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

Exercise#1
Non-radiating transmission element (a microstrip)

Introduction

In contrast to the low-frequency or DC circuit, a communication circuit

i. has the size S, which is usually comparable to the wavelength λ_C at the center frequency f_C of the frequency band; $S > \lambda_C /100$ or so
ii. needs to radiate the electromagnetic signal into the space or receive the electromagnetic signal from an external source.

This implies that the circuit should have all the connections between its elements that are non-radiating and thus behave like the standard wires. At the same time, the circuit should have one special element or component that yet efficiently radiates power into space – an antenna.

The common way to extend the DC behavior of conductors to high frequencies and avoid radiation losses is to employ two very ***closely*** spaced conductors – a transmission line (Fig. 1a). The significant electric field exists only between the conductors; the radiation of two oppositely directed currents nearly cancels in the far field (see King 1958). A number of different transmission line geometries exists (coaxial, microstrip, stripline, CPW, etc.; see Ludwig and Bretchko 2000 or Pozar 2005). Care should be taken of the conductor spacing and the strip width in order to achieve proper characteristic impedance of the transmission line.

Many on-line calculators are available that implement approximate analytical formulas for the characteristic impedance of the transmission lines of different kind; see, for example, the JAVA applet from Rogers Corp., at http://www.rogerscorporation.com/mwu/mwi_java/Mwij_vp.html

Most common are the transmission lines with the second conductor being the same for all the connections – the **large solid ground plane** – see Fig. 1b. The configuration shown in Fig. 1b is called the microstrip. The PCB with the large solid ground plane and multiple microstrip connections on the top of it is standard for the communication circuits.

The antenna concept is exactly the opposite to the transmission line concept; in order to achieve radiation we should move two conductors further apart – see Fig. 1c. The combination shown in Fig. 1c – a "bent transmission line" – is in fact the dipole antenna. Instead of two strips one can use two round wires – the difference will be minor.

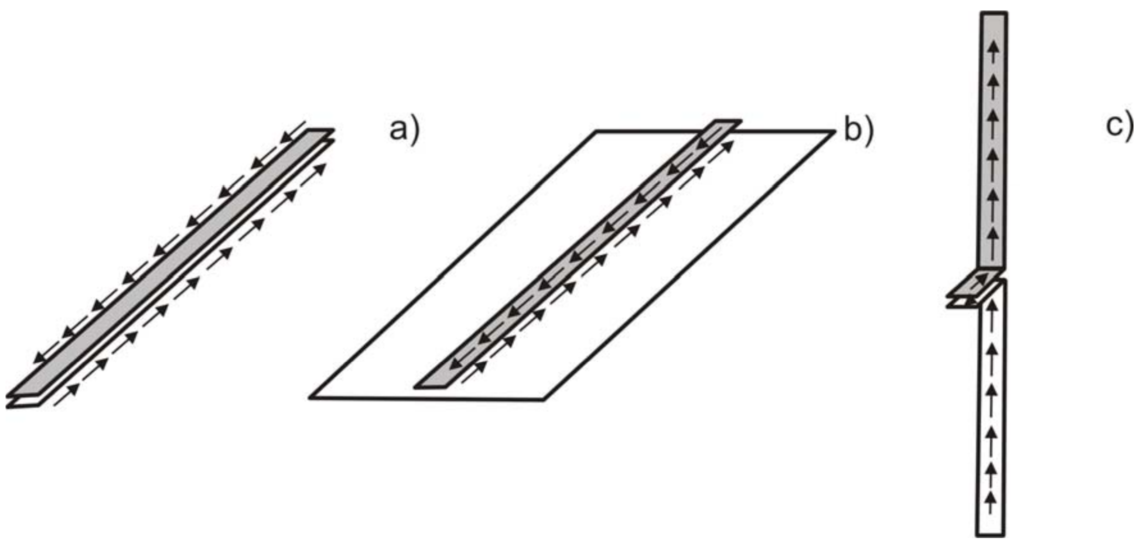


Fig. 1. A transmission line with two equal closely-spaced conductors; b) – a microstrip above the PEC ground plane; c) – a dipole antenna made of two microstrips.

In this and in the following exercise, we will use the full-wave 3D EM software simulator called Ansoft HFFS (v. 10) in order to model these two opposite cases – the microstrip and the dipole antenna. Other software packages (e.g. ADS) may have greater flexibility in the RF circuit design. Yet the Ansoft HFSS is the most reliable and accurate tool for the antenna/resonator design. At the same time, it is rather slow, especially, when electrically larger problems need to be solved.

1. Microstrip

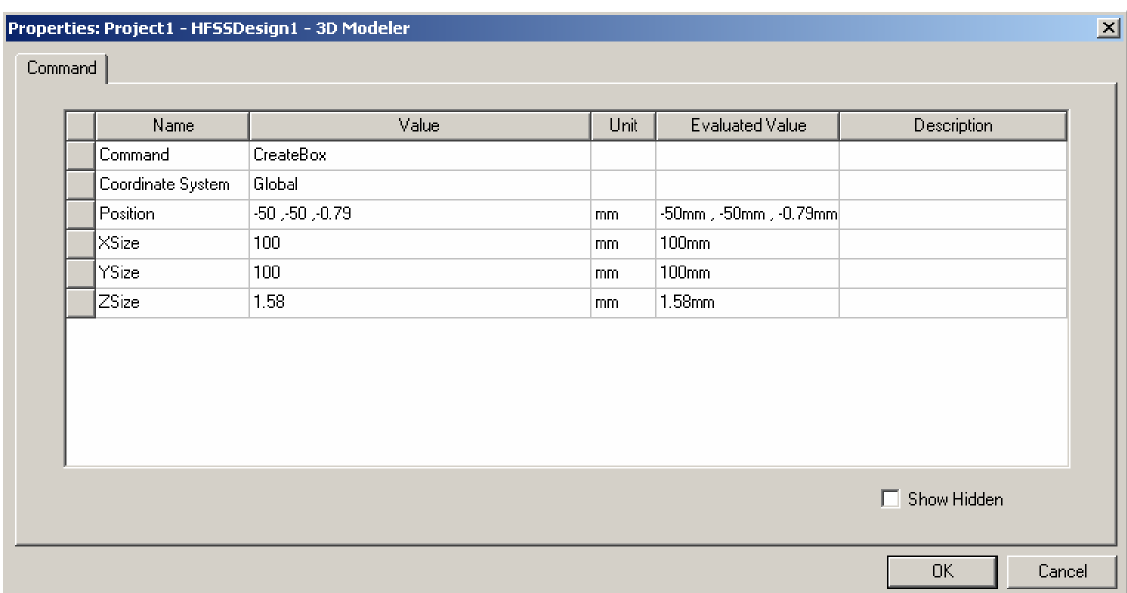
1.1. Geometry

The microstrip 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.

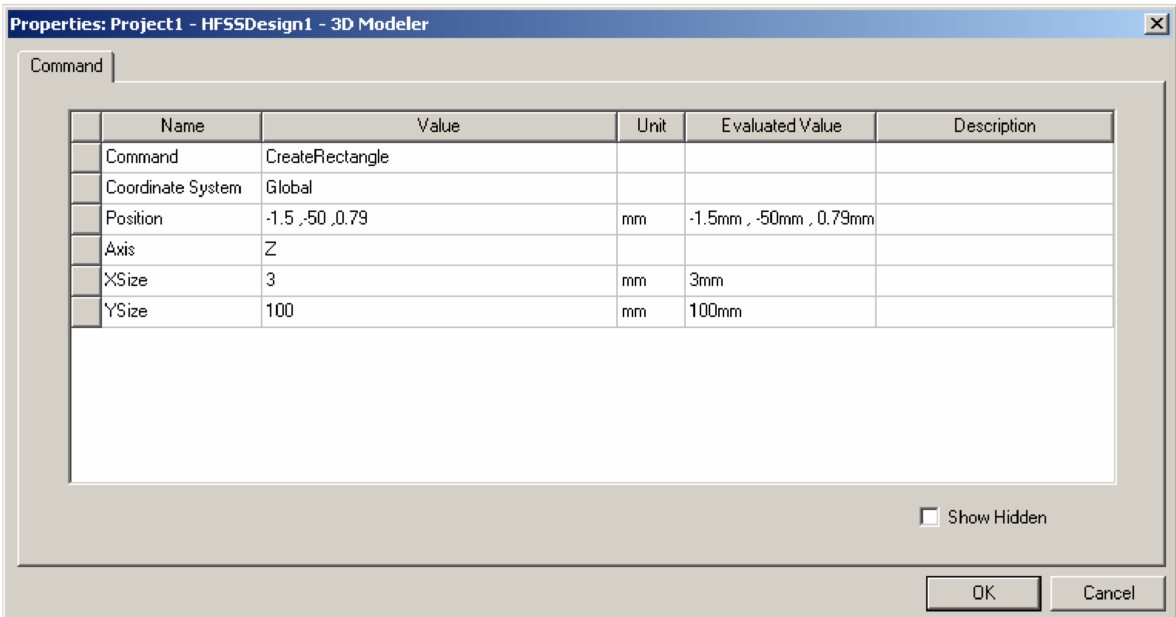
1. Using the applet at http://www.rogerscorporation.com/mwu/mwi_java/Mwij_vp.html (or another microstrip calculator of your choice) find the strip width W that approximately corresponds to the characteristic impedance of 50Ω at 920 MHz.

2. Open Ansoft HFSS. Change both Project directory and Temporary directory to C:\temp. Save the (empty) Ansoft project as Project1.

3. Introduce the dielectric substrate by drawing the box  with the size 100x100x1.58 mm. Center the box about the origin as shown in the dialog window below.



4. Open the material selection list (by using the right mouse click on the selected object). Assign FR4 material to that box.
5. Create a rectangle (along they-axis) corresponding to the microstrip on the top of FR4 as shown in the dialog window below.



Name	Value	Unit	Evaluated Value	Description
Command	CreateRectangle			
Coordinate System	Global			
Position	-1.5 ,-50 ,0.79	mm	-1.5mm , -50mm , 0.79mm	
Axis	Z			
XSize	3	mm	3mm	
YSize	100	mm	100mm	

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

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

1.2. Excitation and boundaries

Two SMA connectors at both ends of the microstrip line are modeled as the so-called lumped ports, with 50 Ω port impedance each. In order to assign the lumped ports:

1. Draw two rectangles connecting the microstrip and the ground plane as shown in the figure below. Use XZ Grid Plane to draw the rectangles.

2. Select one of the small connecting rectangles and assign the lumped port (again after 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.

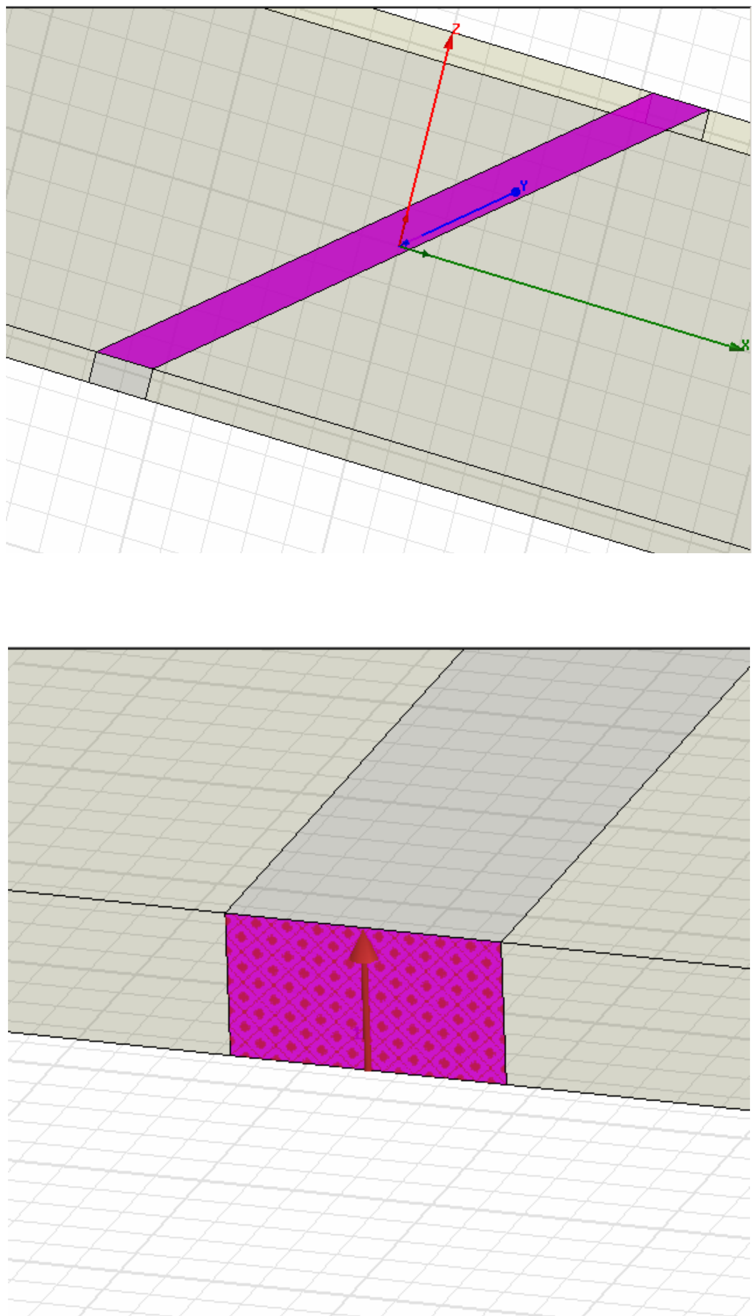
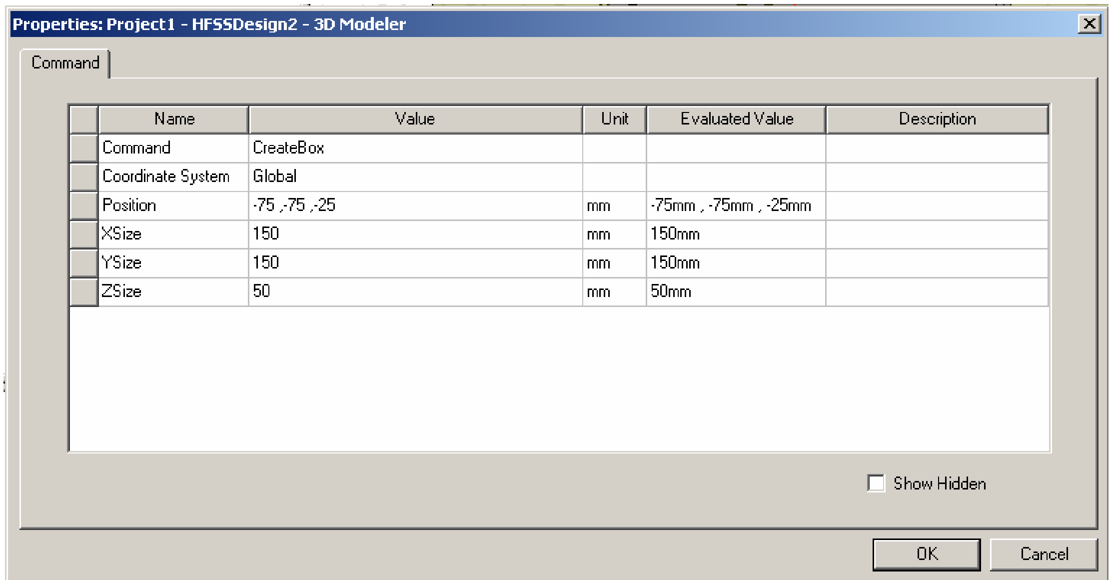


Fig. 2. Top – two rectangles corresponding to the lumped port planes; bottom – the integration line that needs to be given.

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



	Name	Value	Unit	Evaluated Value	Description
	Command	CreateBox			
	Coordinate System	Global			
	Position	-75 ,-75 ,-25	mm	-75mm , -75mm , -25mm	
	XSize	150	mm	150mm	
	YSize	150	mm	150mm	
	ZSize	50	mm	50mm	

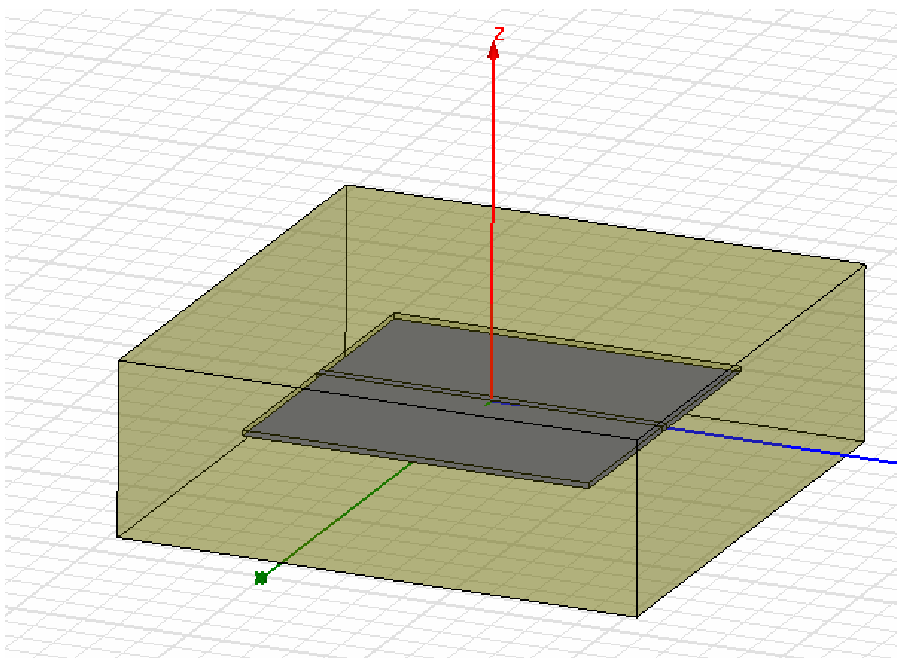
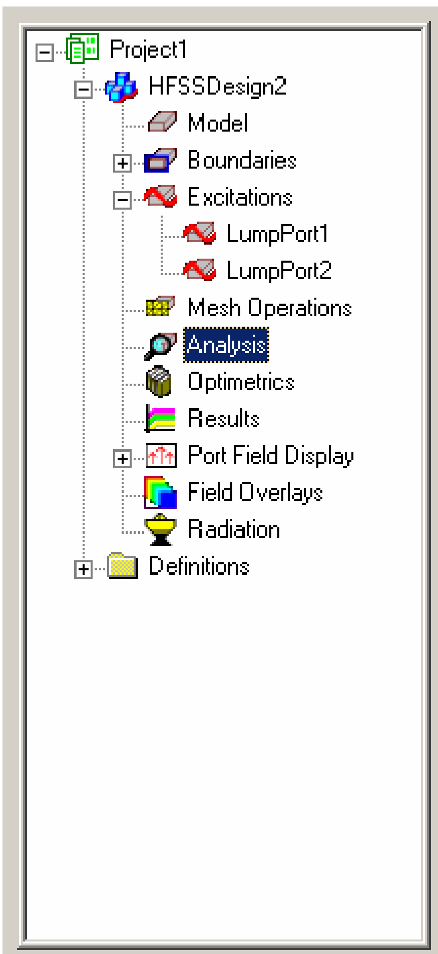


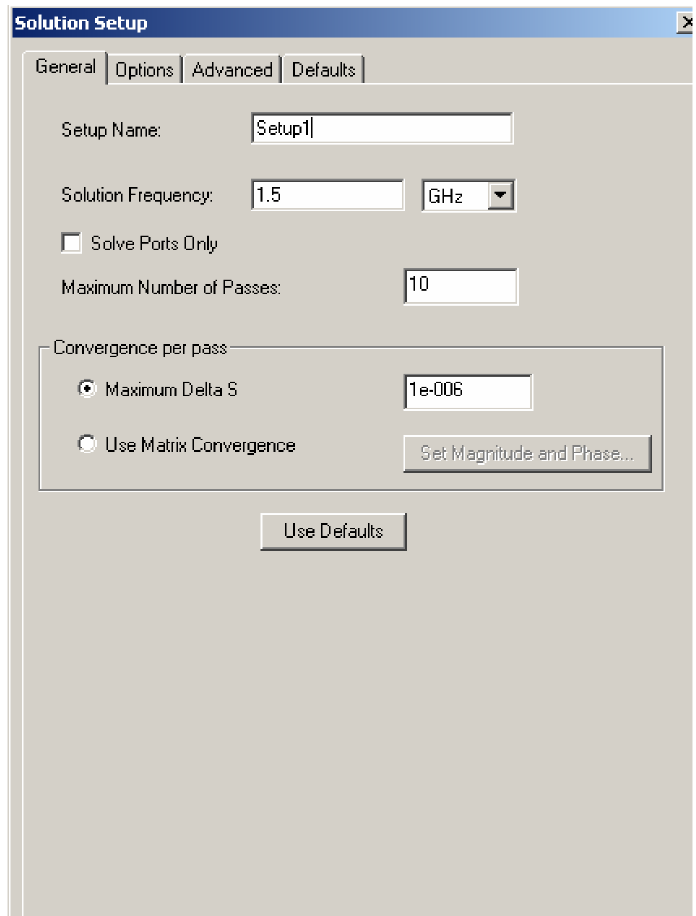
Fig. 3. A boundary box to which the radiation boundary condition is assigned.

1.3. Simulation

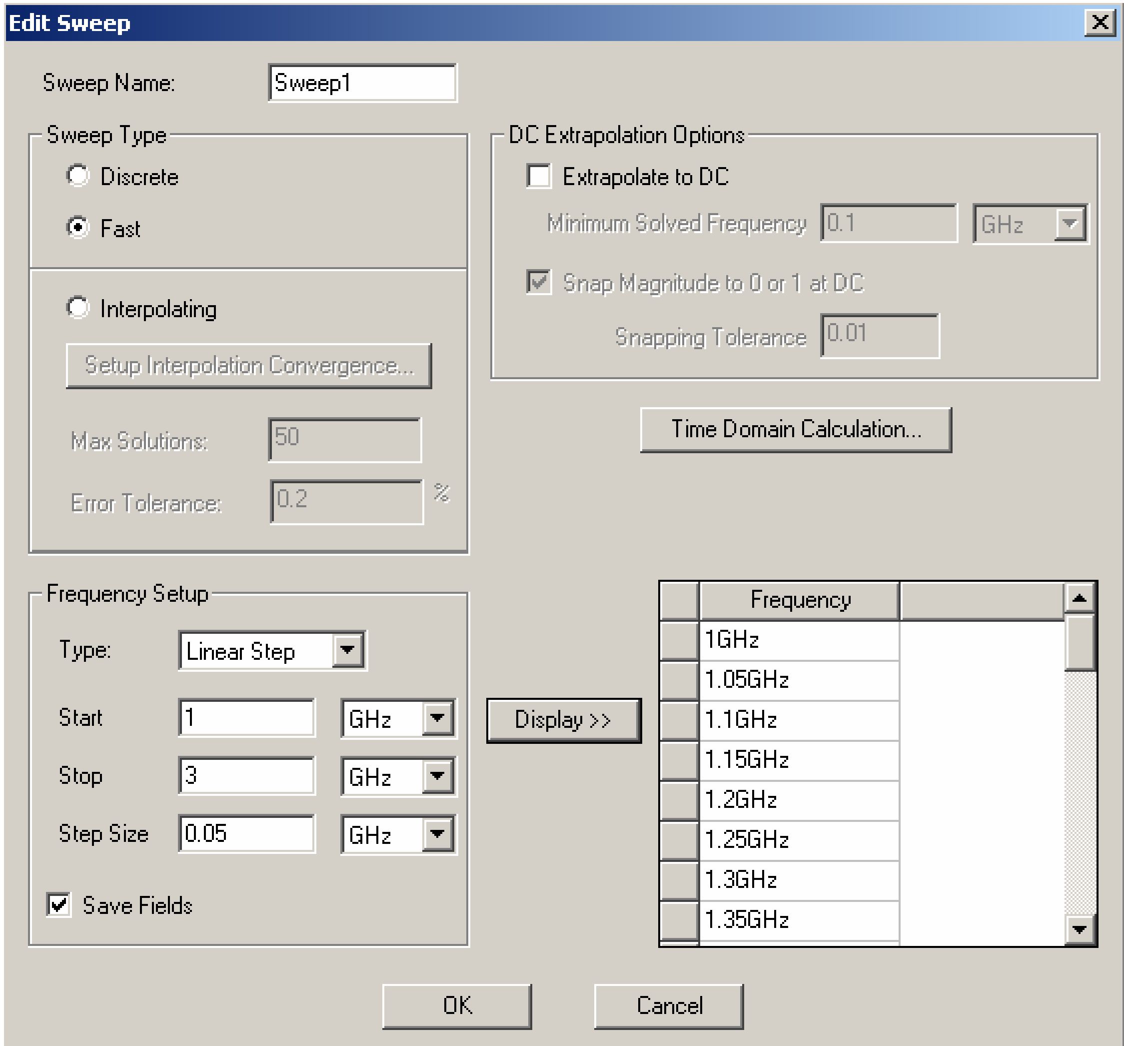
The FEM method adaptively refines the mesh: the more passes we have the more accurate solution is expected. It's user's choice either to solve the problem fast or use more CPU time for a more accurate solution.

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.

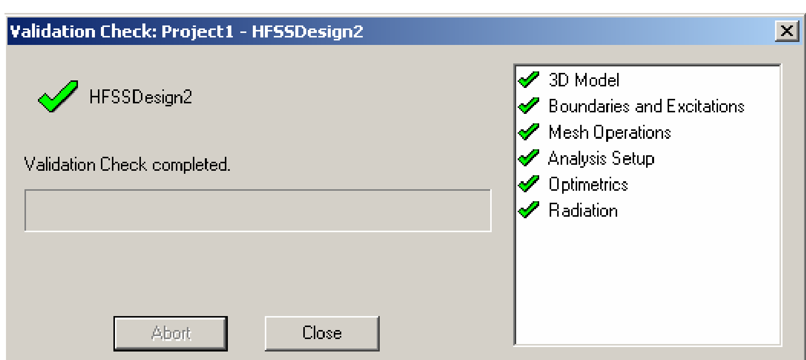




2. After the solution setup (Setup1) is all set, right click on Setup1 to add the frequency sweep. Use the following values for the frequency sweep:



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



2. Microstrip results

After the simulations are done go to Results/CreateReport and create a report for two network parameters: S_{11} and S_{21}. A figure shown below should appear.

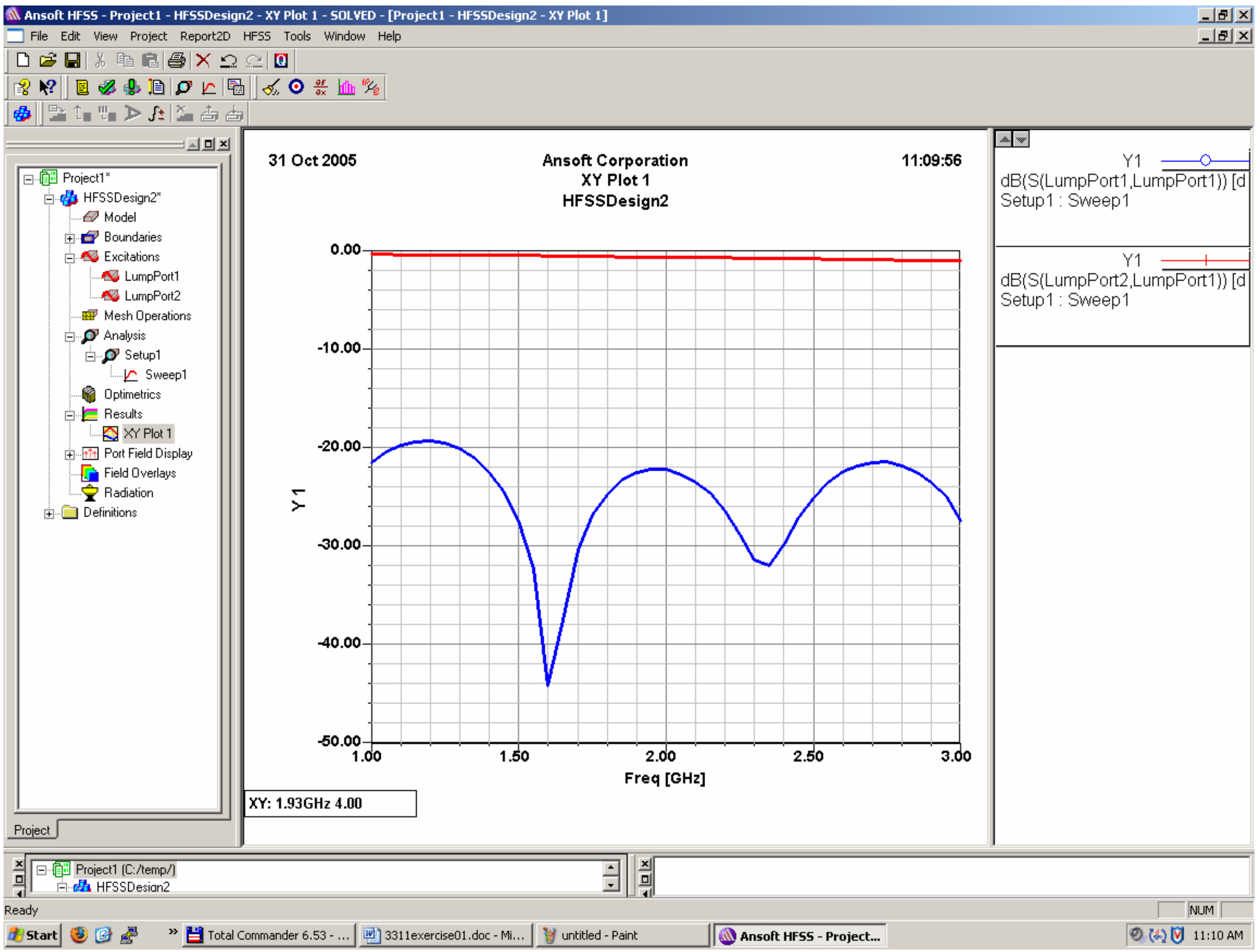


Fig. 4. Return loss and insertion loss for the microstrip.

The blue line (below – 20dB) shows the result for $|S_{11}|_{\mathrm{dB}}$. This is the so-called reflection coefficient (**return loss**),

$$|S_{11}|_{\mathrm{dB}} = +20\log_{10}\left(\left|\frac{Z_{in}-50}{Z_{in}+50}\right|\right); \quad Z = \frac{V}{I}$$

The reflection coefficient or return loss indicates which fraction of RF power is reflected back to the source due to the input impedance mismatch of the microstrip to 50Ω. In the present case, this fraction is insignificant (below -20 dB).

The red line (on the top of the figure) shows the results for $|S_{21}|_{\mathrm{dB}}$. This is the so-called transmission coefficient (**insertion loss**). The transmission coefficient indicates which fraction of RF power is transmitted from port 1 to port 2, in other words, how well the transmission line really functions. This fraction is very significant at 1 GHz (insertion loss of -0.35 dB or 92% of power is transmitted) but drops down at 3 GHz (insertion loss of -0.96 dB or 80% of power is transmitted). The major reason for this drop is the loss in the FR4 that become more significant at higher frequencies.

3. Report

The report to this exercise should be attached to HW#1 on a separate sheet and it should be in the following format:

1. A short description and figure of the created structure.
2. Results (insertion loss/return loss over the frequency band) – a figure is enough.
3. The same results when only three passes are employed in the Analysis Setup. Do you think the results with three passes are accurate?