Antenna Theory and Design
Lab Report

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Abstract

In this lab, LineGauge was used to design a rectangular patch microstrip antenna with a center frequency of 2.3 GHz. The substrate is RT/Duroid 5880 which has a dielectric constant of 2.2. The substrate thickness is 0.787 mm with a lost tangent =0.0009. At the end, S-parameter simulation and plotting the radiation parameters of the rectangular patch was done using slots and without slots.

Technical Method

Microstrip

A microstrip is a thin, flat electrical conductor separated from a ground plane by a layer of dielectric or an air gap. The characteristic impedance (Zc) of the Microstrip-Line is determined by “W”, “d”, and the permittivity of the substrate.

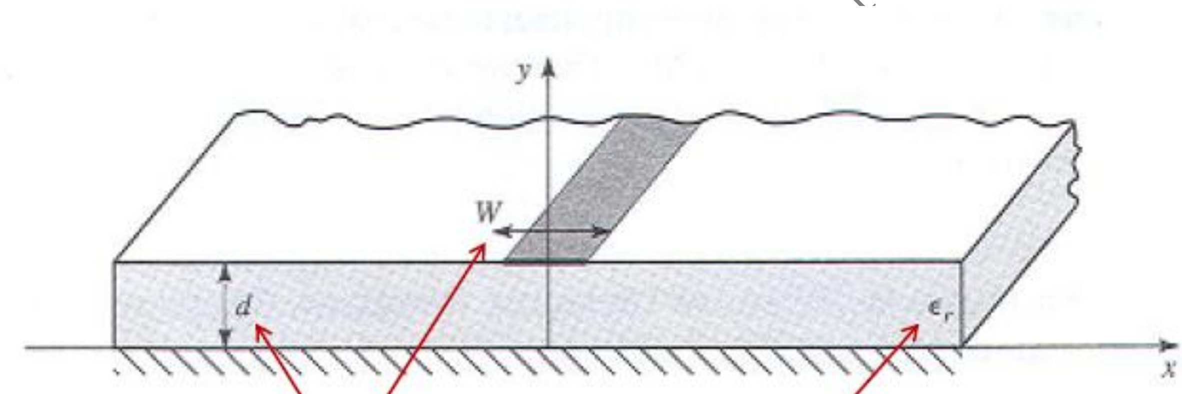

Figure 1(a): Microstrip

Microstrip is a type of electrical transmission line which can be fabricated using printed circuit board technology, and is used to convey microwave-frequency signals. It consists of a conducting strip separated from a ground plane by a dielectric layer known as the substrate. Microwave components such as antennas, couplers, filters, power dividers etc. can be formed from microstrip, the entire device existing as the pattern of metallization on the substrate. Microstrip is thus much less expensive than traditional waveguide technology, as well as being far lighter and more compact.

The EM wave that travels along the microstrip exists partly in the dielectric substrate, and partly in the air. This means the wave is traveling in an inhomogeneous medium (different phase velocities).

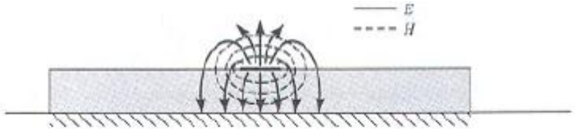

Figure 1(b): Electromagnetic Wave in Microstrip

In one homogenous medium, so the term effective dielectric constant was introduced. We then treat the EM wave as a quasi-TEM wave (a hybrid of TE and TM modes).

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

The characteristic impedance Zo of a microstrip is determined by the width of the strip, the thickness of the substrate and the dielectric constant of the substrate.

$$Z_o(W/d \le 1) = \frac{60}{\sqrt{\varepsilon_e}} \ln\left(\frac{8d}{W} + \frac{W}{4d}\right)$$

$$Z_o(W/d \ge 1) = \frac{120\pi}{\sqrt{\varepsilon_e}\left[W/d + 1.393 + 0.667 \ln(W/d + 1.444)\right]}$$

HyperLynx also provides a way to calculate the characteristic impedance of a microstrip in LineGauge

HyperLynx

HyperLynx is a powerful electromagnetic simulation software. It numerically solves the Maxwell's equations with suitable boundary conditions. It is commonly used among the RF/microwave engineers.

Types of simulation in HyperLynx

- S-Parameter Simulator
- Antenna Characteristics Simulations Including Radiation Pattern, Gain etc.

LineGauge: Analyze and synthesize different types of transmission line structures
S-parameter simulation is used for as following

- Multi-port frequency domain simulation.
- Most commonly used to characterize passive and active RF/microwave components: filters, matching network, LNA, etc.

Flow Chart of the HyperLynx

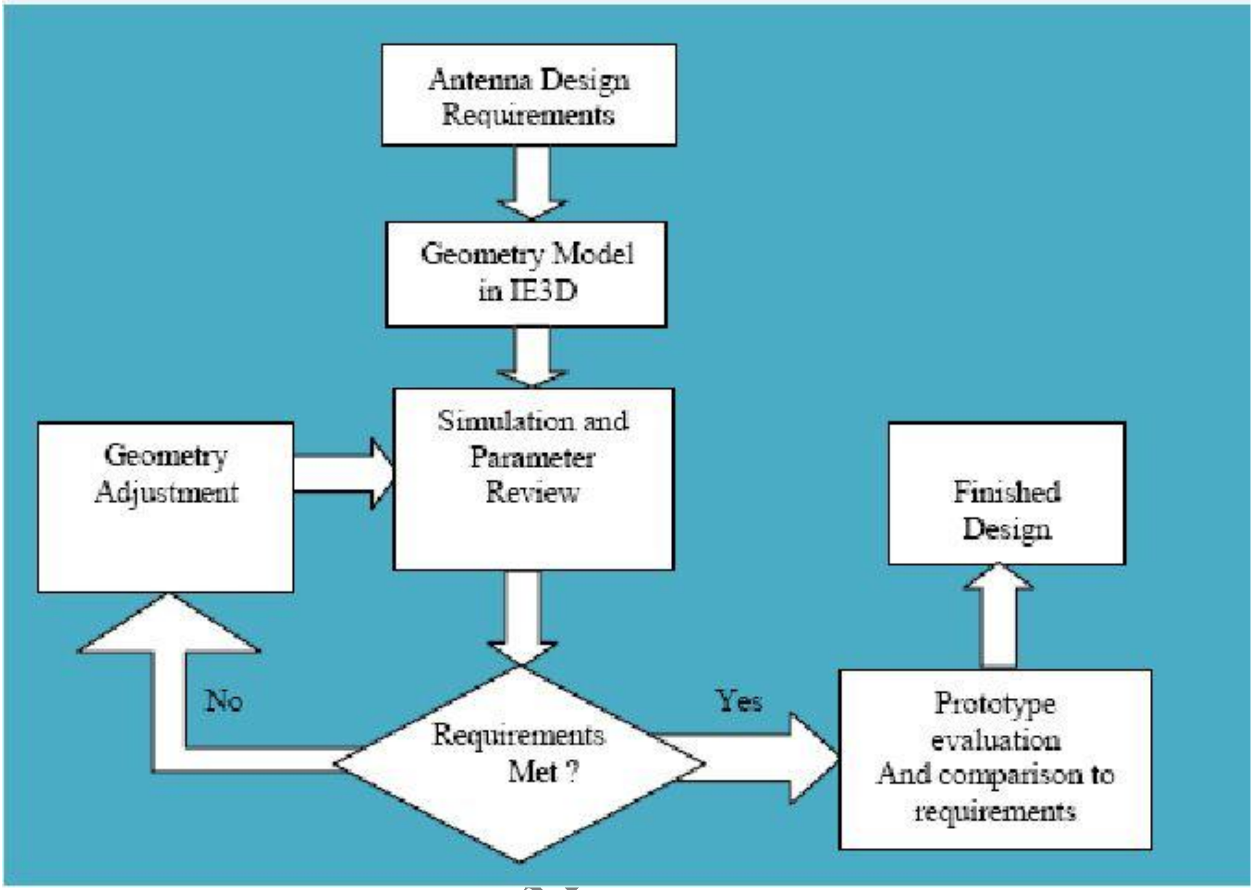

Figure 2: Flow Chart of the HyperLynx

The General Dimension of the Microstrip Antenna

$$W = \frac{v_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} = \frac{3\times10^8}{2\times2\times10^9}\sqrt{\frac{2}{2.2+1}} = 5.9cm$$

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{W}\right]^{-1/2}$$

$$= \frac{2.2+1}{2} + \frac{2.2-1}{2}[1+12\frac{0.787}{59}]^{-0.5}$$
$$= 2.16$$

$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{reff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{reff}-0.258)\left(\frac{W}{h}+0.8\right)}$$

$$= 0.412\frac{(2.16+0.3)(\frac{59}{0.787}+0.264)}{(2.16-0.258)(\frac{59}{0.787}+0.8)}$$

$$= 0.412\times\frac{185.07}{144.11} = 0.529$$

$$\Delta L = 0.787\times0.529 = 0.416mm$$

$$L_e = \frac{\lambda}{2} - 2\Delta L = \frac{300}{2\times2\sqrt{2.16}} - 2\times0.416 = 50.2mm$$

Using the same concept and the equations, the length and width of the microstrip patch is calculated.

$$W = \frac{V_0}{(2f_r)}\sqrt{\frac{2}{\epsilon_r + 1}} = \frac{3.10^8}{2.(2.3G)}\sqrt{2/(2.2+1)} = 0.05156m = 5.156cm = 5.2cm = 52\ mm$$

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left[1 + \frac{12h}{w}\right]^{-0.5} = \frac{2.2+1}{2} + \frac{2.2-1}{2}\left[1 + 12\frac{0.787}{52}\right]^{-0.5} = 2.15$$

$$\frac{\Delta L}{\text{h}} = 0.412\frac{\left(\epsilon_{reff} + 0.3\right)\left(\frac{W}{h} + 0.264\right)}{\left(\epsilon_{reff} - 0.258\right)\left(\frac{W}{h} + 0.8\right)} = 0.412\frac{(2.15 + 0.3)\left(\frac{52}{0.787} + 0.264\right)}{(2.15 - 0.258)\left(\frac{52}{0.787} + 0.8\right)} = 0.529$$

$$\Delta L = 0.787.(0.529) = 0.417\ mm$$

$$L = \frac{\lambda}{2} - 2\boldsymbol{\Delta}\text{L} = 43.6\ \text{mm}$$

Feeding Structures of Microstrip Antennas Equivalent Circuit

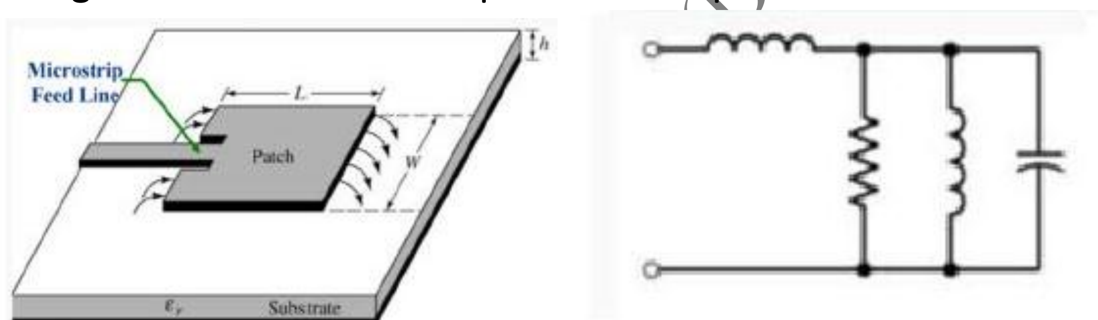

Figure 3: Microstrip Feed line and the Equivalent Circuit

The characteristics of Microstrip Feed are listed below:

- Easy to fabricate
- Simple to match
- Low spurious radiation at around -20dB
- Narrow bandwidth (2-5%)
- The Spurious feed radiation increases as the height of the substrate increases

Structure and Methods

The following steps below were done to get the length and width of the microstrip line.
Step 1: Start “Line Gauge” from Hyperlynx program manager
Step 2: Input Parameters of Microstrip-Lines
Step 3: Do the calculation by click Electrical to Physical (Quarter wavelength)

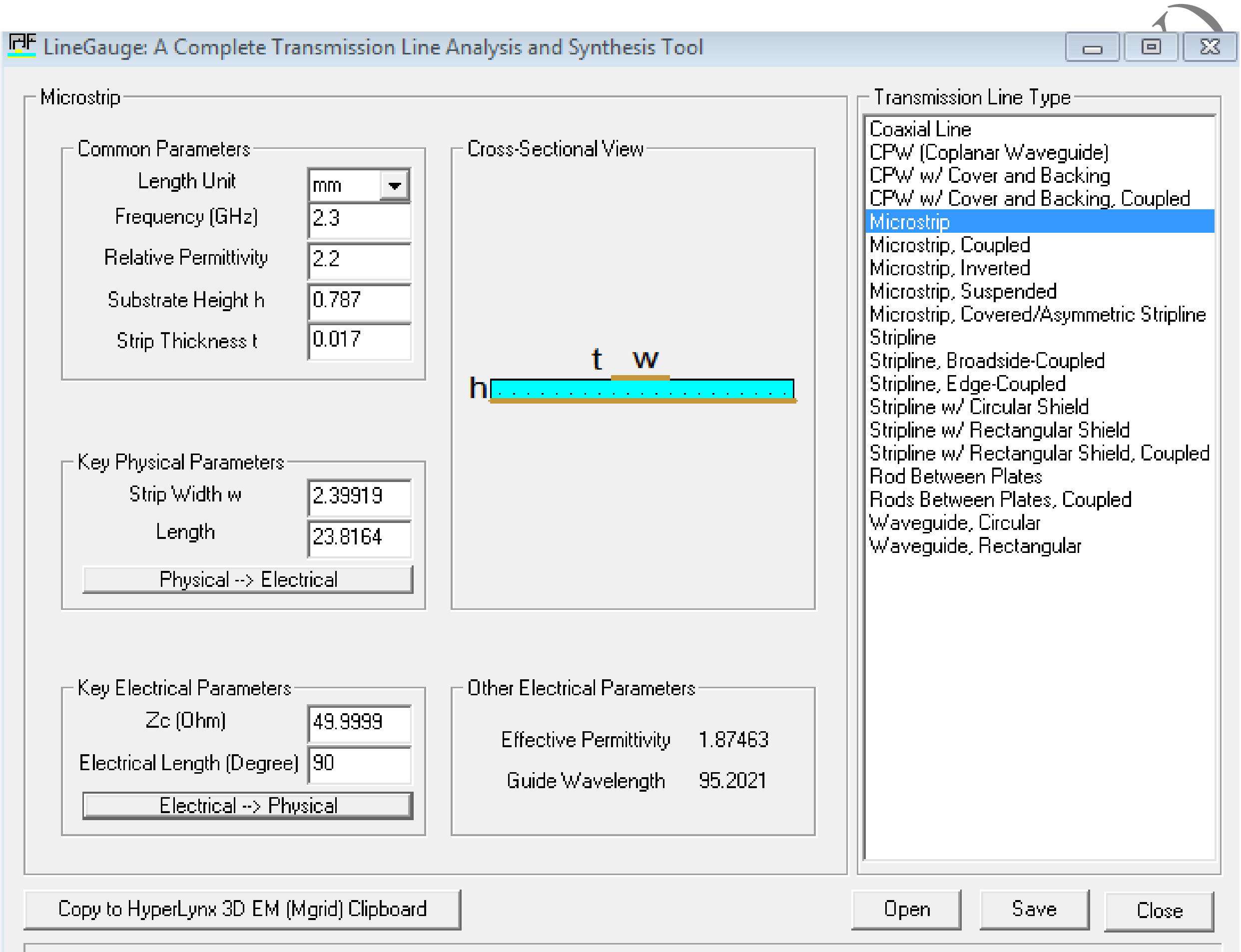

Figure 4: Line Gauge for Microstrip

New Project was created using M-Grid which was selected from Hyperlynx program manager. The following steps below were done.

1. On the main window of the Layout Editor, the icon “file” was clicked and “new” icon was selected.
2. Then the window called “Basic Parameters” popped up
3. The material property was filled using the required values which is shown in figure 5.

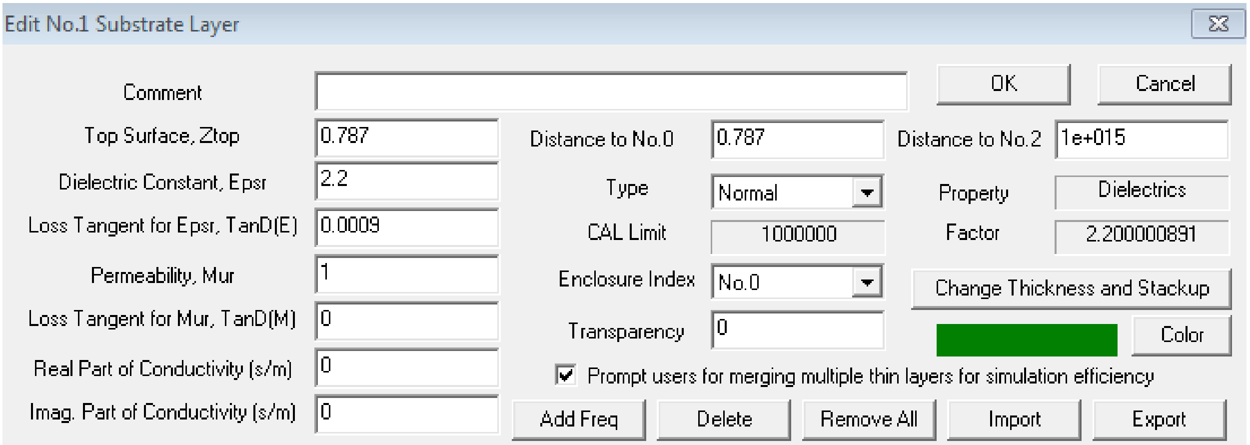

Figure 5: Defining the Substrate Layer (Material Property)

The layout was drawn by using Rectangle entity. The length of the rectangular patch is 43.6 mm and its corresponding width is 52 mm. The length and width of the transmission line is taken from line gauge which is approximately 23.8164 mm in length and 2.39919 mm in width.

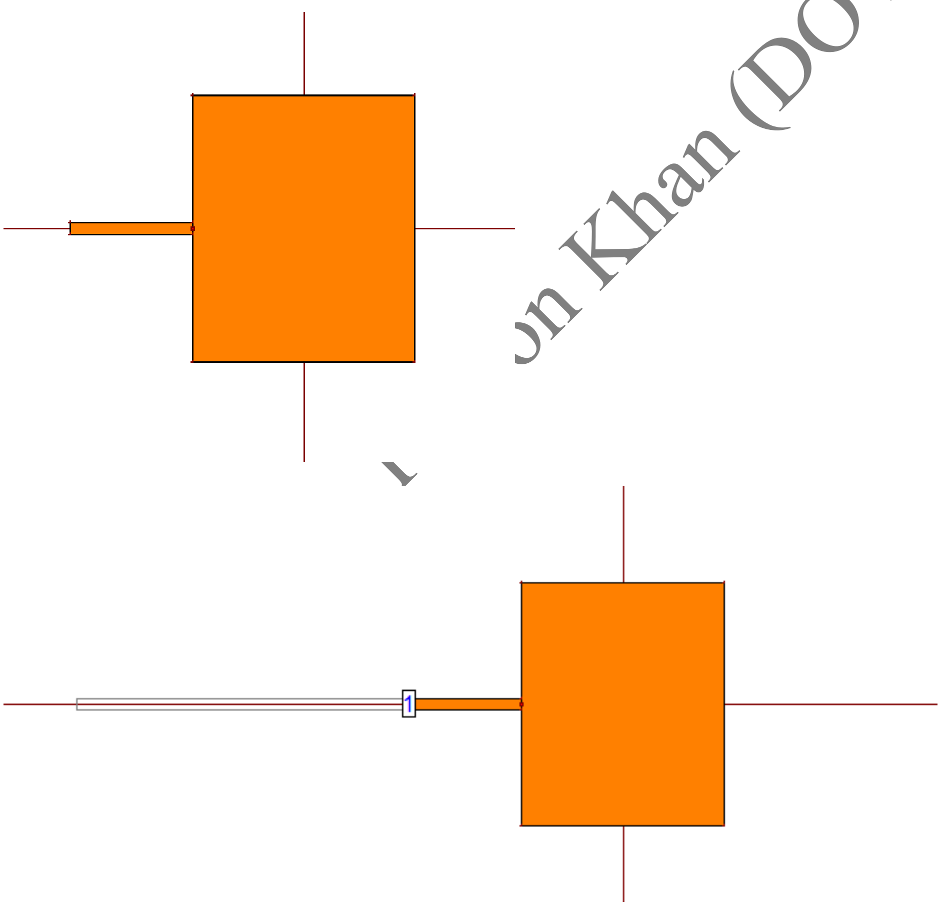

Figure 6: Rectangular patch with transmission line

S-Parameter

The simulation was setup to S-Parameter which are shown in figure 7 and figure 8. S-Parameters are “Scattering Parameters” which are defined to represent the voltage ratios between different ports

Following steps below were followed to setup S-parameter Simulation

- Setup simulation port.
- Setup simulation frequency range.
- Plot simulation results.

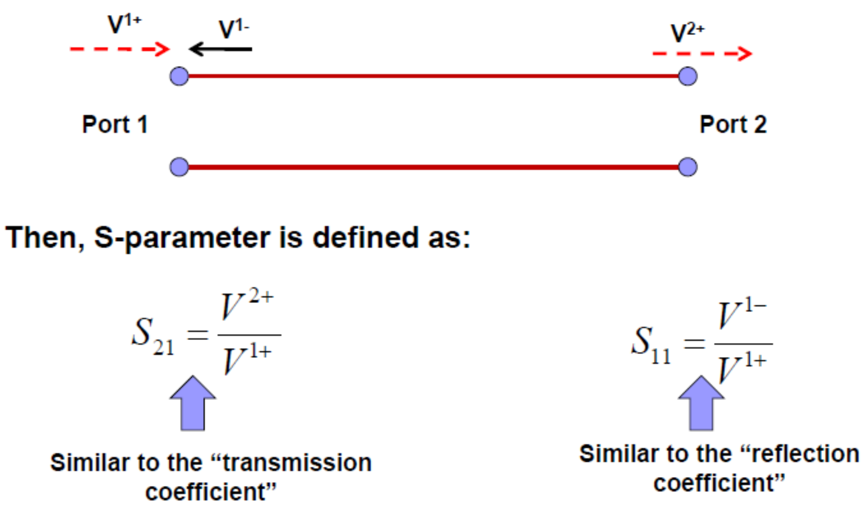

Figure 7: Scattering Properties

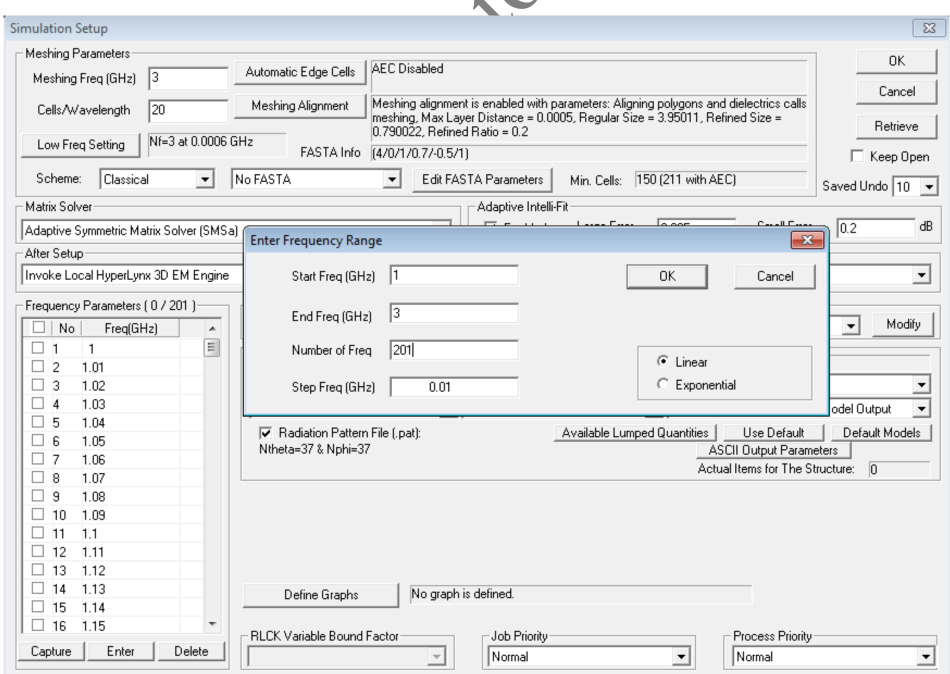

Figure 8: Frequency Range

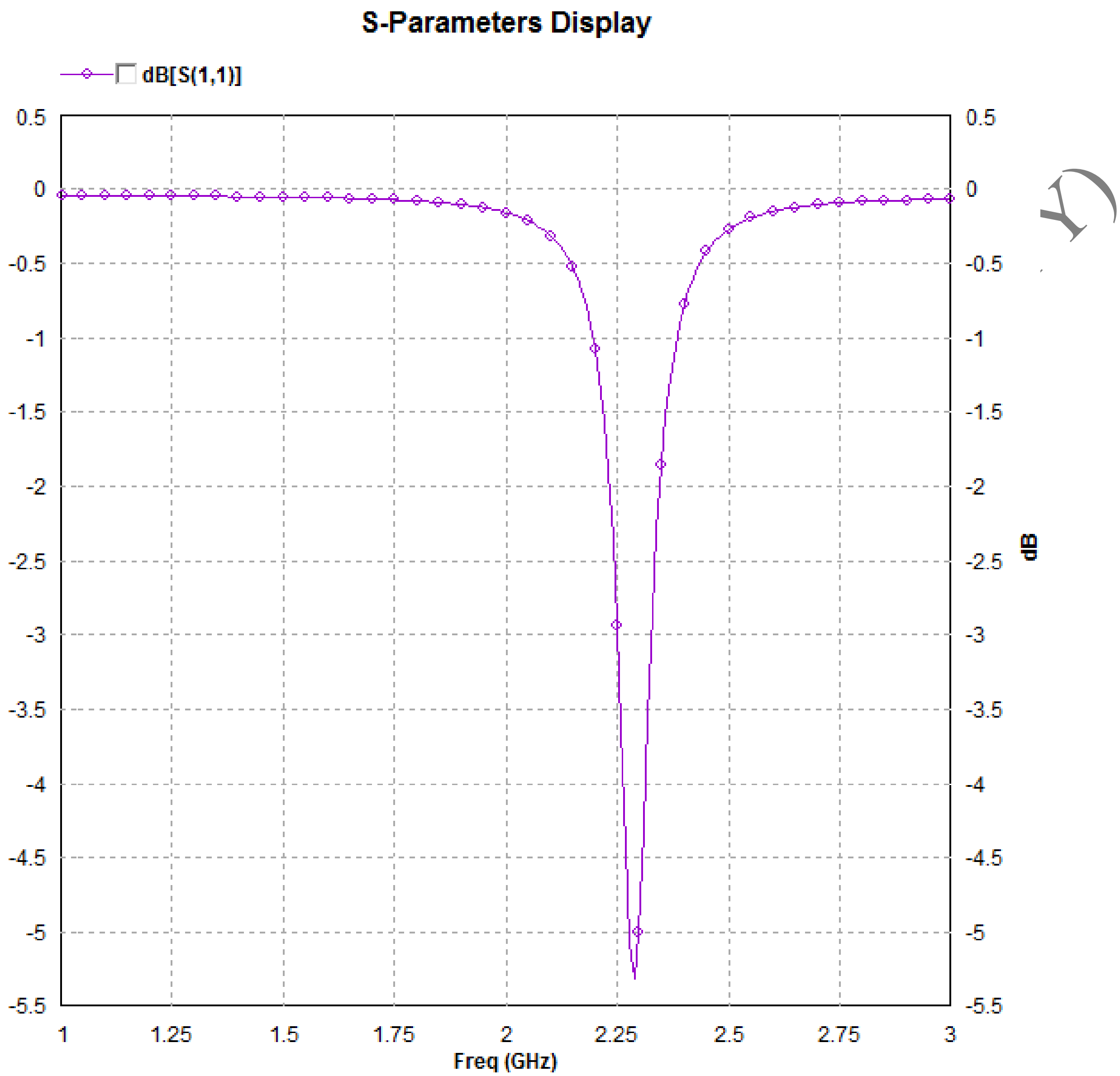

Figure 9: Simulation Graph: Microstrip Patch

The equation below was used to find the original value of the reflection

$$\mathbf{20log_{10}(non\ dB\ value) = (dB\ value)}$$

$$\mathbf{non\ dB\ value = 10^{\frac{dB\ value}{20}}}$$

Therefore, the non-Db value is 0.531.

The designed antenna almost resonates at 2.3 GHz. The S_{11} = -5.5dB is not well matched. Therefore, the impedance matching needs to be improved by creating a slot. Therefore, S_{11} needs to be nearby -20dB (non-dB value = 0.1). The new rectangular patch with a slot is shown below with the simulation graph.

The option for the cut the polygon from the selected edge was chosen and the cut width and length values are shown in Figure 10.

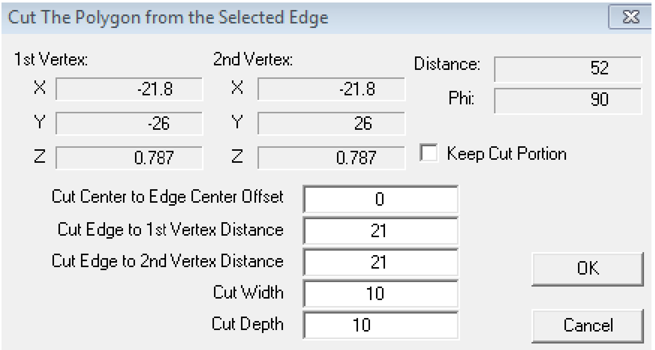

Figure 10: Cut the Polygon from the selected edges

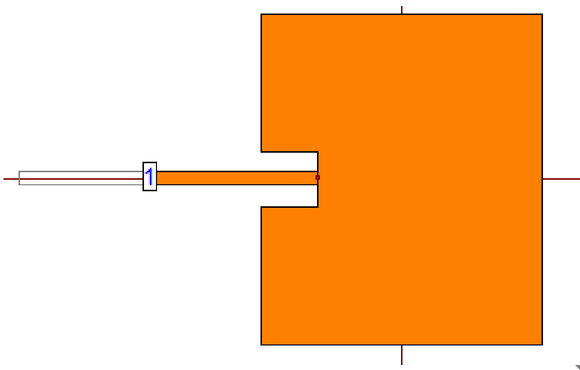

Figure 11: Microstrip Patch with slot

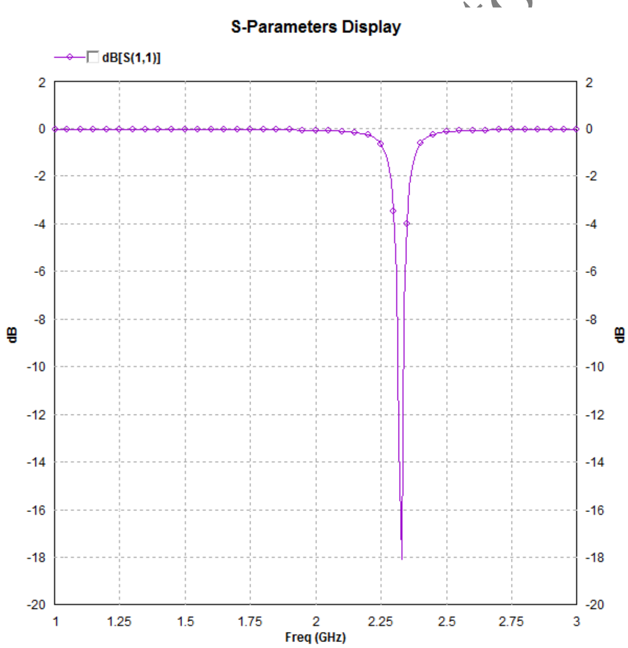

Figure 12: Simulation Graph: Microstrip Patch

S_{11} is nearby -18.0 dB

The graphs related to the simulation are shown below:

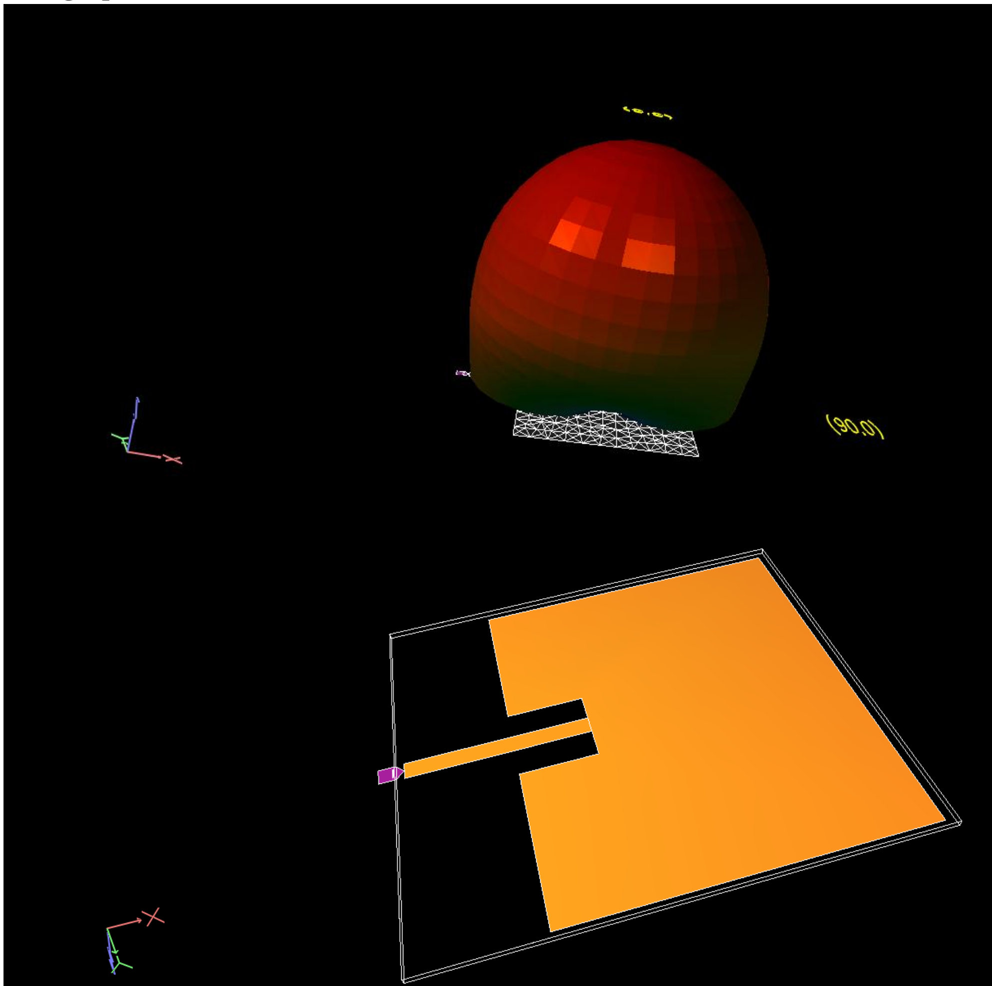

Figure 13: 3D radiation pattern

$$D = \frac{1}{\frac{1}{4\pi}\int_0^{2\pi}\int_0^{\pi}\left|F(\theta,\phi)\right|^2 \sin\theta d\theta d\phi}$$

This equation measures the peak value of radiated power divided by the average, which gives the directivity of the antenna. The typical directivity of the patch microstrip antenna (3.2-6.3) / (5-8 dB) More the directivity more the focused or directional the antenna is. Even though there is no isotropic antenna in real life but it is used as a common reference.

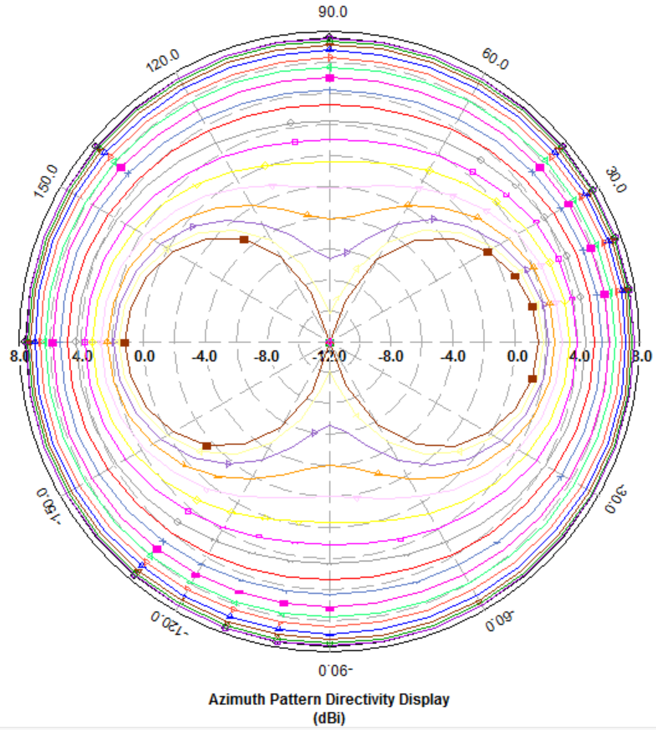

Figure 14: Azimuthal Pattern Directivity Display

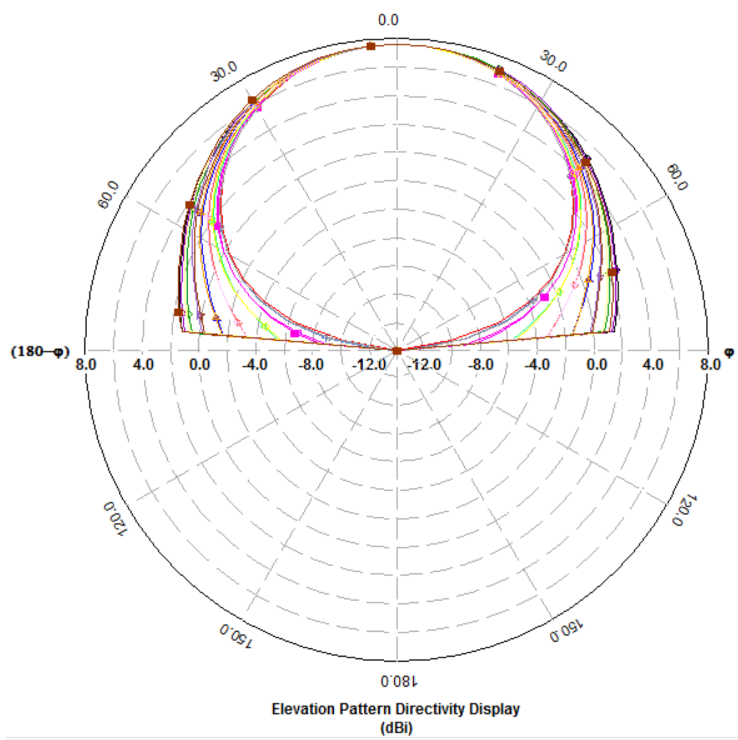

Figure 15: Elevation Pattern Directivity Display

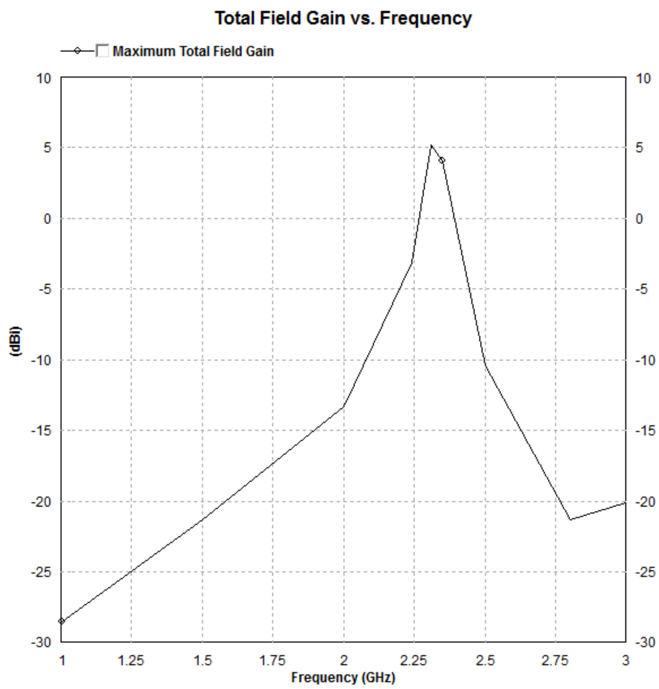

Figure 16: Total Gain versus Frequency Display

From the graph it can be deduced that the total gain is around 4.8dBi at 2.31 GHz but the highest total gain is approximately 5dBi in between 2.25 to 2.31 frequency range.

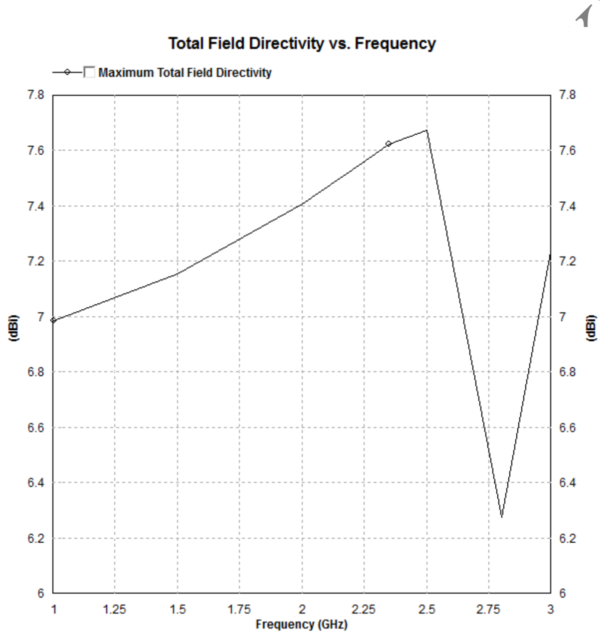

Figure 17: Total Field Directivity versus Frequency Graph

The total directivity is highest at 2.5 GHz which is around 7.6dBi but for 2.31GHz it is 7.55dBi

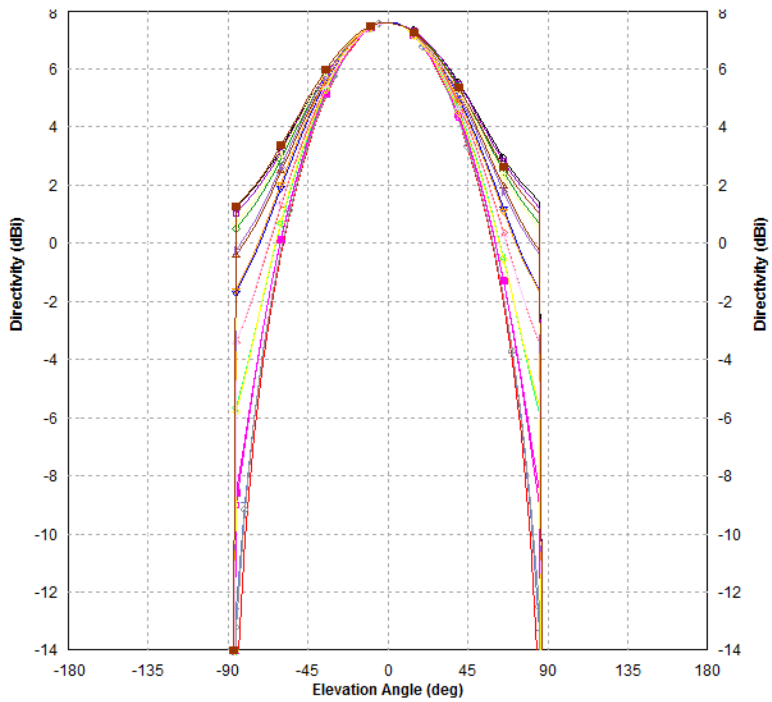

Figure 18: Directivity vs Elevation Angle

The total directivity for 2.31 GHz at 0 degree elevation angle is 7.55 dBi

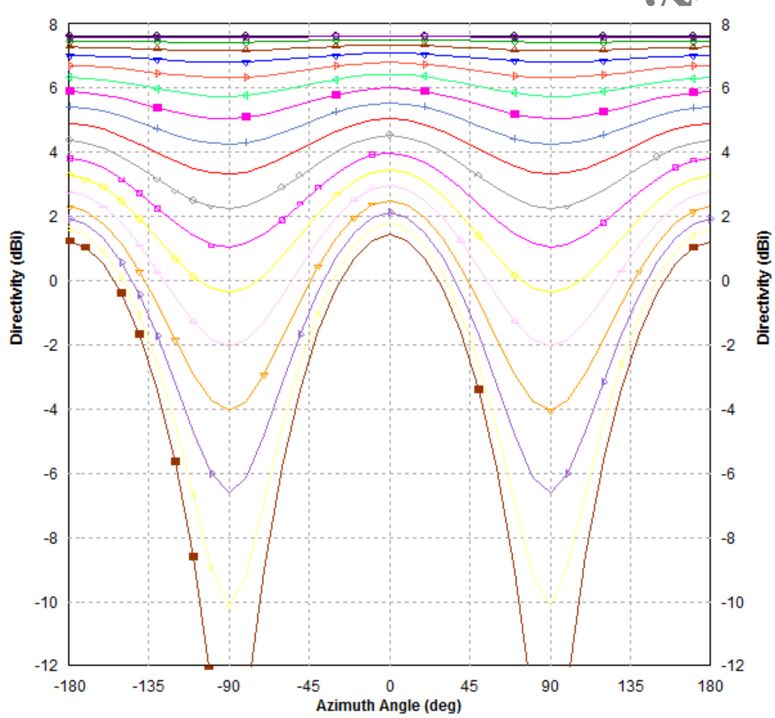

Figure 19: Directivity vs Azimuth angle

Gain, Directivity and Radiation Efficiency

Gain in a direction is given by,

$$G = 4\pi \frac{\text{power radiated per unit solid angle in direction}}{\text{total power accepted from source}}$$

Directivity in a direction is given by,

$$D = 4\pi \frac{\text{power radiated per unit solid angle in direction}}{\text{total power radiated by antenna}}$$

Taking e_r to denote radiation efficiency, when expressed in decibel form, directivity and gain can be related through,

$$G_{dB} = D_{dB} - e_{r\,dB}$$

According to the IEEE standards, gain does NOT include losses arising from:

- Impedance mismatches (reflection losses),
- Polarization mismatches (losses).

$\boldsymbol{G = 4.8\ dBi}$
$\boldsymbol{D = 7.55\ dBi}$
$\boldsymbol{e_r = (7.55 - 4.8)(-1) = -2.75\ dBi}$
$\boldsymbol{Therefore, the\ radiation\ efficiency = 0.53088\ which\ is\ 53\ \%}$

Conclusion and Further Discussion

Problems Faced

The calculations could have been more accurate if the approximate values were not taken. Also, the center frequency moves from 2.3 GHz to 2.31GHz when the slot was implied to the rectangular patch. For calculation for radiation efficiency, it gives the positive dB but that positive value was changed to negative value.

Final Thoughts

This lab helped us to get familiar with the Hyperlynx software. It would further help us to understand the Antenna Theory concepts and calculation inside the transmission line.

References

[1] http://en.wikipedia.org/wiki/Microstrip
[2] Rao, Nannapaneni Narayana. Fundamentals of Electromagnetics for Electrical and Computer Engineering. Upper Saddle River, NJ: Pearson Prentice Hall, 2009. Print.
[3] Balanis, Constantine A. Antenna Theory: Analysis and Design. 3rd ed. Hoboken, NJ: Wiley Interscience, 2005. Print.