**DAYALBAGH EDUCATIONAL INSTITUTE,
DAYALBAGH, AGRA**

Manual

Experiment 9

Hairpin Filter

Experiment 9

Objective:

To design the Hairpin Filter at 1.5 GHz

1. Calculate the design parameters of Hairpin Filter

To simulate the Hairpin Filter

1. Specify the filter 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:

Filters

Microwave filters represent a class of electronic filter, designed to operate on signals in the megahertz to gigahertz frequency ranges. This frequency range is the range used by most broadcast radio, television, wireless communication, and thus most RF and microwave devices will include some kind of filtering on the signals transmitted or received. Such filters are commonly used as building blocks for duplexers and diplexers to combine or separate multiple frequency bands. Filters have one basic function: to pass a particular thing and reject everything else. Each filter provides a clean operation in some form; the idea behind RF and Microwave filters is to provide a clean signal from the system. By clean signal we mean the one and only desired signal or band of signal required for the system's proper operation. The filters reduce or eliminate spurious signal or harmonics.

Basics Types of filters:

Generally speaking, a filter is any passive or active network with a predetermined frequency response in terms of amplitude and phase. They can be classified, depending on their application. Generally four types of filters are used

- Low pass filter
- High pass filter
- Band pass filter
- Band stop filter

Low pass and high pass filters are characterized by their cutoff frequency F_c where the transfer gain usually drops to one half (3 *dB points)*. Conversely, band pass and band stop filters are defined by their center frequencyF_0 along with their 3dB bandwidth. It seems obvious that in a filter design it is not enough to define the cutoff frequencies or 3dB bandwidth. Most applications require a given attenuation at a given frequency- out of band – while maintaining the cutoff values and the 3dB bandwidth. This new requirement will condition the filter response and the number of sections, N.

In the figure 2 we have several low pass filters having the same cutoff frequency of 2.4 GHz with a different number of sections, N.

As we increase the number of section N, we have a stepper transition from the pass band to the stop band while maintaining the pass band characteristic and cut off frequency. If our specification at, for example, 2.56 GHz is that the attenuation should be better than 40 dB, it is necessary to use an order N > 4.

Apart from the order of a filter, we have another important characteristic, that is the filter response, and the choice depends on the application. The most important are:

- Butterworth: maximally flat in amplitude;
- Chebyshev: amplitude pass band equi-ripple;
- Bessel: maximally flat in phase;
- Elliptic: amplitude pass band and stop band equi-ripple.

The choice of one of the above characteristic depends mainly on the system application where the filter should be used as well as the type of signal that is passing through the filter:

- Pure sinusoidal;
- Square (train of pulse);
- AM or FM modulation;
- More complex modulation;

In figure 3 we have three different band pass $N = 3$ filters at the same center frequencyF_0 = 900 MHz and with the same 3dB bandwidth BW = 60 MHz.

The elliptic response exhibits a more abrupt transmission but the stopband has a residual ripple. The Bessel response has a very poor amplitude response but it has an excellent phase behavior. Finally, Butterworth and Chebishev can be consider as a compromise between the other two. In the pass band Chebishev and Elliptic filters have an equi-ripple response while Bessel and Butterworth filters have a flat behavior.

Hairpin Filter

Figure 1.Strip line hairpin filter

Hairpin-line bandpass filters are compact structures. They may conceptually be obtained by folding the resonators of parallel-coupled, half-wavelength resonator filters, into a "U" shape. This type of "U" shape resonator is the so-called hairpin resonator. However, to fold the resonators, it is necessary to take into account the reduction of the coupled-line lengths, which reduces the coupling between resonators. Also, if the two arms of each hairpin resonator are closely spaced, they function as a pair of coupled line themselves, which can have an effect on the coupling as well. To design this type of filter more accurately, a design approach employing full-wave EM simulation will be used.

For this experiment, a microstrip hairpin bandpass filter is designed to have a fractional bandwidth of 20% or $FBW = 0.2$ at a midband frequency $f_0 = 2$ GHz. A five-pole ($n = 5$) Chebyshev lowpass prototype with a passband ripple of 0.1 dB is chosen. The lowpass prototype parameters, given for a normalized lowpass cutoff frequency $\Omega c = 1$, are $g0 = g6 = 1.0$, $g1 = g5 = 1.1468$, $g2 = g4 = 1.3712$, and $g3 = 1.9750$. For designing the hairpin filter firstly calculate all the parameters of microstrip line at 2 GHz frequency having dielectric constant 6.15 and substrate thickness is 1.27 mm.The design equations for this type of filter are given by

$$\frac{J_{01}}{Y_0} = \sqrt{\frac{\pi}{2}\frac{FBW}{g_o g_1}}$$

$$\frac{J_{j,j+1}}{Y_0} = \frac{\pi FBW}{2}\frac{1}{\sqrt{g_j g_{j+1}}} \qquad j = 1 \text{ to } n-1$$

$$\frac{J_{n,n+1}}{Y_0} = \sqrt{\frac{\pi FBW}{2 g_n g_{n+1}}}$$

where go, $g1 \ldots gn$ are the element of a Chebyshev prototype with a normalized cutoff $\Omega c = 1$, and FBW is the fractional bandwidth of bandpass filter. $Jj,j+1$ are the characteristic admittances of J-inverters and Y_0 is the characteristic admittance of the terminating lines. To realize the J-

inverters obtained above, the even- and odd-mode characteristic impedances of the coupled microstrip line resonators are determined by

$$(Z_{0e})_{j,j+1} = \frac{1}{Y_0}\left[1 + \frac{J_{j,j+1}}{Y_0} + \left(\frac{J_{j,j+1}}{Y_0}\right)^2\right] \qquad j = 0 \text{ to } n$$

$$(Z_{0o})_{j,j+1} = \frac{1}{Y_0}\left[1 - \frac{J_{j,j+1}}{Y_0} + \left(\frac{J_{j,j+1}}{Y_0}\right)^2\right] \qquad j = 0 \text{ to } n$$

where the even- and odd mode impedances are calculated for $Y_0 = 1/Z_0$ and $Z_0 = 50$ ohms. The next step of the filter design is to find the dimensions of coupled microstrip lines that exhibit the desired even- and odd-mode impedances. Using the design equations for coupled microstrip lines given in Experiment 1 and 2, the width and spacing for each pair of quarter-wavelength coupled sections are found, The actual lengths of each coupled line section are then determined by

$$l_j = \frac{\lambda_0}{4(\sqrt{(\varepsilon_{re})_j \times (\varepsilon_{ro})_j})^{1/2}} - \Delta l_j$$

Where Δlj is the equivalent length of microstrip open end which is given by

$$\Delta l = \frac{c Z_c C_p}{\sqrt{\varepsilon_{re}}}$$

Where Cp denotes the parallel plate capacitance between the strip and the ground plane, and hence is simply given by

$$C_p = \varepsilon_o \varepsilon_r W/h$$

Having obtained the lowpass parameters, the bandpass design parameters can be calculated by

$$Q_{e1} = \frac{g_0 g_1}{FBW}, \qquad Q_{en} = \frac{g_n g_{n+1}}{FBW}$$

$$M_{i,i+1} = \frac{FBW}{\sqrt{g_i g_{i+1}}} \qquad \text{for } i = 1 \text{ to } n-1$$

where $Qe1$ and Qen are the external quality factors of the resonators at the input and output, and $Mi,i+1$ are the coupling coefficients between the adjacent resonators. For this experiment, we have calculated

$$Qe1 = Qe5 = 5.734$$

$$M1,2 = M4,5 = 0.160$$

$$M2,3 = M3,4 = 0.122$$

We use a commercial substrate (RT/D 6006) with a relative dielectric constant of 6.15 and a thickness of 1.27 mm for microstrip realization. Using a parameter-extraction technique, we then carry out full-wave EM simulations to extract the external Q and coupling coefficient M against the physical dimensions. Two design curves obtained in this way are plotted in Figure 2.It should be noted that the hairpin resonators used to have a line width of 1 mm and a separation of 2 mm between the two arms, as indicated by a small drawing inserted in Figure 2(*a*). Another dimension of the resonator as indicated by L is about $\lambda g_0/4$ long with λg_0 the guided wavelength at the midband frequency, and in this case, L = 20.4 mm. The filter is designed to have tapped line input and output. The tapped line is chosen to have characteristic impedance that matches to a terminating impedance Z_0 = 50 ohms. Hence, the tapped line is 1.85 mm wide on the substrate. Also in Figure 2(*a*), the tapping location is denoted by t, and the design curve gives the value of external quality factor, Qe, as a function of t. In Figure 2(*b*), the value of coupling coefficient M is given against the coupling spacing (denoted by s) between two adjacent hairpin resonators with the opposite orientations as shown. The required external Q and coupling coefficients can be read off the two design curves below, and the filter designed. The layout of the final filter design with all the determined dimensions is illustrated in Figure 3(*a*). The filter is quite compact, with a substrate size of 31.2 mm by 30 mm. The input and output resonators are slightly shortened to compensate for the effect of the tapping line and the adjacent coupled resonator. The EM simulated performance of the filter is shown in Figure 3(*b*). An experimental hairpin filter of this type with a design equation is proposed for estimating the tapping point t as

$$t = \frac{2L}{\pi}\sin^{-1}\left(\sqrt{\frac{\pi}{2}\frac{Z_0/Z_r}{Q_e}}\right)$$

in which *Zr* is the characteristic impedance of the hairpin line, Z_0 is the terminating impedance, and *L* is about λ*g*0/4 long, as mentioned above. And the coupling spacing (denoted by *s*) between two adjacent hairpin resonators

$$S_1 = 1 - \frac{2}{q_{e1}}[Z]_{11}^{-1}$$

$$S_2 = 2\frac{1}{\sqrt{q_{e1}q_{en}}}[Z]_{n1}^{-1}$$

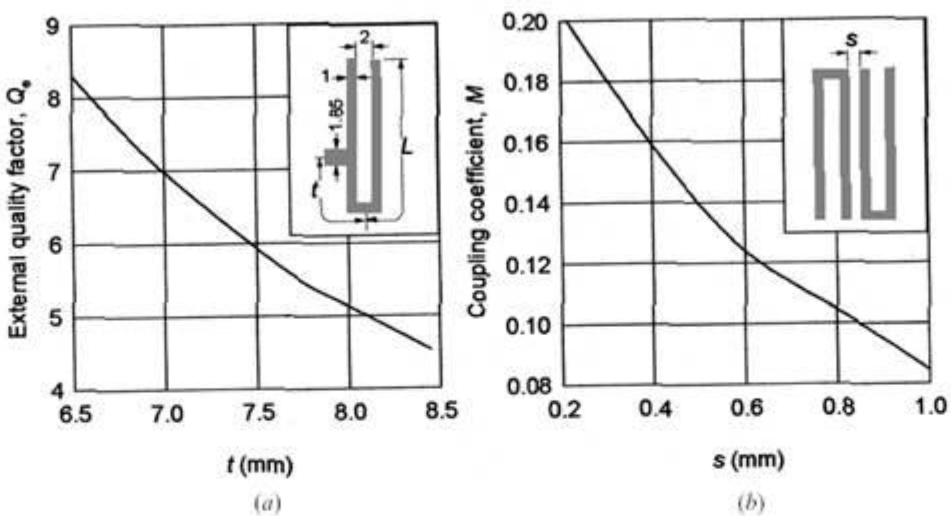
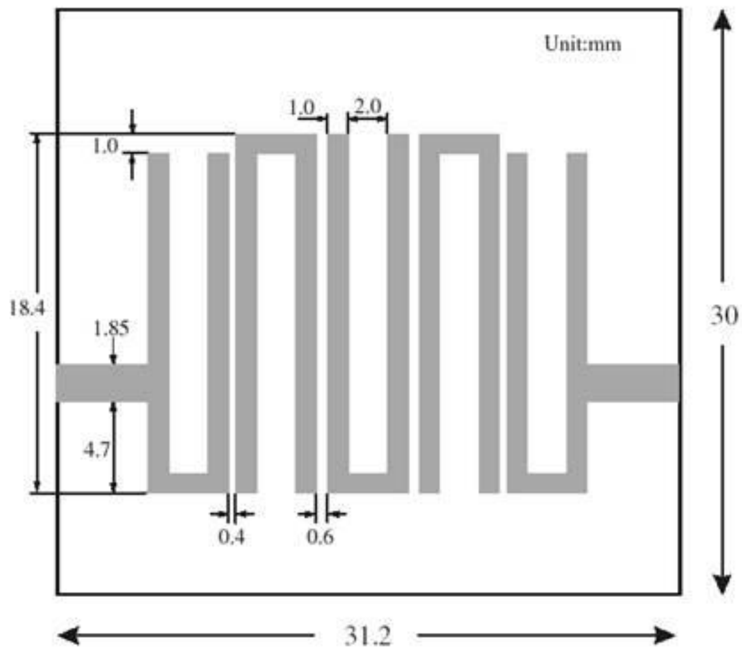
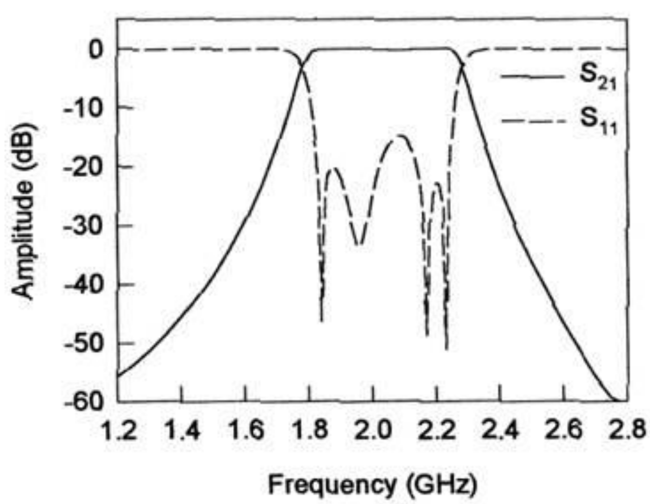


FIGURE 2 Design curves obtained by full-wave EM simulations for design of a hairpin-line microstrip bandpass filter. (*a*) External quality factor. (*b*) Coupling coefficient.

This design equation ignores the effect of discontinuity at the tapped point as well as the effect of coupling between the two folded arms. Nevertheless, it gives a good estimation. For instance, in the filter design example above, the hairpin line is 1.0 mm wide, which results in Zr = 68.3 ohm on the substrate used. Recall that L = 20.4 mm, $Z0$ = 50 ohm, and the required Qe = 5.734. Substituting them into equation for calculating t which will give t = 6.03 mm, which is close to the t of 7.625 mm found from the EM simulation above.



(a)



(b)

Fig. 3 (a) The layout of the final filter design with all the determined dimensions (b) The EM simulated performance of the filter

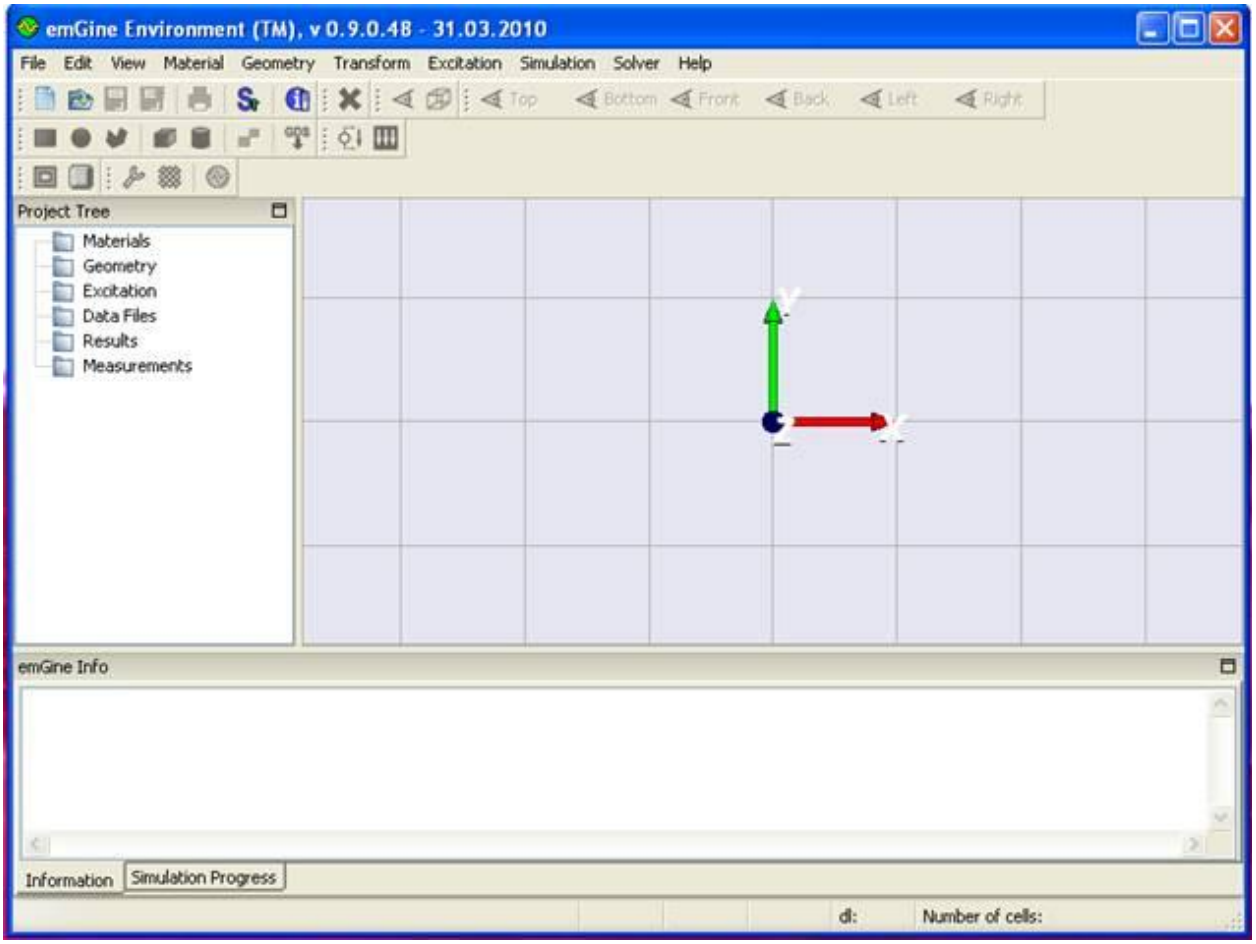
Simulation Procedure:

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 Hairpin Filter. The following explanations on how to model and analyze this device can be applied to other planar devices, as well.

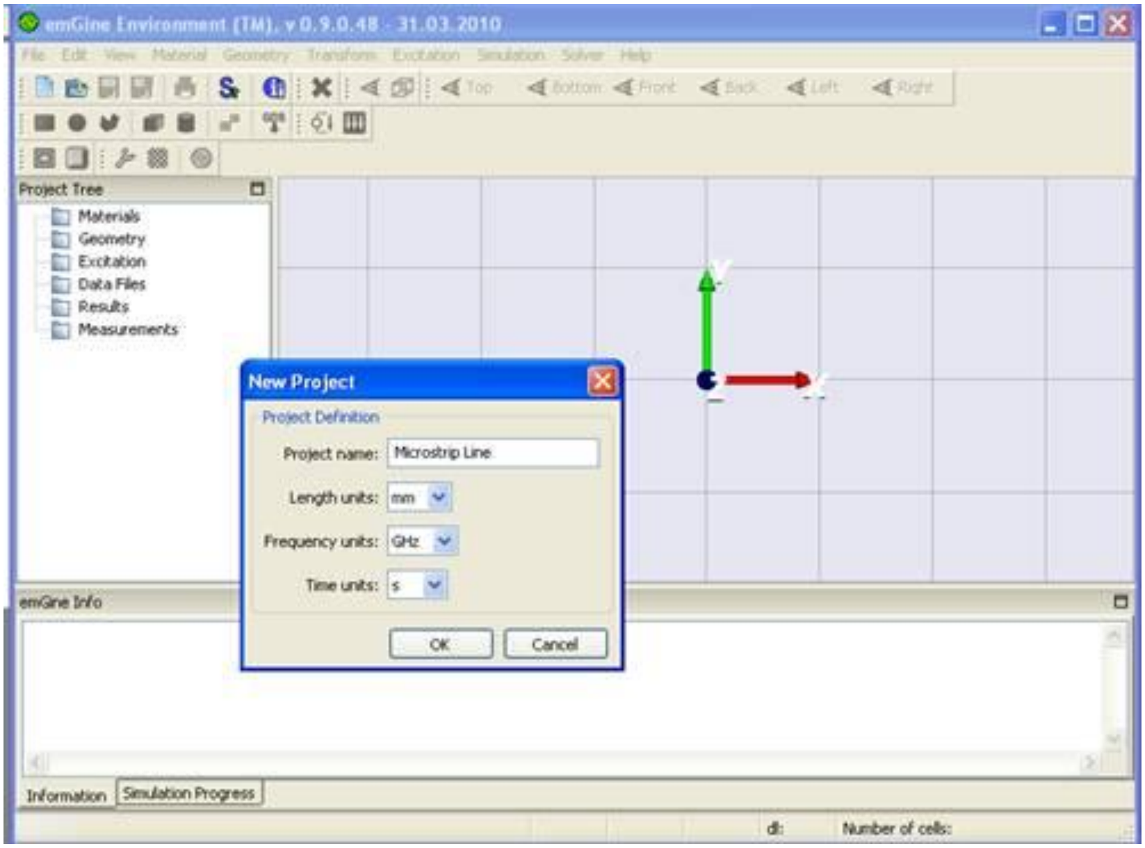
Geometric Construction Steps

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

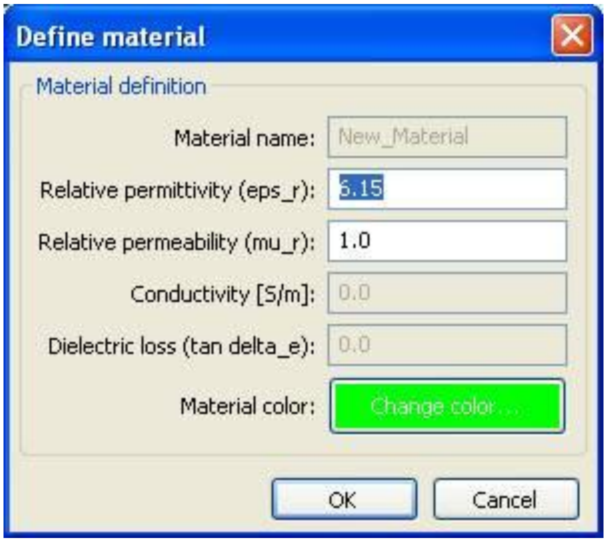
Once you have started emGin, go to file and click on new project a dialog box will open to give the appropriate name for the new project. You should set the units in mm, GHz and s and press ok.



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

Set the Working Planes Properties

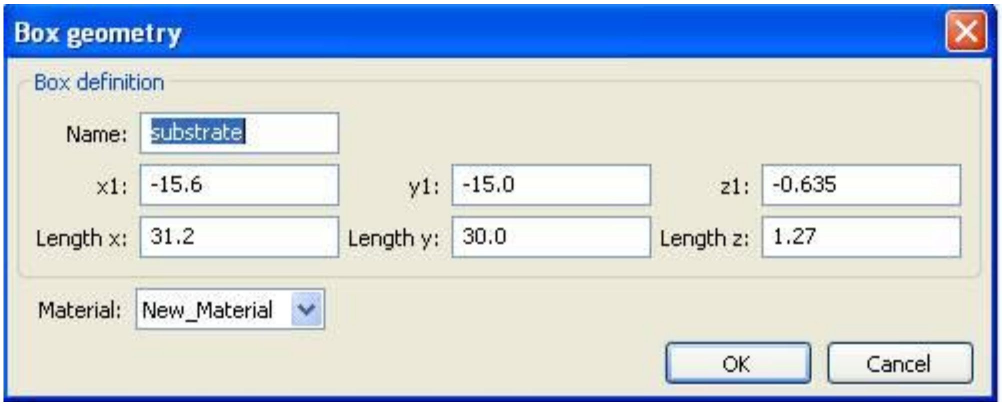
The next step is usually to set the material properties. In this dialog box you should define a new *Material name* (e.g. New_Mtarial). Afterwards, specify the material properties in the *Epsilon* and *Mue* fields. Here, you only need to change the dielectric constant *Epsilon* to 6.15. Finally, choose 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

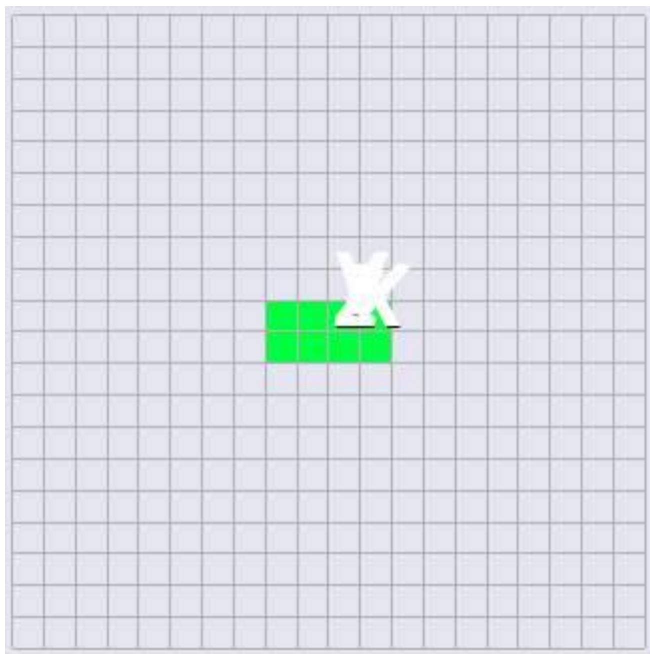
The first construction step for modeling a planar structure is usually to define the substrate layer. This can be easily achieved by creating a brick made of the substrates material. Please activate the brick creation mode (*Geometry - Box*).

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:



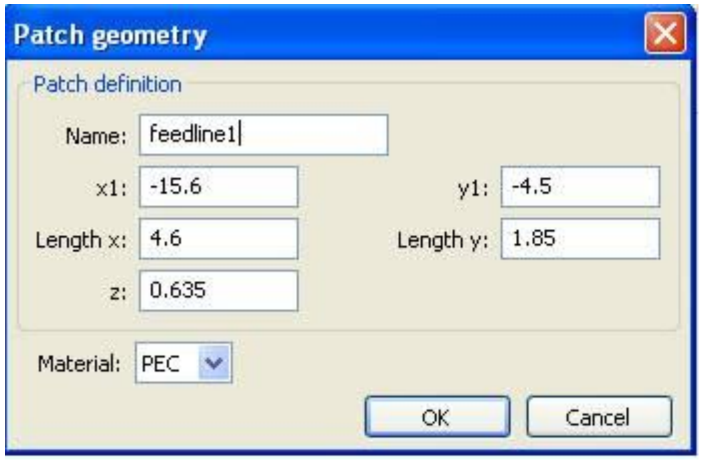
In this example, you should enter a substrate block. The transversal coordinates can thus be described by X 1= -15.6, Y1 = -15, Z1 = -0.635 for the first corner and give the calculated length X = 31.2, Y = 30, Z = 1.27 for creating the brick, assuming that the brick is modeled symmetrically to the origin. 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

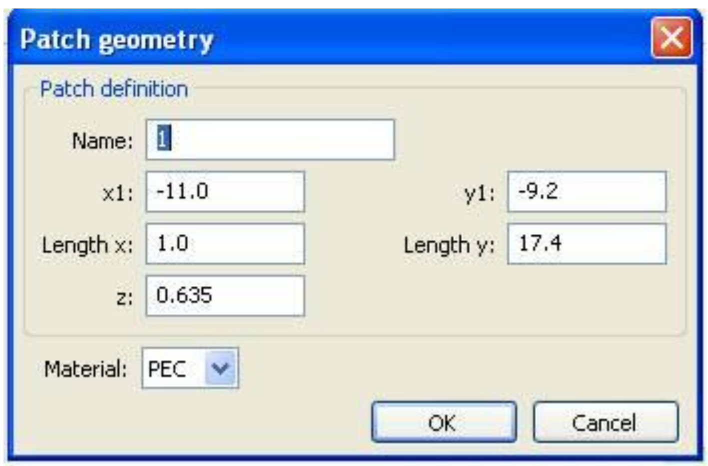


Model the Hairpin Filter

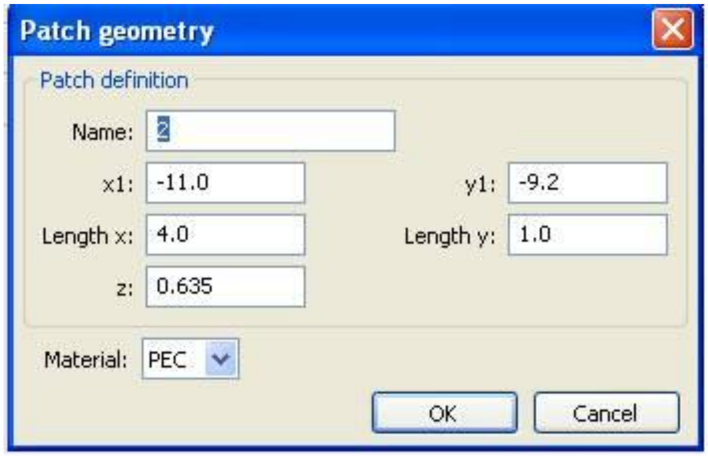
The next step is to model the Hairpin Filter on top of the substrate. The hairpin filter is made by adding many patches. Therefore the dimensions of patches are given in the screen shot below, and every time for creating the hairpin filter you should select the PEC as the material for Hairpin Filter from the material drop down list and in the patch creation dialog box you should press the *OK* button to finally create the patch.



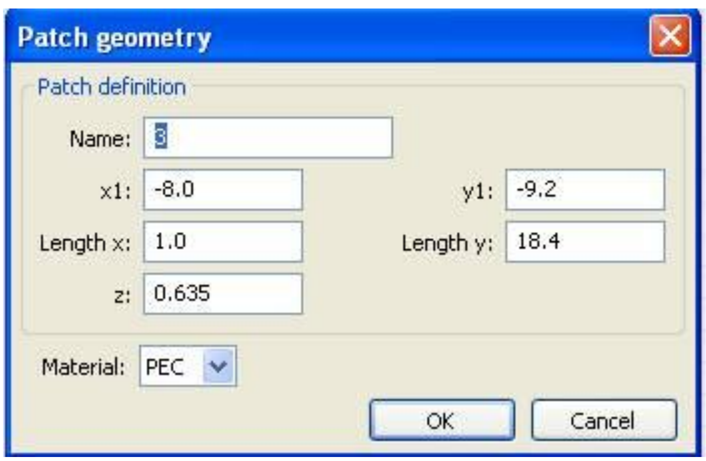
Create patch with the help of following screen shot



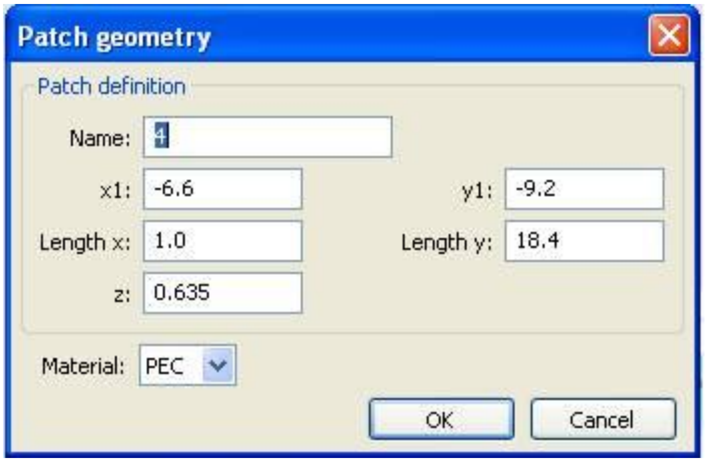
Again create the patch with the help of following screen shot



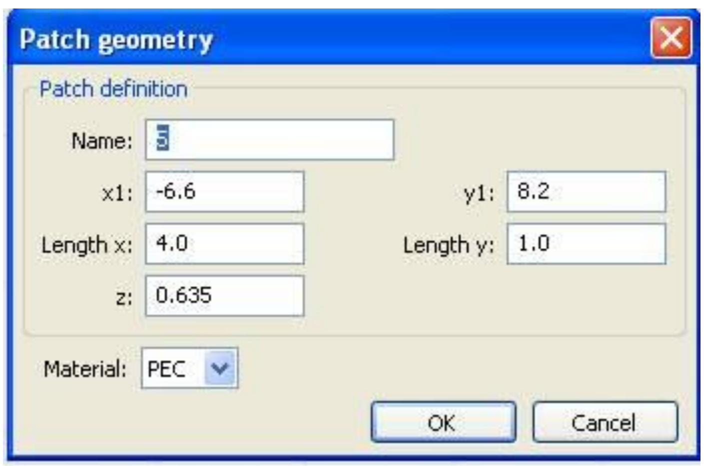
Now design a patch with the help of following screen shot



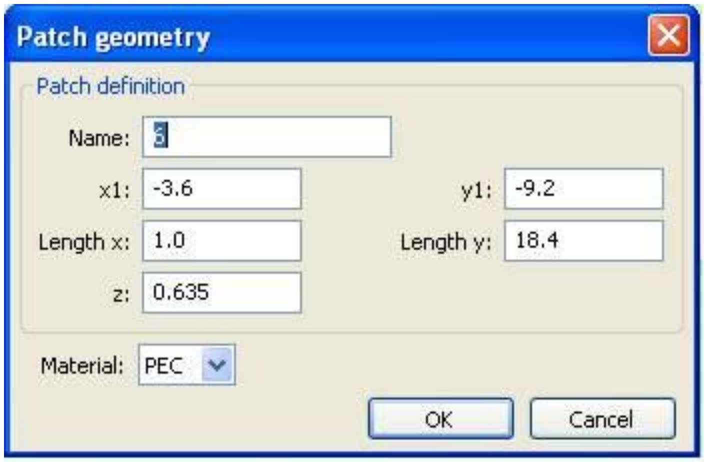
Again design a patch with the help of following screen shot



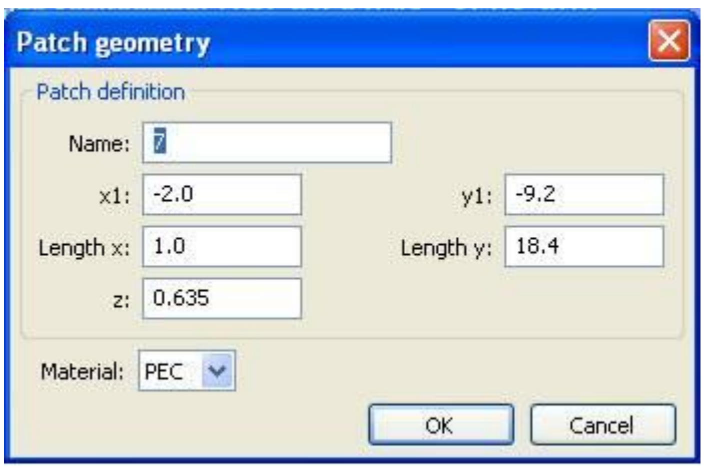
Again design the patch with the help of following screen shot



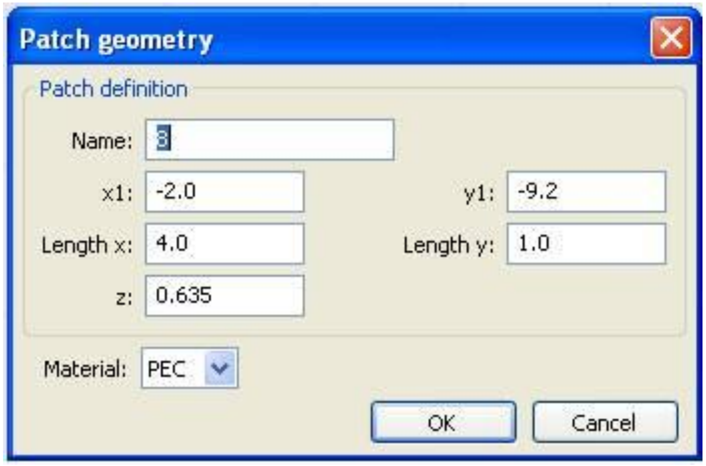
Again design the patch with the help of following screen shot



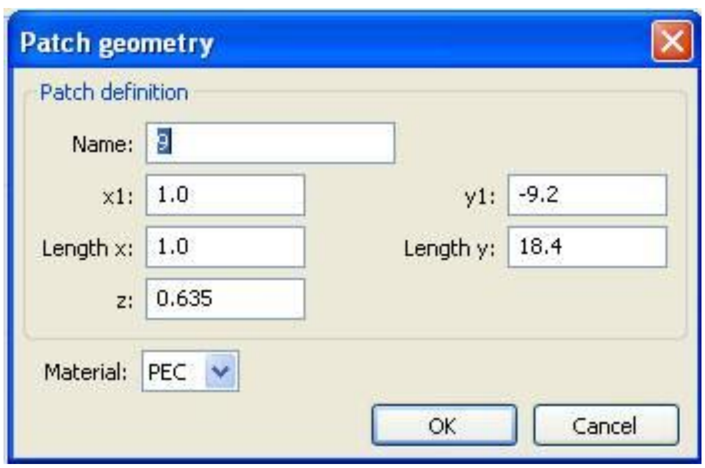
Again design the patch with the help of following screen shot



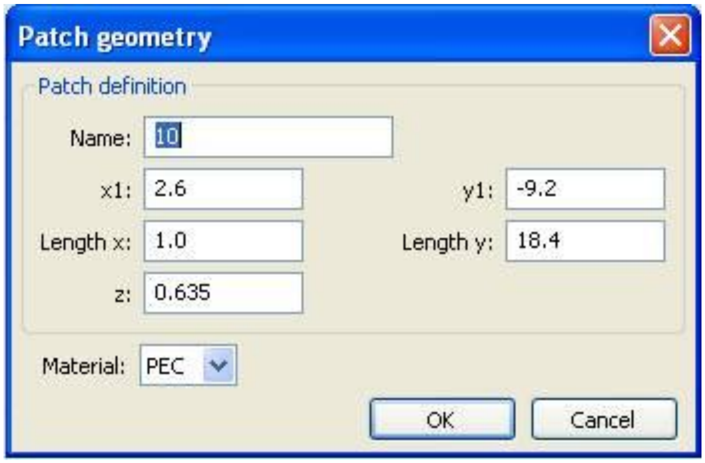
Again design the patch with the help of following screen shot



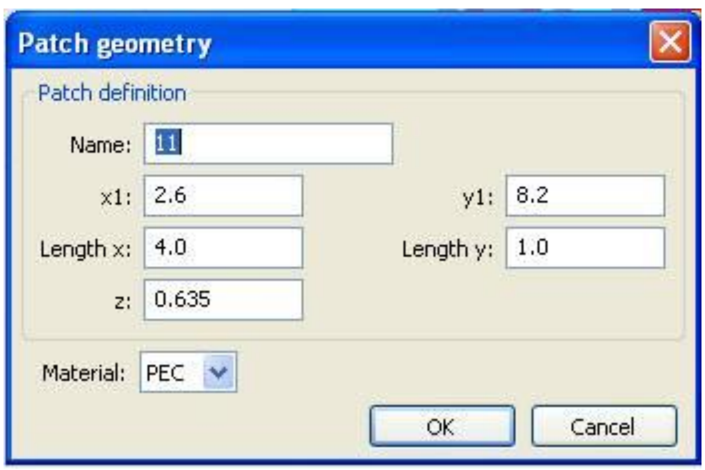
Again design the patch with the help of following screen shot



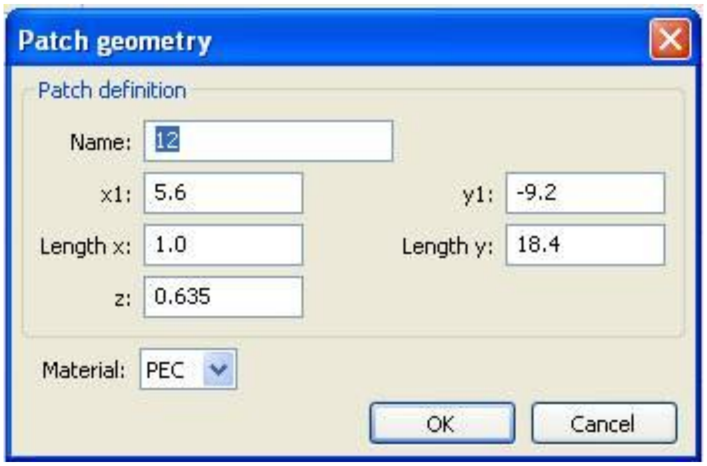
Again design the patch with the help of following screen shot



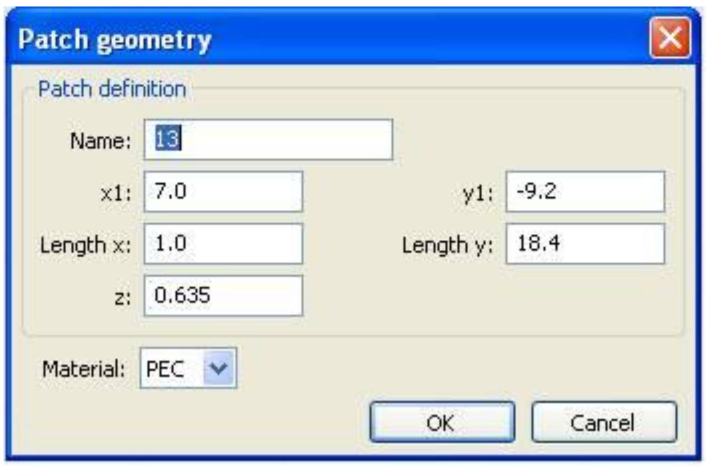
Again design the patch with the help of following screen shot



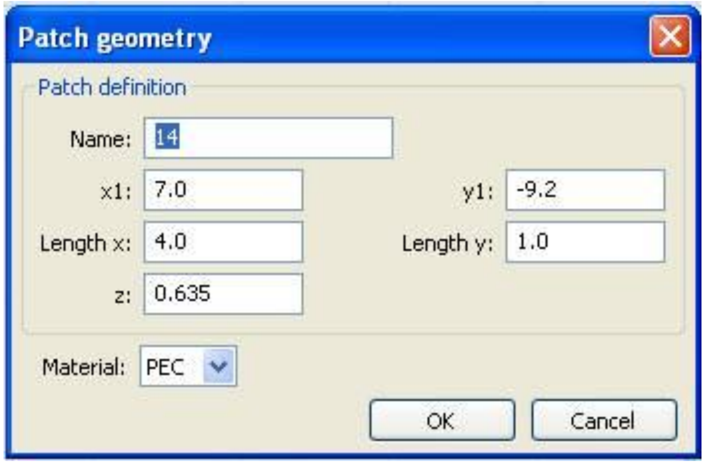
Again design the patch with the help of following screen shot



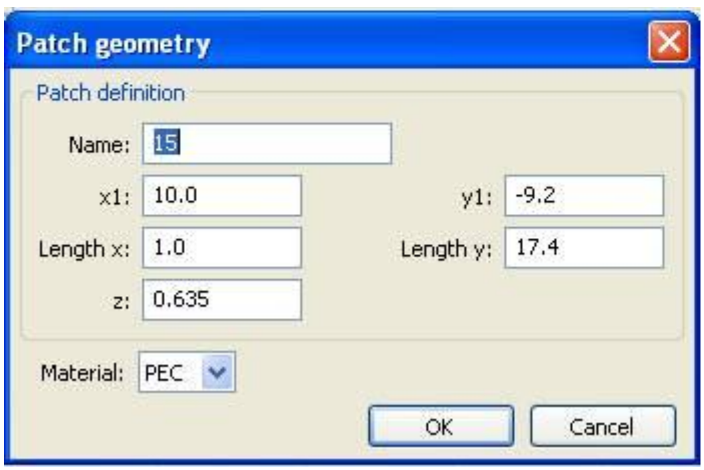
Again design the patch with the help of following screen shot



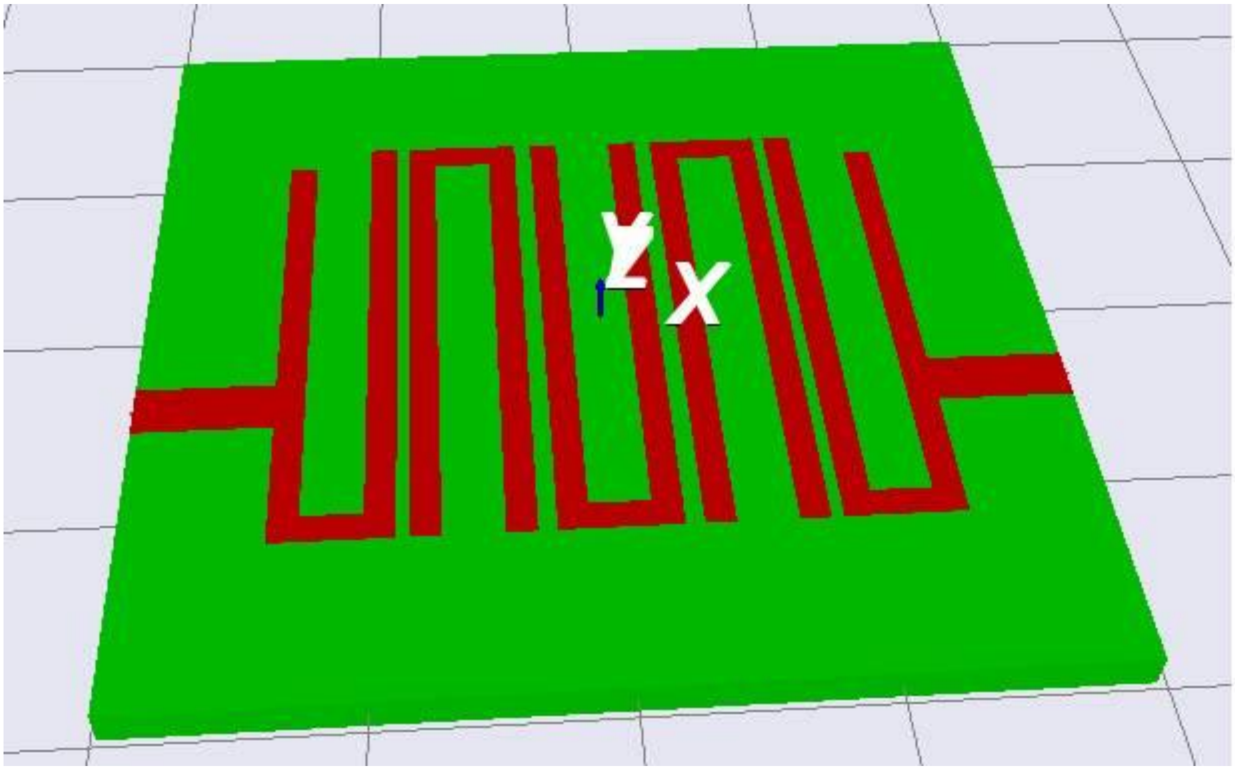
Now design the patch with the help of following screen shot



Now design the patch with the help of following screen shot

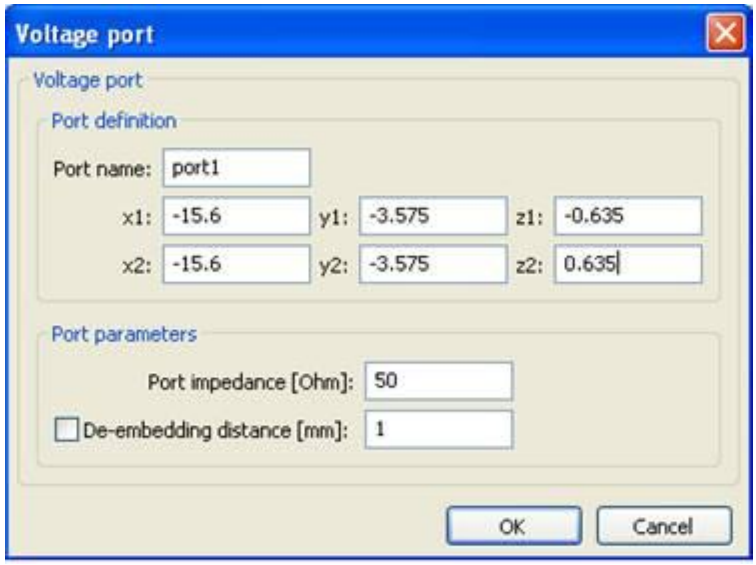


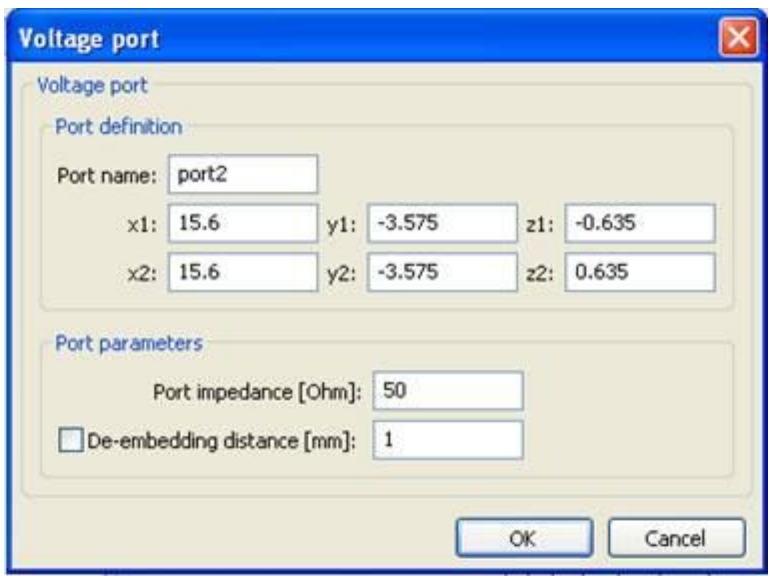
After designing all the components the screen should look like:



Define Ports

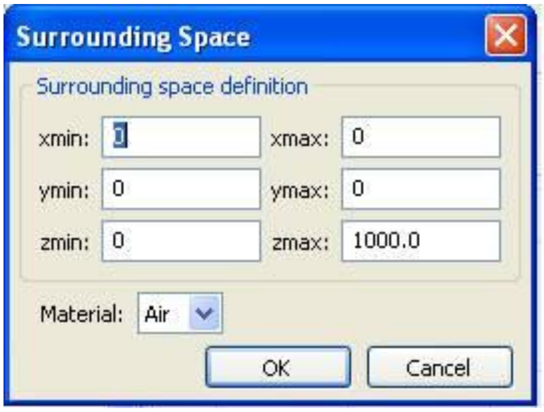
The next step is to add the ports to the Hairpin Filter for which the S-parameters will later be calculated. Each port will simulate Hairpin Filter structure that is connected to the structure at the ports plane. Plane wave ports are the most accurate way to calculate the S-parameters of Hairpin Filter 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.





Define Surrounding Space:

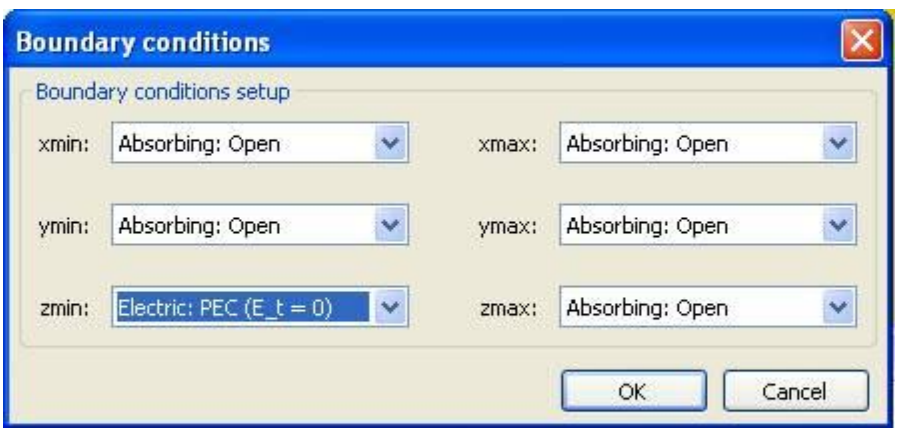
For defining the surrounding space go to simulation and click the surrounding space it will open a dialog box as shown in picture below



Give zmax as 1000 and define air as the surrounding material from the material drop down list and press ok for finalizing the condition.

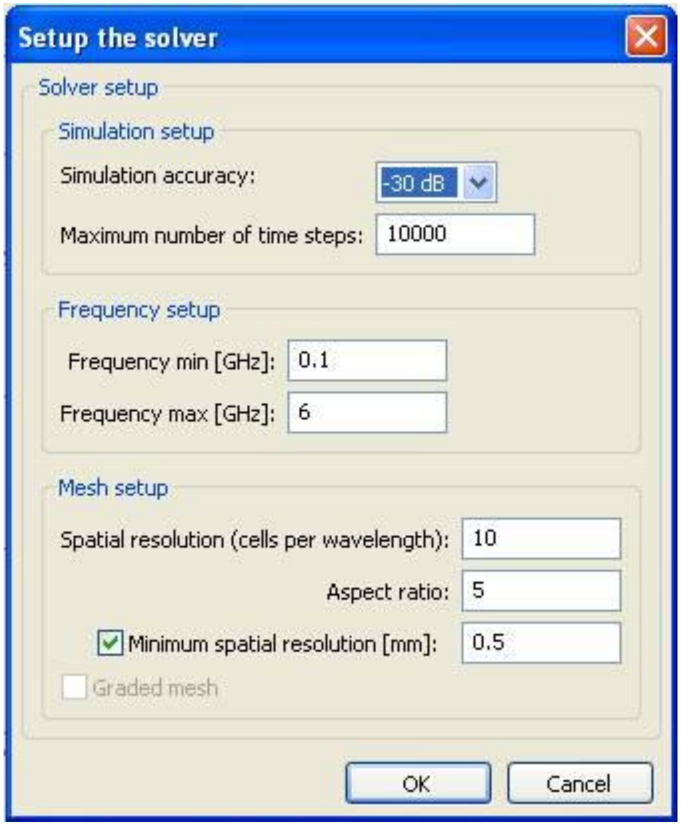
Define the Boundary Conditions

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.



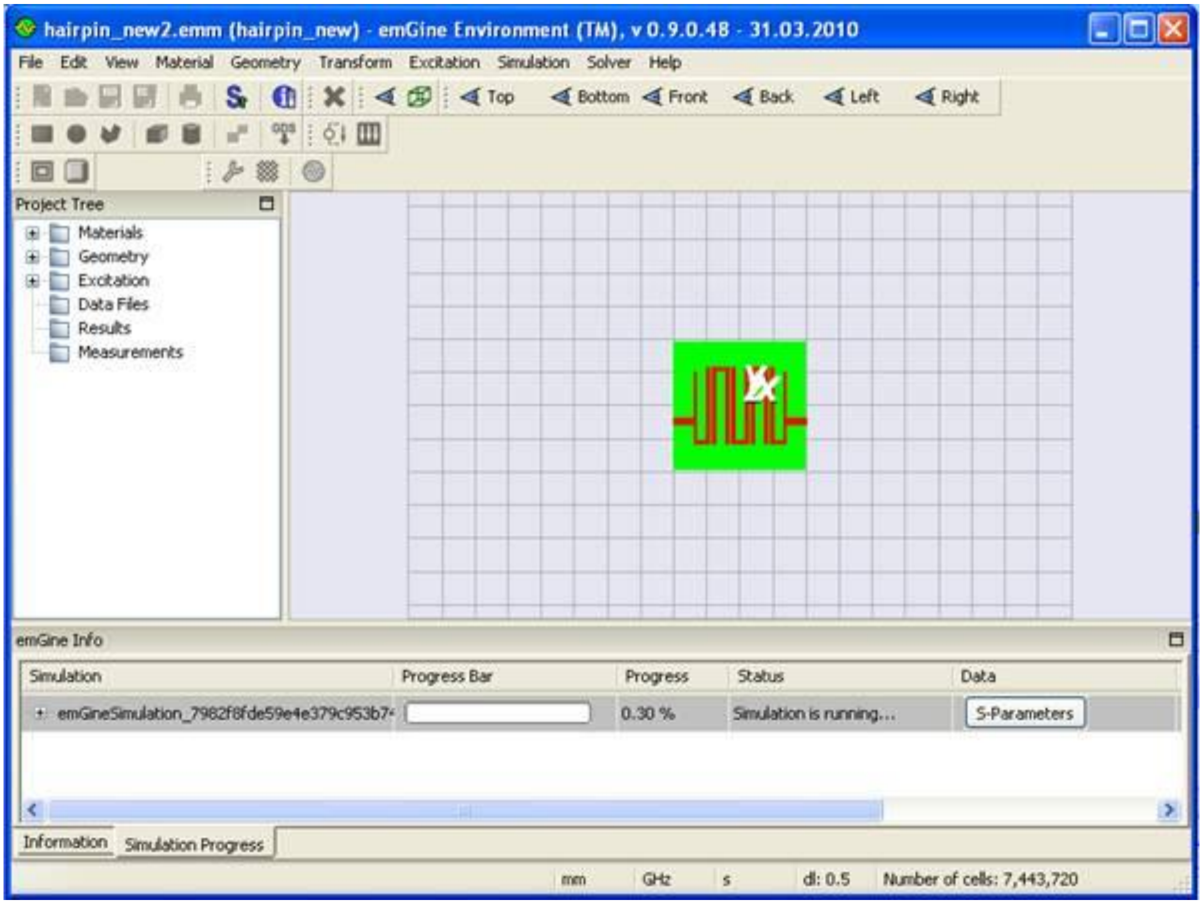
Setup the Solver

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 -50 dB. Choose 10000 steps. After that define the frequency range for the simulations you can set frequency min as 0.1 GHz and frequency max as 6 GHz hence your frequency range is from 0.1 GHz to 6 GHz. Now define Special resolution as 10, and give Aspect ratio as 5. 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.



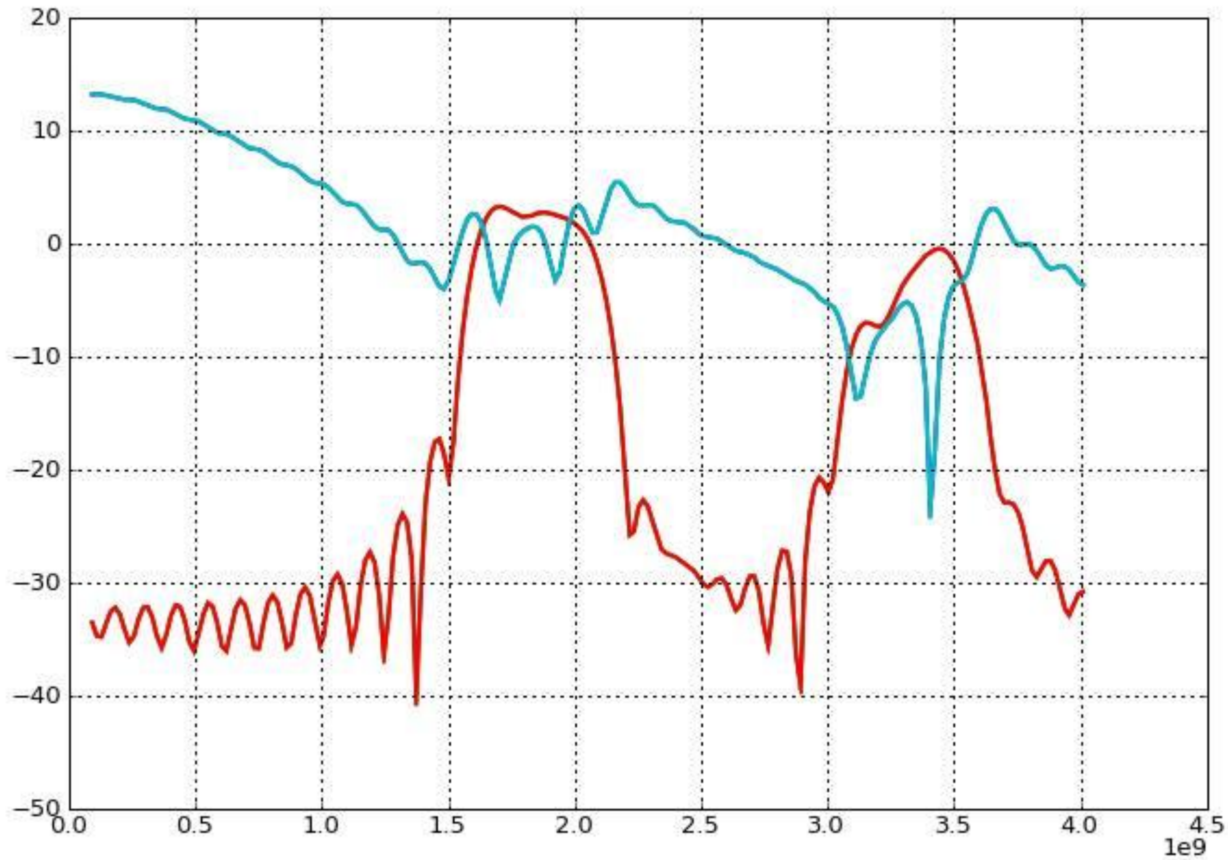
During the simulation, the Message Window will show some details about the performed simulation.

Congratulations, you have simulated the Hairpin Filter ! Lets review the results.

Result:

S-Parameters Results

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



Precautions:

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