. Go to "Radiation" option on the project menu as shown below



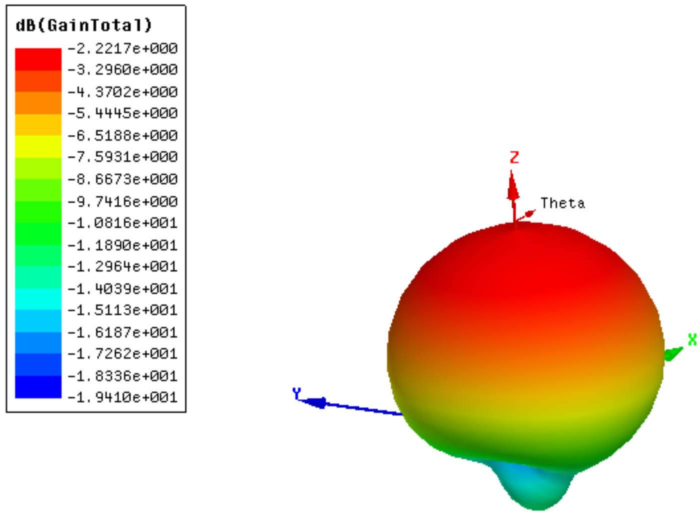
and insert the far-field setup as "Infinite Sphere1". Now, right click on the results and create report for the far field as shown below



The output variable should be the **total gain** in dB:

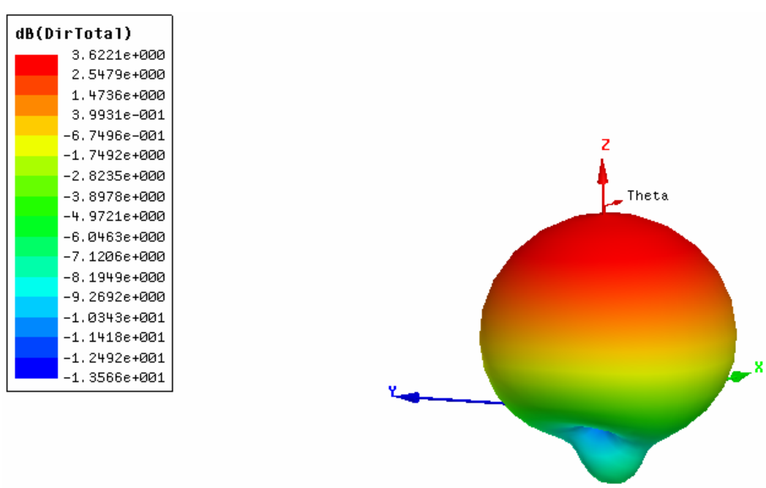


The antenna gain should look like this:



One can see that the patch antenna is directional – the main beam is pointing toward zenith. At the same time, the absolute gain at zenith is small: -2.2 dB. What is the matter??? Why is the gain not, say, +2 dB or +4 dB – as one may expect for the directional patch antenna?

To answer this question you may want to plot the **total directivity** in dB instead of the total gain. The antenna directivity is in fact the antenna gain ***without losses***, i.e. the antenna gain as if it would be for the perfect (non-lossy) dielectric and for the perfect metal sheet. Look at the figure below for the directivity. See the difference? This is the effect of the loss tangent $\tan\delta = 0.02$ for FR4! This is simultaneously the reason to use the low-loss dielectric substrates and … a big profit for some companies (like Rogers Corporation) who produce these (very expensive by the way) low-loss substrates.



III. Report

The report to this exercise should be attached to HW#2 on a separate sheet and it should be in the following format:

1. A short description of the patch antenna structure – figure.

2. Impedance results - input impedance/return loss over the frequency band. Questions in the text.

3. Radiation pattern results: gain plus directivity. What is the gain loss at zenith due to the losses in FR4?

IV. References

1. K. Carver, and J. Mink, "Microstrip antenna technology," IEEE Trans. Antennas and Propagation, vol. AP-29, no. 1, pp. 2-24, Jan 1981.

2. R. Bancroft, Microstrip and Printed Antenna Design, Noble Publishing, 2004, Atlanta, GA.

3. Kin-Lu Wong, Compact and Broadband Microstrip Antennas, Wiley, New York, 2002.