**DAYALBAGH EDUCATIONAL INSTITUTE,
DAYALBAGH, AGRA**

Manual

Experiment 5

Patch Antenna

Experiment 5

Objective:

To design the Patch Antenna at 1.5 GHz

1. Calculate the length and width of Patch Antenna at 1.5 GHz

To simulate the Patch Antenna

1. Specify the Patch Antenna parameter
2. Define the geometric modal
3. Define the material data and boundary conditions
4. Run the simulation
5. Analyze the simulation results

Requirement:

1. Computer facility
2. EMgine Simulation Software

Theory:

Microstrip Patch Antenna

Microstrip patch antenna are the promising candidate for microwave and millimeter wave applications where low cost, low profile, confirmability and ease of manufacture are found to out weight the electrical disadvantages such as narrow bandwidth and low power capability. In arrays, they allow easy integration with active and passive circuit for beam control and signal processing.

Use of printed circuit technology has brought about rapid growth in the development of patch antennas having patch of conducting materials etched on one side of a dielectric substrate, the other side of the board being a metal ground plane. As the resulting printed circuit board is very thin, these are also known as paper thin antennas. The simplest configuration of a microstrip antenna is shown in figue1. The popularity of such antennas arises from the fact that the structure is planar in configuration and enjoys all the advantages of printed circuit technology. The feed lines and matching networks are fabricated simultaneously with the antenna structure. The solid state component can also be added directly on the microstrip antenna board and hence such antennas are compatible with modular designs. These antennas meet the prime requirement i.e. small size, low weight and hence it is easy to manufacture on mass scale with low manufacturing cost. Also these can be applied directly to metallic surface on an aircraft or missile and not disturb aerodynamic flow and thus have better aerodynamic properties. Accordingly these antennas are replacing old and bulky antennas on aerospace vehicles i.e. on satellite, missile, rocket or aircraft etc. The other advantages of microstrip antennas are the linear and circular polarization are possible with simple change in feed position and dual frequency antennas can be made possible.

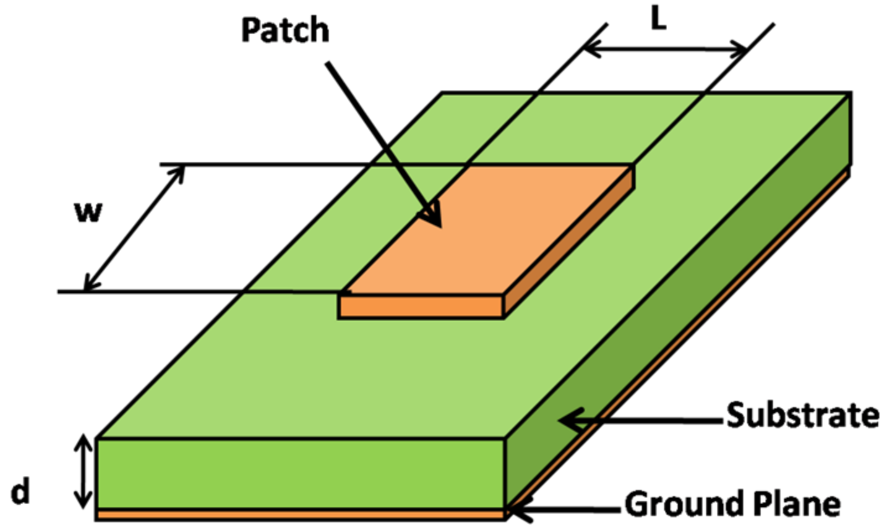

Figure 1 Structure of a Microstrip Patch Antenna

In order to simplify analysis and performance prediction, the patch is generally square, rectangular, circular, triangular, and elliptical or some other common shape as shown in Figure 2.

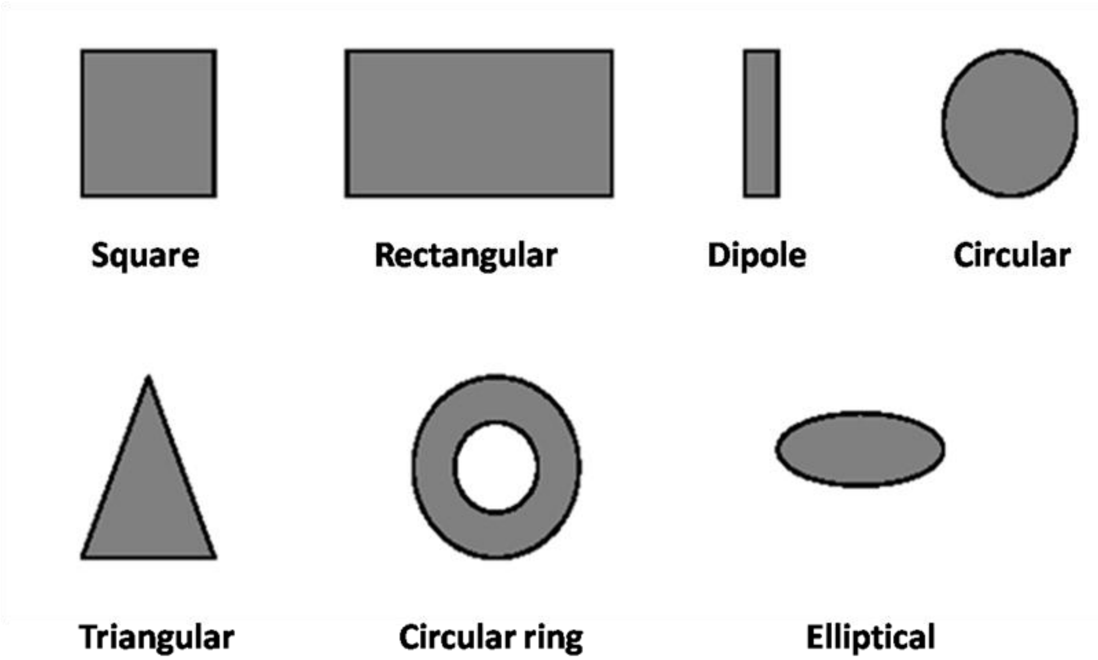

Figure 2 Common shapes of microstrip patch elements

Disadvantages

The disadvantages of patch antenna are

- Narrow bandwidth
- Low efficiency
- Practical limitations on maximum gain (~ 20dB)
- Extraneous radiation from feeds and junctions
- Poor end fire radiator except tapered slot antennas
- Low power handling capacity.
- Possibility of excitation of surface wave

Microstrip patch antennas have a very high antenna quality factor (Q). Q represents the losses associated with the antenna and a large Q leads to narrow bandwidth and low efficiency. Q can be reduced by increasing the thickness of the dielectric substrate.

Transmission Line Model

The patch antenna dimensions are displayed in figure 3. Usually, the patch length L is between $\lambda_o/3$ (where λ_o is the guided wavelength) and $\lambda_o/2$ and its width W is smaller than λ_o (it can not be too small, otherwise the antenna become a microstrip line, which is not a radiator) while its thickness *t* is extremely small. The substrate of thickness d ($\ll \lambda_o$) uses the material whose relative permittivity is normally between 2 and 24. To be a resonant antenna, the length L should be around half of the wavelength. In this case the antenna can be considered a $\lambda_o/2$ transmission line resonant cavity with two open ends where the fringing fields from the patch to the ground are exposed to the upper half space (z > 0) and are responsible for the radiation.

The fringing fields at the ends are separated by $\lambda_o/2$, which means that they are 180^0 degree out of phase but are equal in magnitude. Viewed from the top of the antenna, both fields are actually in phase for the *x* components, which leads to a broadside radiation with a maximum in the *z* direction. As a resonant cavity, there are many possible modes, thus a patch antenna is multimode and may have many resonant frequencies. The fundamental and dominant mode is TM_{100} (a half wave changes along the *x* axis and no changes along the other two axes).

Formula Used:

Because of the fringing effects, electrically the patch of the antenna looks larger than its physical dimensions; the enlargement of L is given by

$$\Delta L = 0.412d\ (\varepsilon_{reff} + 0.3)(W/d + 0.264/\ [(\varepsilon_{reff} - 0.258)(W/d + 0.8)])$$

Where the effective relative permittivity is

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2\sqrt{1 + 12d/W}}$$

This is related to the ratio of *d/W*. the larger the *d/W,* the smaller the effective permittivity.

The effective length of the patch now

$$L_{eff} = L + 2\Delta L$$

The resonant frequency for the TM_{100} mode is

$$f_r = \frac{1}{2L_{eff}\sqrt{\varepsilon_{reff}}\ \sqrt{\varepsilon_o\mu_o}}$$

An optimized width for an efficient radiator is

$$W = \frac{1}{2f_r\sqrt{\varepsilon_o\mu_o}}\sqrt{2/(\varepsilon_r + 1)}$$

Where

εeff = Effective dielectric constant

ε*r* = Dielectric constant of substrate

d = thickness of dielectric substrate

W = Width of the patch

f = Operating frequency

W = Patch's width

L = Patch's length

This model represents the microstrip antenna by a patch of width *W* and height *h* , separated by a transmission line of length L. The microstrip is essentially a nonhomogeneous line of two dielectrics, typically the substrate and air.

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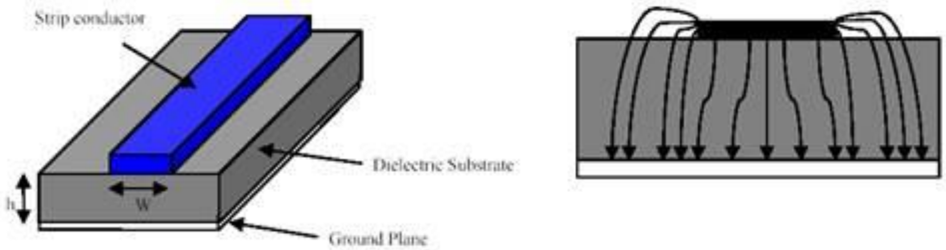


Figure 3: Top view of microstrip antenna and fileld distribution in microstrip antenna

Hence, as seen from Figure 3, most of the electric field lines reside in the substrate and parts of some lines in air. As a result, this transmission line cannot support pure transverse electric magnetic (TEM) mode of transmission, since the phase velocities would be different in the air and the substrate. Instead, the dominant mode of propagation would be the quasi-TEM mode.

Given Parameters:

Frequency $f = 1.5$ GHz

Substrate Thickness $d = 1.1$ mm

Substrate Permittivity $\varepsilon_r = 5.5$

Calculate:

Length of Patch Antenna $L = ?$

Width of the Patch Antenna $W = ?$

Simulation Procedure:

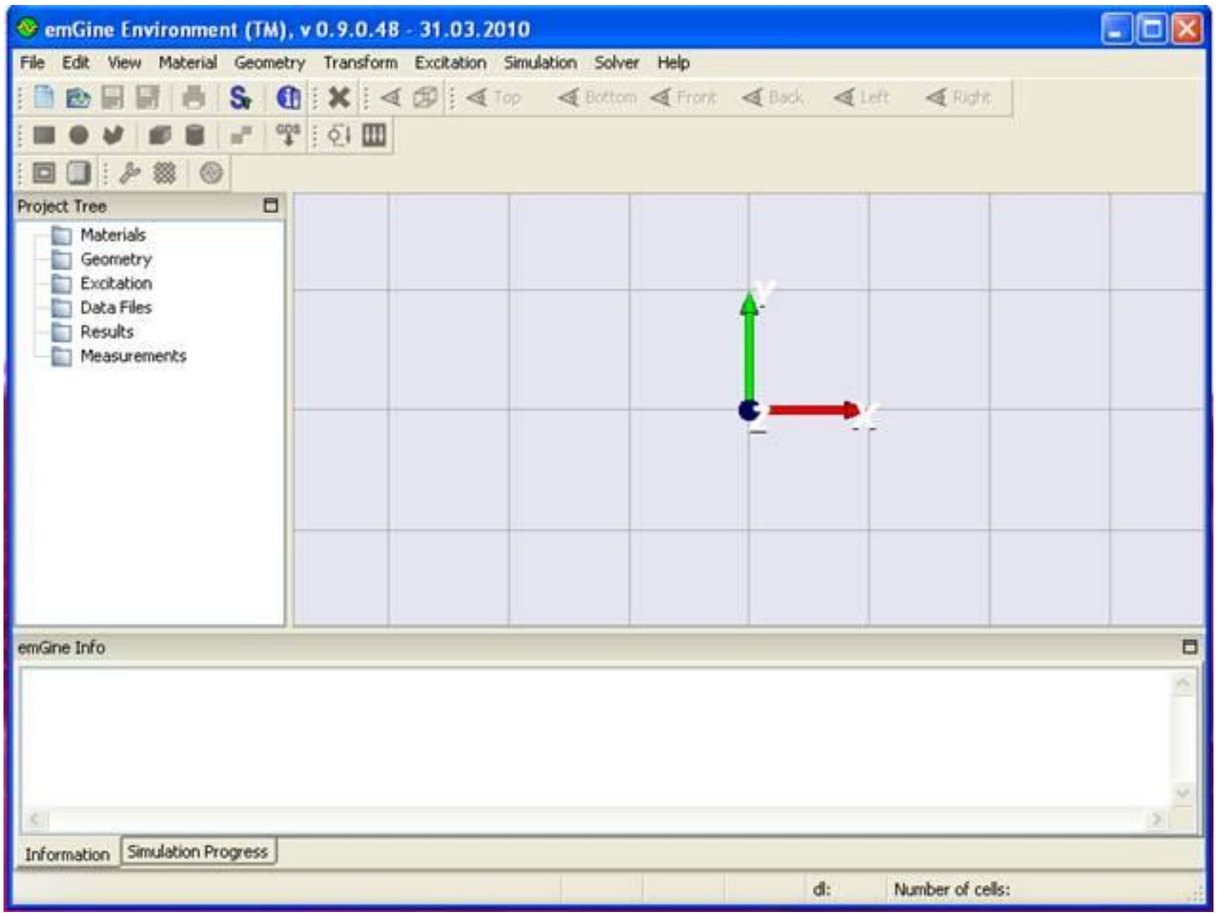
Introduction and Model Dimensions

In this tutorial you will learn how to simulate planar devices. As a typical example for a planar device, you will analyze a planar antenna. The following explanations on how to model and analyze this device can be applied to other planar devices, as well.

Geometric Construction Steps

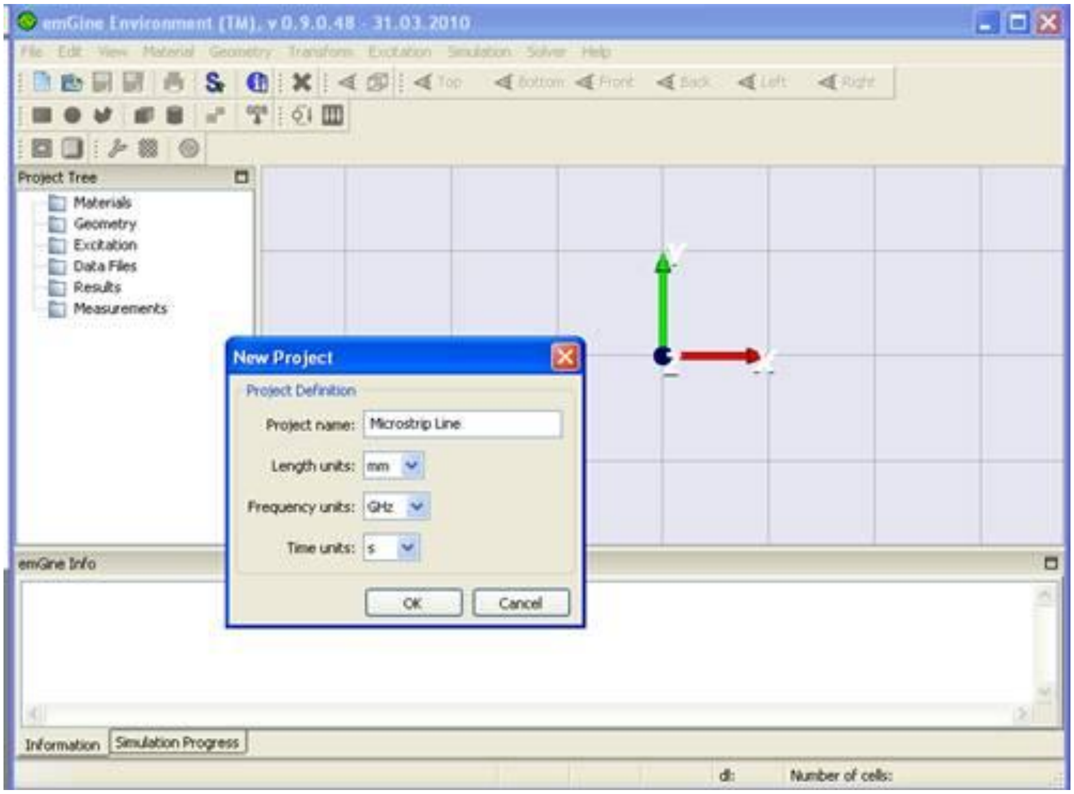
This tutorial will take you step by step through the construction of your model, and relevant screen shots will be provided so that you can double-check your entries along the way.

Download the given link of emGine Environment. Go to emGine in the program file and double click to open the simulator.



Select a Template

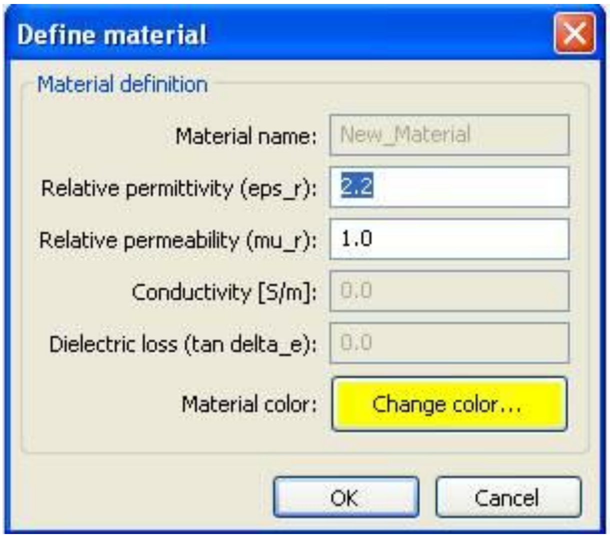
Once you have started emGin, go to file and click on new project a dialog box will open to give the appropriate name for the new project. You should set the units in mm, GHz and s and press ok.



Now again go to file click on save project and save your project at any location in my computer.

Set the Working Planes Properties

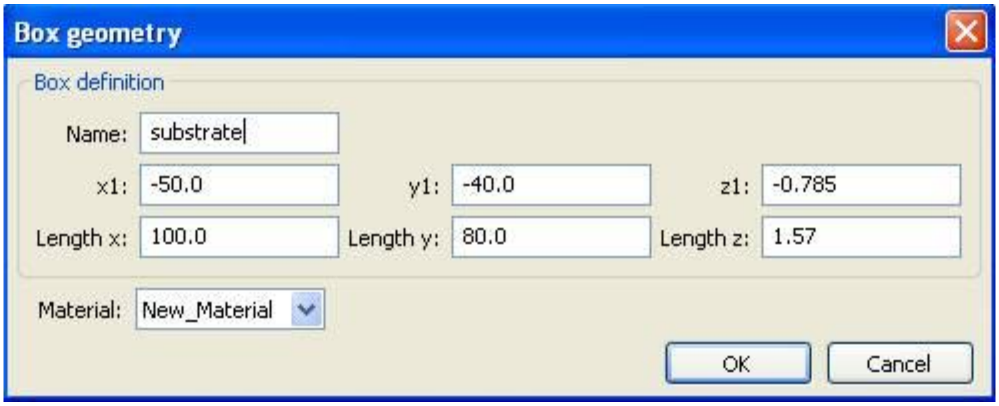
The next step is usually to set the material properties. In this dialog box you should define a new *Material name* (e.g. New_Mtarial). Afterwards, specify the material properties in the *Epsilon* and *Mue* fields. Here, you only need to change the dielectric constant *Epsilon* to 2.2. Finally, choose a color for the material by pressing the *Change* color button. Your dialog box should now look similar to the picture below before you press the *OK* button.



Draw the Substrate Brick

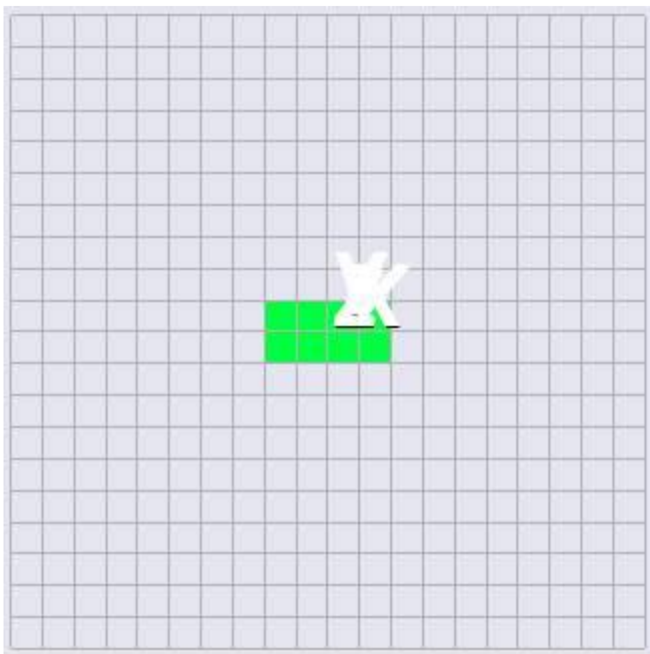
The first construction step for modeling a planar structure is usually to define the substrate layer. This can be easily achieved by creating a brick made of the substrates material. Please activate the brick creation mode (*Geometry - Box*).

When you are prompted to define the first point, you can enter the coordinates numerically by clicking Box that will open the following dialog box:



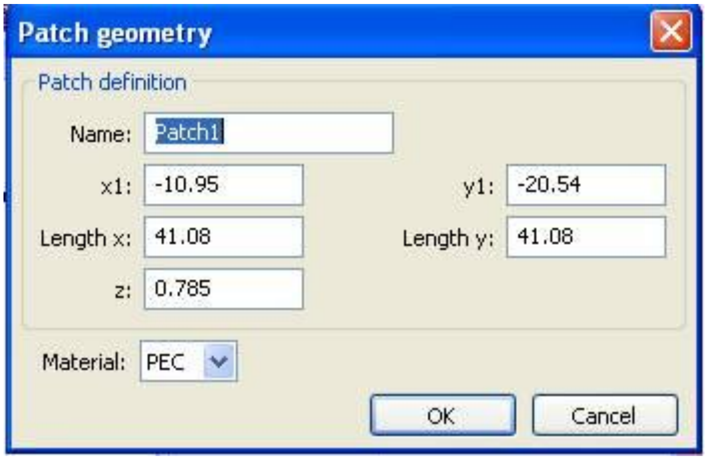
In this example, you should enter a substrate block. The transversal coordinates can thus be described by X 1= -50, Y = -40, Z = -0.785 for the first corner and give the calculated length X = 100, Y = 80, Z = 1.57 for creating the brick, assuming that the brick is modeled symmetrically to the origin. Please check all these settings carefully. If you encounter any mistake, please change the value in the corresponding entry field. You should now assign a meaningful name to the brick by entering e.g. substrate in the *Name* field.

The *Material* setting of the brick must be changed to the desired substrate material. Because no material has yet been defined for the substrate, you should open the layer definition dialog box by selecting New_Material from the *Material* dropdown list. Now in the brick creation dialog box you can also press the *OK* button to finally create the substrate brick. Your screen should now look as follows

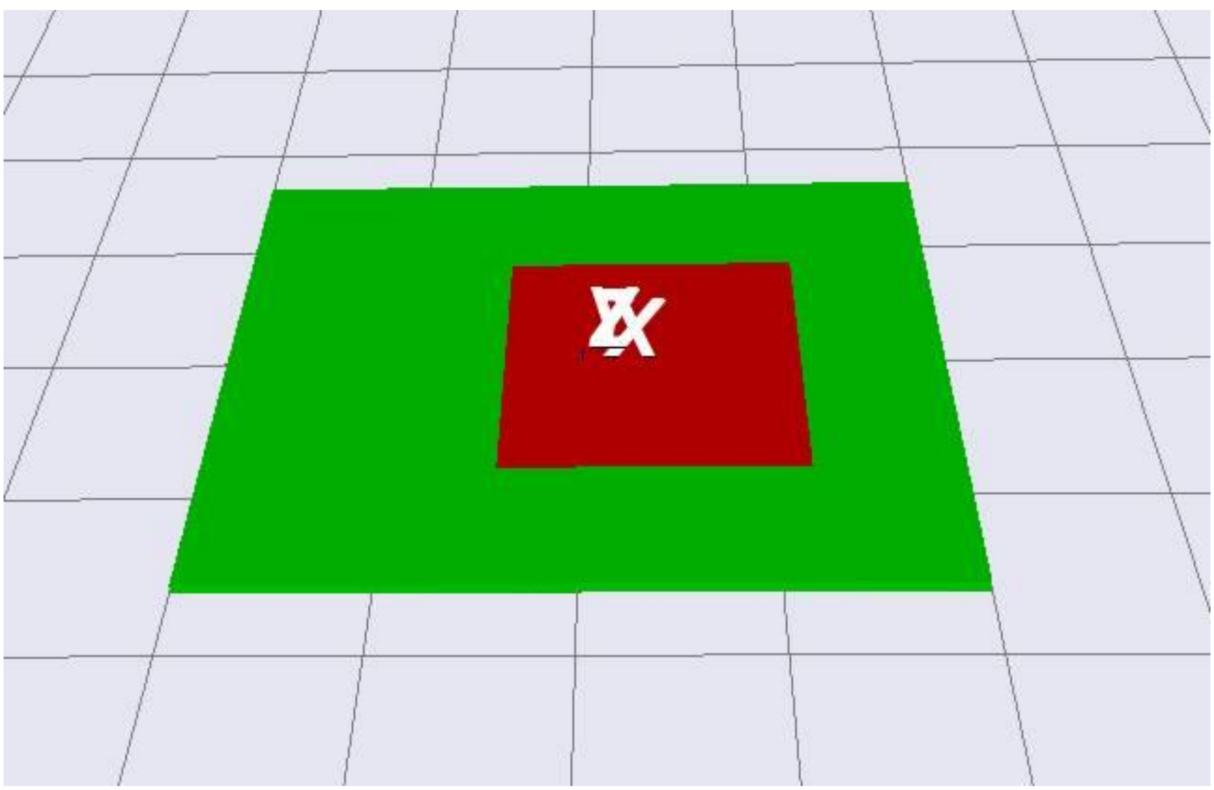


Model the Patch antenna

The next step is to model the patch antenna on top of the substrate. Therefore, you should again do the same process. For the dimensions of patch over substrate, you should design the patch antenna by the given design parameters. The transversal coordinates can thus be described by X1 = -10, Y1 = -20, Z= 0.785 for the first corner and give the actual length as length X = 41.08, length Y = 41.08 as you did above. You should now assign a meaningful name to the brick by entering e.g. patch1 in the *Name* field.

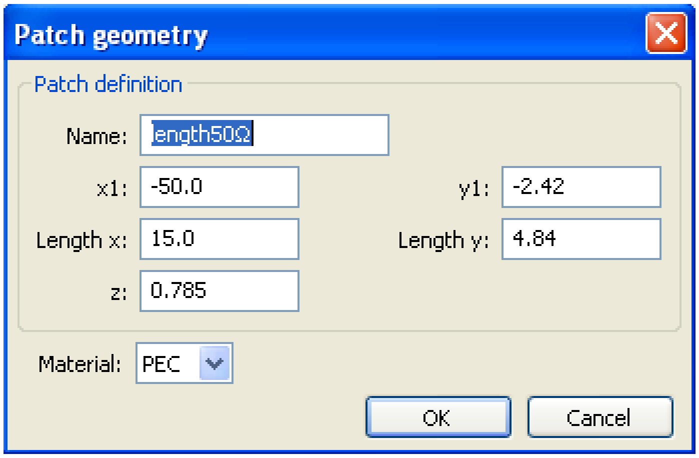


The *Material* setting of the brick must be changed to the desired patch material. Because no material has yet been defined for the patch antenna, you should select the PEC as the material for patch antenna from the material drop down list and in the brick creation dialog box you can also press the *OK* button to finally create the patch. Your screen should now look as follows

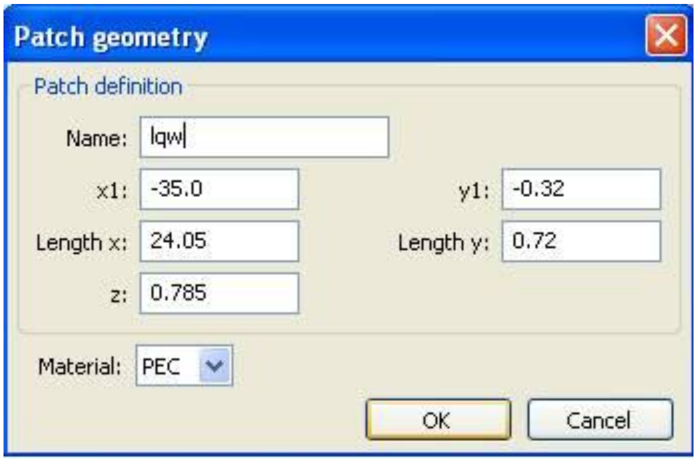


Model the feed lines

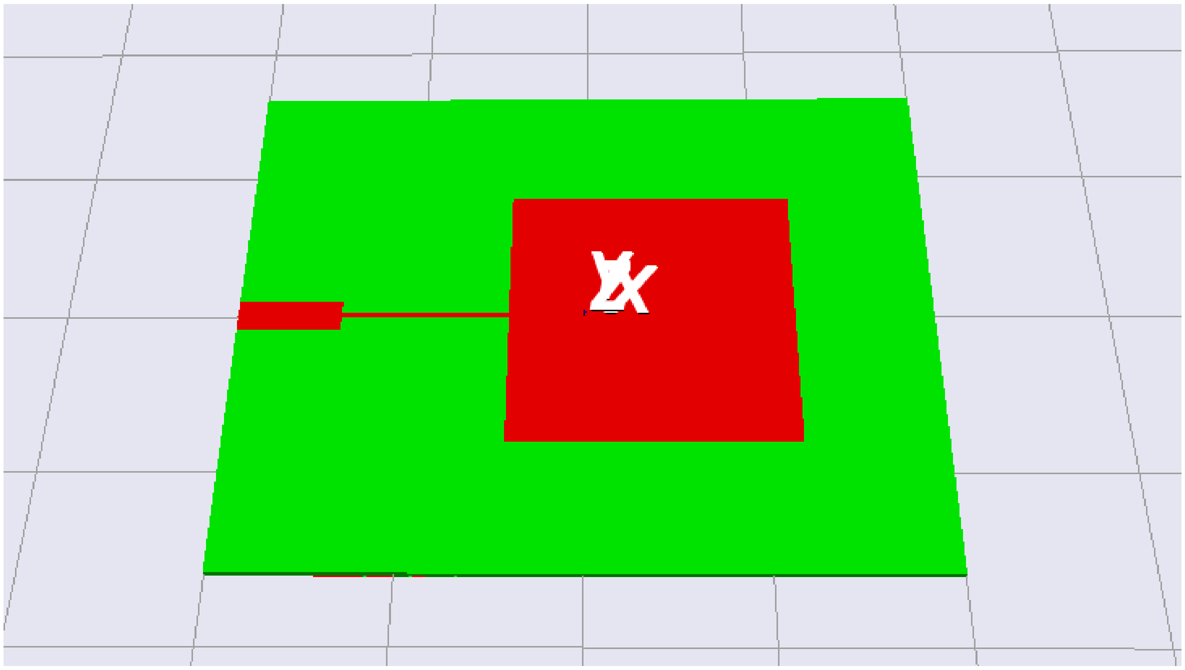
Next, the input impedance of the patch at the edge was determined by placing a length of 50 Ohm transmission line at the edge. By de-embedding the 50 Ohm transmission line, the edge input impedance was determined to be 343 Ohm. Therefore, a quarter wave length transformer was used to match 343 Ohm input impedance to a 50 Ohm system. Hence the dimensions of 50 Ohm transmission line is given in the picture below



And the dimensions of quarter wave length transformer is given in the picture below

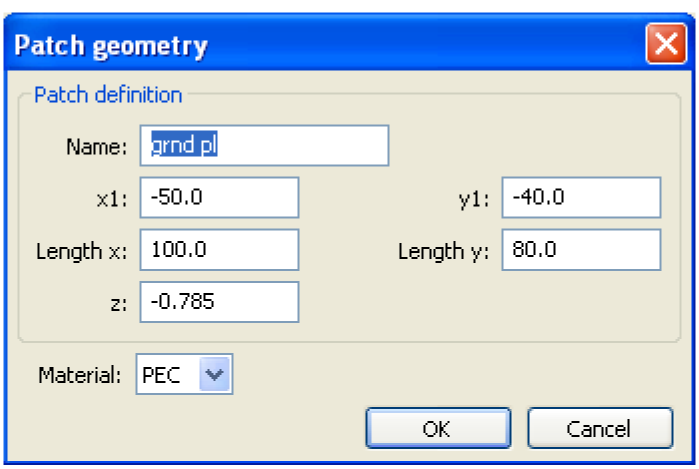


After defining the two feed line for the patch antenna the screen should look as follows

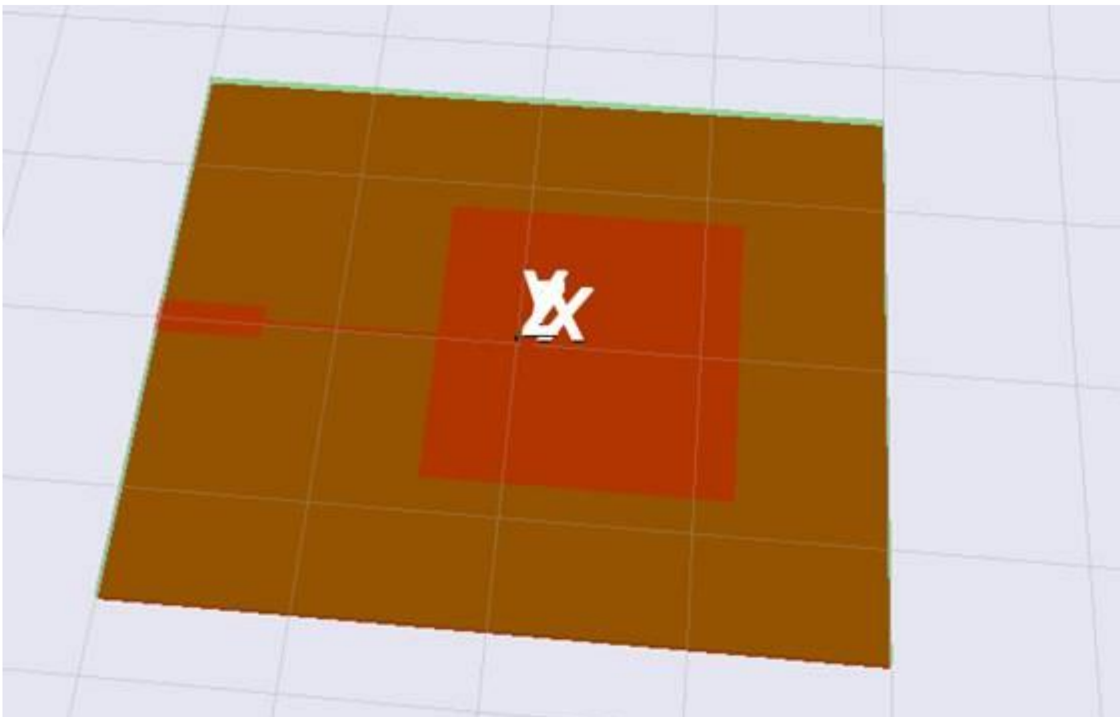


Model the metallic ground plane

The next step is to model the ground plane below substrate. Therefore, you should again do the same process. For the dimensions of ground plane below substrate, you should design the ground plane brick. The transversal coordinates can thus be described by X1 = -50, Y1 = -40, Z =- 0.785 for the first corner and give the actual length as length X = 100, length Y = 80, length as u did above. You should now assign a meaningful name to the brick by entering e.g. ground plane in the *Name* field

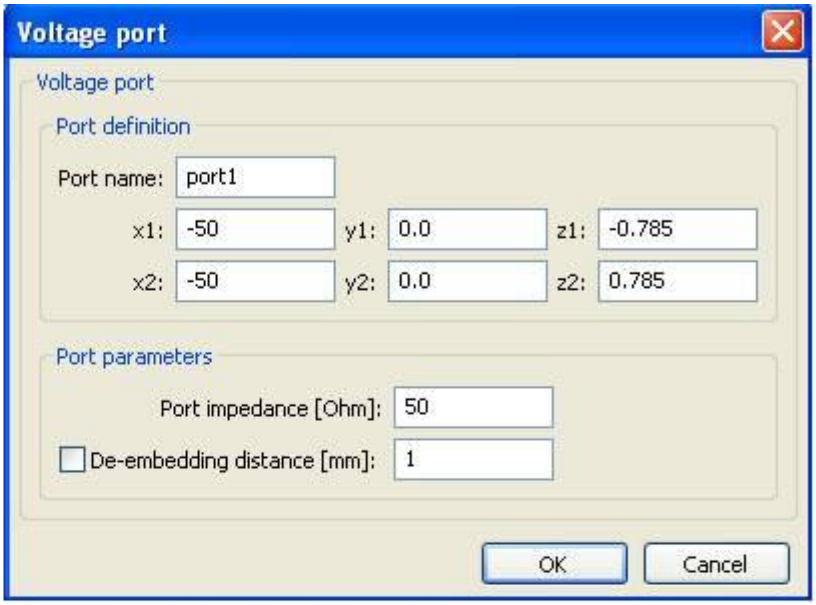


The *Material* setting of the brick must be changed to the desired ground plane. Because no material has yet been defined for the ground plane, you should select PEC as the material for ground plane from the material drop down list and in the brick creation dialog box press the *OK* button to finally create the ground plane. Your screen should now look as follows



Define Ports

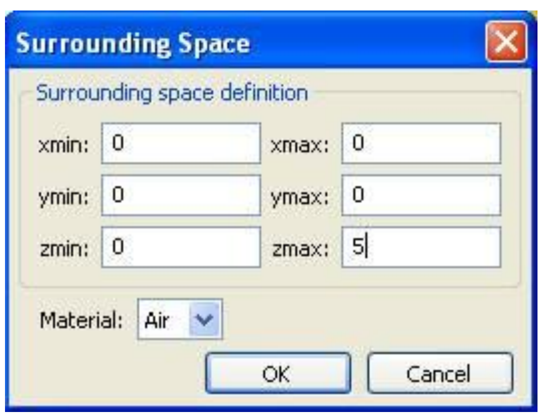
The next step is to add the ports to the patch antenna for which the S-parameters will later be calculated. Each port will simulate patch antenna structure that is connected to the structure at the ports plane. Plane wave ports are the most accurate way to calculate the S-parameters of patch antenna and should thus be used here. To define the port, go to excitation and select voltage port. A dialog box will open then in the dialog box give the port name as port1 and then define the coordinates as shown below and press ok to finalize



Note: patch antenna is a single port device.

Define Surrounding Space:

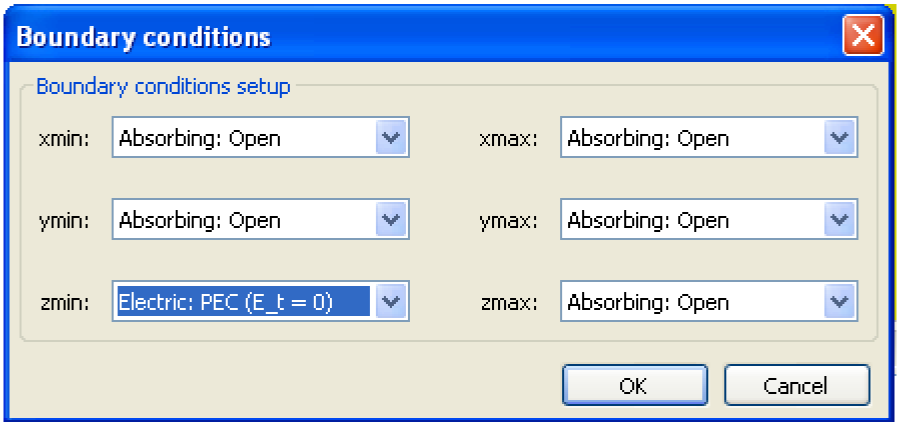
For defining the surrounding space go to simulation and click the surrounding space it will open a dialog box as shown in picture below



Give zmax as 5 and define air as the surrounding material from the material drop down list and press ok for finalizing the condition.

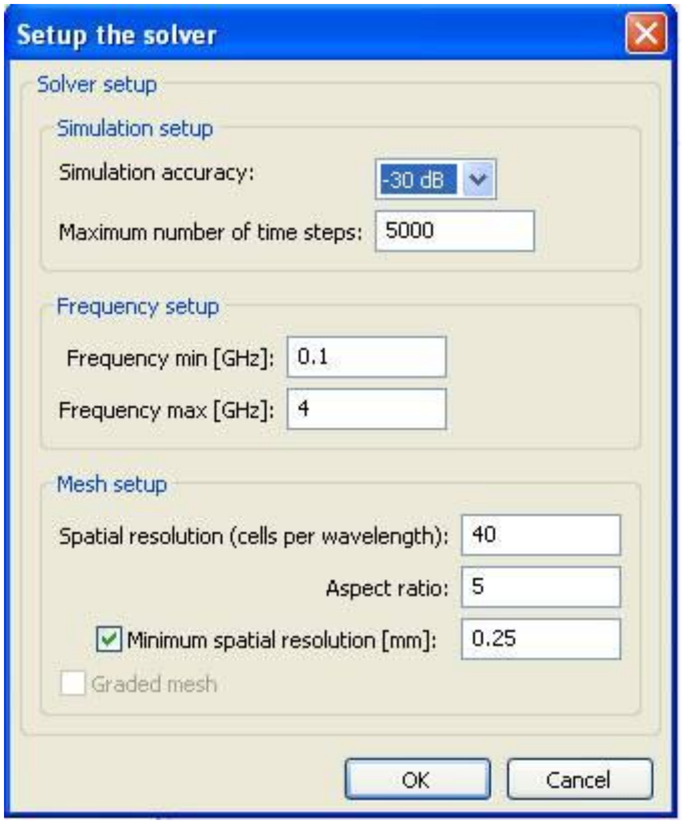
Define the Boundary Conditions

Go to simulation and double click on boundary condition then a boundary condition setup box will open give zmin as Electric: PEC (E_t = 0) and press ok.



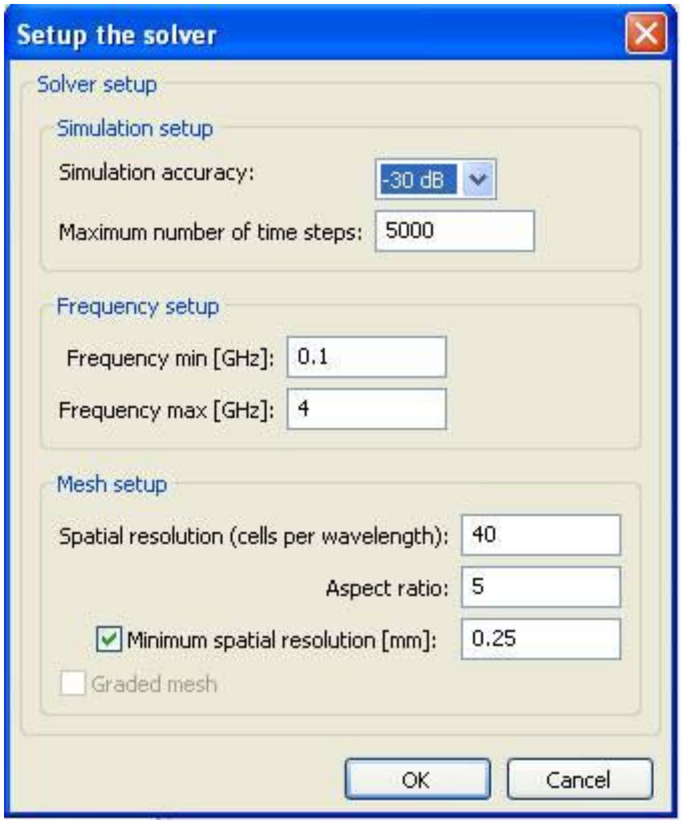
Setup the Solver

The next step is solver setting for this go to sovler and by pressing setup a dialog will open. In this box simulation accuracy should be -30dB. You can choose maximum number of the time steps between 500 and 5000. Choose 5000 steps. After that define the frequency range for the simulations you can set frequency min as 0.1 GHz and frequency max as 4 GHz hence your frequency range is from 0.1 GHz to 4 GHz. Now define Special resolution as 40, Aspect ratio as 5 and give minimum spatial resolution (mm) as 0.25. For finalizing the setup solver press ok.



Simulation

Finally to start the simulations go to solver and press *Simulation* button to start the calculation. A progress bar will appear in the status bar, displaying some information about the solver stages



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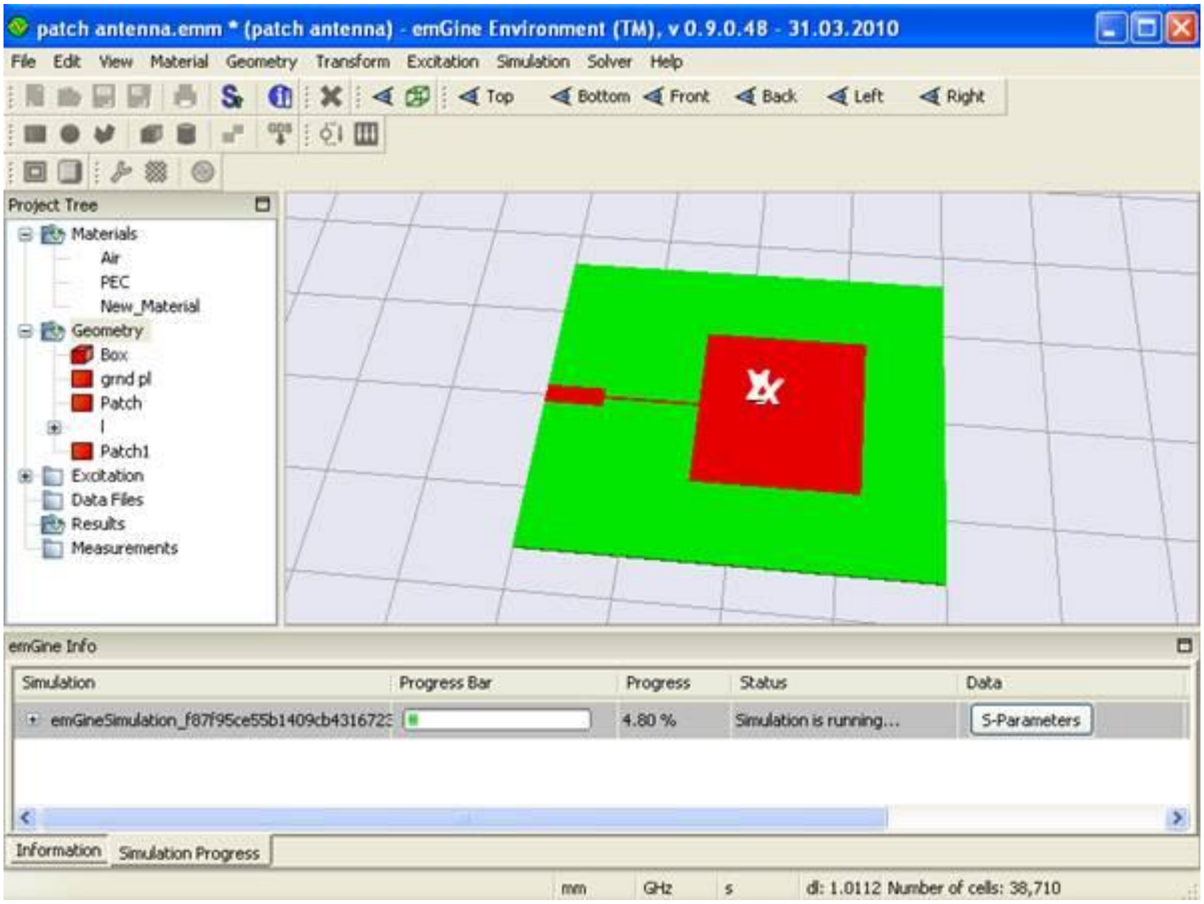


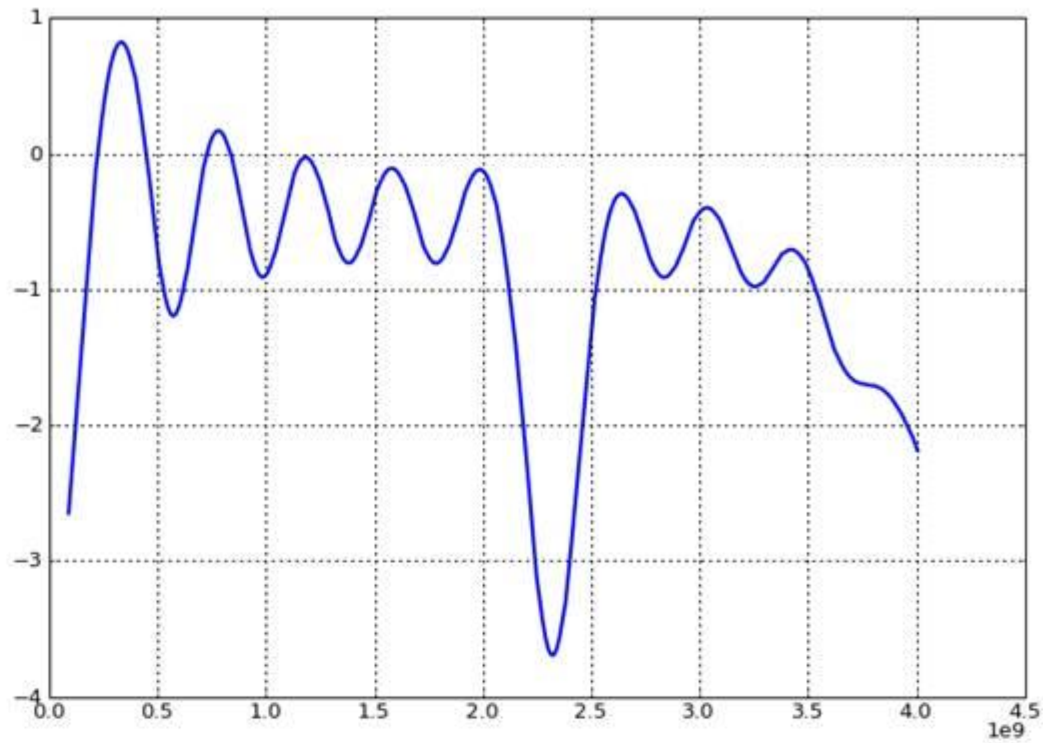
During the simulation, the Message Window will show some details about the performed simulation.

Congratulations, you have simulated the patch antenna! Let’s review the results.

Result:

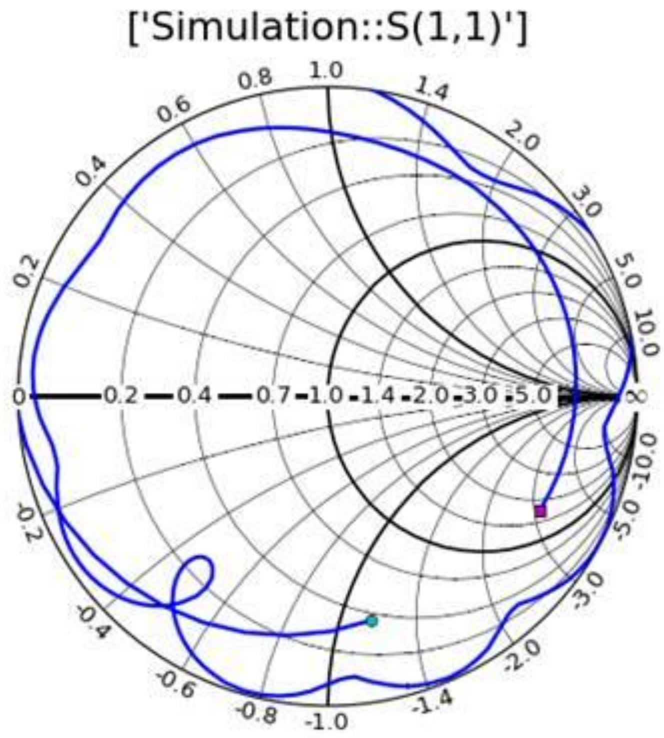
S-Parameters Results

The S-parameters magnitude in dB scale can be plotted by clicking on the *Results: dB* folder



Smith Chart:

The smith chart can also be seen from Smith chart folder.



Precautions:

- Follow instructions carefully.
- EMgine software should be properly installed.