DAYALBAGH EDUCATIONAL INSTITUTE, DAYALBAGH, AGRA

Manual

Experiment 4

Half Wavelength Capacitively Coupled Linear Resonator

Experiment 4

Objective

To design the Linear Resonator at 1.5 GHz

1. Calculate the length and width of Linear Resonator at 1.5 GHz

To simulate the Linear Resonator

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

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Requirement:

1. Computer facility
2. EMgine Simulation Software

Theory:

Microstrip Linear Resonators

Microstrip linear resonator is an open transmission line that supports a sanding wave at a frequency for which the length of the line is exactly a half wavelength. The transmission line may be through of resonant at a frequency, where the sending a wave pattern sets up a constant total energy and energy is oscillating between the electric and magnetic fields. Due to the open circuit ends, a considerable proportion of the field fringes exists beyond the physical ends of the line, and this effect is known as open-end effect. It is the best accounted for considering the electrical or effective length of the *leo* somewhat longer than the physical length *l*. As the resonators have the open ends on both the sides, an end correction factor *l* should be added two times of the physical length *l* to get the effective length l_e of the resonator.

$$l_e = l + 2\Delta l$$

$$= n\frac{\lambda_g}{2}$$

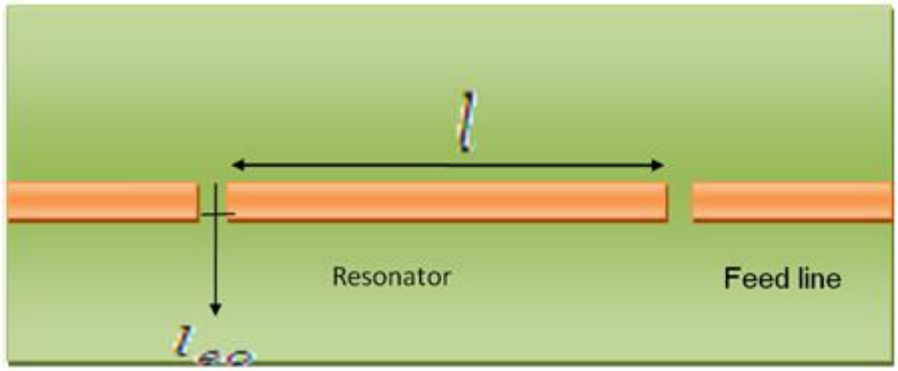


Figure 2.3linear resonator

Where l is physical length and l_{eo} is the additional length representing the open circuit the length of the fringing field can be calculated from

$$l_{eo} = 0.412d\left(\frac{\varepsilon_{eff}+0.3}{\varepsilon_{eff}-0.258}\right)\left(\frac{\frac{W}{d}+0.262}{\frac{W}{d}+0.813}\right)$$

Where W and d are the width of the line and height of the substrate respectively and guided wavelength is given by

$$\lambda_g = \left(\frac{\lambda_0}{\sqrt{\varepsilon_{eff}}}\right)$$

Where ε_{e} is the effective permittivity of substrate and λ_0 is the free space wavelength and *leo* is the length of capacitive coupling gap. To use the resonating structure for measurement, it has to be coupled to an external circuit. We have selected the capacitive coupling mechanism of the resonator to couple it to the external circuit. Two identical microstrip lines with symmetrical gaps at the two opposite sides of the resonators have been designed. Coupling gap, for the microstrip linear resonators, is constructed by a prime requirement that the degree of coupling be kept as low as possible , while still offering a tolerable signal to noise ratio for measurement. Even slight loading due to external circuit will affect the resonant frequency.

Formula Used:

To design the Half Wavelength Linear Resonator, we have to calculate the width and length of the linear resonator.

Procedure is given as following:

Width of microstrip line

To calculate the width of the linear resonator, we will use following formula.

(Note: calculations of width and guided wavelength of linear resonator is same as we did in microstrip line. The only difference is that we consider the length of the linear resonator as half of the guided wavelength. Width of the linear resonator is same as you have already calculated for microstrip line)

$$\frac{W}{d} = \begin{cases} \frac{8e^{A}}{e^{2A}-2} & for\ W/d < 2 \\ \frac{2}{\pi}\left[B-1-\ln(2B-1)+\frac{\epsilon_r-1}{2\epsilon_r}\left\{\ln(B-1)+0.39-\frac{0.61}{\epsilon_r}\right\}\right] & for\ \frac{W}{d} > 2 \end{cases}$$

Where w= width of linear resonator

ε_r = substrate permittivity

d= substrate thickness

and value of A and B is given by following equations

$$A = \frac{Z_0}{60}\sqrt{\frac{\epsilon_r+1}{2}} + \frac{\epsilon_r-1}{\epsilon_r+1}\left(0.23+\frac{0.11}{\epsilon_r}\right)$$

$$B = \frac{377\pi}{2Z_0\sqrt{\epsilon_r}}$$

Using given parameters, we can calculate the ratio W/*d*. Now value of d is given already. After substituting that value, we can get width of linear resonator.

Length of Linear Resonator

Length of linear resonator is equal to half of guided wavelength. Therefore to calculate length of linear resonator, first we have to calculate the guided wavelength which is given by following formula

$$\lambda_g = \frac{c}{\sqrt{\varepsilon_{eff}}.f}$$

Where c = speed of light

ε_{eff} = effective permittivity

f= operating frequency

and effective permittivity ϵ_e is given by following formula

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

The length of linear resonator is

$L = \lambda_g/2$

Linear Resonator is designed by considering the resonator of length $\lambda_g/2$ plus two feed lines of length $\lambda_g/4$. The resonators have the open ends on both the sides and these open ends called as coupling gaps because these gaps are situated between resonator and feed lines. We can calculate the length of coupling gap by given formula:

$$l_{oo} = 0.412d\left(\frac{\varepsilon_{eff}+0.3}{\varepsilon_{eff}-0.258}\right)\left(\frac{\frac{W}{d}+0.262}{\frac{W}{d}+0.813}\right)$$

Total Length of the device = 2(length of feed line) + 2(coupling gap) + length of resonator

Example: Calculate the length and width of linear resonator at 1.5 GHz by using following

Given Parameters:

Frequency f = 1.5 GHz

Substrate Thickness d = 1.1 mm

Substrate Permittivity ε_r = 5.5

Characteristic Impedance z_0 = 50 Ω

Solution:

Calculate the value of A

A = $\frac{Z_0}{60}\sqrt{\frac{\epsilon_r+1}{2}} + \frac{\epsilon_r-1}{\epsilon_r+1}\left(0.23 + \frac{0.11}{\epsilon_r}\right)$

A= $\frac{50}{60}\sqrt{\frac{5.5+1}{2}} + \frac{5.5-1}{5.5+1}\left(0.23 + \frac{0.11}{5.5}\right)$

A = 1.67

Now calculate the value of B

B = $\frac{377\pi}{2Z_0\sqrt{\epsilon_r}}$

B = $\frac{377 \times 3.14}{2\times 50\sqrt{5.5}}$

B = 5.04

Now calculate the width W

$$\frac{W}{d} = \begin{cases} \frac{8e^{A}}{e^{2A}-2} & for\ W/d < 2 \\ \frac{2}{\pi}\left[B - 1 - \ln(2B-1) + \frac{\epsilon_r - 1}{2\epsilon_r}\left\{\ln(B-1) + 0.39 - \frac{0.61}{\epsilon_r}\right\}\right] & for \frac{W}{d} > 2 \end{cases}$$

$$\frac{W}{d} = \frac{8e^{1.67}}{e^{2\times 1.67} - 2}$$

$$W = 1.78\ mm \qquad for\ W/d < 2$$

$$\frac{W}{d} = \frac{2}{3.14}\left[5.04 - 1 - \ln(2\times 5.04 - 1) + \frac{5.5 - 1}{2\times 5.5}\left\{\ln(5.04 - 1) + 0.39 - \frac{0.61}{5.5}\right\}\right]$$

$$W = 1.77\ mm \qquad for\ for\frac{W}{d} > 2$$

Hence the width of the microstrip line is 1.77 mm

Now calculate effective permittivity ϵ_e

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

$$\varepsilon_{eff} = \frac{5.5+1}{2} + \frac{5.5-1}{2}\frac{1}{\sqrt{1+12\times 1.1/1.77}}$$

$$\varepsilon_{eff} = 4.023$$

Calculate the value of guided wavelength (length of the microstripline)

$$\lambda_g = \frac{c}{\sqrt{\varepsilon_{eff}}\cdot f}$$

$$\lambda_g = \frac{3\times 10^8}{\sqrt{4.023}\times 1.5\times 10^9}$$

$$\lambda_g = 0.0997\ m\ \ or\ 99.7\ mm$$

Since the length of the linear resonator = $\lambda_g/2$

Hence **$\lambda_g/2$ = 49.85 mm**

Length of feed line = **$\lambda_g/4$ = 24.925mm**

Width of linear resonator is 1.77 mm

Coupling gap =

$$l_{eo} = 0.412d\left(\frac{\varepsilon_{eff} + 0.3}{\varepsilon_{eff} - 0.258}\right)\left(\frac{\frac{W}{d} + 0.262}{\frac{W}{d} + 0.813}\right)$$

$$l_{eo} = 0.412 \times 1.1\left(\frac{5.5 + 0.3}{5.5 - 0.258}\right)\left(\frac{\frac{1.77}{1.1} + 0.262}{\frac{1.77}{1.1} + 0.813}\right)$$

***l_{oe}*= 0.41mm**

$$total\ lenght = 2 \times 24.925 + 2 \times 0.43 + 49.85$$

***total length*= 100.52mm**

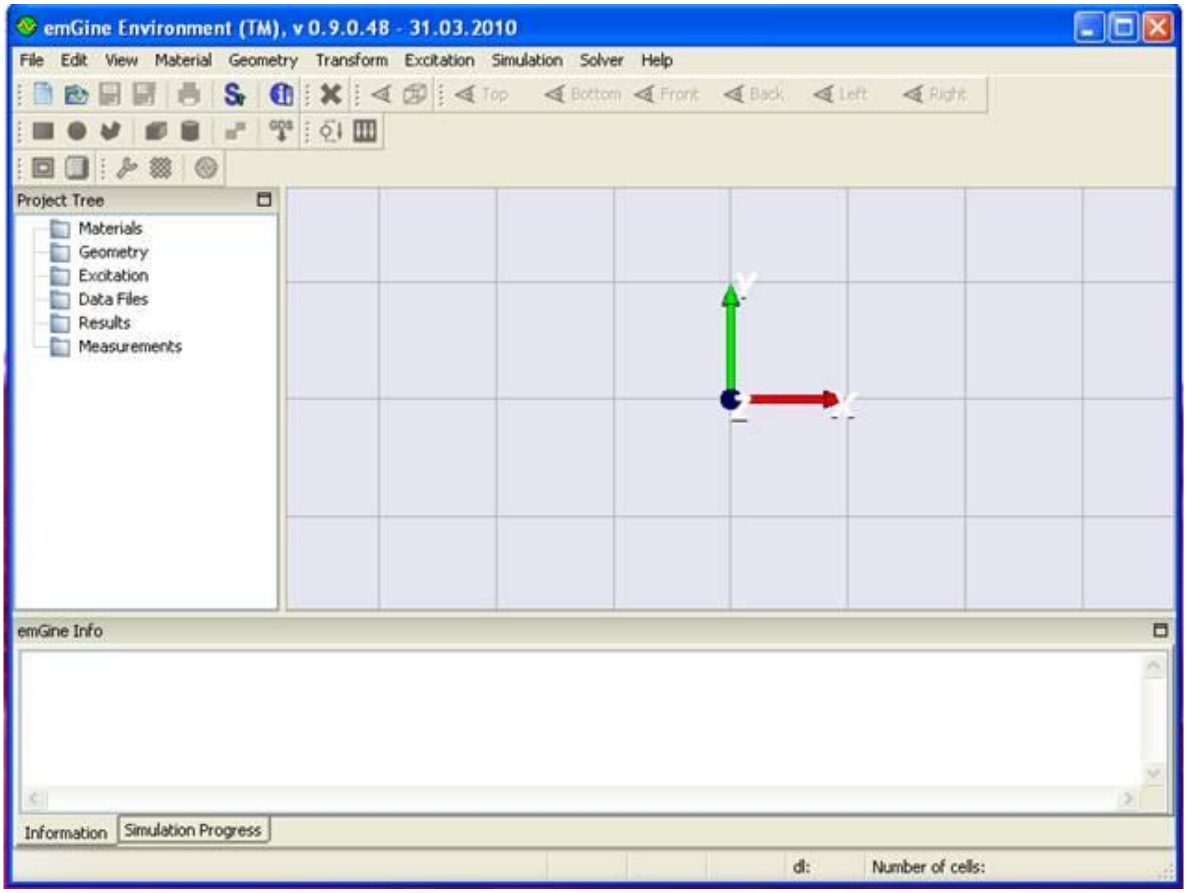
Simulation Procedure:

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 half wavelength linear resonator. The following explanations on how to model and analyze this device can be applied to other planar devices, as well.

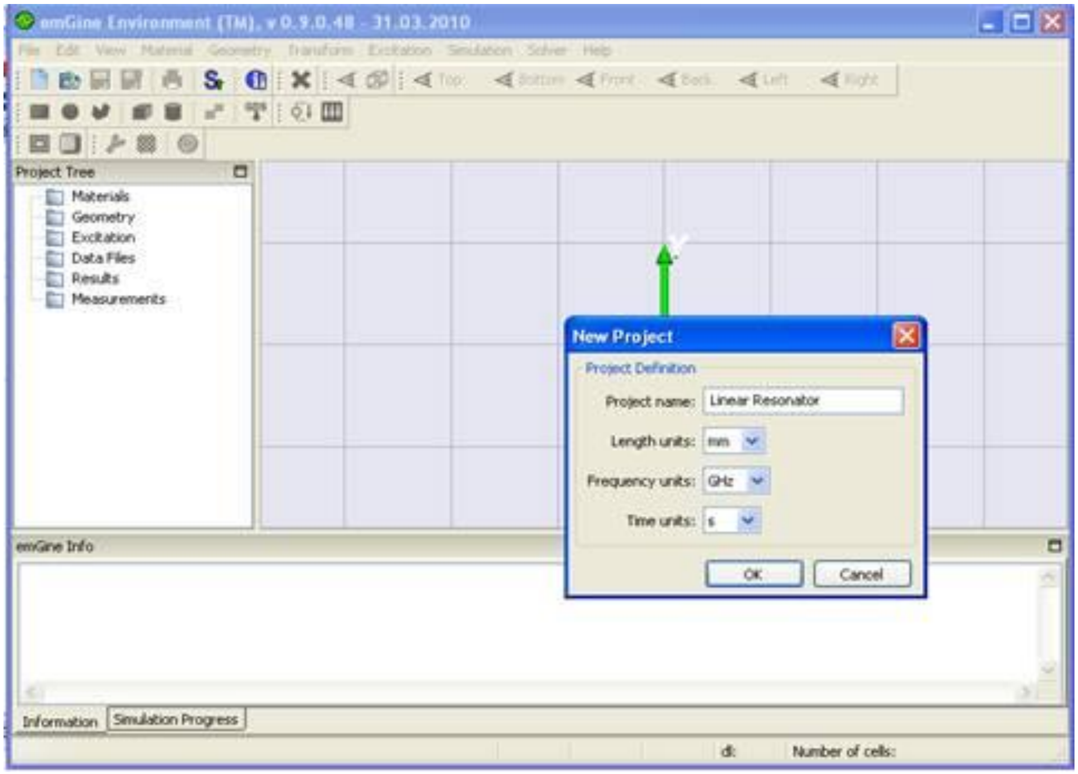
Geometric Construction Steps

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.

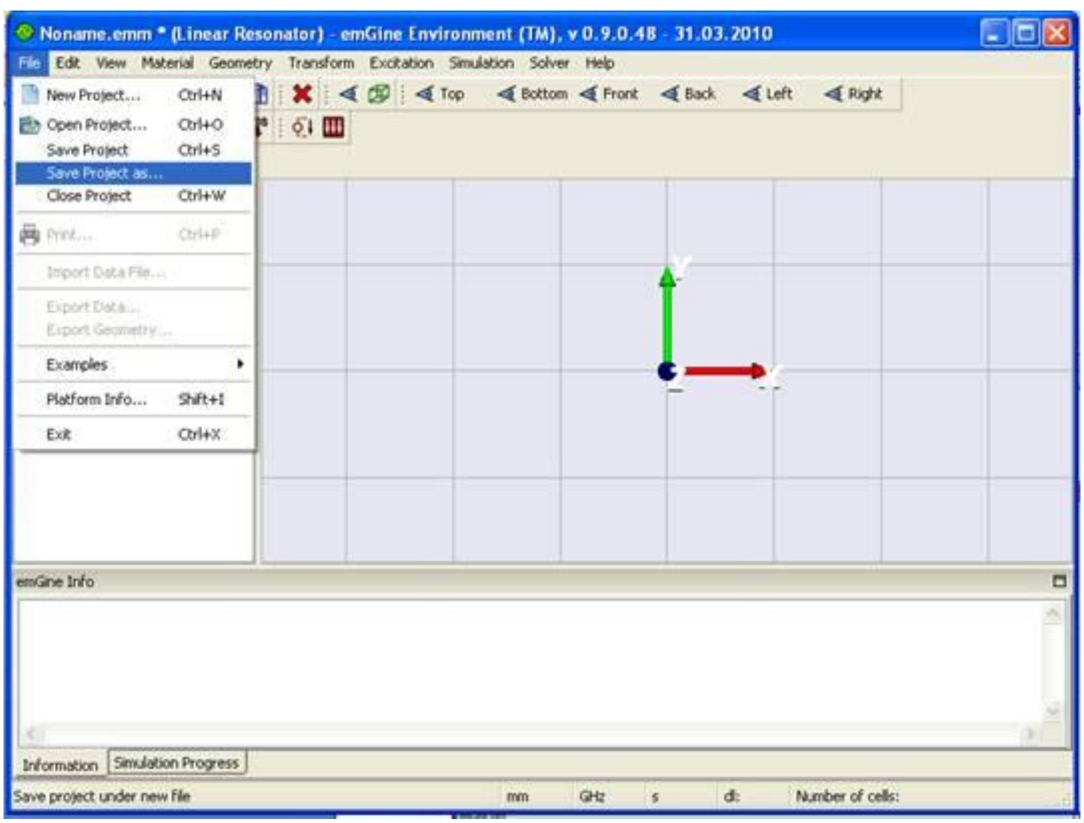


Select a Template

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.

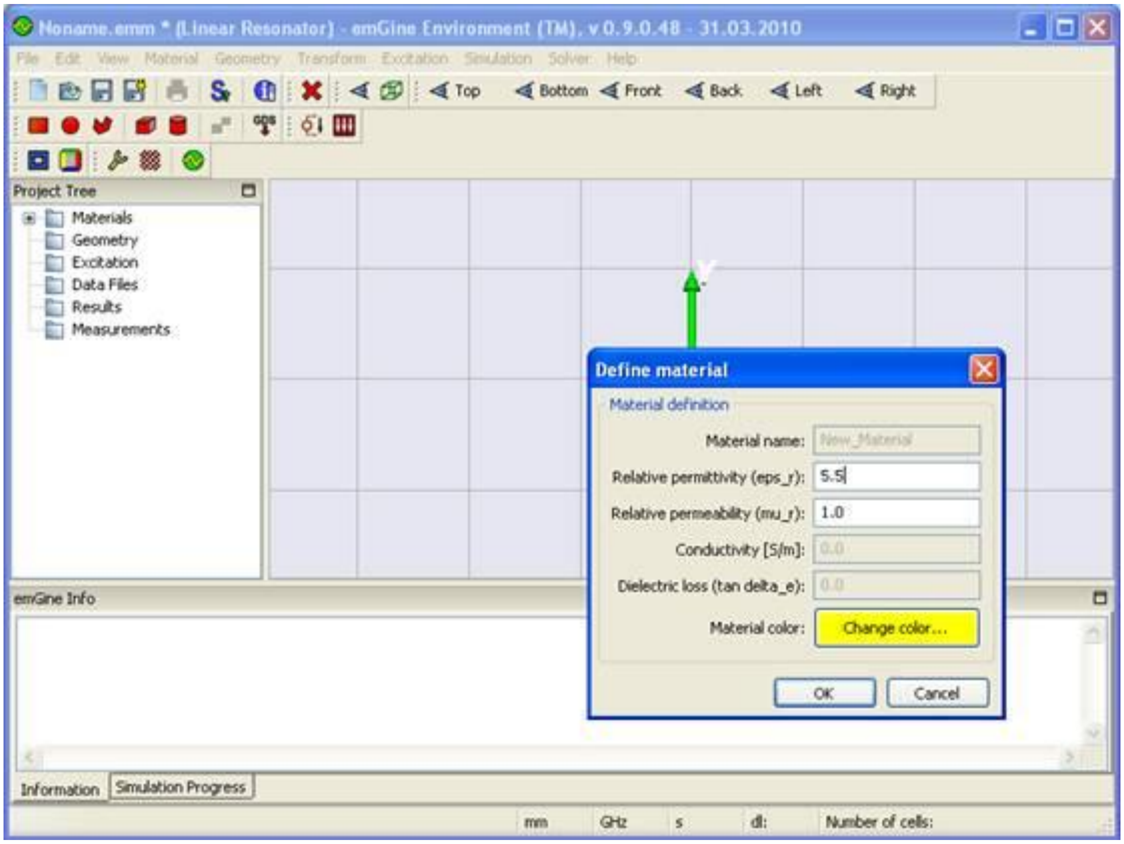


Now again go to file click on save project and save your project at any location in my computer.



Set the Working Planes Properties

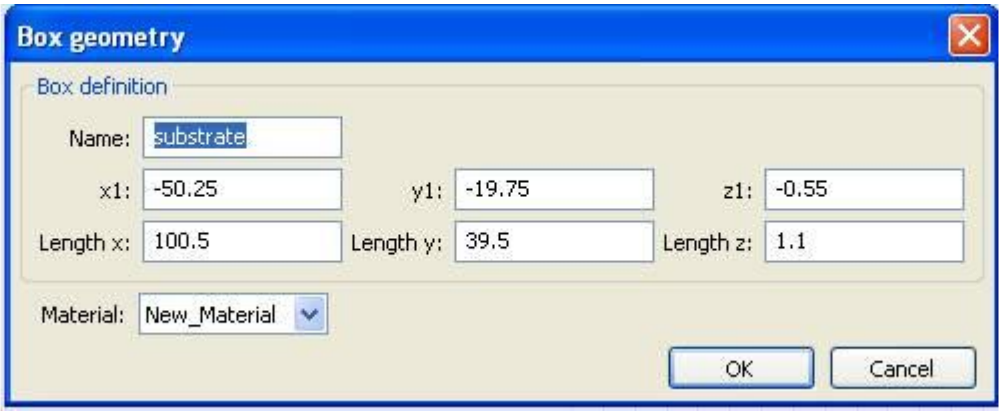
The next step is usually to set the material properties. In this dialog box you should define a new *Material name* (e.g. New_Mtarial). Afterwards, specify the material properties in the *Epsilon* and *Mue* fields. Here, you only need to change the dielectric constant *Epsilon* to 5.5. Finally, choose 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

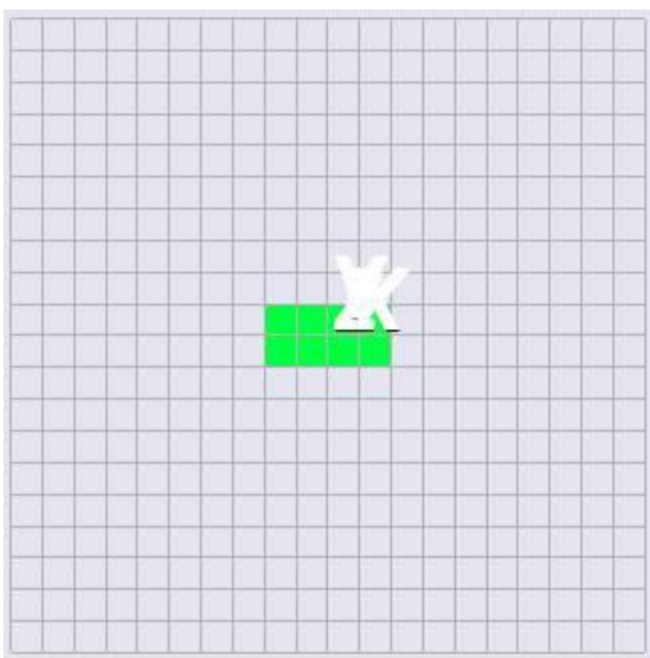
The first construction step for modeling a planar structure is usually to define the substrate layer. This can be easily achieved by creating a brick made of the substrates material. Please activate the brick creation mode (*Geometry* - *Box*).

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:



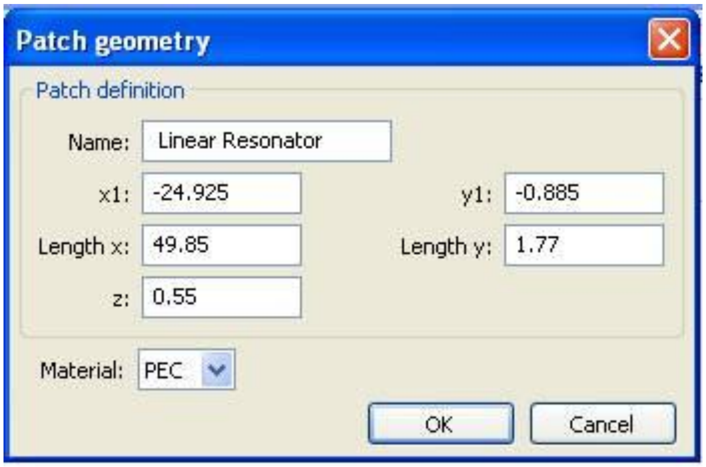
In this example, you should enter a substrate block. The transversal coordinates can thus be described by X 1= -50.25, Y1 = -19.75, Z1 = -0.55 for the first corner and give the calculated length X = 100.5, length Y = 39.5, length Z = 1.1 for creating the brick, assuming that the brick is modeled symmetrically 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.

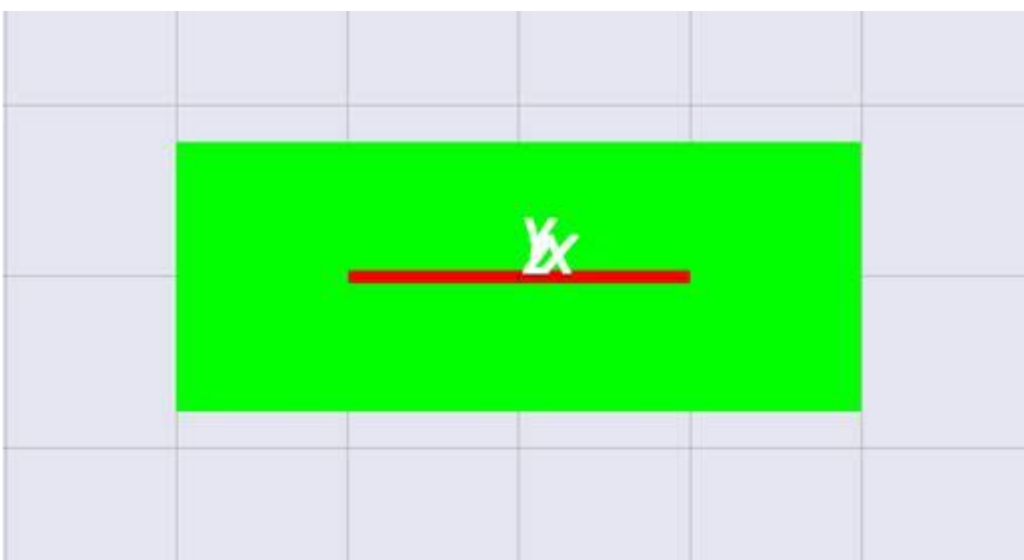


Model the Linear Resonator

The next step is to model the Half Wavelength Linear Resonator on top of the substrate. Therefore, go to Geometry select patch then a patch geometry dialog box will open. The transversal coordinates can thus be described by X1 = -24.925, Y1 = -0.885, Z1= 0.55 for the first corner and give the actual length as length X = 49.85, length Y = 1.77, as you did above. You should now assign a meaningful name to the brick by entering e.g. Linear Resonator in the *Name* field.

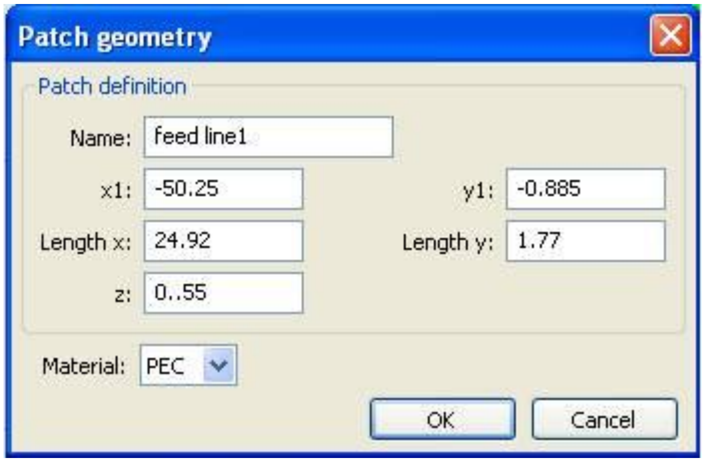


The *Material* setting of the brick must be changed to the desired Linear Resonator material. Because no material has yet been defined for the Linear Resonator, you should select the PEC as the material for Linear Resonator from the material drop down list and in the brick creation dialog box you can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



Model the Feed Lines

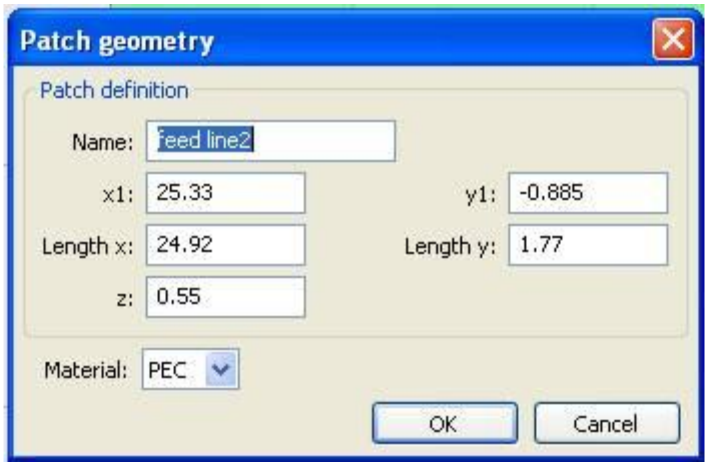
The next step is to model the l/4 feed lines on top of the substrate. Therefore, go to Geometry select patch then a patch geometry dialog box will open. The transversal coordinates can thus be described by X1 = -50.25, Y1 = -0.885, Z= 0.55 for the first corner and give the actual length as length X = 24.92, length Y = 1.77, as you did above. You should now assign a meaningful name to the brick by entering e.g. feed lines 1 in the *Name* field. You should select the PEC as the material for feed line from the material drop down list.



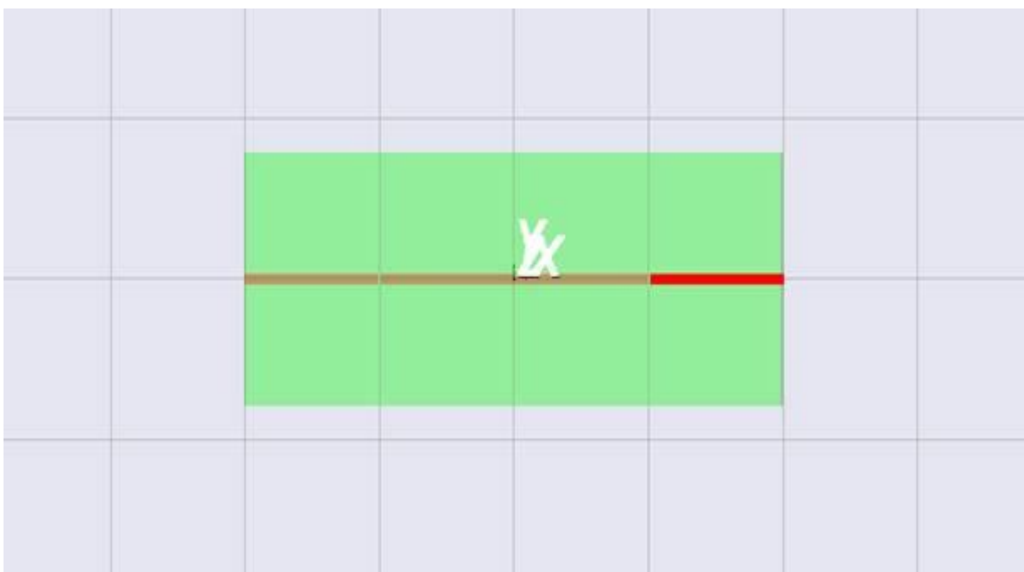
Now press the *OK* button to finally create the Feed Line for one side. Your screen should now look as follows

The next step is to model the l/4 feed lines on top of the substrate for other side. Therefore, again do the same process go to Geometry select patch then a patch geometry dialog box will open. The transversal coordinates can thus be described by X1 = 25.33., Y1 = -0.885, Z= 0.55 for the first corner and give the actual length as length X = 24.92, length Y = 1.77, as you did above.

You should now assign a meaningful name to the brick by entering e.g. feed lines 2 in the *Name* field. You should select the PEC as the material for feed line from the material drop down list.

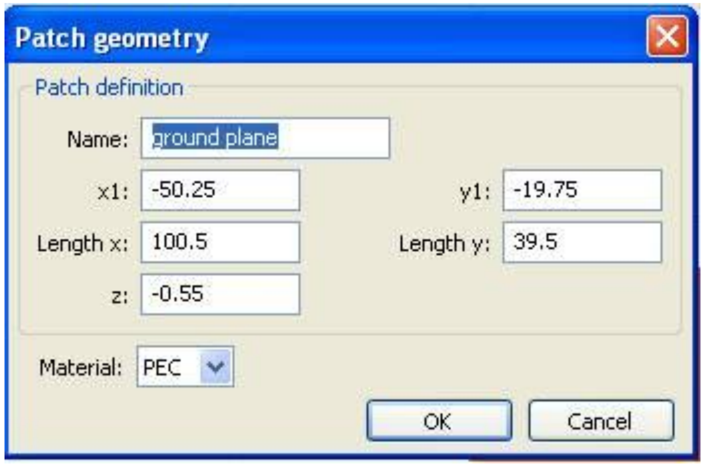


Now press the *OK* button to finally create the Feed Line for one side. Your screen should now look as follows.

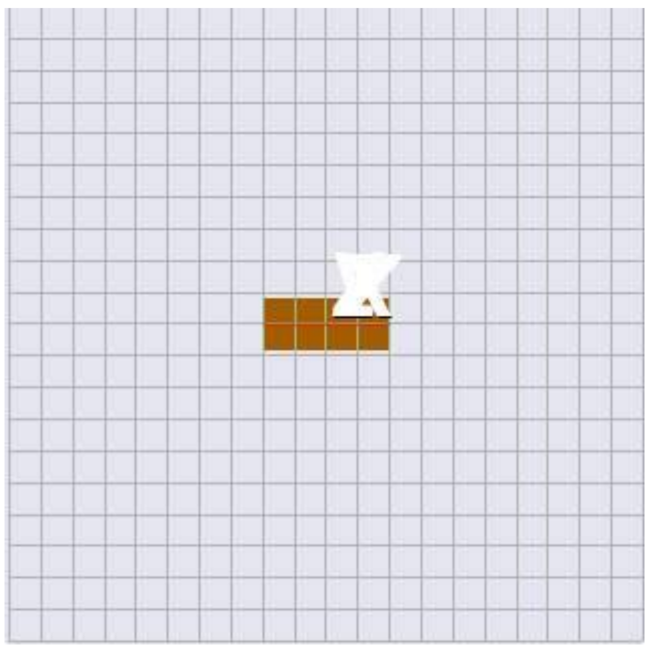


Model the metallic ground plane

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 = -50.25, Y1 = -19.75, Z = - 0.55 for the first corner and give the actual length as length X = 100.5, length Y = 39.5, as you did above. You should now assign a meaningful name to the brick by entering e.g. ground plane in the *Name* field.

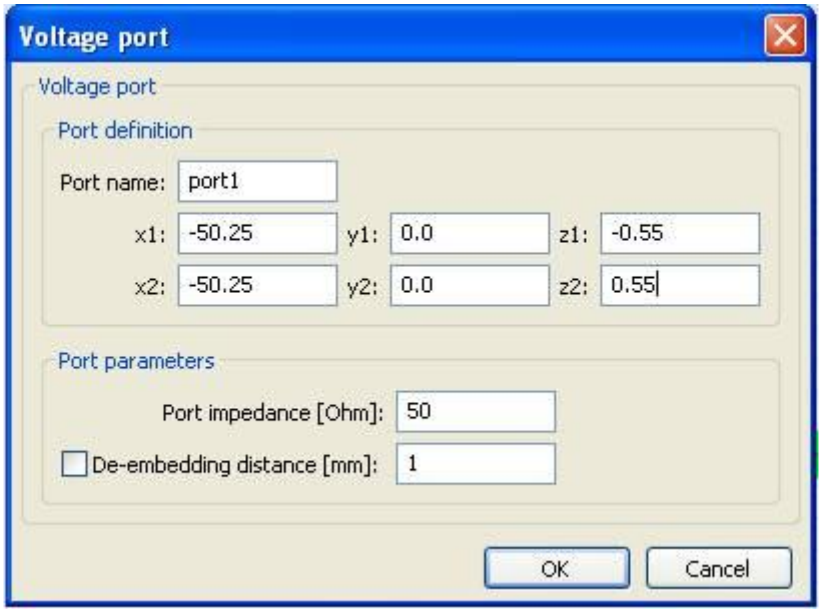


The *Material* setting of the brick must be changed to the desired ground plane. You should select PEC as the material for ground plane from the material drop down list and in the brick creation dialog box press the *OK* button to finally create the ground plane. Your screen should now look as follows.

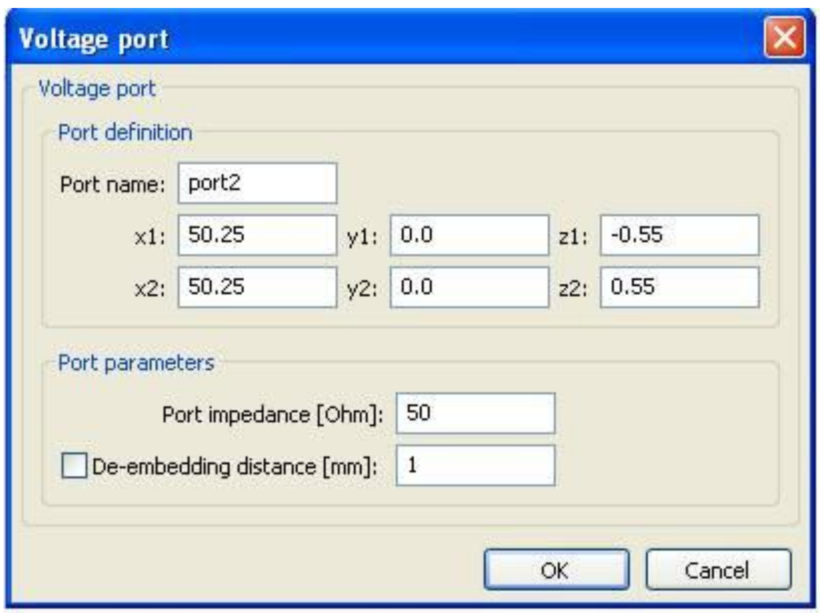


Define Ports

The next step is to add the voltage ports to the linear resonator device for which the S-parameters will later be calculated. Each port will simulate linear resonator 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 any microwave device and should thus be used here. To define the port 1 go to excitation and then choose voltage port, it will open a dialog box, give the port name and appropriate dimension to define the exact port. You can define port as shown in picture below

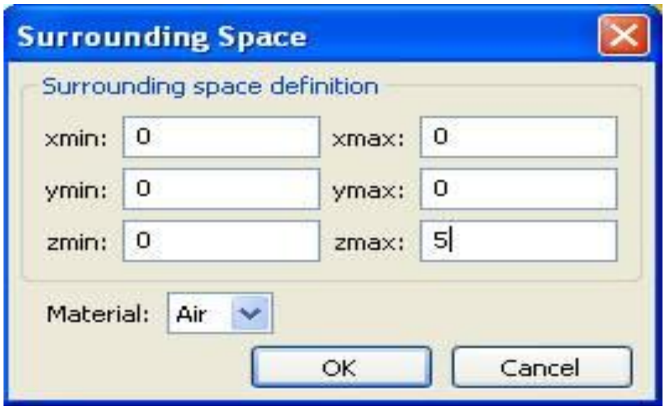


Similarly define the second port and press ok.



Define Surrounding Space:

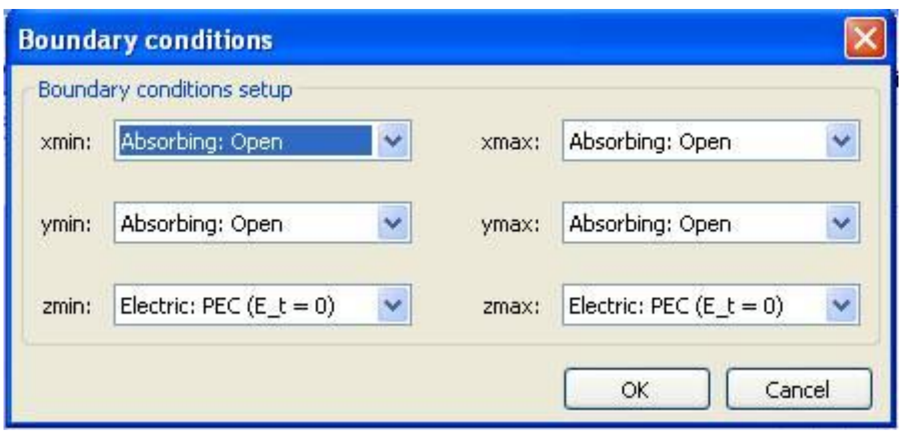
For defining the surrounding space go to simulation and click the surrounding space it will open a dialog box as shown in picture below.



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

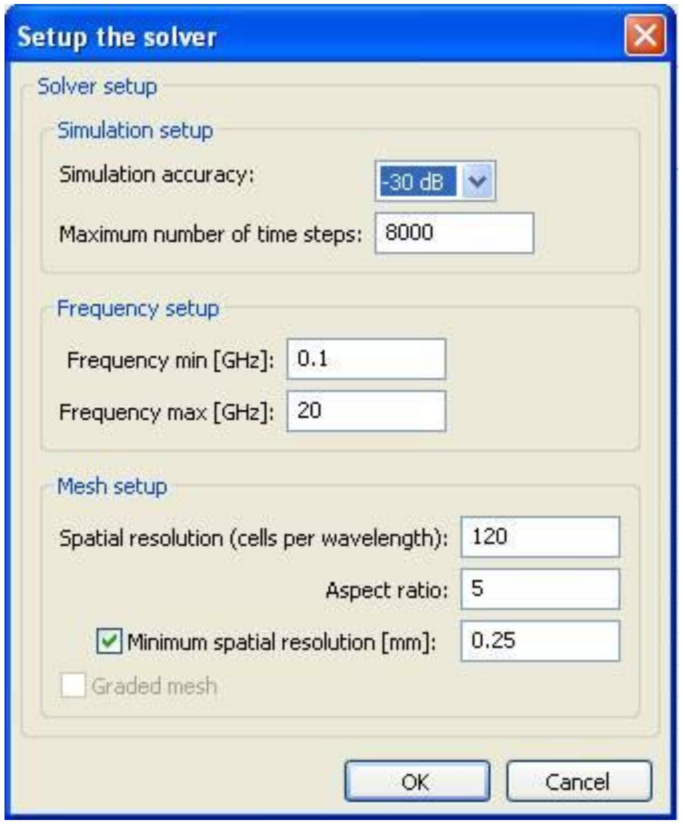
Define the Boundary Conditions

Go to simulation and double click on boundary condition then a boundary condition setup box will open give the boundary condition as shown in picture below then press ok.



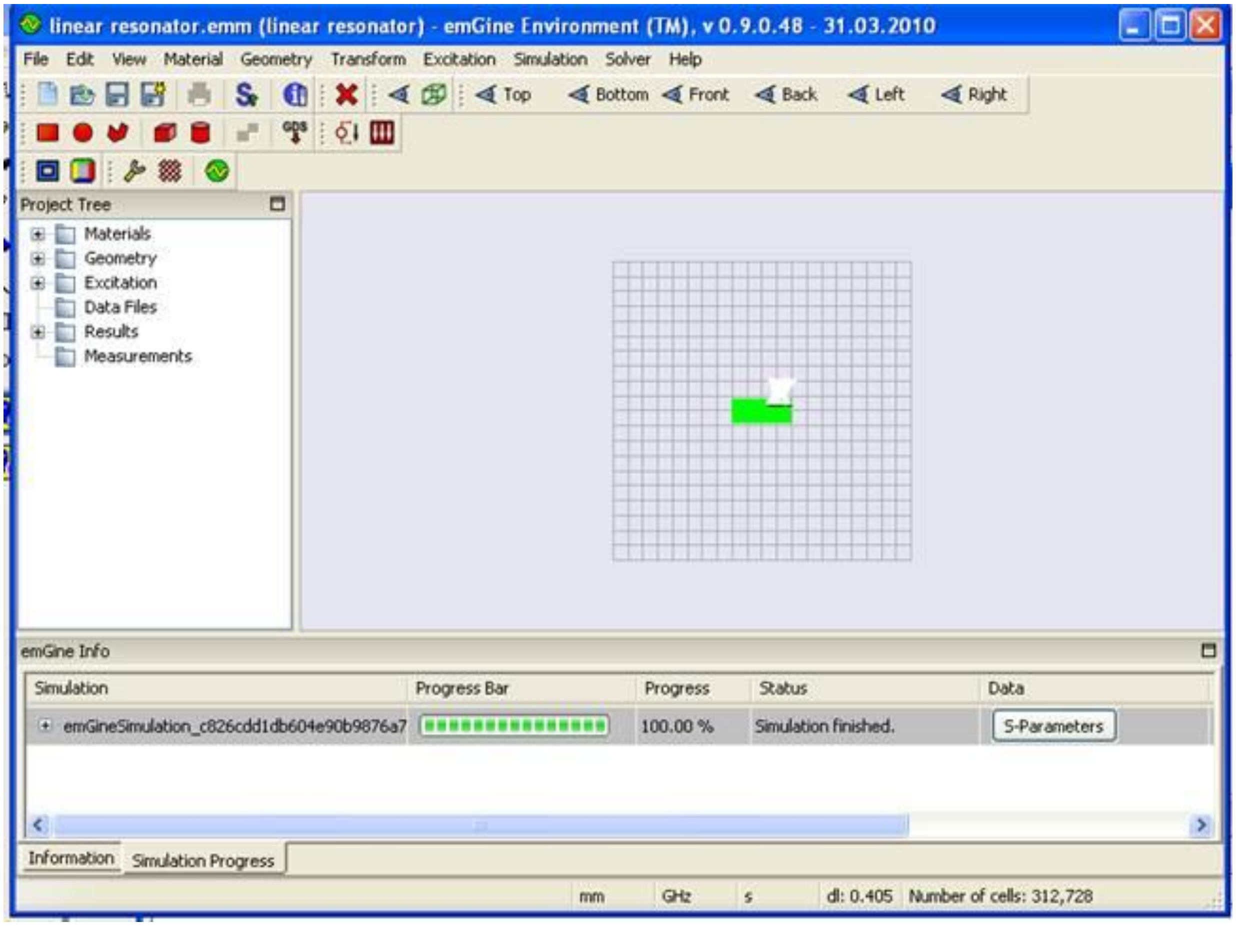
Setup the Solver

The next step is solver setting, for this go to solver 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 10000. Choose 8000 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 2.5 GHz. Now define Special resolution as 120, 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.



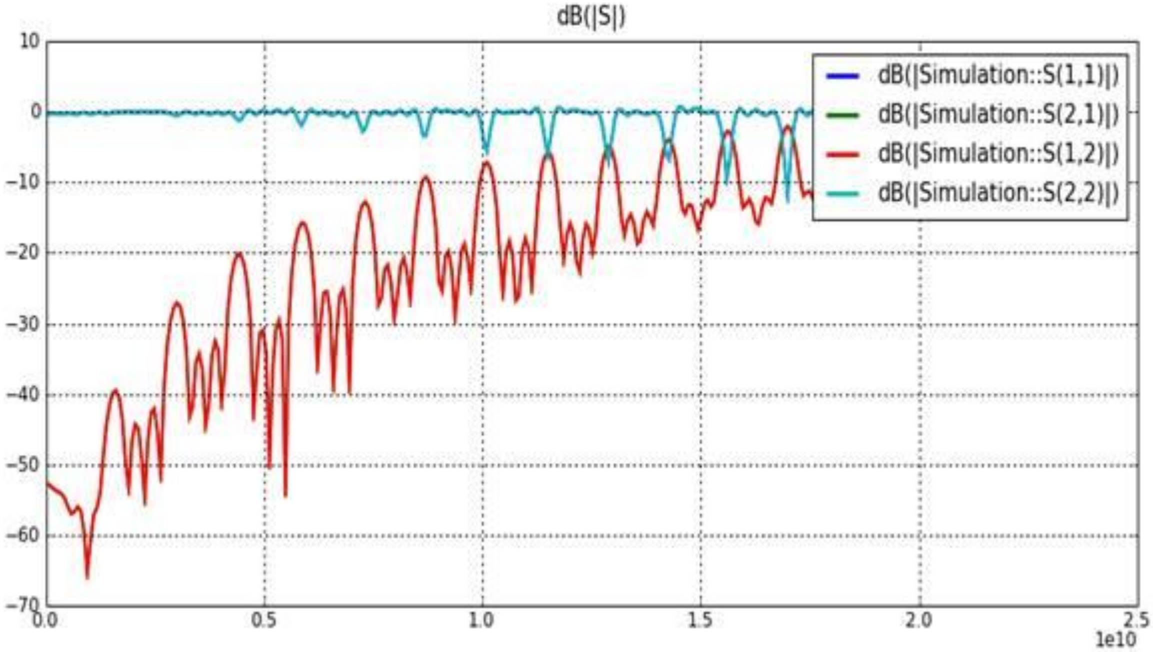
During the simulation, the Message Window will show some details about the performed simulation.

Congratulations, you have simulated the linear resonator! Let's review the results.

<u>Results:</u>

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.