DAYALBAGH EDUCATIONAL INSTITUTE,
DAYALBAGH AGRA

Manual

Experiment 2

Design and Characterization of Microstrip Line

Experiment 2

Objective:

To design the Microstrip line at 1.5 GHz

1. Calculate the length and width of Microstrip line at 1.5 GHz

To simulate the Microstrip line

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

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Requirement:

1. Computer facility
2. EMgine Simulation Software

Theory:

Transmission lines in microwave circuit are normally used to carry information or energy from one point to other and as circuit element for passive circuits such as filters, impedance transformers, couplers, and delay lines. Passive elements in conventional microwave circuits are mostly distributed and employ sections of transmission line and waveguide. This is because the sizes of discrete lumped elements (resistors, inductors, and capacitors) used in electronic circuits at lower frequencies become comparable to the wavelength at microwave frequencies. However, when the size is lumped elements are reduced to dimensions much smaller than the wavelength, they are used in microwave frequencies.

Multiconductor structures that support TEM or non - TEM modes of propagation are commonly referred to as “transmission lines”. Waveguides or dielectric rods or their derivatives support the non TEM mode of propagation. The TEM transmission lines are characterized by four basic parameters, the characteristics impedance Z_o, the phase velocity v_p, the attenuation constant a, and peak power-handling capability P_{max}, in terms of physical parameters (such as the geometric cross section) and properties of the dielectric and the conductor materials used.

In a TEM line (perfectly terminated), the ratio of the voltage to the current at any point along the line is constant having the units of resistance for a loss-less medium. This ratio is defined as the characteristic impedance. The propagation constant for a lossy transmission structure is a complex quantity, comprising a real part known as the attenuation constant (which contains information about phase velocity). The attenuation constant is defined as

$$\alpha = \frac{\text{average power lost per unit length}}{2 \text{ x power transmitted}}$$

Consider a uniform transmission line with series resistance $(\overline{R})$,series inductance $(\overline{L})$, shunt conductance,$(\overline{G})$, and shunt capacitance, $(\overline{C})$all defined per unit length of the line, as shown in Fig. Important transmission-line expressions are summarized in Table1.

An extensive variety of transmission and waveguide structures are used at microwave frequencies. Figure shows cross-sectional views of commonly used structures. Half-wavelength, quarter-wavelength, or smaller sections of these lines from the basic building blocks in most microwave circuits.

The power-handling capability of a transmission line is limited by dielectric breakdown and by heating due to attenuation. The electrical breakdown limits the peak power, while the increase in temperature due to conductor and dielectric losses limits the average power.

At normal temperature and pressure, the breakdown electric field of dry air is 2.9 x 10^6 V/m. Using this and by calculating the maximum field strength, the peak power-handling capability of a transmission line is readily determined.

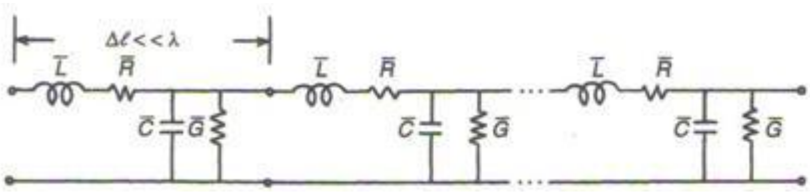


Figure 1 Lumped circuit representation of a transmission line.

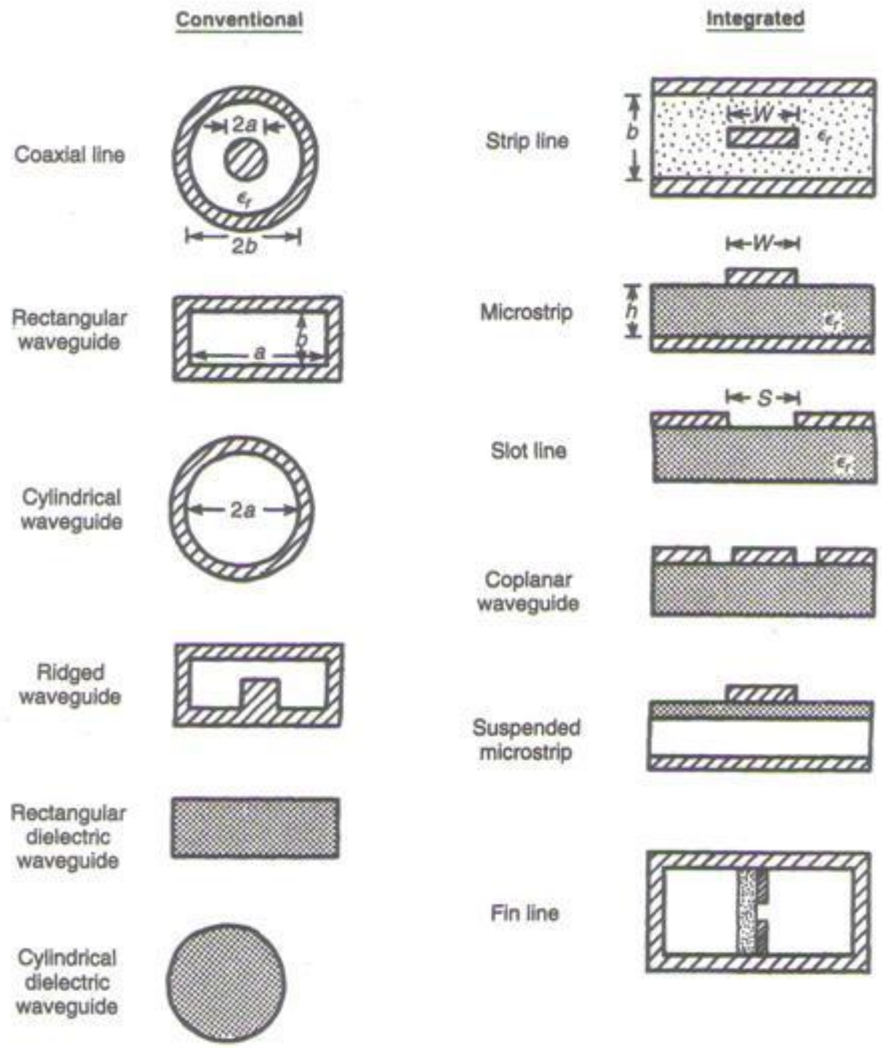


Figure 2: Transmission structure for microwave circuits.

The average power-handling capability of a transmission is determined by the temperature rise of the line in an air environment. The parameters that play major roles in the calculation of average power capacity are attenuation constant, surface area of the line, maximum tolerable temperature rise, and ambient temperature (i.e., the temperature of the medium surrounding the transmission structure. Thus the average power rating can be raised, if desired, by choosing a higher temperature limit and using forced cooling or cooling fins.

Characteristics of Planar Transmission Lines

For a transmission structure to be suitable as a circuit element in MICs, one of the principal requirements is that the structure should be “planar” in configuration. A planar geometry implies that the characteristics of the element can be determined from the dimensions in a single plane. As shown in Fig., various forms of planar transmission lines have been developed for use in MICs. The strip line, microstrip , inverted microstrip line, slot line, coplanar waveguide, and coplanar strip line, are representative planar transmission lines. The circuits realized using any one of the aforementioned transmission lines or combinations of them have distinct advantages, such as light weight, small size, improved performance, better reliability and reproducibility, and low cost, as compared to conventional microwave circuits. They are also compatible with solid state strip chip devices. Integrated circuits employing these structures at microwave frequencies have been widely discussed in the literature.

Microstrip

Unlike the strip line, the microstrip line (shown in Fig3) is an inhomogeneous transmission line, since the field lines between the strip and the ground plane are not contained entirely in the substrate. Therefore, the mode propagation along the microstrip is not purely TEM but quasi-TEM.

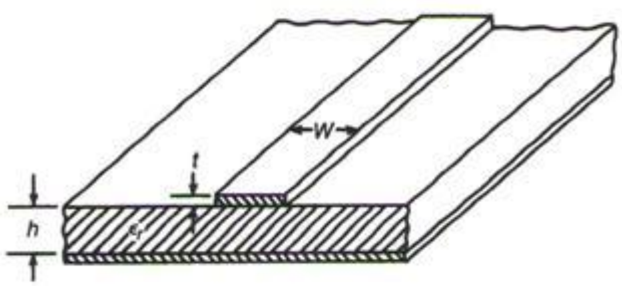


Figure 3: Microstrip line configuration

Extensive literature dealing with the analytical and numerical solutions of this medium exists. Of these solutions, the quasi-static approach is perhaps the simplest but has a limited range of validity, while the full-wave approach is complete and rigorous. In the quasi-static method, the nature of the mode of propagation is considered to be pure TEM, and the transmission line characteristics are calculated from the electrostatic capacitances of the structure. It is found that this analysis is adequate for designing circuits when the strip width and the substrate thickness are much smaller than the wavelength in the dielectric material. In the quasi-static approach, the transmission characteristics are calculated from the values of two capacitances: one is C_a, for a unit length of the microstrip configuration with the dielectric materials replace by air, and the other is C, for a unit length of the microstrip with the dielectric present. The characteristics impedance Z_0 and the phase constant β can be written in terms of these capacitances as:

$$Z_0 = \frac{1}{C\sqrt{CC_a}}$$

$$\beta = k_0\left(\frac{C}{C_a}\right)^{1/2} = k_0\sqrt{\epsilon_e}$$

where

$$\epsilon_e = \left(\frac{\lambda_0}{\lambda_g}\right)^2 = \frac{C}{C_a}$$

λ_0 being the free-space wavelength and λ_g the guide wavelength. The effective dielectric constant ε_e takes into account the fields in the air region. Numerical methods for the characterization of microstrip lines involve extensive computations. Closed-form expressions are necessary for optimization and computer aided design of microstrip circuits. Closed-form expression for Z_0 and ε_e have been reported by Wheeler, Schneider, and Hammerstad. Both wheeler and Hammerstad have also given synthesis expression for Z_0. The variation of characteristics impedance with W/h at different values of effective dielectric constant is shown in Figure 4.

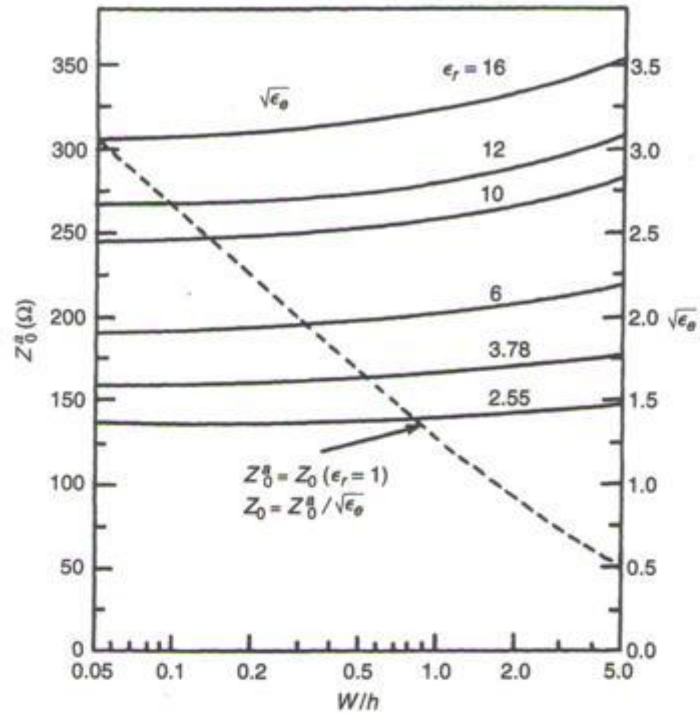
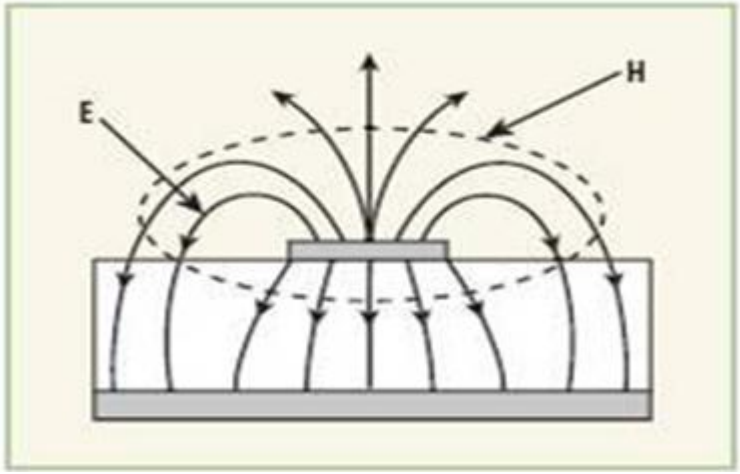


Figure 4: The variation of characteristics impedance with W/h at different values of effective dielectric constant

Inhomogeneity

In microstrip line, some part of the electromagnetic wave is propagated through substrate and some part through air above it. Since the substrate and air both have different dielectric constant. So wave propagates with different velocities in both medium. This inhomogeneity in the medium produces a discontinuity in the electric and magnetic field. This make the analysis complicated. To simplify the analysis, we define the effective dielectric constant of the microstrip line which is the dielectric constant of an equivalent homogeneous medium. Due to this inhomogeneity, microstrip line support a quasi TEM wave because electric and magnetic field both have component in the direction of wave propagation. As the frequency increases, the effective dielectric constant also increases. This results in the decrease of phase velocity. So micostrip line become dispersive at high frequencies. Similarly characteristic impedance of microstrip line also either increases or decreases or first decreases then increases with increase of frequency.



. **Figure 2:** Field distribution pattern in Microstrip line

A conductor of width W is printed on a thin, grounded dielectric substrate of thickness d and relative permittivity ε_r sketch of the field lines is shown in figure 2. If the dielectric were not present we could think of the line as a two-wire line consisting of two flat strip conductors of width W, separated by a distance d. In those cases we would have a simple TEM transmission line, width v_p= c and β=k_0.The presence of the dielectric does not fill the air region above the strip (y>d), complicated the behavior and analysis of microstripline, where all the fields are contained within a homogeneous dielectric region, concentrated between the strip conductor and the ground plane and some fraction the air region above the substrate. For this reason the microstripline cannot support the pure TEM wave, since the phase velocity of TEM fields in the air region would be c/e_r, but the phase velocity of TEM fields in the air region would be impossible to attain for a TEM-type wave. The dielectric substrate is electrically very thin (d<< λ), and so the fields are quasi TEM. In other words, the fields are essentially the same as those of the static case. Formulas for Effective Dielectric Constant, Characteristic Impedance, and Attenuation the effective dielectric constant of a microstripline is given approximated by

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

The effective dielectric constant of a homogeneous medium that replaces the air and dielectric region of the microstrip, the phase velocity and propagation constant are then given by

$$V_0 = c/\sqrt{\epsilon_e}$$

$$\beta = k_0\sqrt{\epsilon_e}$$

Given the dimension of the microstripline the characteristic impedance can be calculated as

$$Z_0 = \begin{cases} \frac{60}{\sqrt{\epsilon}}\ln\left(\frac{8d}{W}+\frac{W}{4d}\right) & for W/d \leq 1 \\ \frac{120\pi}{\sqrt{\epsilon}\left[\frac{W}{d}+1.393+0.667ln\left(\frac{W}{d}+1.444\right)\right]} & for\ W/d \geq 1 \end{cases}$$

For a given characteristic impedance Z_0 and dielectric constant e_r, the W/d ratio can be found as:

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

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

Where

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

$$Ko = 2\pi f/\ c$$

$$l = 360° \frac{\frac{\pi}{180°}}{k_o\lambda}$$

Hence effective dielectric constant and width of microstrip line calculated by the above equation and guided wave length of microstrip line is calculated by:

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

Formula Used:

To design the microstrip line, we have to calculate the width and length of the microstrip line.

Procedure is given as 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

Width of microstrip line

To calculate the width of the microstrip line, we will use following formula

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

Where w= width of microstripline

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 microstrip line.

Length of microstrip line

Since length of microstrip line is equal to the guided wavelength of the microstrip line.

Therefore to calculate length of microstrip line, first we have to calculate the value of guided wavelength which is given by following formula

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

Where c = speed of light

ε_{eff}

= effective permittivity

f= operating frequency

andeffective permittivity ε_e is given by following formula

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

Example: Calculate the length and width of microstrip line 1.5 GHz by using following 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

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

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

A=

A = 1.67

Now calculate the value of B

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

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

B =

B = 5.04

Now calculate the width W

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

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

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

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

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

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)

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

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

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

Hence length of the microstrip line is 99.7 mm and width of microstrip line is 1.77 mm

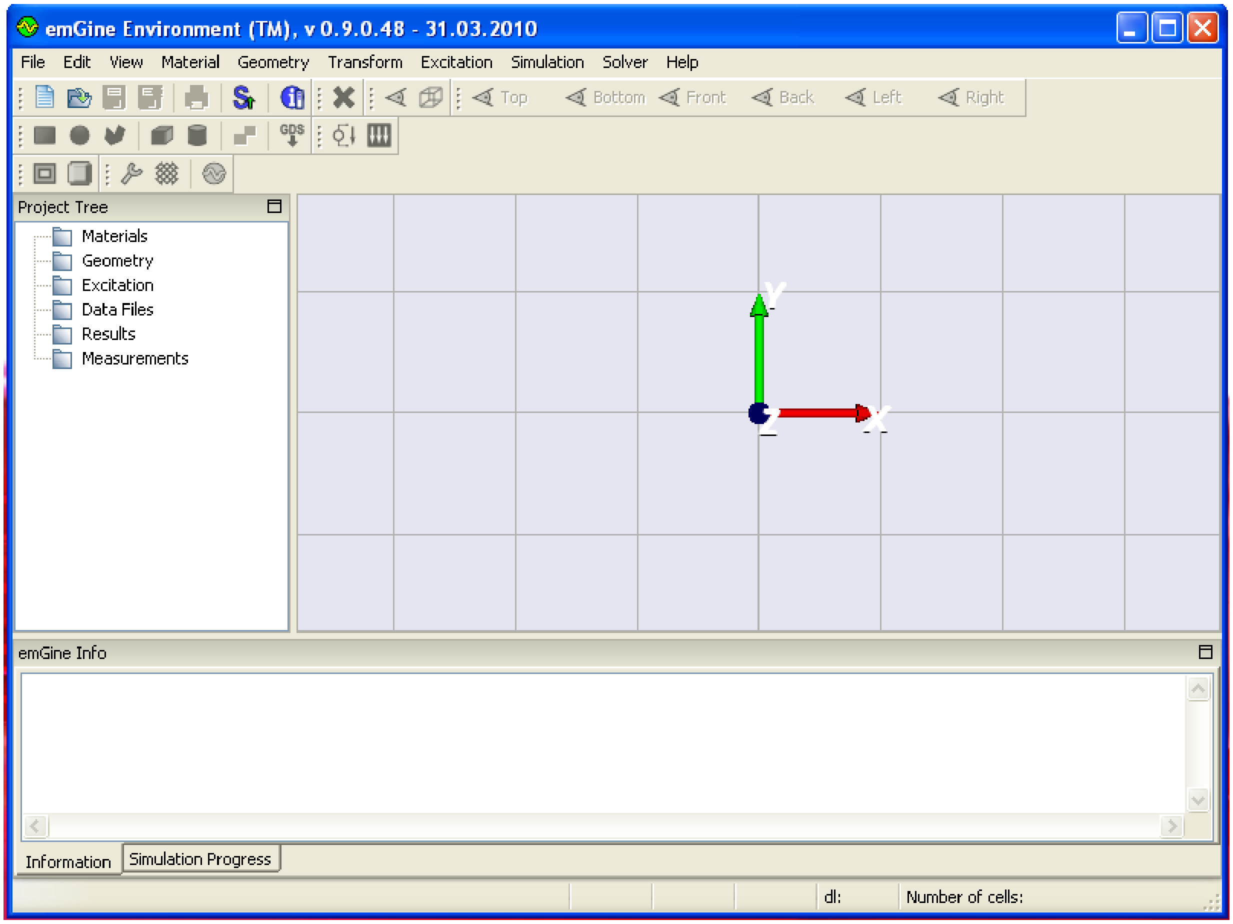
Simulation Procedure:

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

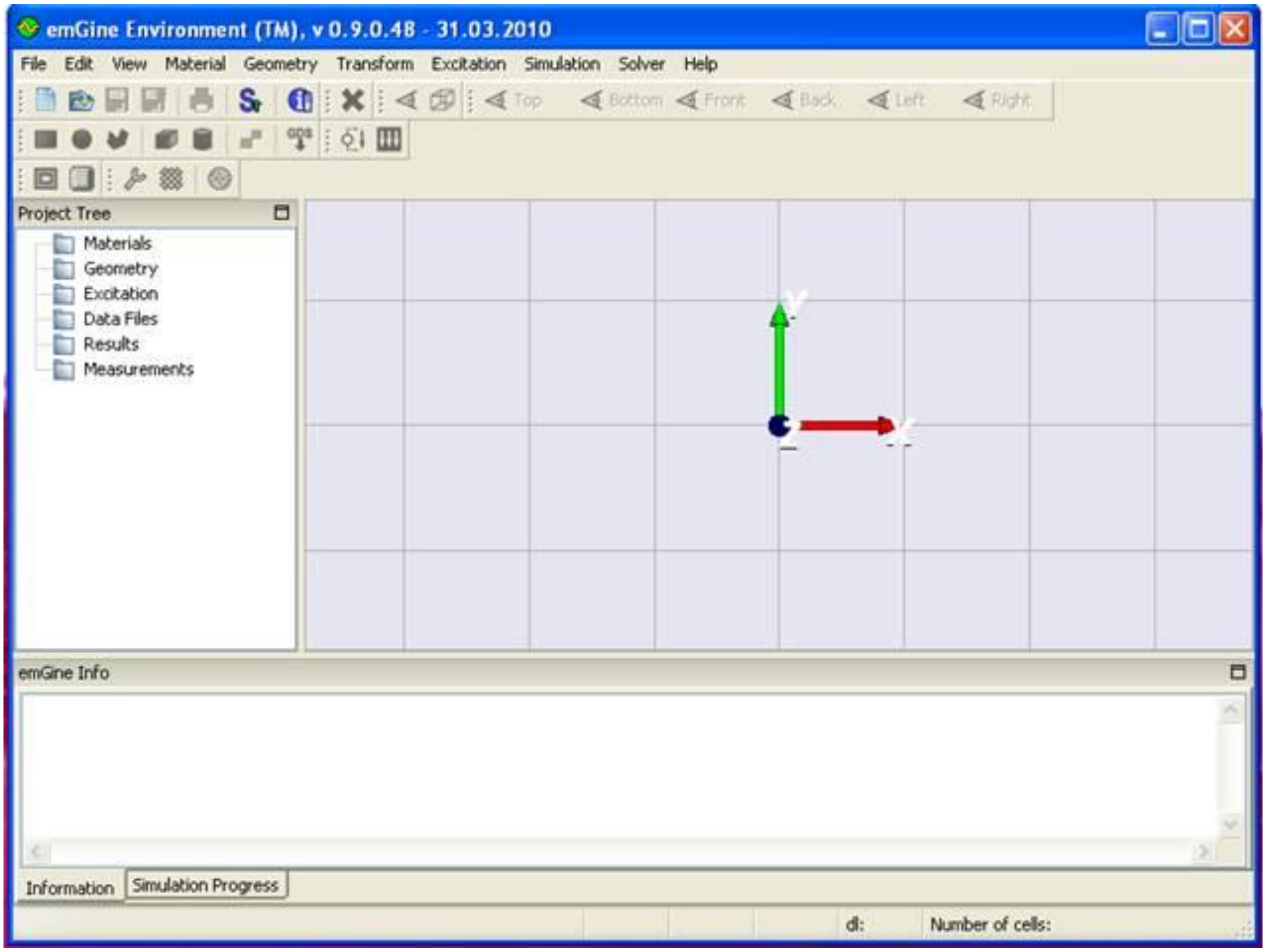
Geometric Construction Steps

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.

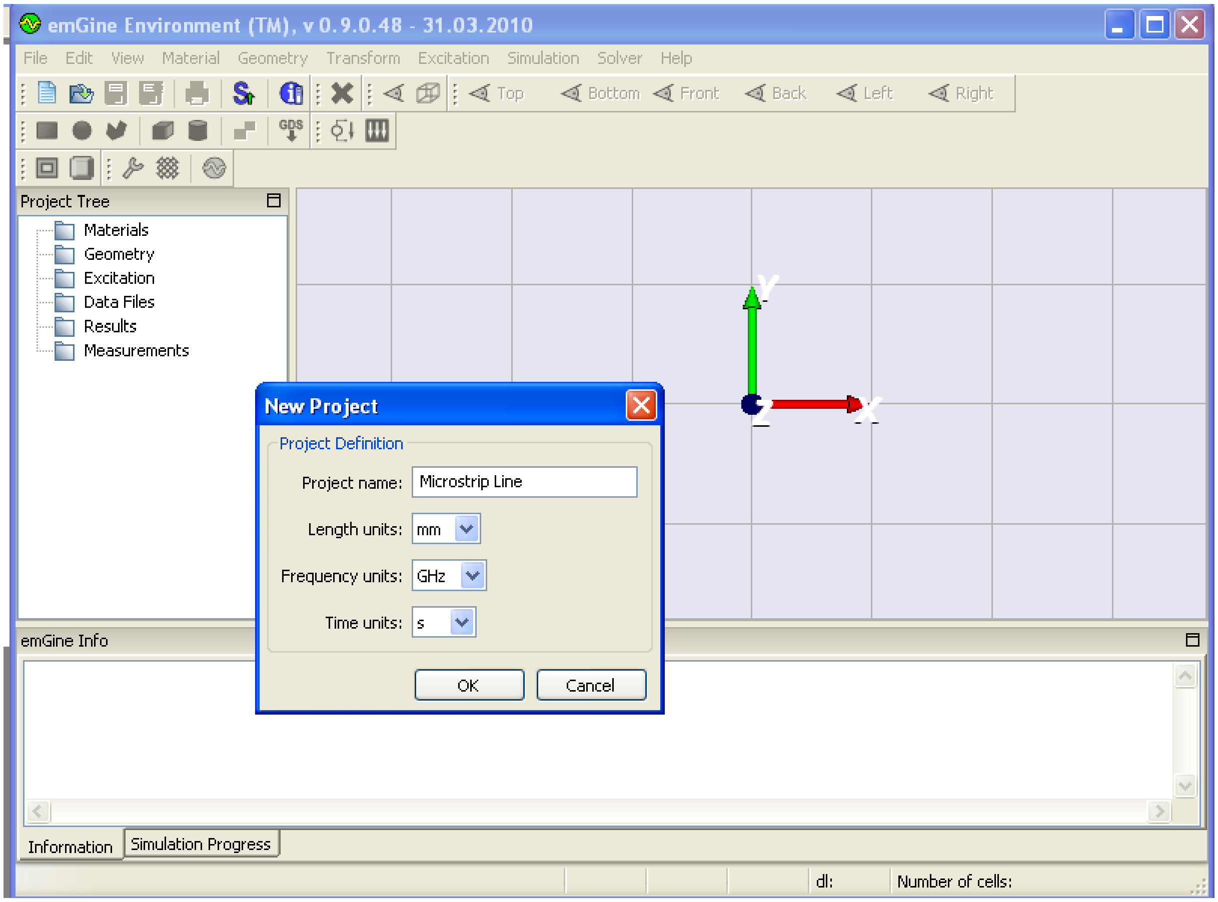


Select a Template

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.

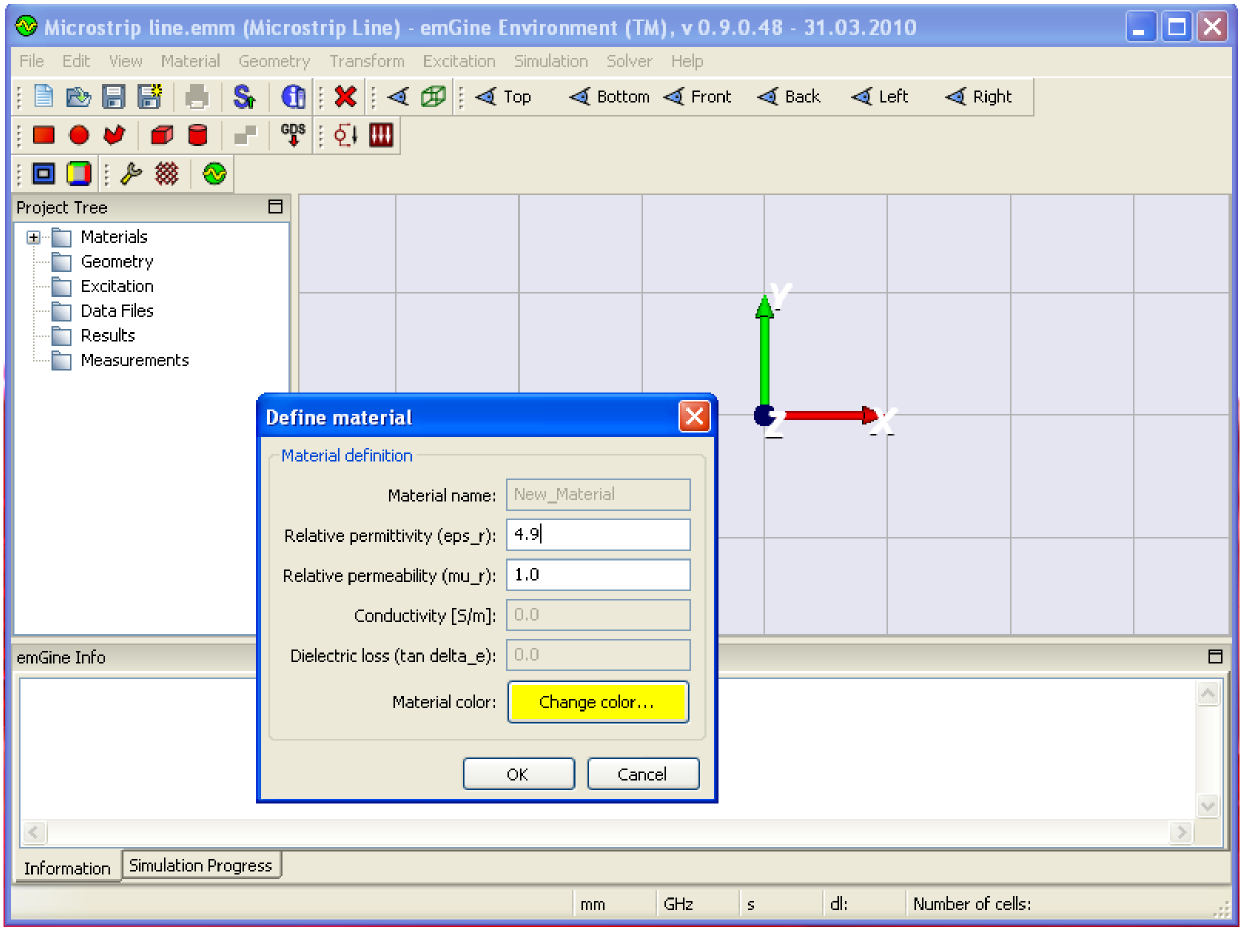


Now again go to file click on save project and save your project at any location in my computer.



Set the Working Planes Properties

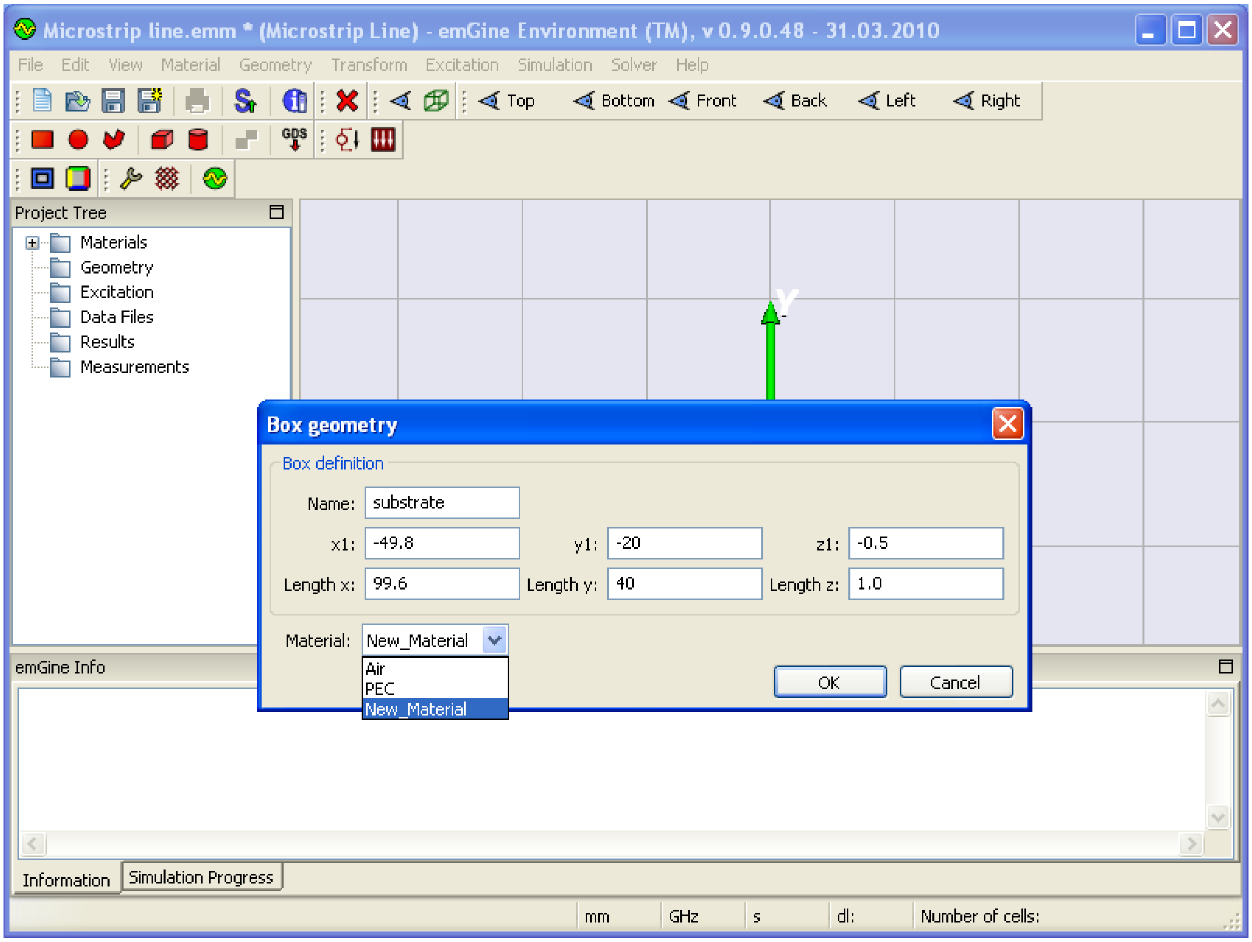
The next step is usually to set the material properties. In this dialog box you should define a new *Material name* (e.g. New_Mtarial). Afterwards, specify the material properties in the *Epsilon* and *Mue* fields. Here, you only need to change the dielectric constant *Epsilon* to 4.9. Finally, choose 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

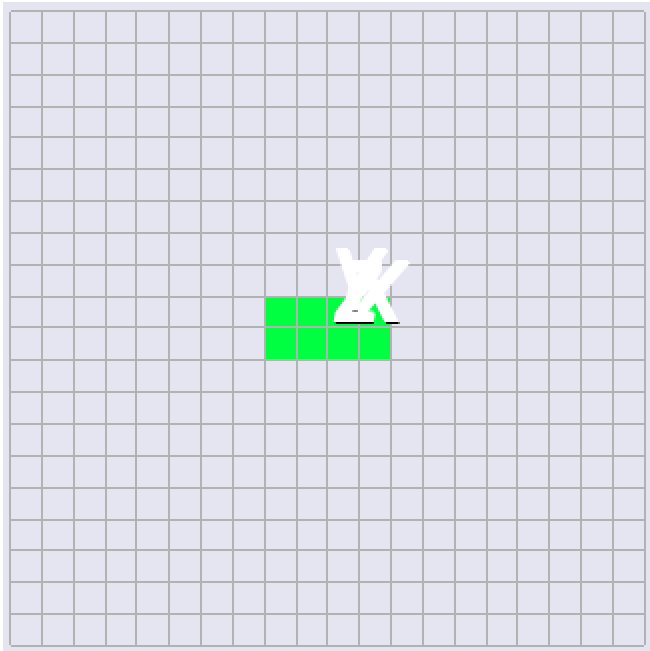
The first construction step for modeling a planar structure is usually to define the substrate layer. This can be easily achieved by creating a brick made of the substrates material. Please activate the brick creation mode (*Geometry - Box*).

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:



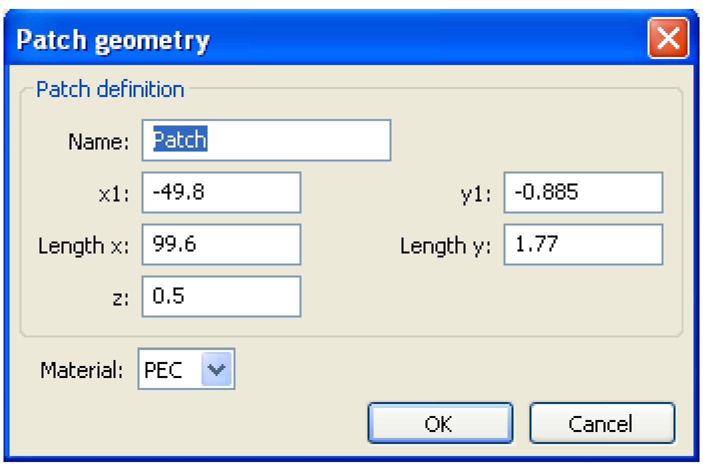
In this example, you should enter a substrate block. The transversal coordinates can thus be described by X 1= -49.8, Y1 = -20, Z1 = -0.5 for the first corner and give the calculated length X = 99.6, length Y = 40, length Z = 1 for creating the brick, assuming that the brick is modeled symmetrically 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

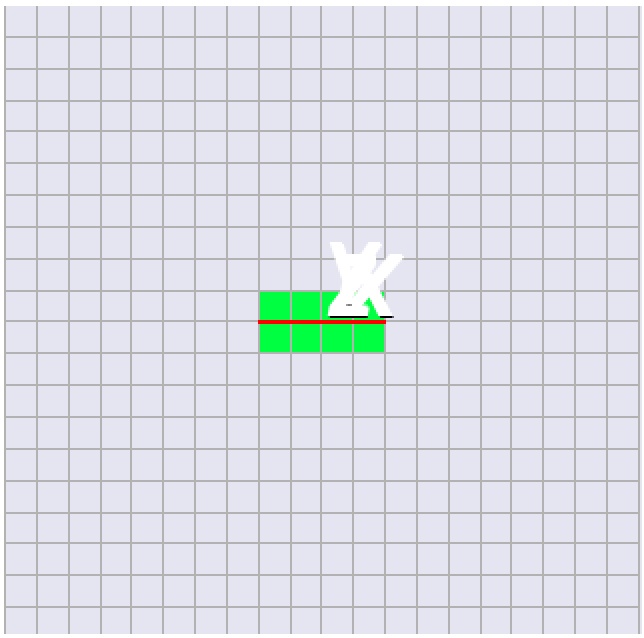


Model the Microstripe line

The next step is to model the microstrip line metallization on top of the substrate. Therefore, you should again do the same process. For the dimensions of microstrip line over substrate, you should design the microstrip line. The transversal coordinates can thus be described by X1 = -49.8, Y1 = -0.885, Z1= 0.50 for the first corner and give the actual length as length X = 99.6, length Y = 1.77, length Z = .04 as you did above. You should now assign a meaningful name to the brick by entering e.g. msl (micro strip line) in the *Name* field.

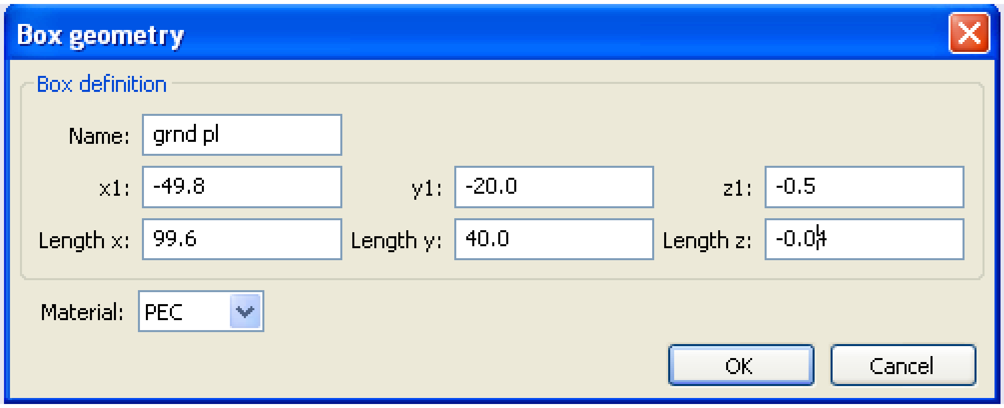


The *Material* setting of the brick must be changed to the desired microstripline material. Because no material has yet been defined for the microstrip line, you should select the PEC as the material for msl from the material drop down list and in the brick creation dialog box you can also press the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

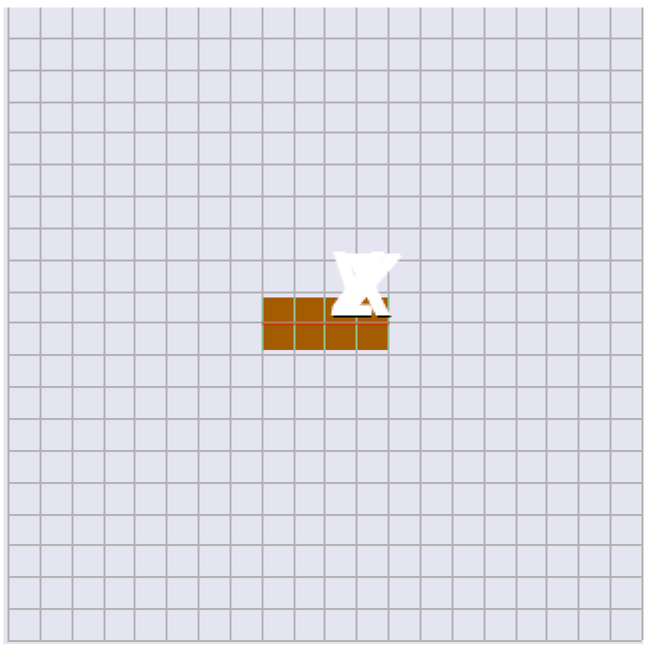


Model the metallic ground plane

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 = -49.8, Y1 = -20, Z1=-0.50 for the first corner and give the actual length as length X = 99.6, length Y = 40, length Z = -0.04 as you did above. You should now assign a meaningful name to the brick by entering e.g. ground plane in the *Name* field.

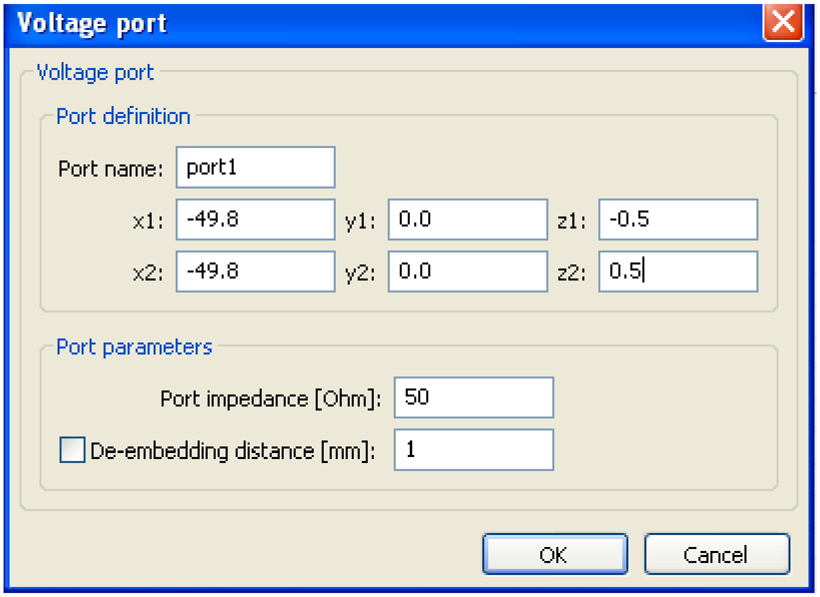


The *Material* setting of the brick must be changed to the desired ground plane. Because no material has yet been defined for the ground plane, you should select PEC as the material for ground plane from the material drop down list and in the brick creation dialog box press the *OK* button to finally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

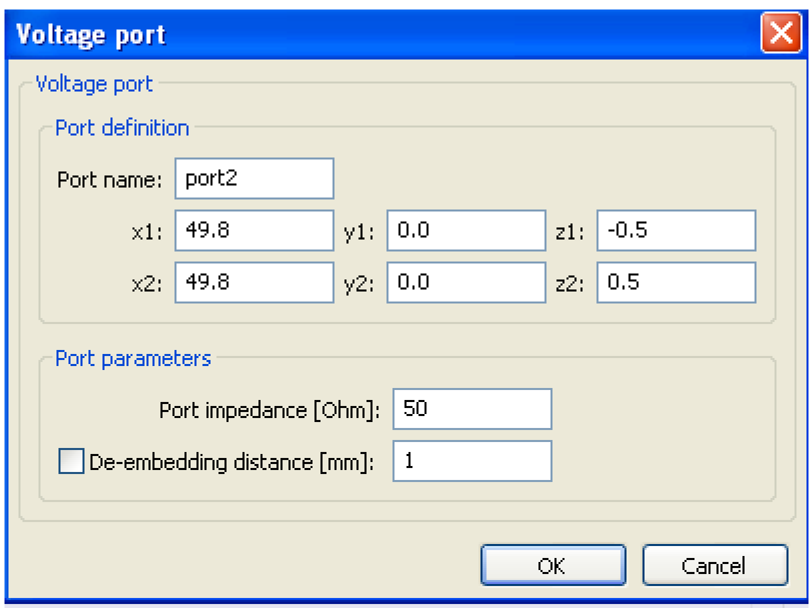


Define Ports

The next step is to add the ports to the microstrip line device for which the S-parameters will later be calculated. Each port will simulate microstripline 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 microstrip devices 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.

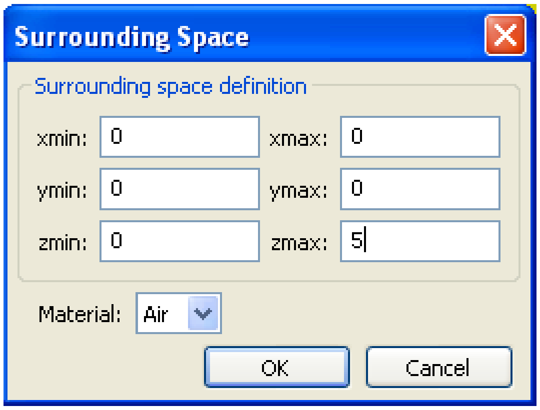


Similarly for port 2 give the port name as port 2 and then define the coordinates as you did above.



Define Surrounding Space:

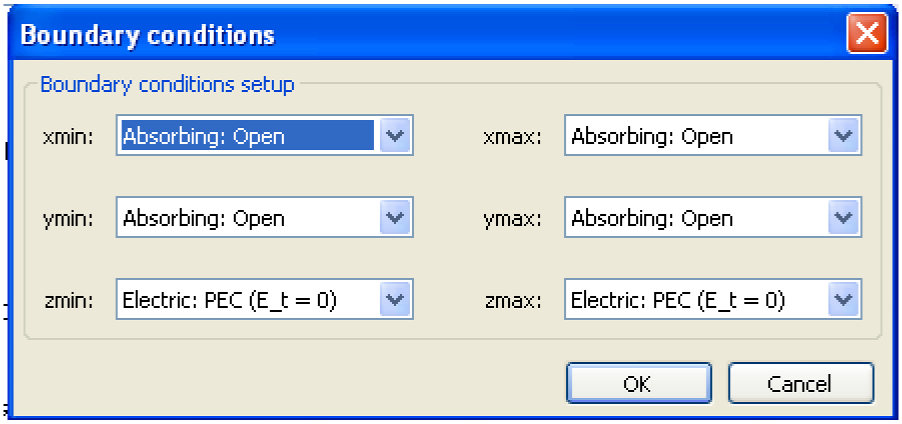
For defining the surrounding space go to simulation and click the surrounding space it will open a dialog box as shown in picture below



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

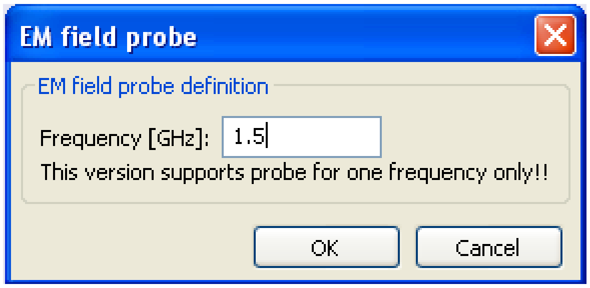
Define the Boundary Conditions

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.



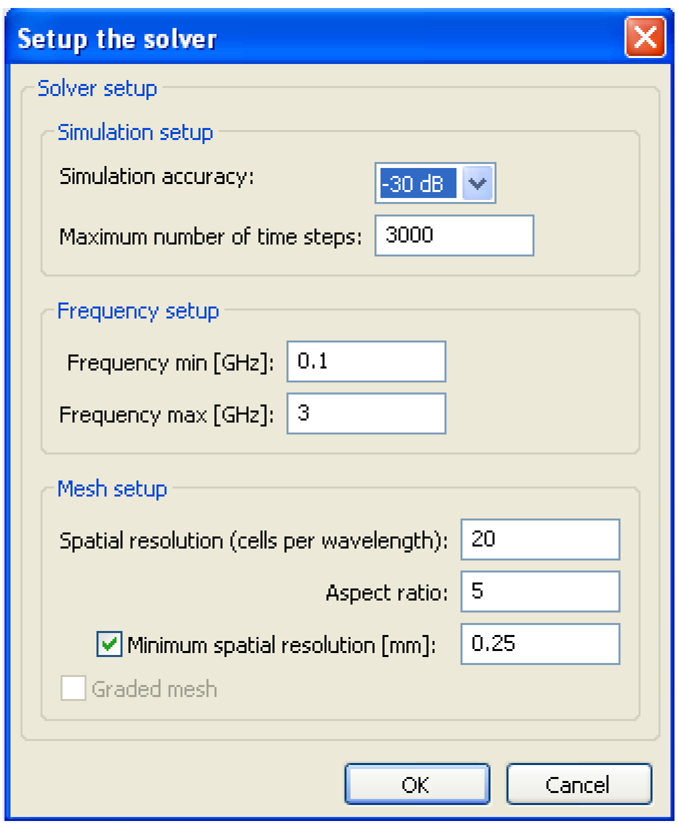
Define the EM Field Visualization

Go to probes and choose EM Field Visualization then an EM Field probe setup box will open Choose 1.5 GHz as frequency and press ok.



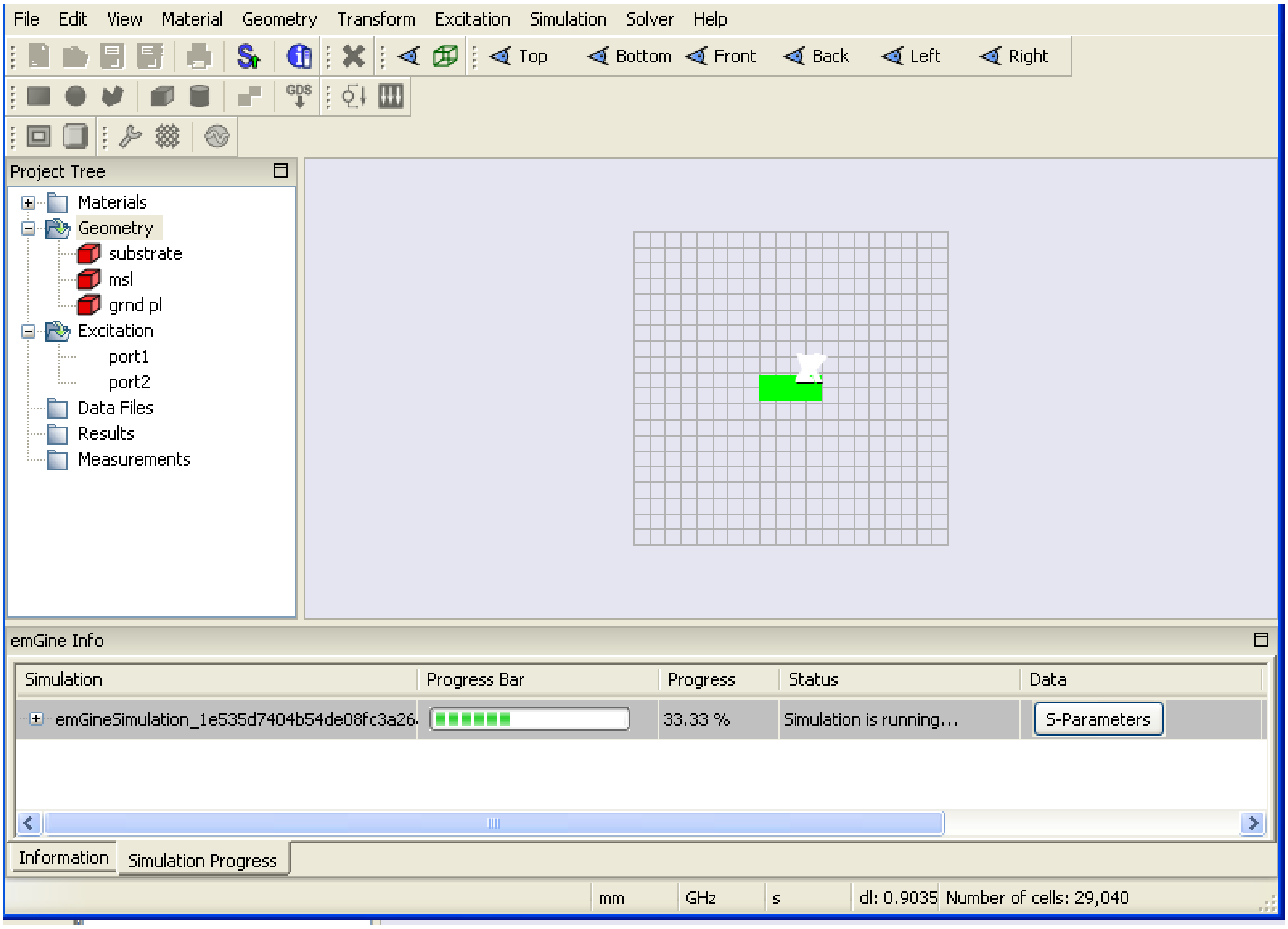
Setup the Solver

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 to 5000. Choose 1000 steps. After that define the frequency range for the simulations you can set frequency min as 0.1 GHz and frequency max as 5 GHz hence your frequency range is from 0.1 GHz to 5 GHz. Now define Special resolution as 80, 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.



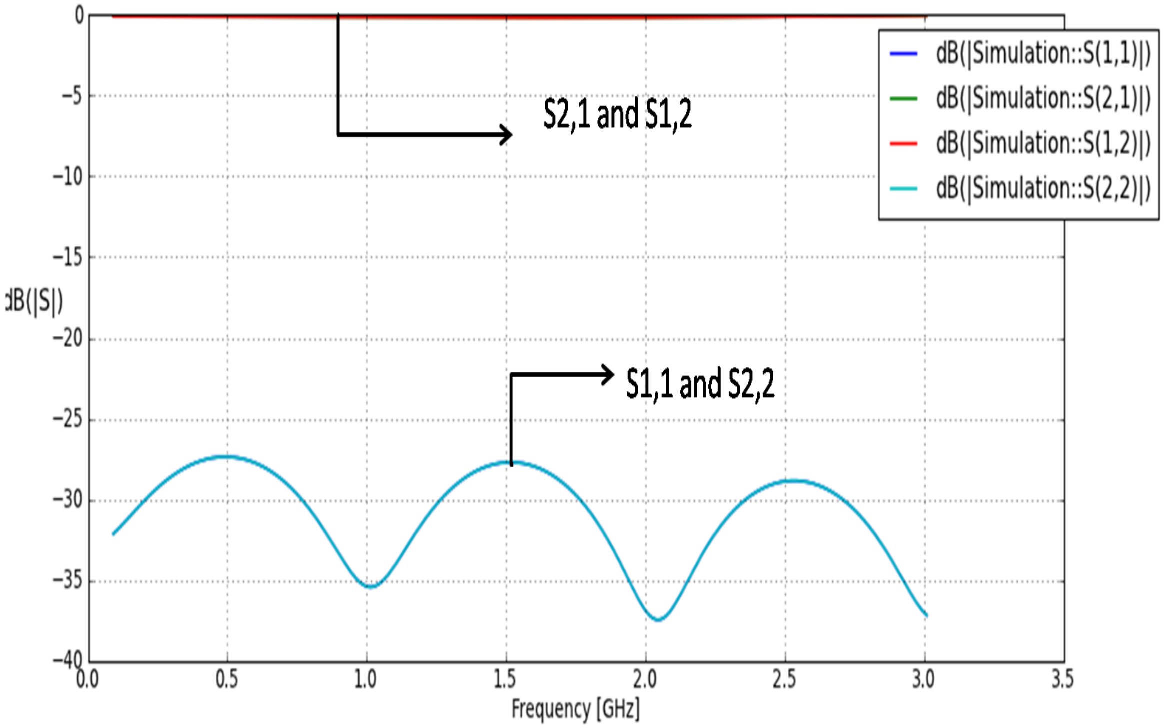
During the simulation, the Message Window will show some details about the performed simulation.

Congratulations, you have simulated the microstripline ! Lets review the results.

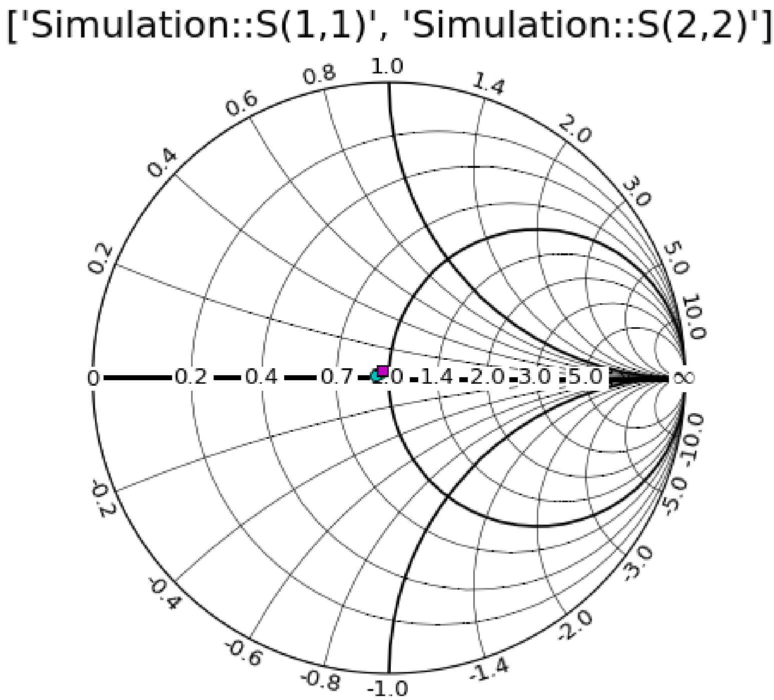
Results:

S-Parameters Results

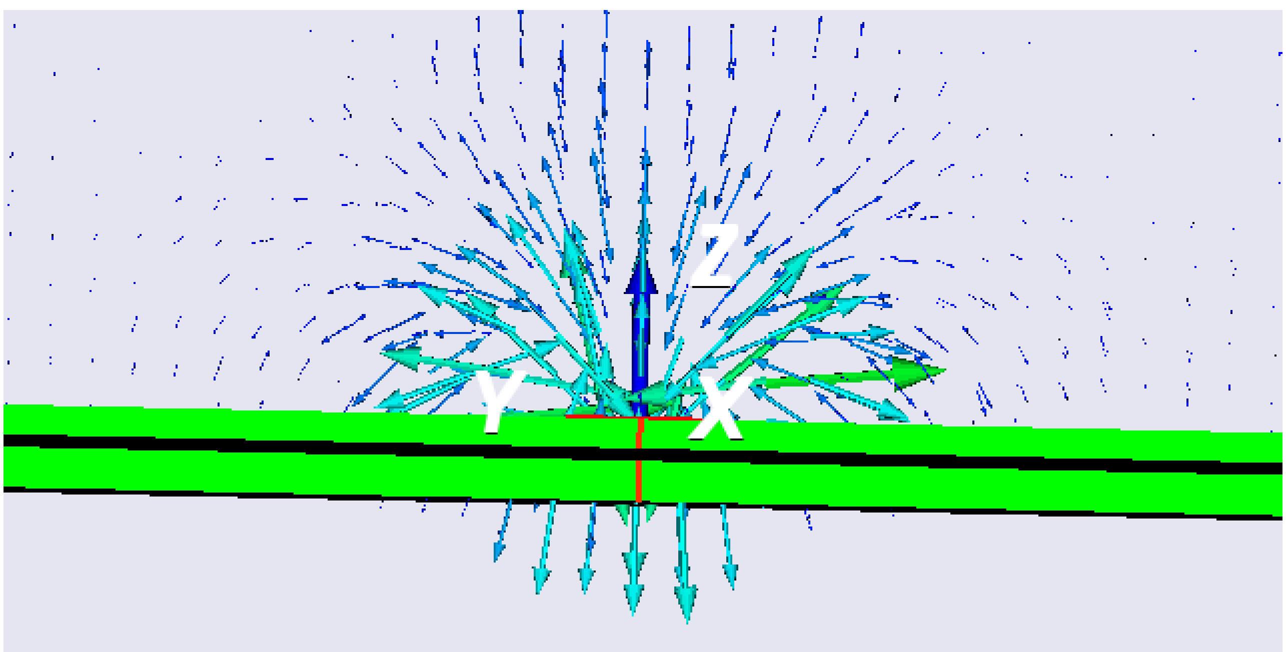
The S-parameters magnitude in dB scale can be plotted by clicking on the *Results: dB* folder



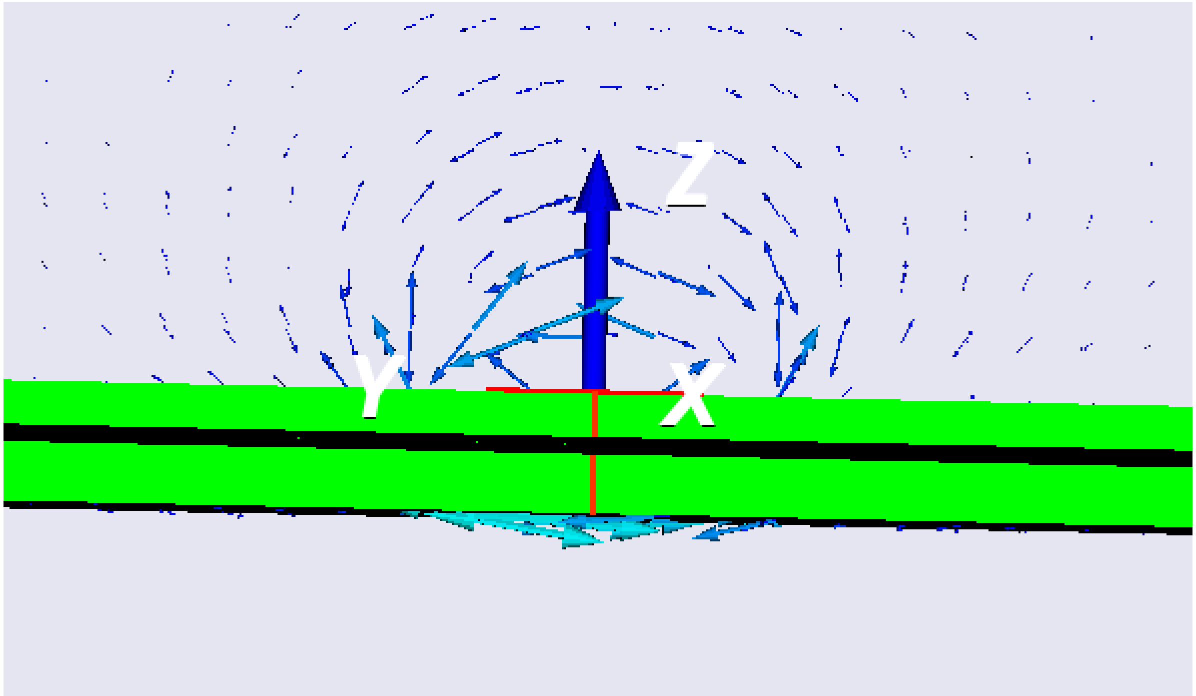
The smith chart can also be seen from Smith chart folder.



The computed electric field – E-field at 1.5 GHz – of the Microstrip Line.



The computed electric field – H-field at 1.5 GHz – of the Microstrip Line.



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Precautions:

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