PROJECT REPORT

ON

ANTENNA DESIGN, SIMULATION AND FABRICATION

This project report is submitted to IIITN in partial fulfillment of the requirements for the degree of "Bachelor of Technology in Electronics and Communication"

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CERTIFICATE

This is to certify that **Mr. Vipra Nagaich and Mr. Richaansh Gour** *have carried out their project work on* **Antenna Design, Simulation and Fabrication** *in the Electronics and Communication Department of IIIT, Nagpur during the year* **2022-2023**. *Their work is approved for submission in partial fulfillment of the requirements for the degree of "Bachelor of Technology".*

Dr. P. D. Peshwe
Project Guide
Dept. of ECE, IIIT, Nagpur

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ABSTRACT

Wireless technology is one of the main areas of research in the world of communication systems today and a study of communication systems is incomplete without an understanding of the operation and fabrication of antennas. This was the main reason for our selecting a project focusing on this field.

The field of antenna study is an extremely vast one, so, to grasp the fundamentals I have first design and simulated a triple band the inset fed microstrip patch antenna for mobile application and relocation (2.4 GHz, 3.9GHz & 4.5 GHz) using CST software and then fabrication and testing is done in communication lab.

Introduction to Antennas

Our project focuses on the hardware fabrication and software simulation of several antennas. To completely understand the above, it is necessary to start off by understanding various terms associated with antennas and the various types of antennas. This is what is covered in this introductory chapter.

1.1 Antenna parameters

An antenna is an transducer which converts electrical energy into EM energy and vice-versa.

Transmitter - Radiates electromagnetic energy into space
Receiver - Collects electromagnetic energy from space

The IEEE definition of an antenna as given by Stutzman and Thiele is, “That part of a transmitting or receiving system that is designed to radiate or receive electromagnetic waves”. The major parameters associated with an antenna are defined in the following sections.

1.1.1 Antenna Gain

Gain is a measure of the ability of the antenna to direct the input power into radiation in a particular direction and is measured at the peak radiation intensity. Consider the power density radiated by an isotropic antenna with input power P_0 at a distance R which is given by $S = P_0/4\pi R^2$. An isotropic antenna radiates equally in all directions, and its radiated power density S is found by dividing the radiated power by the area of the sphere $4\pi R^2$. An isotropic radiator is considered to be 100% efficient. The gain of an actual antenna increases the power density in the direction of the peak radiation:

$$S = \frac{P_0 G}{4\pi R^2} = \frac{|\mathbf{E}|^2}{\eta} \quad \text{or} \quad |\mathbf{E}| = \frac{1}{R}\sqrt{\frac{P_0 G \eta}{4\pi}} = \sqrt{S\eta}$$

Equation 1.1

Gain is achieved by directing the radiation away from other parts of the radiation sphere. In general, gain is defined as the gain-biased pattern of the antenna.

$$S(\theta,\phi) = \frac{P_0 G(\theta,\phi)}{4\pi R^2} \qquad \text{power density}$$

$$U(\theta,\phi) = \frac{P_0 G(\theta,\phi)}{4\pi} \qquad \text{radiation intensity}$$

Equation 1.2

1.1.2 Directivity

Directivity is a measure of the concentration of radiation in the direction of the maximum.

$$\text{directivity} = \frac{\text{maximum radiation intensity}}{\text{average radiation intensity}} = \frac{U_{\max}}{U_0}$$

Equation 1.3

Directivity and gain differ only by the efficiency, but directivity is easily estimated from patterns. Gain—directivity times efficiency—must be measured. The average radiation intensity can be found from a surface integral over the radiation sphere of the radiation intensity divided by 4π, the area of the sphere insteradians:

$$\text{average radiation intensity} = \frac{1}{4\pi}\int_0^{2\pi}\int_0^{\pi} U(\theta,\phi)\sin\theta\, d\theta\, d\phi = U_0$$

Equation 1.4

This is the radiated power divided by the area of a unit sphere. The radiation intensity *U(θ,φ)* separates into a sum of co- and cross-polarization components:

$$U_0 = \frac{1}{4\pi}\int_0^{2\pi}\int_0^{\pi} [U_C(\theta,\phi) + U_\times(\theta,\phi)]\sin\theta\, d\theta\, d\phi$$

Both co- and cross-polarization directivities can be defined:

$$\text{directivity}_C = \frac{U_{C,\max}}{U_0} \qquad \text{directivity}_\times = \frac{U_{\times,\max}}{U_0}$$

Equation 1.5

Directivity can also be defined for an arbitrary direction *D(θ,φ)* as radiation intensity divided by the average radiation intensity, but when the coordinate angles are not specified, we calculate directivity at $U_{\max}$.

1.1.3 Input Impedance

The input impedance of an antenna is defined as "the impedance presented by an antenna at its terminals or the ratio of the voltage to the current at the pair of terminals or the ratio of the appropriate components of the electric to magnetic fields at a point". Hence the impedance of the antenna can be written as given below.

$$Z_{in} = R_{in} + jX_{in}$$

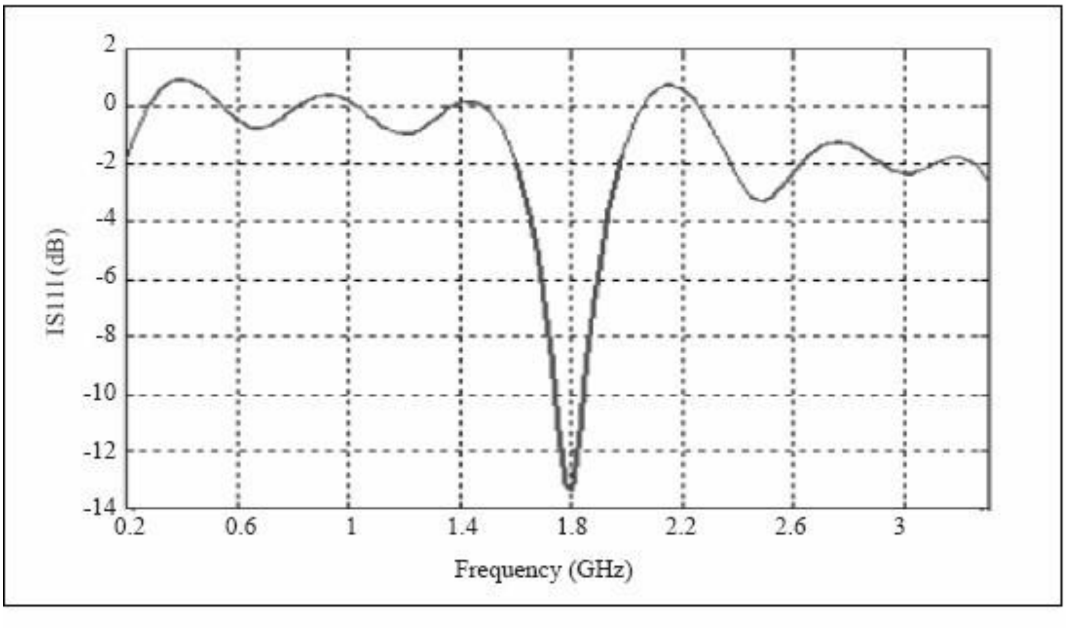
Equation 1.6

where Z_{in} is the antenna impedance at the terminals
R_{in} is the antenna resistance at the terminals
X_{in} is the antenna reactance at the terminals

The imaginary part, X_{in} of the input impedance represents the power stored in the near field of the antenna. The resistive part, R_{in} of the input impedance consists of two components, the radiation resistance R_r and the loss resistance R_L. The power associated with the radiation resistance is the power actually radiated by the antenna, while the power dissipated in the loss resistance is lost as heat in the antenna itself due to dielectric or conducting losses.

1.1.4 Return Loss

It is a parameter which indicates the amount of power that is "lost" to the load and does not return as a reflection. Hence the RL is a parameter to indicate how well the matching between the transmitter and antenna has taken place. Simply put it is the S11 of an antenna. A graph of s11 of an antenna vs frequency is called its return loss curve. For optimum working such a graph must show a dip at the operating frequency and have a minimum dB value at this frequency. This parameter was found to be of crucial importance to our project as we sought to adjust the antenna dimensions for a fixed operating frequency (say 1.9 GHz). A simple RL curve



is shown in Figure 1

Figure 1 – RL curve of an antenna

1.1.5 Radiation Pattern

The radiation pattern of an antenna is a plot of the far-field radiation properties of an antenna as a function of the spatial co-ordinates which are specified by the elevation angle (θ) and the azimuth angle (φ). More specifically it is a plot of the power radiated from an antenna per unit solid angle which is nothing but the radiation intensity. It can be plotted as a 3D graph or as a 2D polar or Cartesian slice of this 3D graph. It is an extremely parameter as it shows the antenna's directivity as well as gain at various points in space. It serves as the signature of an antenna and one look at it is often enough to realize the antenna that produced it.

1.1.6 Beamwidth

Beamwidth of an antenna is easily determined from its 2D radiation pattern and is also a very important parameter. Beamwidth is the angular separation of the half-power points of the radiated pattern. The way in which beamwidth is determined is shown in figure 2.

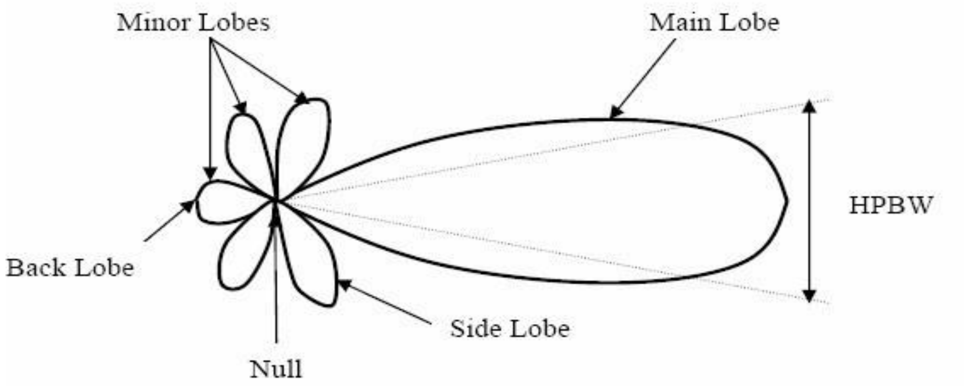


Figure 2 – Determination of HPBW from radiation pattern

1.1.7 VSWR

Voltage Standing Wave Ratio (VSWR) is the wave in the transmission line where distribution of electric parameters like current, voltage or field strength is formed by superposition of two waves of same frequency that propagate in the opposite direction. This voltage standing wave along the line produces a series of nodes and anti-nodes at fixed positions. The VSWR is defined as in [1]:

$$VSWR = \frac{Vmax}{Vmin} = \frac{1+|K|}{1-|K|}$$

Equation 1.7

VSWR should lie between 1 and 2 for efficient antenna performance.

Software Aspects – Design and Simulation of Microstrip Patch Antennas

The software simulations of our project focused on designing and testing of patch antennas using software called CST. Before the software results are presented the theory behind patch antennas is elucidated.

2.1 Introduction

Microstrip antennas are planar resonant cavities that leak from their edges and radiate. Printed circuit techniques can be used to etch the antennas on soft substrates to produce low-cost and repeatable antennas in a low profile. The antennas fabricated on compliant substrates withstand tremendous shock and vibration environments. Manufacturers for mobile communication base stations often fabricate these antennas directly in sheet metal and mount them on dielectric posts or foam in a variety of ways to eliminate the cost of substrates and etching. This also eliminates the problem of radiation from surface waves excited in a thick dielectric substrate used to increase bandwidth.

In its most basic form, a Microstrip patch antenna consists of a radiating patch on one side of a dielectric substrate which has a ground plane on the other side as shown in Figure 3. The patch is generally made of conducting material such as copper or gold and can take any possible shape. The radiating patch and the feed lines are usually photo etched on the dielectric substrate. Arrays of antennas can be photoetched on the substrate, along with their feeding networks. Microstrip circuits make a wide variety of antennas possible through the use of the simple photoetching techniques.

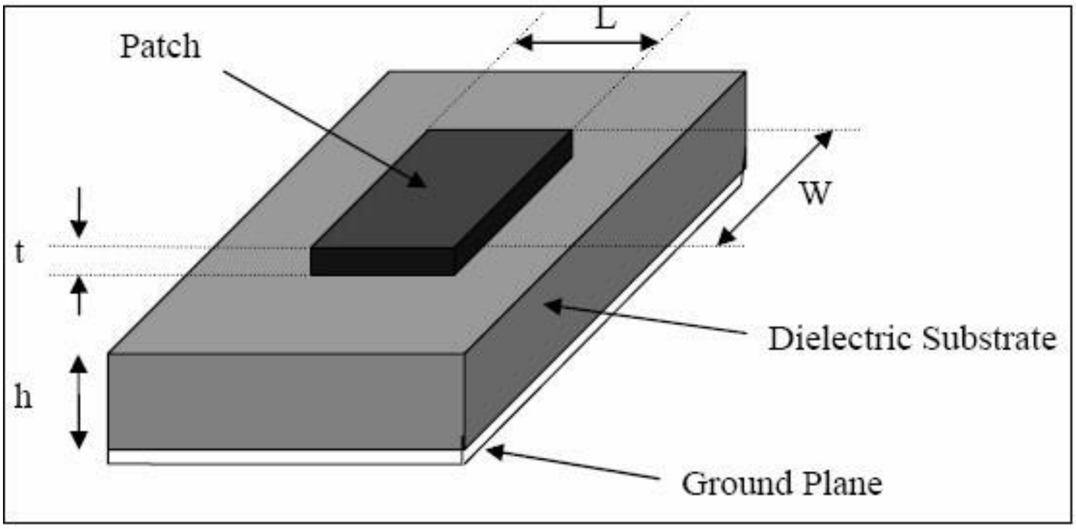


Figure -3 – A Typical Microstrip Patch Antenna

In order to simplify analysis and performance prediction, the patch is generally square, rectangular, circular, triangular, elliptical or some other common shape as shown in Figure 4. For a rectangular patch, the length L of the patch is usually $0.3333\lambda_o < L < 0.5\lambda_o$, where λ_o is the free-space wavelength. The patch is selected to be very thin such that $t << \lambda_o$ (where t is the patch thickness). The height h of the dielectric substrate is usually $0.003\ \lambda_o \leq h \leq 0.05\ \lambda_o$. The dielectric constant of the substrate (ε_r) is typically in the range $2.2 \leq \varepsilon_r \leq 12$.

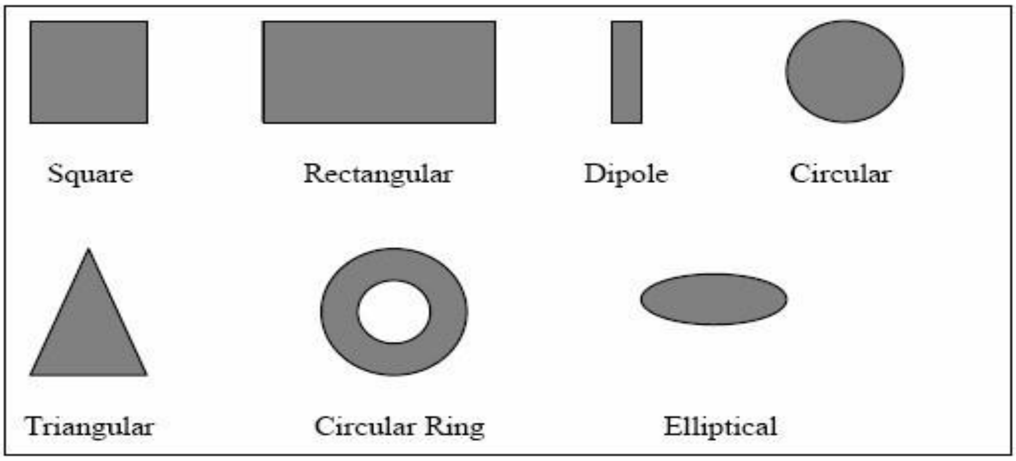


Figure -4 – Typical patch shapes

A patch radiates from fringing fields around its edges. The situation is shown in Figure 5. Impedance match occurs when a patch resonates as a resonant cavity. When matched, the antenna achieves peak efficiency. A normal transmission line radiates little power because the fringing fields are matched by nearby counteracting fields. Power radiates from open circuits and from discontinuities such as corners, but the amount depends on the radiation conductance load to the line relative to the patches. Without proper matching, little power radiates. The edges of a patch appear as slots whose excitations depend on the internal fields of the cavity. A general analysis of an arbitrarily shaped patch considers the patch to be a resonant cavity with metal (electric) walls of the patch and the ground plane and magnetic or impedance walls around the edges.

For good antenna performance, a thick dielectric substrate having a low dielectric constant is desirable since this provides better efficiency, larger bandwidth and better radiation. However, such a configuration leads to a larger antenna size. In order to design a compact Microstrip patch antenna, higher dielectric constants must be used which are less efficient and result in narrower bandwidth. Hence a compromise must be reached between antenna dimensions and antenna perform

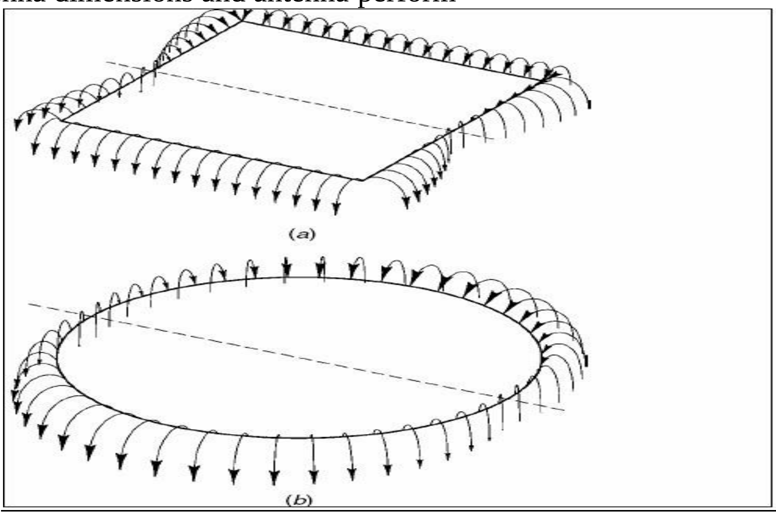


Figure – 5 – Fringing Fields in Patch Antennas

2.2 Simulation of Rectangular Microstrip Patch Antenna

A rectangular was simulated using CST Microwave Studio. The simulation of any antenna requires to go through three basic steps. Firstly, all the unknown parameters are calculated from the list of known parameters. Then port is created, and basic simulation is done to find the S11 parameters. The more simulation is done for further analysis for the patch antenna.

2.2.1 Geometrical Parametrized Design

In the design of the rectangular microstrip patch antenna, the following parameters were known.

- Resonant Frequencies: 2.4GHz, 3.9 GHz and 4.5GHz
- Dielectric Constant: 4.3
- Substrate Material: FR4 (Lossy)
- Microstrip Material: Copper (Annealed)
- Speed of Light: $3*10^8$ m/s

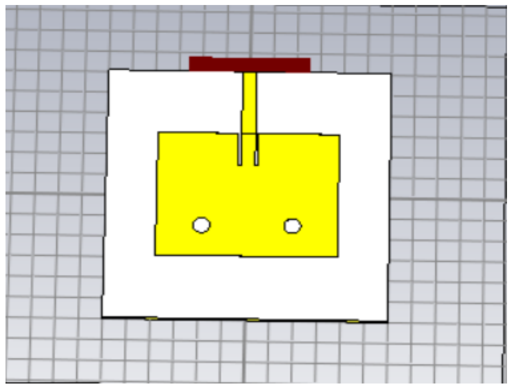


FIGURE 6: Rectangular Micro- strip Patch in CST

Quantity	Symbol	Dimension (mm)	
Length of Patch	L	29.77	
Width of Patch	w	38.39	
Length of Substrate	Ls	60	
Width of Substrate	Ws	60	
Height of Substrate	hs	1.6	
Height of Patch and Ground	Hc	0.035	
Microstrip length	L1	22	
Width of Microstrip	Wf	3	
Radius of circles	R	0.6	
Length of slot	Ll	5	
Width of slot	Wf	0.6	

TABLE 1.1: **Calculated Parameters**

2.2.2 Port Creation and Simulation

The post is fed into the feed-line where a sample decaying input signal is fed. Before simulation of the antenna in CST, some of the properties were set for proper simulation and further simulation and further analysis.

- Frequency range is set from Fmin = 0 to Fmax = 2 GHz.
- Field Monitor (E-Field (2.4 GHz), H-Field (2.4 GHz) & Farfield (2.4 GHz).

2.2.3 Analysis and Return Loss Plot

After the simulation all the parameters were analyzed to check for the desired output of the antenna design. As we can see in figure 7, the S_{11} curve has been plotted. As we can see from the curve the Reflection Coefficient is -27.6 dB at 2.356 GHz, -22.09 dB at 3.64 GHz and -21.41 at 4.694 GHz and have Bandwidth of 80 MHz at 2.36 GHz, 120 MHz at 3.95 GHz and 140 MHz at 4.54 GHz and Gain of 2.19 dBi and beamwidth of 95.2 degree.

We can also visualize the 3-D radiation pattern where the areas in red represent directions having higher antenna gain as compared to area having green color. The areas having blue color have no directivity in the direction indicated. The 3-D plot has been further converted into a 2-D plot with varying equatorial and axial plane angles.

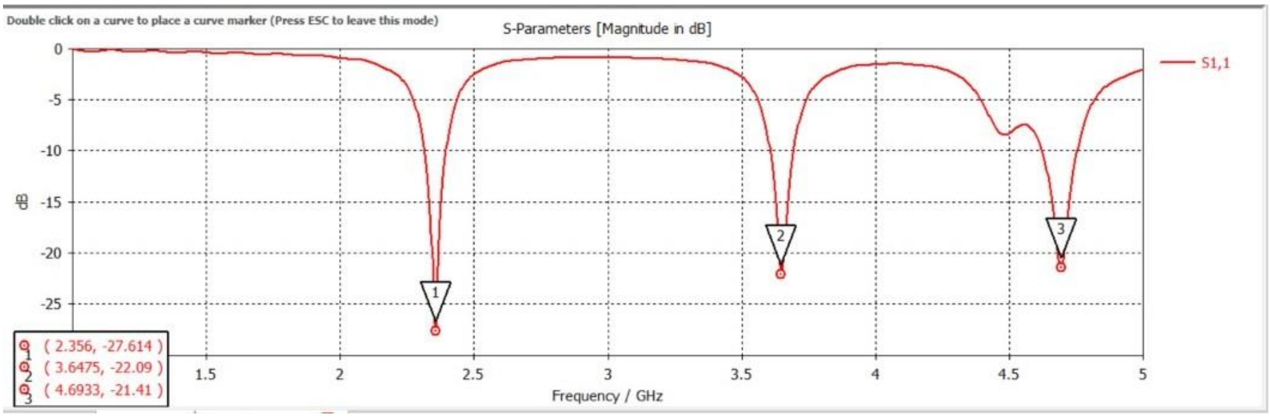


FIGURE 7: S-Parameter Curve Showing the Resonant Frequencies, Bandwidth and corresponding S11 value.

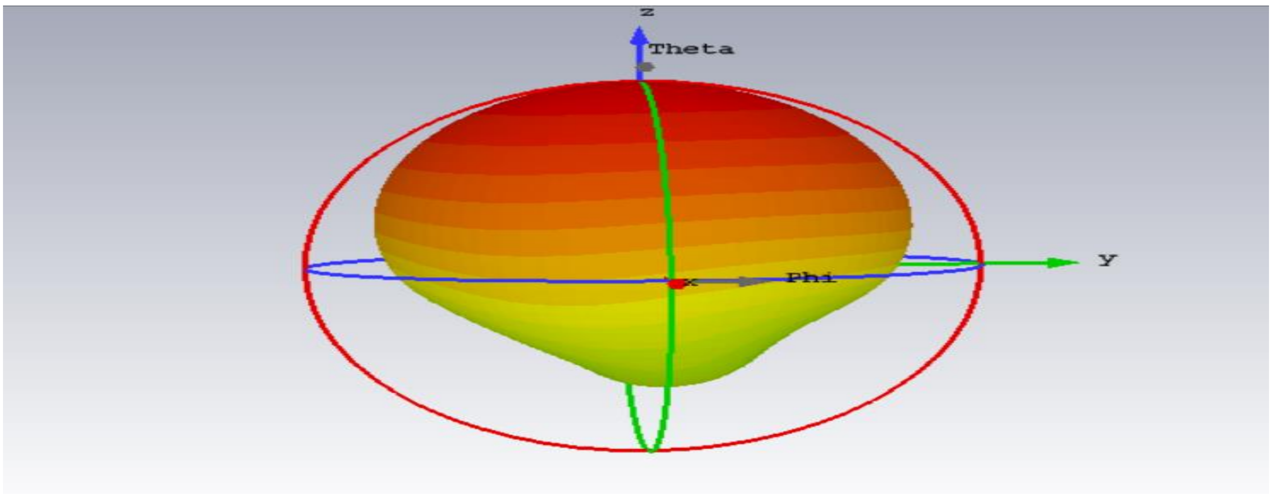


FIGURE 8: Radiation Pattern in 3-D plane

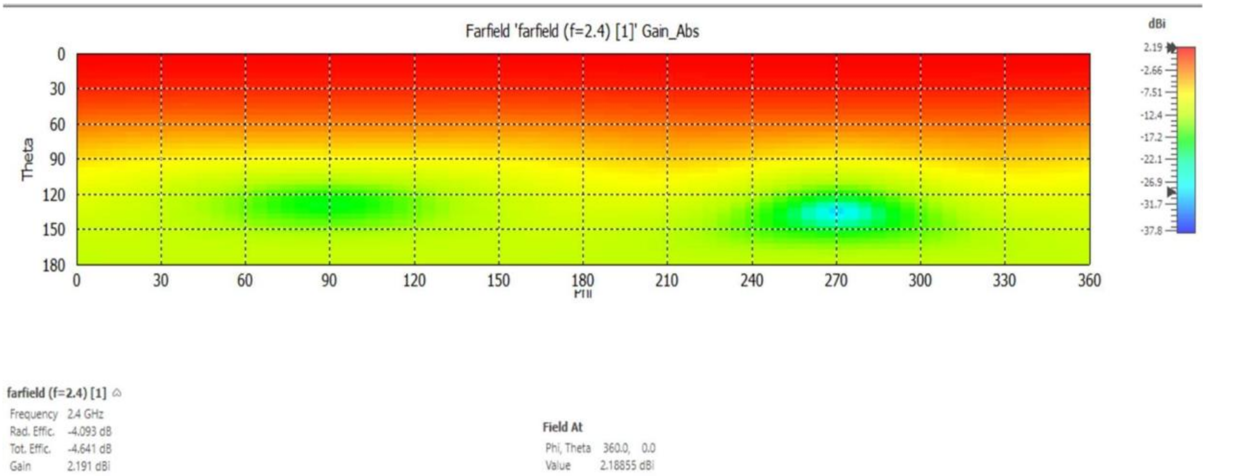


FIGURE 9: Radiation Pattern in 2-D plane

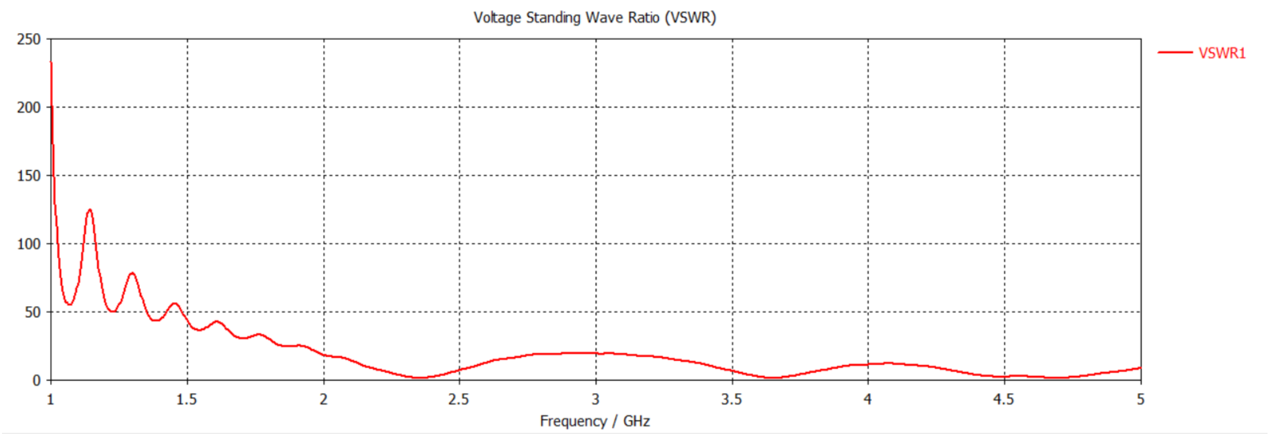


Figure 10: VSWR Results

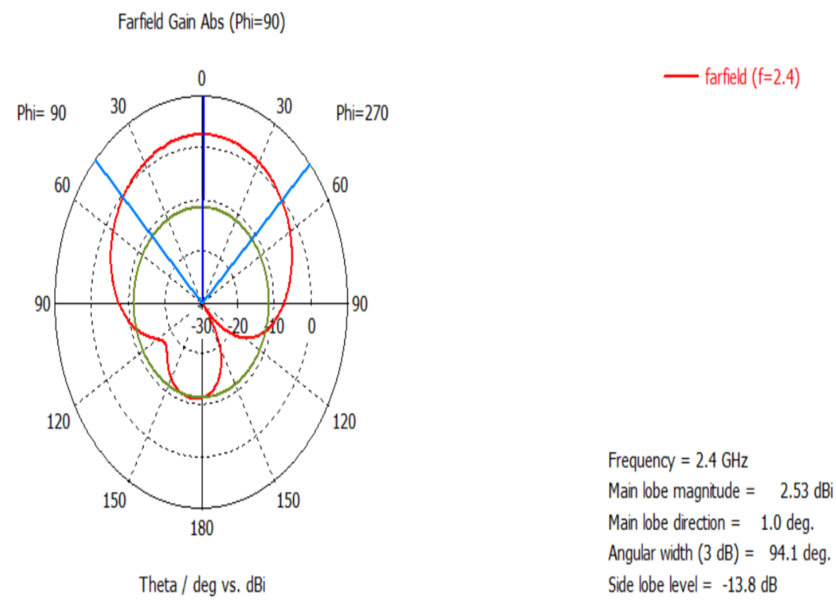


Figure 12. Tested Results are shown here.

3. Conclusions

Upon the conclusion of our project we made the following assessment of our work:

The overall working of antennas was understood. The major parameters (such as Return Loss curves, Radiation Patterns, Directivity and Beamwidth) that affect design and applications were studied and their implications understood. The constructed antennas operated at the desired frequency and power levels. The above design is not a much-optimized design since the VSWR value exceeds the normal value of 100. VSWR is generally expected to lie in between 1 and 2 ideally at the operating frequency.

4. References

- Modern Antenna Design by Thomas Milligan (2nd edn – Thomas Wiley and Sons)
- C. A. Balanis, “Antenna Theory: Analysis and Design”, 1997 by John Wiley & Sons, Inc
- Design of tri band antenna for mobile handset applications