Superior College, Raiwind Road, Lahore

Design and Comparative Analysis of 2.45GHz Rectangular Microstrip Patch Antenna

by

Wardah Ali Haider

Khujasta Khalid

Zeeshan Haider

Jawad Hadi

Zaigham Abbas

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By

Wardah Ali (BAEM-F15-006)

Khujasta Khalid (BAEM-F15-011)

Zeeshan Haider (BAEM-F15-026)

Jawad Hadi (BAEM-F15-031)

Zaigham Abbas (BAEM-F15-032)

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Wardah Ali (BAEM-F15-006)
Khujasta Khalid (BAEM-F15-011)
Zeeshan Haider (BAEM-F15-026)
Jawad Hadi (BAEM-F15-031)
Zaigham Abbas (BAEM-F15-032)

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Abstract

Over the years there has been plenty of development in communication systems which requires the development of low cost, minimum weight, low profile antennas that are efficient for maintaining great performance over a wide spectrum of frequency. The aim of this thesis is to simulate, design and fabricate a rectangular micro-strip patch antenna for analytical studies and global WLAN applications. The antenna is designed to operate at 2.45 GHz resonant frequency. FR-4 is used as a dielectric substrate with relative permittivity of 4.4 and thickness of 1.6 mm for applications like Wi-Fi, Wireless USB , Wireless phones, Bluetooth, Microwave ovens, ZigBee etc. The antenna proposed here have been modeled and simulated using high-frequency structure simulator (HFSS) and designed using MATLAB. The obtained results of antenna's simulation indicate that the designed antenna fulfills the requirements and characteristics for different frequency bands. It also shows good and improved radiation pattern.

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Abbreviations

ISM BAND	Industrial Scientific and Medical Radio BAND
EM WAVE	Electromagnetic Wave
AC	Alternating Current
DC	Direct Current
MS	Micro-strip
MATLAB	Matrix Laboratory
HFSS	High Frequency Simulation Software
VSWR	Voltage Standing Wave Ratio
HPBW	Half Power Bandwidth
BW	Bandwidth
MPA	Micro-strip Patch Antenna

Symbols

ϵ_r	Relative permittivity of the material
$\epsilon_{r_{eff}}$	Effective relative permittivity of the material
W_p	Width of the patch antenna (mm)
L_p	Length of the patch antenna (mm)
ΔL	Change in length of the patch antenna (mm)
W_f	Width of of the fed line for the patch antenna (mm)
L_f	Length of of the fed line for the patch antenna (mm)
h	Height of the substrate (mm)
F	Resonant frequency (GHz) of the patch antenna
d	Inset distance for the patch antenna (mm)
g	Inset gap for the patch antenna (mm)
Z_o	Characteristics impedance of the patch antenna
G	Gain of the patch antenna
D	Directivity of the patch antenna
Γ	Return Loss (reflection coefficient) of the patch antenna
v	Speed of light in free space (3×10^8 ms^{-1})
ε_o	Permittivity of free space

Chapter 1

Introduction

This thesis deals with the software simulation and hardware fabrication of micro-strip rectangular patch antenna for its comparative analysis. To understand that completely, it's better to start by understanding different antenna parameters and its types.

1.1 History

Micro-strip patch antennas belongs to the category of printed antennas: which means utilization of printed circuit manufacturing processes by radiating elements to develop radiating structure and the feed. Of all the printed antennas, including tapered slots, dipoles and slots, micro-strip patches are the most adaptable and popular. This is because of all their key features: including ease of integration, good radiation control and low cost of production. The expression "patch" is derived from the shape of the printed conductor of the antenna: traditionally circular or rectangular [1].

1.2 Problem Statement

In high-performance planes, spacecraft, satellite, and missile technologies where size, weight, expense, efficiency, installation ease, and aerodynamic design are constraints, low-profile antennas maybe required. There are currently many other government and commercial applications with comparable requirements, such as mobile radio and wireless communications. To fulfill these demands, micro-strip antennas can be used [2].

1.3 Scope of this Work

The Micro-strip patch antennas are well known for their performance and their robust design, fabrication and their extent usage. The advantages of this Micro-strip patch antenna are to overcome their de-merits such as easy to design, light weight etc., the applications are in the various fields such as in the medical applications, satellites and of course even in the military systems just like in the rockets, aircraft missiles etc. the usage of the Micro-strip antennas are spreading widely in all the fields and areas and now they are booming in the commercial aspects due to their low cost of the substrate material and the fabrication. It is also expected that due to the increasing usage of the patch antennas in the wide range this could take over the usage of the conventional antennas for the maximum applications [3].

Characteristics of micro-strip patch antenna such as impedance bandwidth can be improved by using multi-layer dielectric configuration. Such a design can be used to avoid detection by foe/enemy by facilitating the use of proposed antenna in communication systems and defense applications in radar.

Micro-strip patch antenna has several applications like:

- Mobile and satellite application
- Global Positioning System (GPS)

- Radio Frequency Identification (RFID)
- Worldwide Interoperability for Microwave Access (WiMax)
- Radar Application
- Rectenna Application
- Telemedicine Application

1.4 Definition

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". So, an antenna can be defined as an array of elements (conductors), connected to a transmitter or a receiver electrically, where;

Transmitter – radiates electromagnetic energy into free space Receiver – intercepts that electromagnetic energy from free space

1.5 Types of Antenna

There are several types of antennas which are briefly discussed below in figure 1.1.

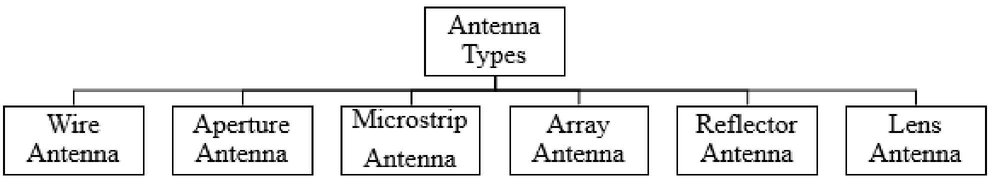


FIGURE 1.1: Antenna types

1.5.1 Wire Antenna

Wire antennas are the most common because they are virtually seen everywhere; on buildings, automobiles, aircrafts, ships etc. These can be of different shapes like single wire, loop and helix etc. Different shapes of wire antennas are shown in figure 1.2

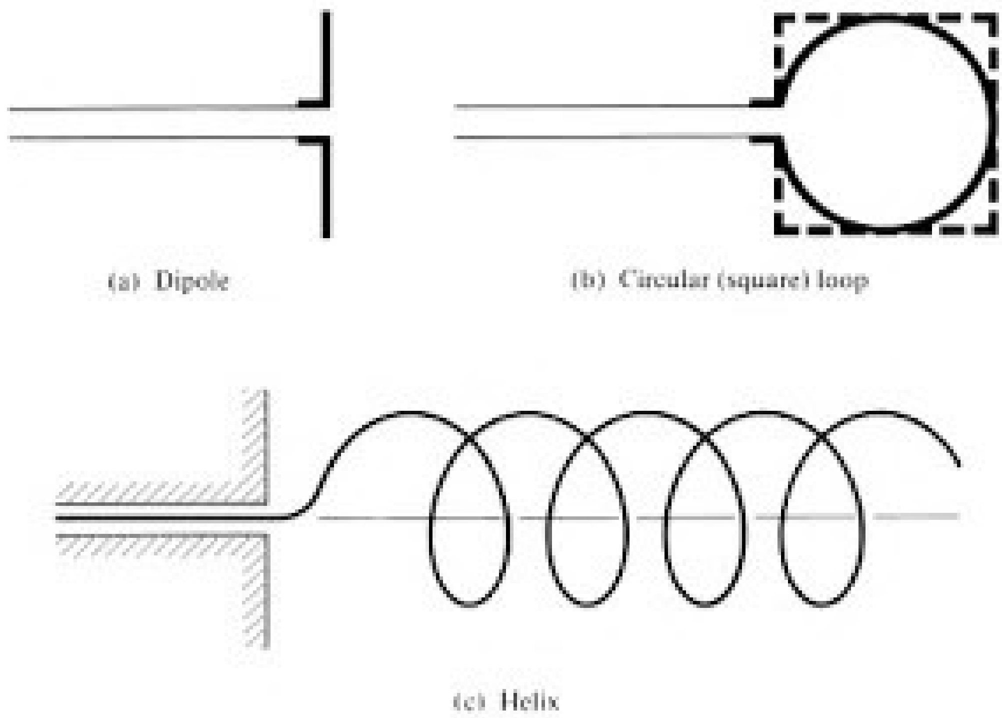
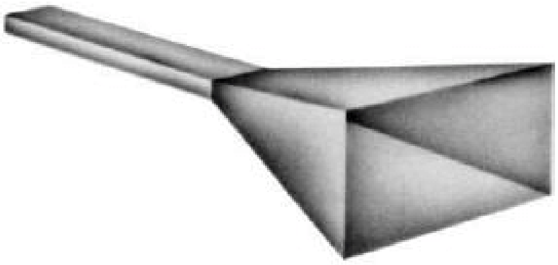


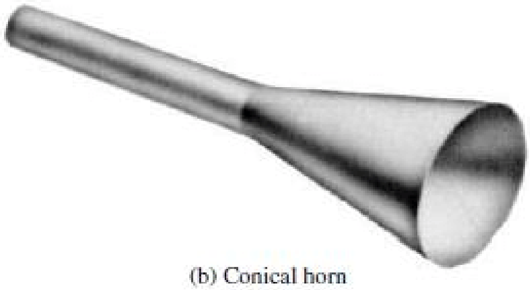
FIGURE 1.2: Wire antenna

1.5.2 Aperture Antenna

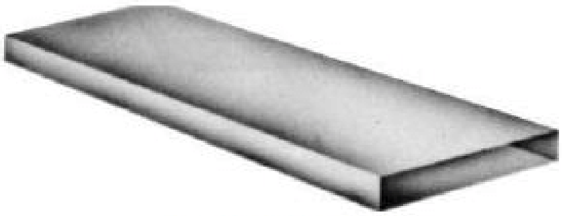
Aperture antenna are becoming more common now-a-days and people are becoming more familiar with them because of the increasing demand for more sophisticated form of antenna and higher frequency utilizations. This type of antennas are very useful for spacecraft and aircraft applications, because the process of mounting them on the skin of an aircraft or a spacecraft is rather convenient. In addition, to protect them from hazardous environmental conditions they can be covered with a dielectric material. Aperture antennas are shown in figure 1.3



(a) Pyramidal horn



(b) Conical horn



(c) Rectangular waveguide

FIGURE 1.3: Aperture antenna

1.5.3 Micro-strip Antenna

Micro-strip antennas started gaining popularity around 1970s mainly because of spaceborne applications. Today they are used for several applications, be it on government level or commercial level. These antennas consist of a metallic patch on a grounded substrate. The metallic patch can take many different configurations, as shown in the figures below. However, the rectangular and circular patches are the most popular because of ease of analysis and fabrication, and their attractive radiation characteristics, especially low cross-polarization radiation. These antennas are low profile, simple and economical to fabricate using PCBs. They are also mechanically robust when placed/mounted on hard or rigid surfaces, compatible with Monolithic microwave integrated circuit (MMIC) designs and very versatile in terms of resonant frequency, polarization, pattern, and impedance. These antennas can be mounted on the surface of aircraft, satellites, spacecraft, cars, missiles, and even handheld mobile phones. Different shapes of MA are shown in figure 1.4

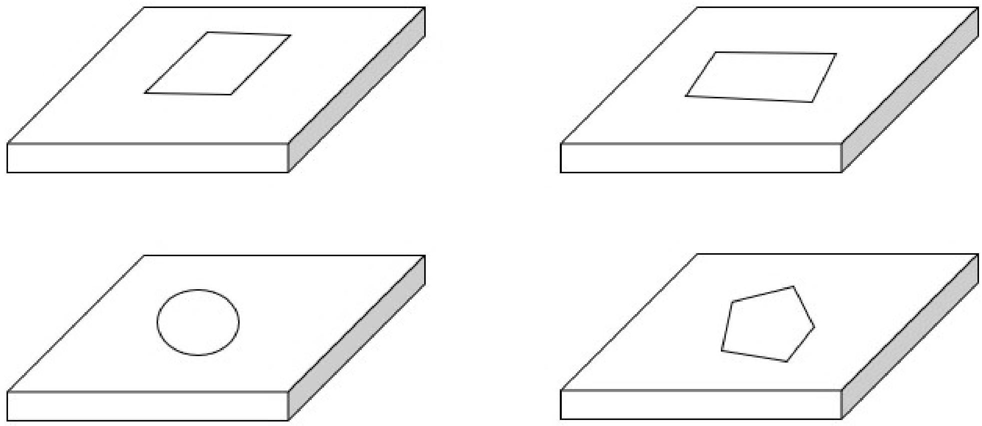


FIGURE 1.4: MPA and its different shapes

1.5.4 Array Antenna

In this antenna aggregate of radiating elements in an electrical or geometrical arrangement (array) results in the desired radiation characteristics. The arrangement of the array may be such that the radiation from the elements adds up to give a radiation maximum in a particular direction or directions, minimum in others, or otherwise as desired. Different types of array antenna are shown in figure 1.5

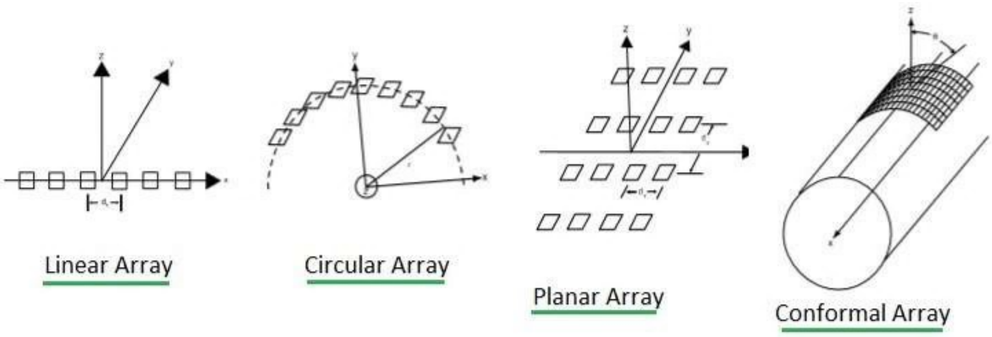


FIGURE 1.5: Various types of array antenna

1.5.5 Reflector Antenna

The success in the exploration of outer space has resulted in the advancement of antenna theory.Because of the need to communicate over great distances, sophisticated forms of antennas had to be used in order to transmit and receive signals that had to travel millions of miles.Reflectors antenna are used for that purpose and shown in figure 1.6

FIGURE 1.6: Reflector antenna

1.5.6 Lens Antenna

Lenses are primarily used to collimate incident divergent energy to prevent it from spreading in undesired directions. By properly shaping the geometrical configuration and choosing the appropriate material of the lenses, they can transform various forms of divergent energy into plane waves. They can be used in most of the same applications as are the parabolic reflectors, especially at higher frequencies. Their dimensions and weight become exceedingly large at lower frequencies. Lens antennas are classified according to the material from which they are constructed, or according to their geometrical shape and its shown in figure 1.7

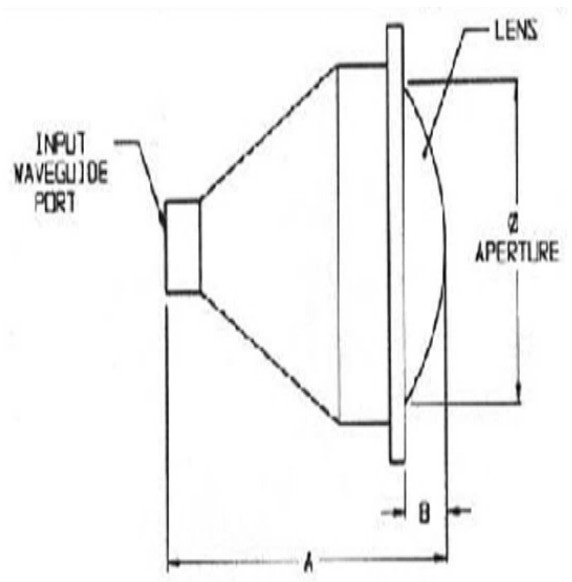


FIGURE 1.7: Lens antenna

1.6 Antenna Parameters

Some of the major antenna parameter like antenna gain, antenna efficiency, raditaion pattern, HPBW etc are discussed in the section below

1.6.1 Antenna Gain

Antenna gain can be defined as " the 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 [4].

Consider the power density radiated by an isotropic antenna with input power P_o at a distance R which is given by $S = P_o/4\pi R^2$.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:

$$S = \frac{P_o\ G}{4\pi R^2} = \frac{|E|^2}{\eta} \tag{1.1}$$

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

$$\text{power density} = S(\theta,\varphi) = \frac{P_o G(\theta,\varphi)}{4\pi R^2} \tag{1.2}$$

$$\text{radiation density} = U(\theta,\varphi) = \frac{P_o G(\theta,\varphi)}{4\pi R^2} \tag{1.3}$$

1.6.2 Antenna Efficiency

The surface integral of the radiation intensity over the radiation sphere divided by the input power P_o is a measure of the relative power radiated by the antenna, or the antenna efficiency [4].

$$\frac{P_r}{P_o} = \int_0^{2\pi}\int_0^{\pi} \frac{G(\theta,\varphi)}{4\pi} \quad \sin\theta d\theta d\varphi = \eta e \tag{1.4}$$

where P_r is the radiated power. Material losses in the antenna or reflected power due to poor impedance match reduce the radiated power.

1.6.3 Effective Area

Antennas capture power from passing waves and deliver some of it to the terminals. Given the power density of the incident wave and the effective area of the antenna, the power delivered to the terminals is the product [4].

$$P_d = SA_{eff} \tag{1.5}$$

For an aperture antenna such as a horn, parabolic reflector, or flat-plate array, effective area is physical area multiplied by aperture efficiency. In general, losses due to material, distribution, and mismatch reduce the ratio of the effective area to the physical area. Typical estimated aperture efficiency for a parabolic reflector is 55%. Even antennas with infinitesimal physical areas, such as dipoles, have effective areas because they remove power from passing waves.

1.6.4 Directivity

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

$$\text{Directivity} = \frac{\text{(maximum radiation intensity)}}{\text{(average radiation intensity)}} = \frac{U_m}{U_o} \tag{1.6}$$

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 in steradians.

$$\text{average radiation intensity} = \frac{\pi}{4}\int_0^{2\pi}\int_0^{\pi} U(\theta,\varphi)\sin\theta d\theta d\varphi = U_o \tag{1.7}$$

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} [4].

It is the ratio between power as gain but has particular direction of field strength.

$$D = \frac{4\pi A_e}{\lambda^2} \tag{1.8}$$

$$D = \frac{4\pi}{\Omega_p} \tag{1.9}$$

Where;

Ω_p = Beam width (degree)

1.6.5 Path Loss

We combine the gain of the transmitting antenna with the effective area of the receiving antenna to determine delivered power and path loss. The power density at the receiving antenna is given by equation 1.3 and the received power is given by equation 1.5. By combining the two, we obtain the path loss as given below [4]

$$\frac{P_d}{P_t} = \frac{A_2 G_1(\theta, \varphi)}{4\pi R^2} \tag{1.10}$$

1.6.6 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 [2]

$$Z_{in} = R_{in} + jX_{in} \tag{1.11}$$

Where;

Z_{in} = Antenna impedance at the terminals

R_{in} = Antenna resistance at the terminals

X_{in} = 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 RL. 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.

1.6.7 Antenna Faactor

The EMC community uses an antenna connected to a receiver such as a spectrum analyzer, a network analyzer, or an RF voltmeter to measure field strength E. Most of the time these devices have a load resistor ZL that matches the antenna impedance. The incident field strength Ei equals antenna factor AF times the received voltage Vrec. We relate this to the antenna effective height: [4]

$$AF = \frac{E_i}{V_{rec}} = \frac{2}{h} \tag{1.12}$$

AF has units $meter^{-1}$ but is often given as dB(m^{-1}).

1.6.8 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 S_{11} of an antenna. A graph of S_{11} 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 1.8 below:

1.6.9 Effective Aperture

Effective aperture is the measure of how much effective an antenna is at receiving radio waves. It is determined by the product of power density and physical are physical area of the antenna.

$$A_e = P_d \times A_{phy} \tag{1.13}$$

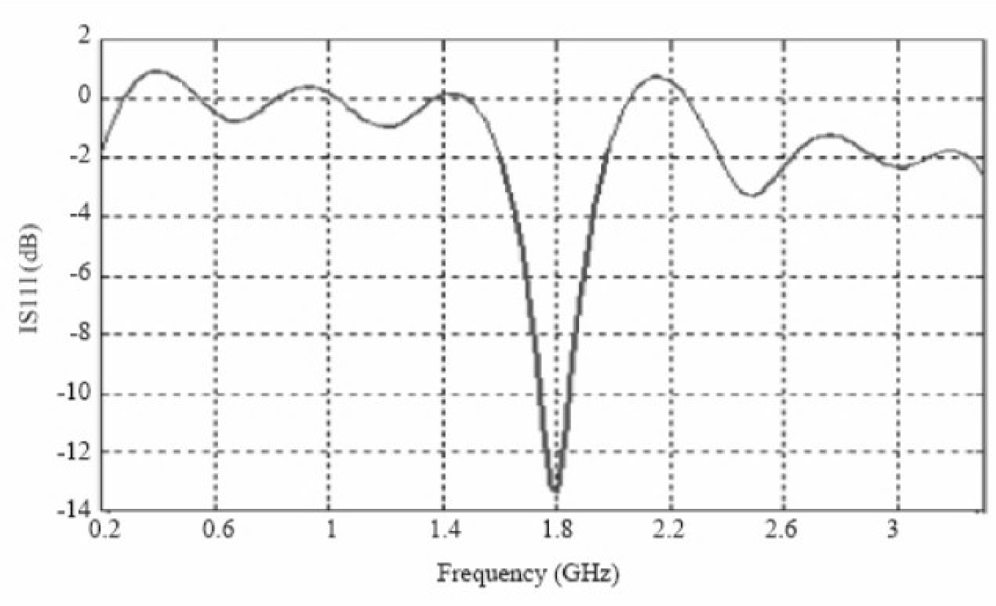


FIGURE 1.8: R-L curve of an antenna

where;

P_d = Power Density

A_{phy} = Physical Area

The effective aperture can also be calculated if the gain and frequency at which the antenna is operating are known.

$$A_e = \frac{G\lambda^2}{4\pi} m^2 \tag{1.14}$$

where;

G = Gain

A_e = Effective Aperture

λ = Wavelength at the operating frequency

As the wavelength increases the effective aperture also increases which increases the size of the antenna and therefore the cost also increases. Hence the higher the operating frequency smaller will be the size of antenna so it can operate on low power easily.

1.6.10 Effective Length

Effective length is the ratio of induced open circuit voltage and the incident field strength. It is measured in meters (m).

$$L_e = \frac{G\lambda^2}{4\pi} m \tag{1.15}$$

1.6.11 Half Power Beamwidth

Half power beam width (HPBW) is the half of the beam width (BW) angle also measured in degrees as shown in Fig 1.9 below:2

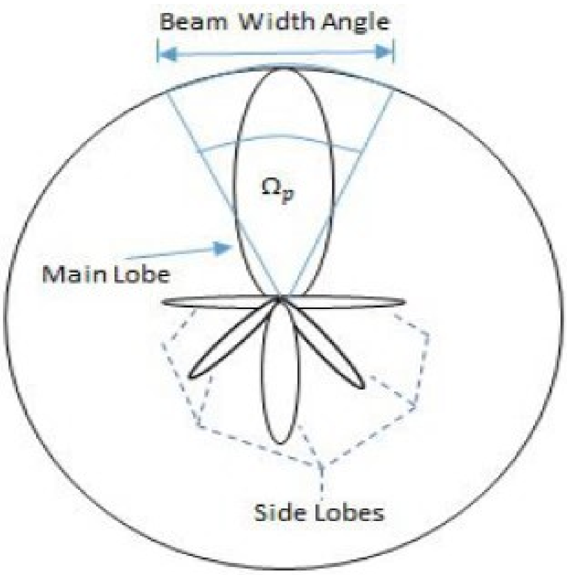


FIGURE 1.9: Main lobe represents the desired useful power and Ω_p beam width angle

1.6.12 Bandwidth

Bandwidth is the range of frequencies over which an antenna properly radiates energy and receive energy. The bandwidth is the difference between high frequency and low frequency. It can be represented by 'B'.

$$B = F_{high} - F_{low} \tag{1.16}$$

1.6.13 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 important 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. Because this parameter was so important to our software simulation, we needed to understand it completely. For this purpose, we obtained the 2D polar plots of radiation patterns for our antennas in our lab using an infinite technology antenna trainer kit IT-8400 shown in figure 1.10

FIGURE 1.10: Antenna trainer kit IT-8400

1.7 Summary

In this chapter we have defined the basic scope of our work and different parameters of antenna that are useful to know before diving into the design, simulation and fabrication phase of proposed antenna. Different types of antenna and how they are being used in different fields is also covered in this chapter.

Chapter 2

Literature Review

2.1 Introduction

These are following research papers in which microstrip rectangular patch antenna is developed such as:
Nuraddeen Ado Muhammad et al. [1] designed and analyzed a simple line fed microstrip patch antenna for global WLAN applications and analyzed its different parameters like directivity, gain, band width, VSWR, return loss and far-field etc. The antenna designed in this has 2.45 GHz resonant frequency and Rogers RT5870 as a dielectric substrate having relative permittivity of 2.33 and thickness of 0.787 mm for standard applications such as IEEE 802.11 Wi-Fi, IEEE 802.15.1 Bluetooth, IEEE 802.15.4 ZigBee, wireless USB, microwave oven, codeless phone etc. Good results were obtained due to proper impedance matching at the optimized feed point on the design the Voltage standing wave ratio (VSWR) is 1.1604 and the bandwidth of 25.5MHz were obtained.

Margarita et al. [5] designed a pentagonal antenna as equivalent to a circular patch antenna for global positioning system (GPS) operating frequency. A simple design equation of circular antenna was used to design this because it only requires the knowledge of group wavelength, effective permittivity and operating frequency. But this equation is only recommended for the substrate FR-4, because antenna's low cost is based on the substrate material used , but for commercial purposes the substrate must be changed in order to obtain a bigger and competitive patch antenna gain.

Srivatsa et al. [6] did parametric study, design and implementation of single patch, wide band aperture coupled microstrip patch antenna for 2 GHz frequency range. Aperture coupled microstrip patch antenna was designed for 25% bandwidth and was fabricated and was measured to have 23% band width. The foam substrate was used for this design with the thickness of 17 mm. The structure designed was only a two-cavity structure but to increase the bandwidth further increase the number of resonant cavities in the structure which leads to other wide banding techniques such as design with stacked patches, slots on ground plane. Also making the S_{11} flat all through the band helps in having uniform gain all over the band. Hence along with the presently designed structure if additional resonant cavities are added it leads to significant improvement in the band width.

Rajesh et al. [7] investigated air gap between single patch antenna and aperture coupled microstrip antenna. By using air gap variation between single patch antenna and aperture coupled microstrip antenna is obtained dual- band operation. It is observed from experimental results good impedance matching at both resonant frequencies. The overall band width is also achieved 35% of the aperture coupled microstrip antenna. The ratio of resonance frequency ratio is found decreasing (2.1 to 1.6 GHz) with increasing the air gap variation. The main advantage of this type antenna is increased the bandwidth of the antenna as compared to a single layered patch antenna. Therefore, the proposed antenna can be used for dual sim mobile application. The two resonant frequencies can vary over a wide frequency range and the input impedance is easily matched for both frequencies. The input impedance and VSWR return loss have been measured with the help of Network analyzer.

Umair et al. [8] presented the design of a dual band 8-element microstrip patch antenna (MPA) for future 5G mobile communications. The proposed antenna array is compact and precise with size of 16 x 16 mm^2 at 28 and 38 GHz, respectively. The dual-band response is achieved by etching an inverted U-shaped slot from the main radiator. It is observed from the results that the proposed array is able to provide resonance for desired frequency bands. The proposed antenna array also assure reduced mutual coupling with an acceptable gain and radiation characteristics Furthermore, the proposed antenna array exhibits omni-directional radiations and offer an acceptable gain for both frequency bands.

Indrasen et al. [3] discussed the microstrip antenna, types of microstrip antenna, feeding techniques and application of microstrip patch antenna with their advantage and disadvantages over conventional microwave antennas. The study of microstrip patch antennas has made great progress in recent years. Compared with conventional antennas, microstrip patch antennas have more advantages and better prospects. They are lighter in weight, low volume, low cost, low profile, smaller in dimension and ease of fabrication and conformity. Moreover, the microstrip patch antennas can provide dual and circular polarizations, dual-frequency operation, frequency agility, broad bandwidth, feedline flexibility, beam scanning omnidirectional patterning

E. Aravindraj et al. [9] did a comparative study in which four rectangular microstrip antennas were designed at different frequencies like 2.4 GHz, 3.5 GHz, 5.2 GHz and 5.8 GHz using two different antenna design tool kits i.e. Advance Deign Software (ADS) and High Frequency Signal Simulation (HFSS). FR-4 is used as a substrate and microstrip feed line is used to excite the feed. The comparison is based on the variations obtained in the design parameters like length, width and height and their respective simulation parameters. This paper concludes that the both the tools provides an efficient simulation parameter but taking design parameter under account HFSS tool provides accurate design for an operating frequency.

A. A. Qureshi et al. [10] investigated the use of FR-4 substrate for antenna design in the X-band. To do that single microstrip patch antenna have been designed at frequencies ranging from 2-10 GHz. For the comparison metric between the simulated and fabricated antennas S-parameters.

Ahmed Al-Shaheen et al. [11] proposed that the antenna performance such as S_{11} and bandwidth can be affected in the presence of human body. To minimize such affects they presented a new patch antenna as a hexagonal patch operating in the Industrial Scientific Medical (ISM) frequency band at 2.45 GHz. The result demonstrates that the new antenna has negligible effect compared with that of the rectangular patch antenna.

M.A.R. Ohi et al. [12] proposed various structures having slots on both sides of the substrate to get an efficient microstrip patch antenna having single resonant frequency at 2.45 GHz of ISM band. For calculation of various parameters of proposed antenna simulation, CST microwave studio was used and then the characteristics of the fabricated antennas are measured using Vector Network Analyzer (VNA). In the end it's concluded that two slots on patch gives the best results.

Rajan Fotedar et al. [13] proposed the design and comparative performance analysis of microstrip patch antenna with different patch designs using FR-4 substrate at a resonant frequency of 2.4 GHz and concluded that rectangular patch gives better results than triangular and circular patch when FR-4 is used at frequency 2.4 GHz.

2.2 Flow Chart of the Project

Our project design is divided in to two parts. The first part consist of antenna design using HFSS software and antenna parameters are calculated using MATLAB coding. The second part consist of hardware testing and calculation. It is shown in figure 2.1

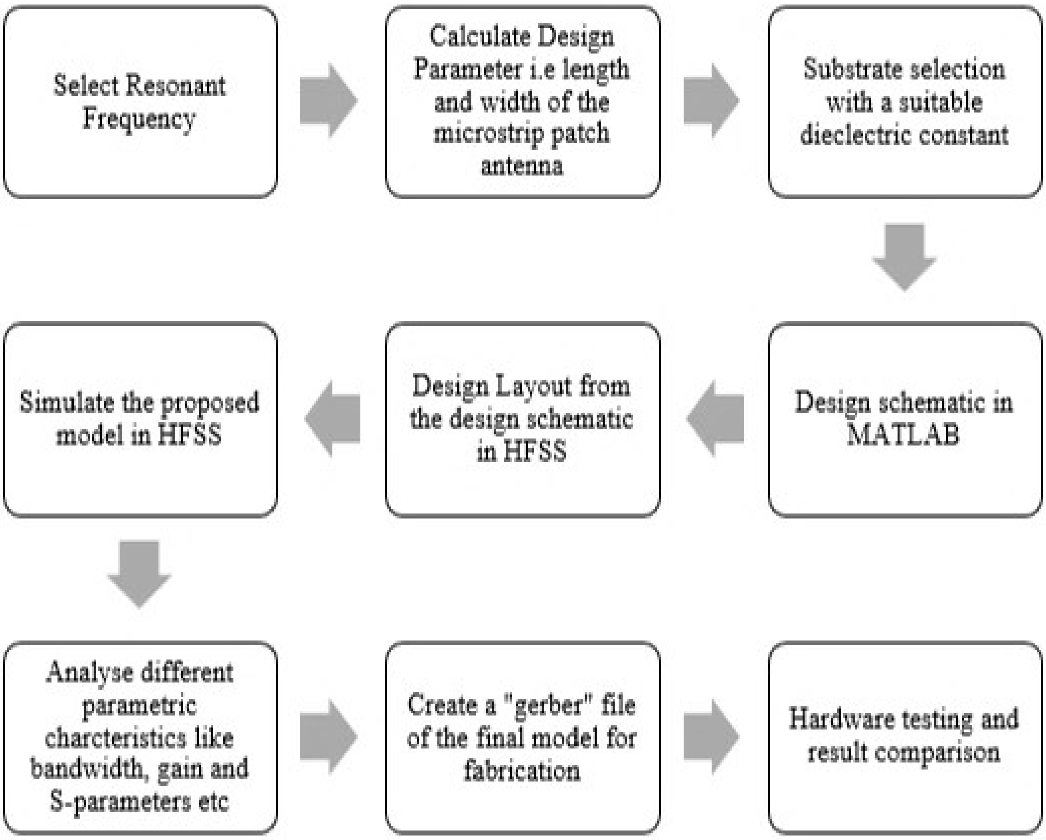


FIGURE 2.1: Flow chart of the project

2.3 Maximum Power Transfer Theorem

It states that maximum power is transfer from source to load if load impedance is equal to source impedance.
Friis equation for received power by an antenna:

$$P_r = \frac{P_t \lambda^2 G_t G_r}{4\pi r^2} \tag{2.1}$$

Where;

P_r = Received power by the antenna.

P_t = Transmitted power by the antenna.

G_r = The gain of received antenna.

G_t = The gain of transmitted antenna.

2.4 Antenna Parameters

In our work we have designed micro strip inset feed rectangular patch antenna using HFSS and MATLAB. Finally, the gerber file is created for fabrication process. To start with the designing phase first we have to calculate different parameters of our proposed antenna like length and width etc. and for line calculation for Patching terms of length L, Width W, Height H, and characteristics impedance Z_o at resonant frequency of 2.45 GHz can be calculated by following calculation. The width of the feed line is (mm):

$$W_f = \left(\frac{8e^A}{e^A - 2}\right) \times h \tag{2.2}$$

$$A = \left(\frac{Z_o}{60}\right)\left(\frac{\epsilon_r + 1}{2}\right)^{\frac{1}{2}} + \left(\frac{\epsilon_r - 1}{\epsilon_r + 1}\right)\left[0.23 + \frac{0.11}{\epsilon_r}\right] \tag{2.3}$$

where;

Z_o = Input impedence.

ϵ_r = Relative permitivity of the medium.

$$\lambda_g = \frac{\lambda_o}{\sqrt{\epsilon_{reff}}} \tag{2.4}$$

and

$$\lambda_o = \frac{c}{f_r} \tag{2.5}$$

Where;

$c = 3 \times 10^8$.

f_r= resonance frequency of the antenna.

ϵ_{reff} = Effective relative permitivity of the free space.

$$\epsilon_{reff} = \left(\frac{\epsilon_r + 1}{2}\right) + \left(\frac{\epsilon_r - 1}{2}\right)\left[1 + 12\frac{h}{W_f}\right]^{-\frac{1}{2}} \tag{2.6}$$

Length of the feed is (mm):

$$L_f = \frac{\lambda_g}{4} \tag{2.7}$$

The width of the patch is (mm):

$$W_p = \left(\frac{c}{2f_r}\right)\sqrt{\frac{2}{\epsilon_r + 1}} \tag{2.8}$$

The length of the patch is (mm):

$$L_p = \frac{\lambda_o}{2\sqrt{\epsilon_{reff}}} - 2\delta L \tag{2.9}$$

where

$$\delta L = h \times \left[\frac{\left(\epsilon_{reff} + 0.3\right)\left(\frac{W_p}{h} + 0.264\right)}{\left(\epsilon_{reff} - 0.258\right)\left(\frac{W_p}{h} + 0.8\right)}\right] \tag{2.10}$$

Where;

h = height or thickness of the substrate.

The output impedance of the antenna is (ohm):

$$Z_o = R_{in}\cos^2\left[\frac{\pi}{L_p \times d}\right] \tag{2.11}$$

Where;

R_{in} = The input impedance of the antenna (50 ohm).

d = The inset distance of the feed.

$$g = \frac{c}{\sqrt{2 \times \epsilon_{reff}}} \times \frac{4.65 \times 10^{-12}}{f_r} \tag{2.12}$$

Where;

g = The inset gap of the feed.

2.5 Antenna Parameters using Matlab

The microstrip inset feed rectangular patch antenna parameters have been calculated using MATLAB software. The input values of frequency, thickness of the substrate, dielectric constant, and input impedance have been provided the user.

```
clear all
format long
disp('                                                                    ');
disp('Microstrip Inset Feed Rectangular Patch Antenna Design');
disp('                                                                    ');
er=input('Enter the dielectric costant:');
h=input('Enter the substrate thickns (in mm):');
f=input('Enter the frequency (GHz):');
z=input('Enter the input impedence (ohm):');
disp('Calculating. Please wait.');
f=f*1e9;
Lo=(3*1e11/f); %Lo is the wavelength at that frequency
Ko=((2*pi)/Lo);
%calculate the value of 'A'
A=(((z/60)*(sqrt((er+1)/2)))+(((er-1)/(er+1))*(0.23+(0.11/er))));
%calculate the width of feed (Wf)
Wf=(((8*exp(A))/((exp(2*A))-2))*h);
%er_eff = effective value of the reletive permitivity
er_eff=(((er+1)/2)+(((er-1)/2)*(1/sqrt(1+((12*h)/Wf)))));
%Lg is the guide wavelength at that frequency
Lg=(Lo/sqrt(er_eff));
%calculate the length of feed (Lf)
```

```
e the width of patch (Wp)
11/(2*f))*sqrt((2/(er+1))));
 = effective value of the reletive permitivity for patch
(((er+1)/2)+(((er-1)/2)*(1/sqrt(1+((12*h)/Wp)))));
 the change in length
(0.412*(((er_eff_p+0.3)*((Wp/h)+0.264))/((er_eff_p-0.258)*((Wp/h)+
e the length of patch (Lp)
2*sqrt(er_eff_p)))-(2*del_L));
                                                  ');
rostrip Inset Feed 2.45GHz Patch Antenna');
                                                  ');
e reletive permitivity of the substrate (er) is: ',num2str(er),'']
e height of substrate (h) is: ',num2str(h),' mm']);
lue of A is: ',num2str(A),'']);
e width of the feed line (Wf) is: ',num2str(Wf),' mm']);
lue of Lo is: ',num2str(Lo),' m']);
e effective reletive permitivity for the feed is: ',num2str(er_eff
lue of Lg is: ',num2str(Lg),' m']);
e length of the feed line (Lf) is: ',num2str(Lf),' mm']);
e width of the patch (Wp) is: ',num2str(Wp),' mm']);
e reletive permitivity for the patch is: ',num2str(er_eff_p),'']);
lue of delta L  is: ',num2str(del_L),'']);
e length of the patch (Lp) is: ',num2str(Lp),' mm']);
```

FIGURE 2.2: Matlab code for antenna parameters

2.6 Summary

In this chapter an overview of antenna characteristics and applications are presented by giving a brief literature review. Furthermore, formulas used for calculating antenna parameters are discussed and used on MATLAB for the calculation of microstrip's length and width and patch's length and width and some other parameters as well.

Chapter 3

Software Aspects - Design and Simulation of Microstrip Patch Antenna

Before moving toward hardware, we first analyze our idea on a software for better understanding and for visualization. When we get our desired design of antenna and its results on software then we move towards the hardware. We design microstrip patch antenna inset feed rectangular on HFSS and MATLAB and obtained their results and compare these results with the research paper that we studied and described in our literature review. The parameters of antenna is calculated from MATLAB by using the formulas that are derived already and discussed in the literature review. By finding out the parameters from the formulas we then design our antenna on HFSS according to these parameters and analyze the output i.e. gain, return loss, S-parameters etc. And compare these results with the previous research paper results that we studied.

3.1 Introduction

Micro strip antennas were radiate signals from end points, and these are plane resonant cavities. To manufactured cheap and low-grade antennas printed circuit methods are used on soft substrate. The antennas fabricated on compliant substrates withstand tremendous shock and vibration environments. For mobile communication the antennas is fabricated on metal sheets and place a dielectric post on them in order to reduce the cost of the antennas. It also reduce the problem of radiation from the antenna surface wave which is excited in a dielectric substrate layer in order to maximize the bandwidth. The basic type micro strip patch antenna is that it's one layer that contain patch used for radiating the waves and signal and the other layer is used for ground. The patch is mostly a conducting metal that are copper gold etc. and it can also be in any shape. The radiating patch and the feed lines are usually photo etched on the dielectric substrate. The arrays of antenna and antenna can be etched with a variety feeding techniques [2].

3.2 Antenna Feeding Techniques

There are many techniques for feeding an antenna. They are divided into two main categories:

- Contacting
- Non-Contacting

Contacting Techniques: The radiating patch is fed straightly with RF power with the help of connecting element i.e.

1. Micro strip line
2. Coaxial probe

Non-Contacting Techniques: In this technique the electromagnetic field coupling is carried out by transferring the power among the micro strip line and the patch that is radiating. The most useable techniques in non-contacting are:

1. Aperture coupling
2. Proximity coupling

We are using micro strip line feed technique in our project.

3.2.1 Micro-strip line feeding

In this technique the conducting wire is connected directly with the end corner of the micro strip patch. This conducted wire is smaller in width as compared to the patch and this arrangement gives the benefit in a way that the feed can be etched on the same substrate to provide a planar structure. The purpose of the inset cut in the patch is to match the impedance of the feed line to the patch without the need for any additional matching element. It can be achieved by manipulating the inset position. This is easy to fabricate and feeding the patch, it also have an advantage of simplicity in modeling and impedance matching. However, the antenna bandwidth can be hampered by increasing the thickness of the dielectric substrate, surface waves and spurious feed radiation. Due to the feed radiation unwanted cross polarized radiation can cause.

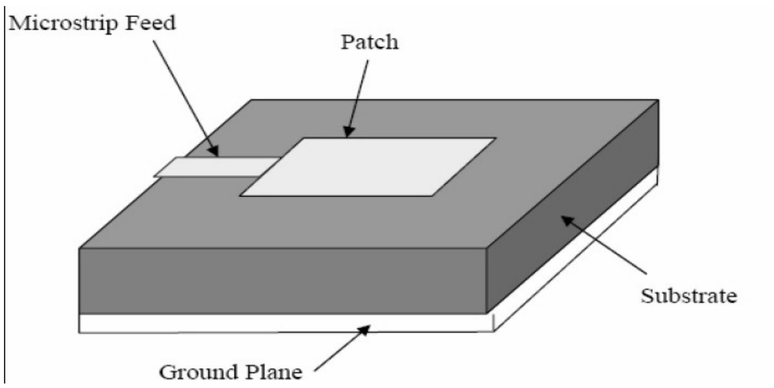


FIGURE 3.1: Micro-strip feed

3.2.2 Coaxial Feed

For feeding micro strip patch antenna coaxial is the easiest and accessible technique. The internal conducting wire of the coaxial connector is continuing throughout towards the dielectric and then it is solder to the radiated patch on the other hand the external conductor is attached with the ground surface. The most common advantage of this feeding technique is that the feed can be put at any desired place in the internal side pf the patch so it can meet with the input impedance. It gave us low spurious radiation and also, it's very convenient for fabrication. Moreover, it gave us some disadvantage that are narrow bandwidth and is difficult to model since a hole has to be drilled in the substrate and the connector protrudes outside the ground plane, thus not making it completely planar for thick substrates (h > 0.02 λ_o). Also, for thicker substrates, the increased problem.

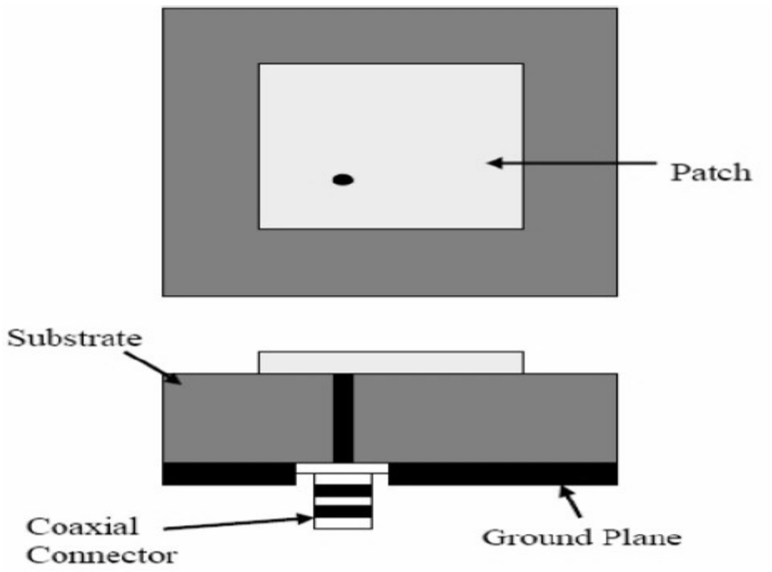


FIGURE 3.2: Coaxial feed

3.2.3 Aperture Couple Feed

In this technique the radiating patch and the micro strip feed are distanced by the ground plane. The pairing in between the patch and feed line is built with the help of slot or an aperture in the ground plane. The pairing aperture is most of the time kept in center behind the patch and leading to minimum cross polarization because of synchronization of the configuration. The size of coupling towards the feedline and plane is found from the architecture, amount and area of the aperture. As the patch and feed line is distanced by the ground plane in order to minimize the spurious radiation. Commonly an immensely dielectric material is being used for the lower substrate and a thick, low dielectric constant material; is being used for upper substrate better radiation radiated from the patch. The most con of this technique is that it cause many difficulties in fabrication because of numerous layers that maximize the antenna width that gave us narrow bandwidth.

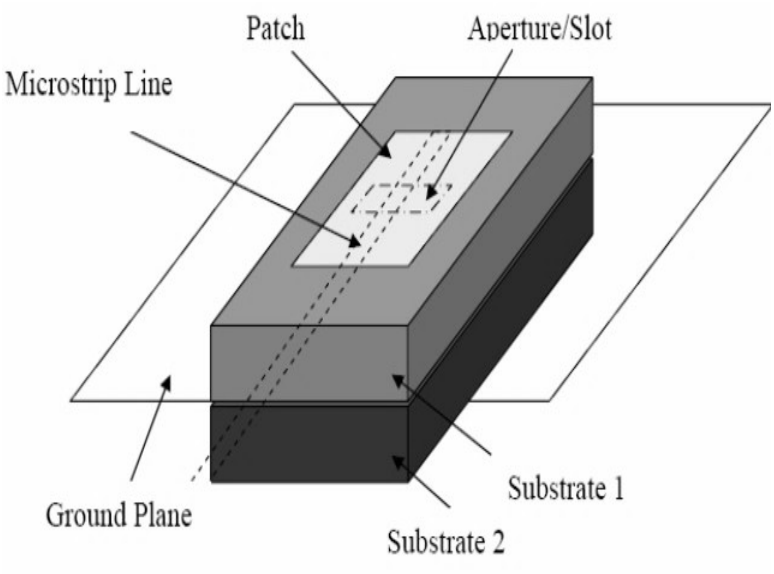


Figure 3.3: Aperture couple feed

3.2.4 Proximity Coupled Feed

It also known as electromagnetic coupling scheme. In this feeding technique the two dielectric substrates were utilized in a way that a feed line is centered between the two substrate and the radiating patch is on the upper top side of the substrate. One of the most common benefit of this technique is that it minimize the spurious feed radiation and gave us maximum bandwidth as high as 13% because of the increase in the width of the micro strip patch antenna. It can also give you an option to choose between the two various dielectric media, in which one dielectric is used for the patch and the other one is used for the feed line to maximize the separate activities. Coordination can be attained by regulating the size of the feed line and the thickness to line ratio of the patch. The most important con of this technique is that it is hard to fabricate due to two layers of dielectric that required proper adjustment. Plus, it can also maximize the width of the antenna.

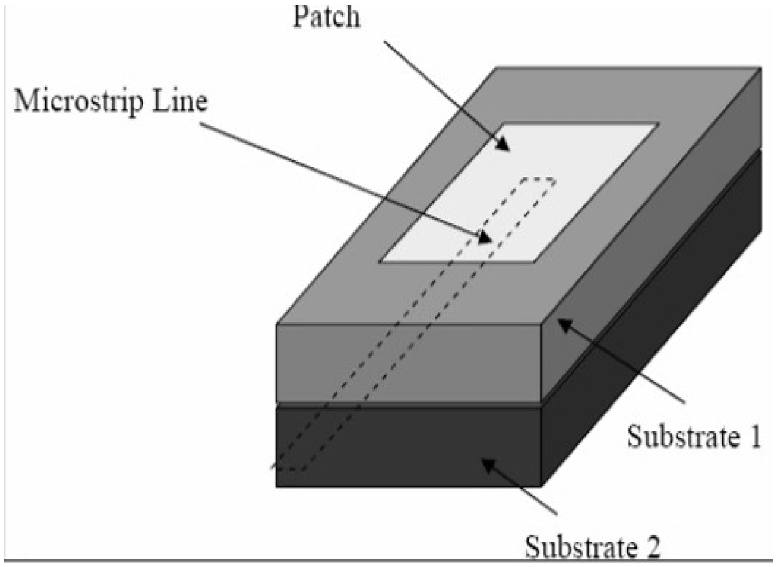


FIGURE 3.4: Proximity couple feed

3.3 MATLAB Calculations

We first write fundamental formula for calculating antenna feed width, feed length, patch width, patch length, inset gap, and inset distance of the patch antenna. We defined variables for each parameter. We use mm unit for each vale. We take the input value such as the resonance frequency, thickness (h=1.6), dielectric constant of the material (ϵ_r=4.4) in our case for FR-4 substrate. The acquired results are shown in the figure 3.5

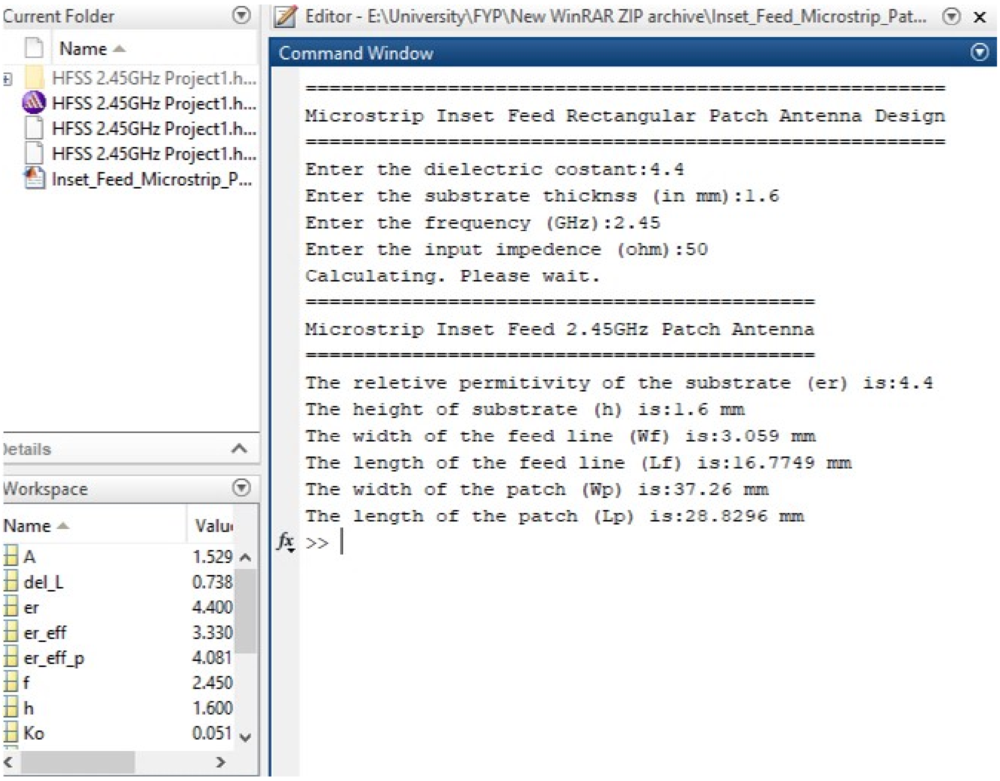


FIGURE 3.5: MATLAB results

3.4 HFSS Results

In HFSS we design antenna, the single patch micro-strip inset feed antenna and simulated the gain directivity, VSWR, and reflection coefficient, etc.

3.4.1 Designing of Patch Antenna

The radiation boundaries are defined perfect "E" for ground and the patch surface. The antenna is excited from the front edge of the feed line. The inset feed is used for minimum reflecting coefficient so that the maximum power is received, and the conversion efficiency can be improved. The rectangular slot in the patch will tune the antenna for improved gain. The simulation model is shown in figure 3.6 In HFSS, by using the values that are obtained from the formulas we draw a micro strip patch antenna in HFSS by using those dimensions that are height, width, length size etc. By using the dielectric constants, we can find these dimensions from the formulas that are derived earlier in research papers. Moreover, by designing this antenna we can analyze our antennas parameters and also can visualize and observe the antenna gain, returns loss, S-parameters etc.

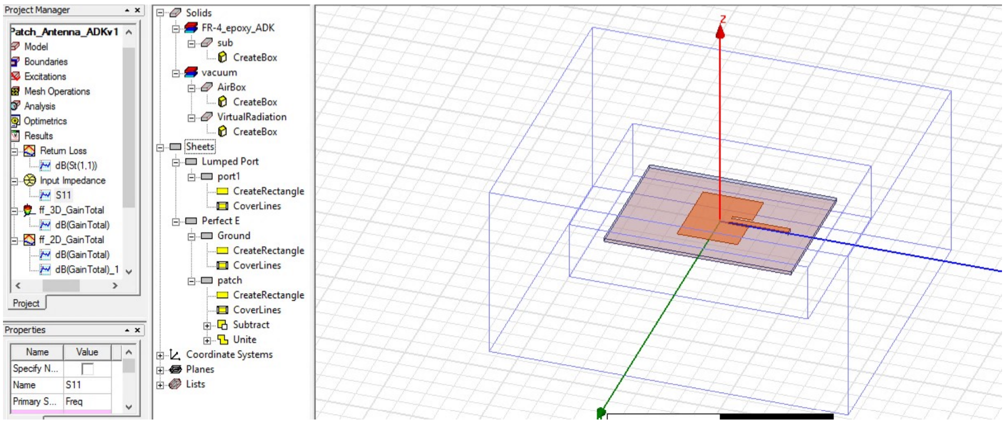


FIGURE 3.6: HFSS simulation model

3.4.2 Antenna gain (3D polar plot)

The maximum gain achieved from the patch antenna is 2.984 dB which is nearly equal to 3.00 dB by using FR-4 substrate of thickness 1.6 mm. Our designed antenna maximum gain is 3.00 dB and have respective return loss. 3D gain pattern from maximum to minimum is shown in figure 3.7.

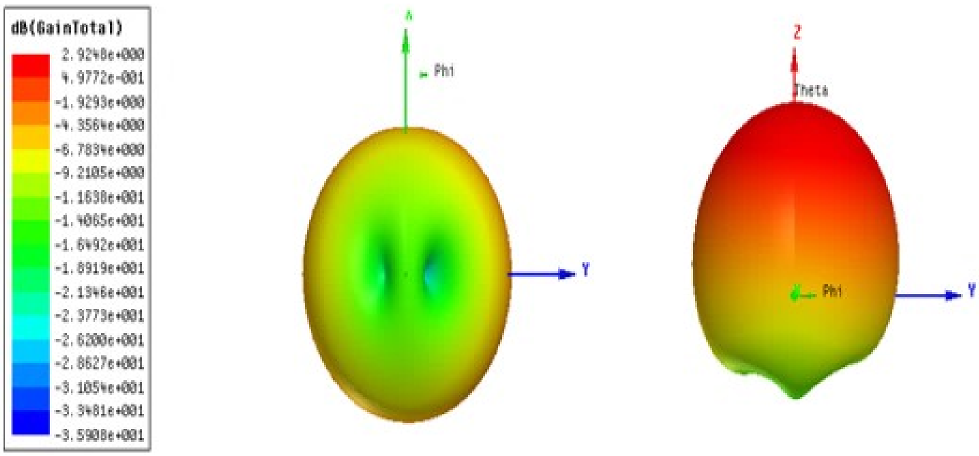


FIGURE 3.7: Antenna gain (3D polar plot)

3.4.3 Patch Antenna Return Loss

The single patch antenna when operating at 2.45 GHz produced reflection coefficient of -15.02 dB which can be further improved if we increase the number of elements of the antenna. It is shown in the figure 3.8

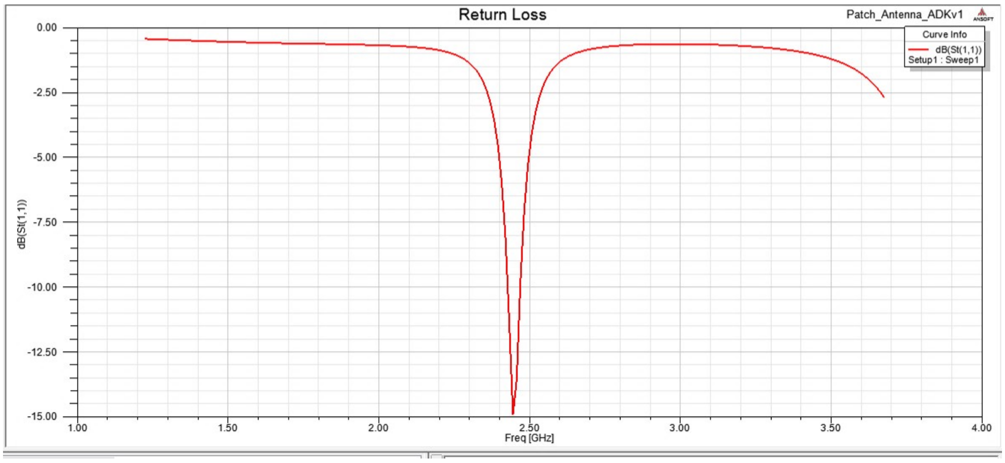


FIGURE 3.8: Return loss graph via HFSS

3.4.4 2-D gain of patch antenna

The 2-D gain of the patch antenna is showed in figure 6 in a form of graph. It shows the reflection coefficient -15.02 dB. This can be improved by increasing the width and thickness and number of elements. It is shown in the figure 3.9

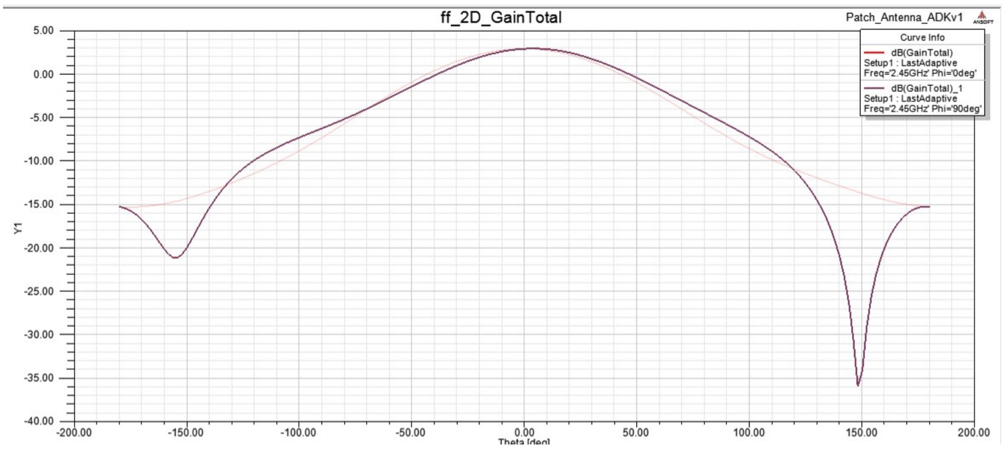


FIGURE 3.9: 2-D gain of MPA

3.5 MATLAB Results

In MATLAB we design antenna, the single patch micro-strip inset feed antenna and simulated the gain directivity, VSWR, and reflection coefficient, etc.

3.5.1 Designing of patch antenna in MATLAB

The radiation boundaries are defined perfect "E" for ground and the patch surface. The antenna is excited from the front edge of the feed line. The inset feed is used for minimum reflecting coefficient so that the maximum power is received, and the conversion efficiency can be improved. The rectangular slot in the patch will tune the antenna for improved gain. MATLAB model is shown in figure 3.10

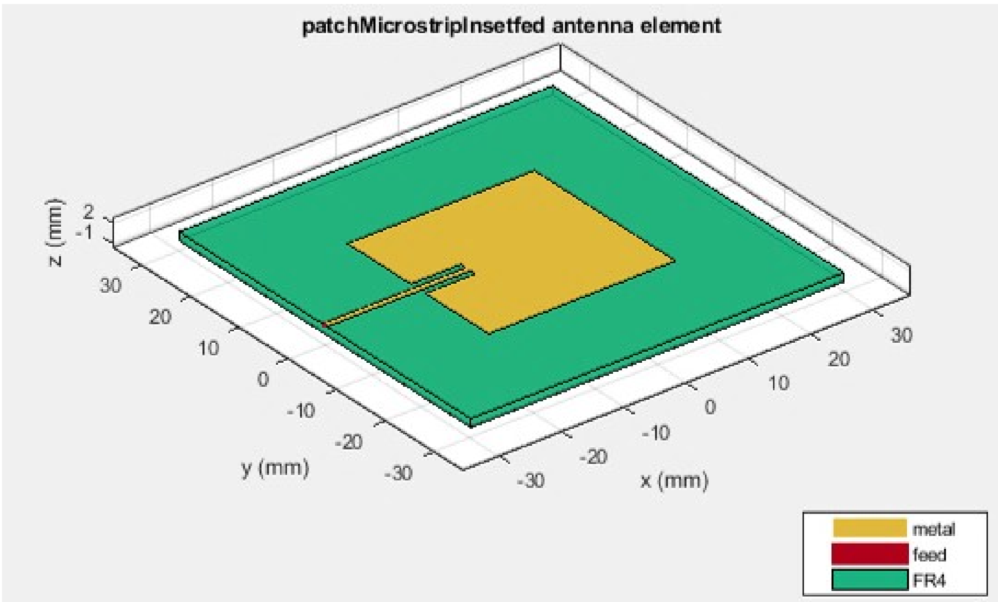


FIGURE 3.10: Inset feed MPA

3.5.2 Antenna gain (3-D polar plot) using MATLAB

The maximum gain achieved from the patch antenna is 6.15 dBi by using FR-4 substrate of thickness 1.6 mm. Our designed antenna maximum gain is 6.15 dBi and have minimum gain -22.9 dBi. Gain polar plot is shown in figure 3.11

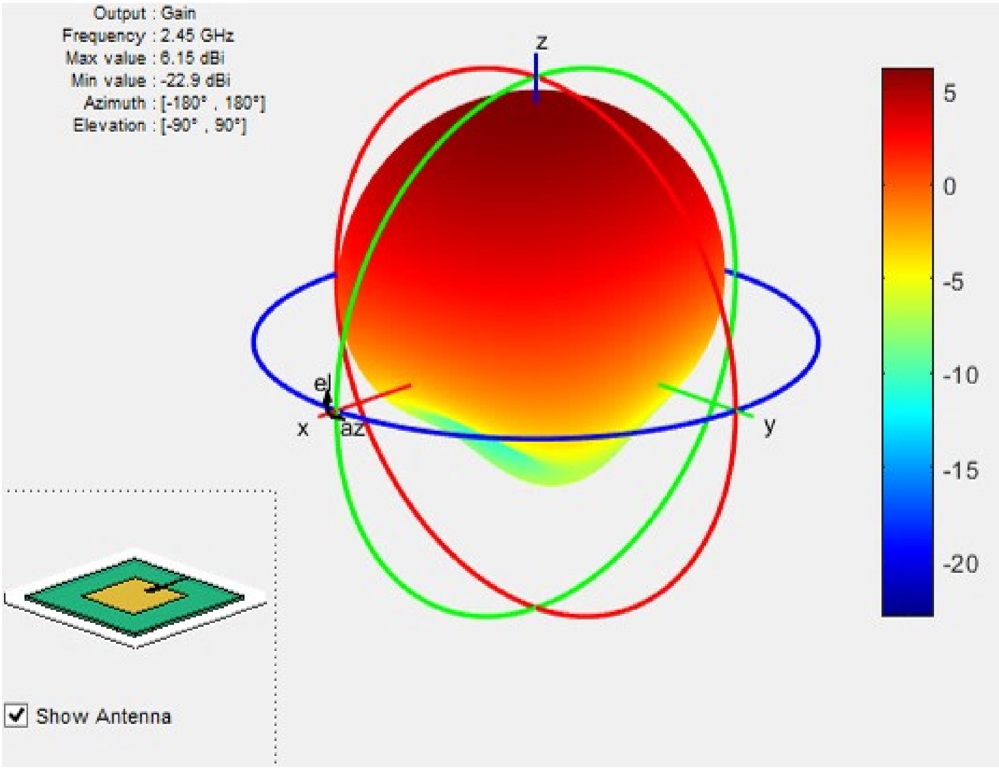


FIGURE 3.11: Gain 3-D polar plot via MATLAB

3.5.3 Patch antenna return loss in MATLAB

The 2-D gain of the patch antenna is showed in figure 6 in a form of graph. It shows the reflection coefficient -15.02 dB. This can be improved by increasing the width and thickness and number of elements. It is shown in the figure 3.12

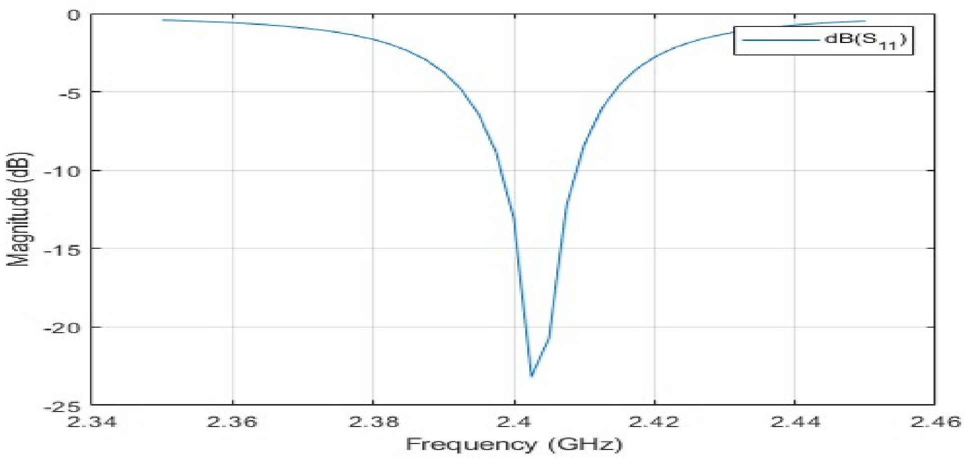


FIGURE 3.12: Return loss via MATLAB

3.6 Summary

In this chapter we discussed the simulation results for antenna design. We analyzed the antenna results in HFSS and found that the gain of the antenna increases as the number of elements increases. Also, we noted that as the number of elements increases the antenna beam width become narrower and make the antenna more directional. The antenna design is done in HFSS software. It gave us maximum gain and minimum reflection coefficient.

Chapter 4

Hardware Aspect: Fabrication, Testing and Comparative Analysis

4.1 Introduction

In hardware demonstration final fabricated design of the antenna is presented. It consist of two antennas one used for transmitting and other one is used for the receiving. The two units are fabricated separately to use them for transmission and receiving. These antennas are then tested, and their results are then compared with those research paper that we have studied and described in our literature review. In the end we conclude our experiment by describing that how the gain and directivity changes when the dielectric frequency permittivity changes.

4.2 Hardware Testing

By testing the hardware in lab on available equipment following result is we get from our antenna that is approximately equal to the far field radiation pattern that we get from the software simulation. We then draw the far field radiation pattern

FIGURE 4.1: Hardware model

of the results that we get by testing our antennas. Obtained far-field radiation pattern and 2-D polar plot by rotating the antenna at 360 degree are shown in figure 4.2 and figure 4.3 respectively.

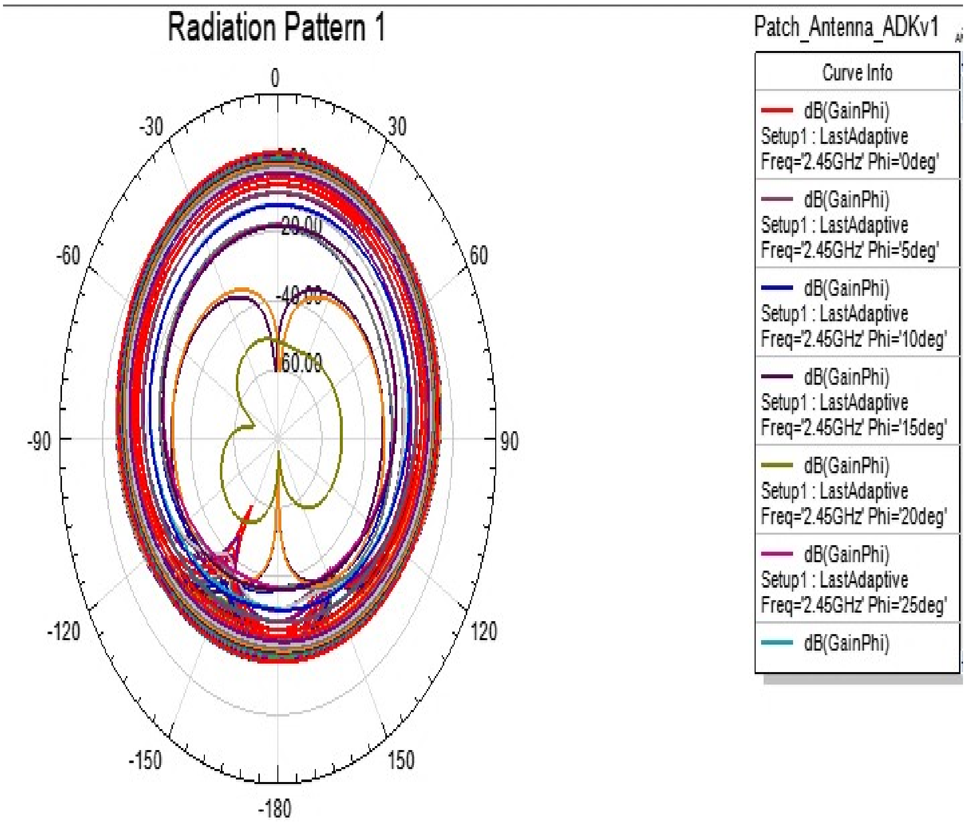


FIGURE 4.2: Far field radiation pattern

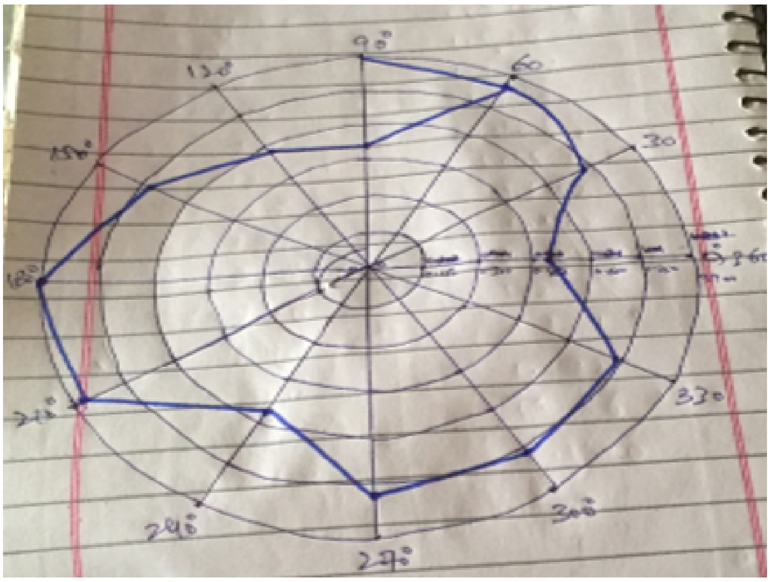


FIGURE 4.3: 2-D polar plot

4.3 Comparative Analysis

After testing the hardware, we then moved towards the comparative analysis of our results with the research paper that we have studied. We use three research paper for comparison that are described below:

4.3.1 First Research Paper

The research paper named "Design and Analysis of Rectangular Micro-strip patch antenna for Global WLAN Applications Using MATLAB and CST Micro-studio Software [1]". The parameters that they have used for designing their patch antennas are shown in table 4.1:

By using these parameters, they design a micro-strip patch antenna on CST software and simulate it and then check their different graphs return losses gain directivity etc. It is shown in figure 4.4 The 3-D polar plot of their patch antenna is viewed below. This polar plot shows the gain 8.01dB. and it also shows the radiation pattern in 3-D. It is shown in Fig. 4.5. The far field radiation pattern of this micro-strip patch antenna is drawn by combining all points obtained by

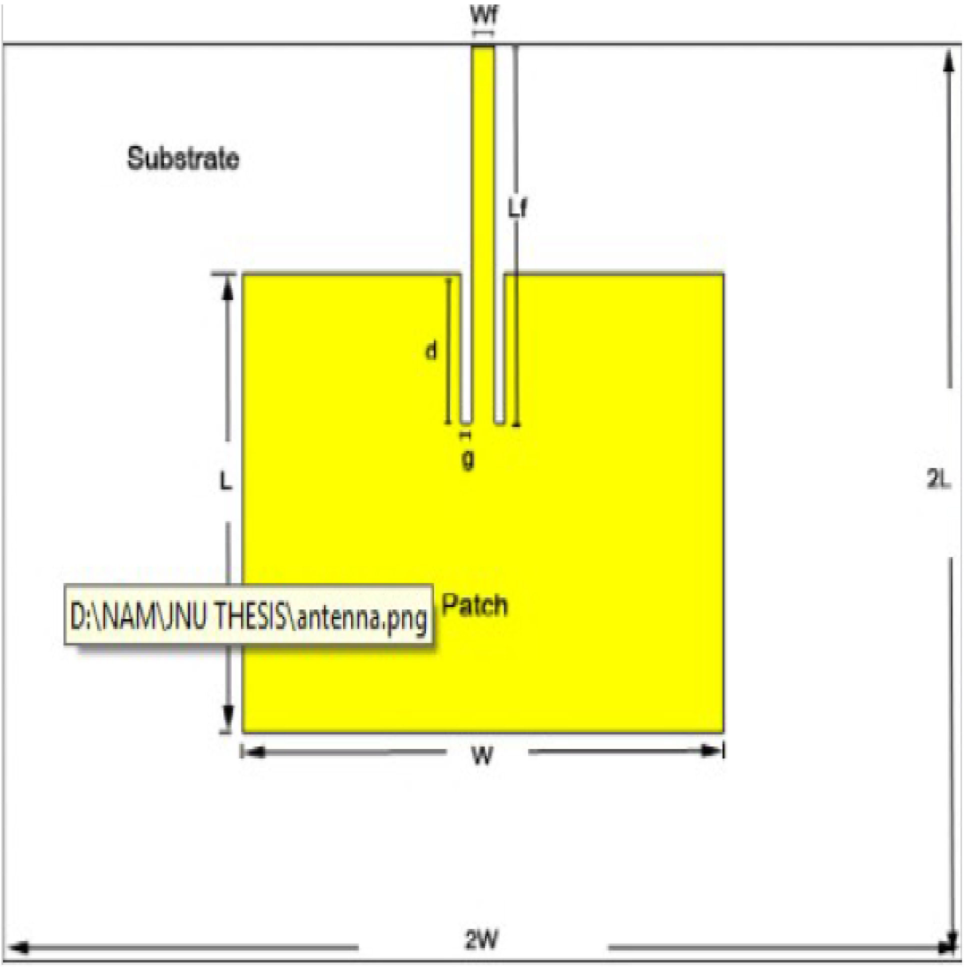


FIGURE 4.4: Antenna design on CST software [1]

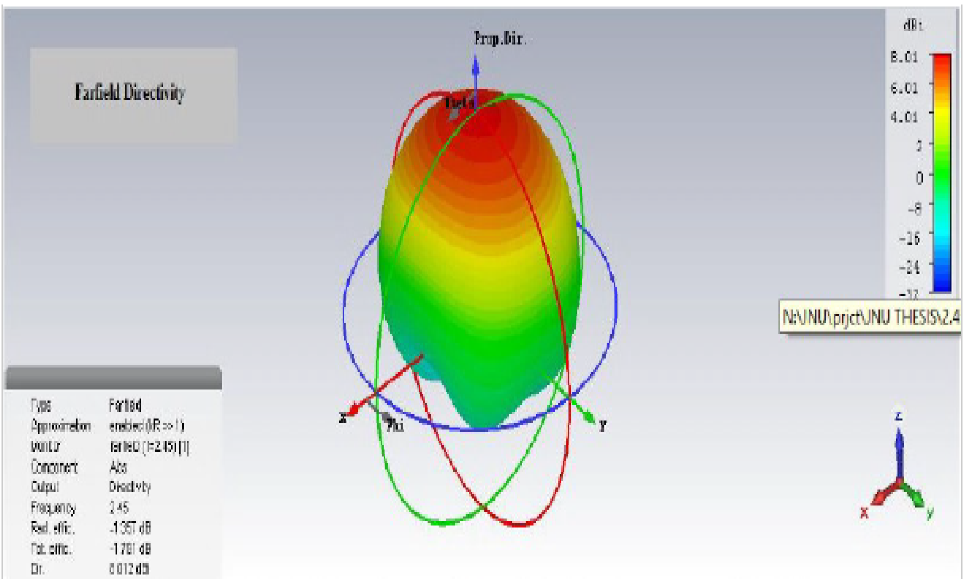


FIGURE 4.5: Antenna 3-D polar plot [1]

TABLE 4.1: Antenna parameters from 1st research paper [1]

Parameters	Description	Value(mm)
W_f	Width of Micro-strip feed	2.3
W	Width of Patch	47
T	Thickness of Patch	0.07
L_f	Length of Micro-strip feed	32
L	Length of Patch	39
H	Thickness/Height of Substrate	0.787
G	Gap between micro-strip and Patch	1.0
D	Distance of inset-feed	12.7

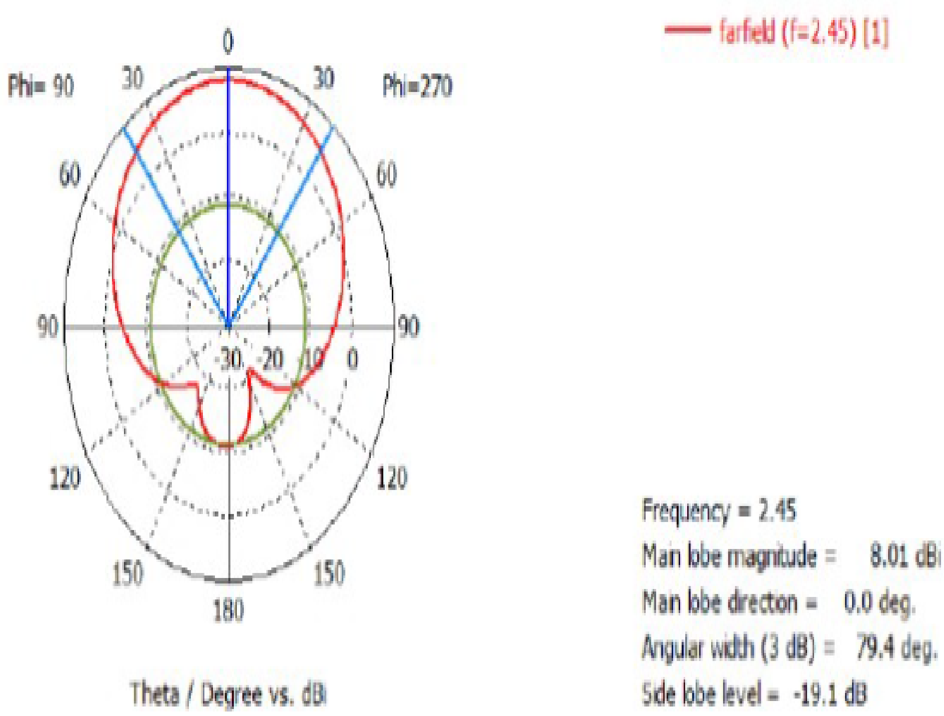


FIGURE 4.6: Far field radiation pattern [1]

rotating the transmitter at 360 degree and getting the pattern shown in figure 4.6: And the return loss of the patch antenna is shown in figure 4.7:

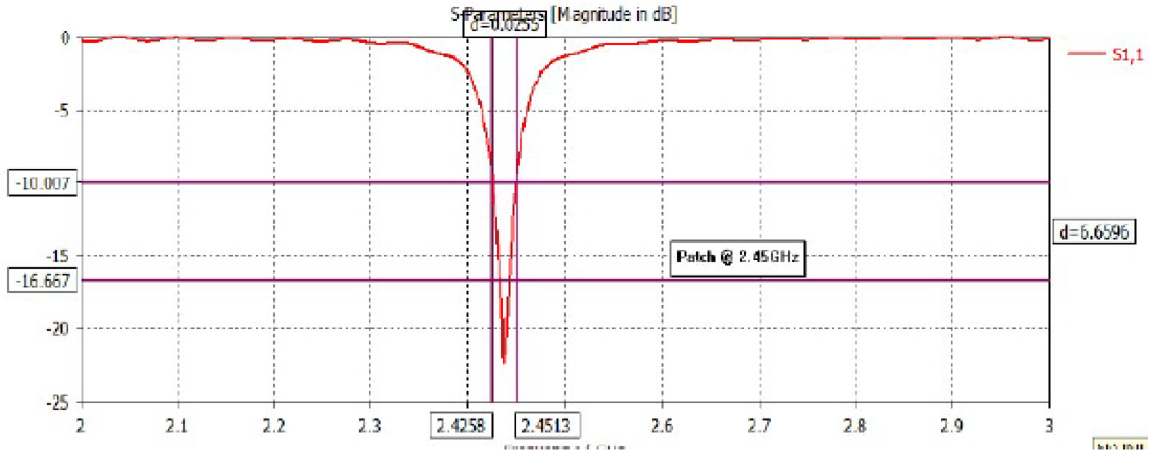


FIGURE 4.7: Return loss [1]

4.3.2 Second Research Paper

The research paper named "Design and Performance Analysis of Rectangular Micro-strip Patch Antenna at 2.45 GHz. The parameters that they have used for designing their patch antennas are shown in table 4.2:

TABLE 4.2: Antenna parameters from 2^{nd} research paper [14]

Performance Parameters	Single Elemnt RMPA
Resonant Frequency (GHz)	2.451
Return Loss (dB)	-38.5
Directivity (dBi)	7.48
Gain (dB)	5.49
Input Impedaance	50.63
VSWR	1.02
Bandwidth (MHz)	59

By using these parameters, they design a micro-strip patch antenna on CST microwave studio 2010 software and simulate it. It is shown in figure 4.8 and then check their different graphs of gain (figure 4.9), far-field radiation pattern (figure 4.10), return losses(figure 4.11) and directivity etc.Following figure represents the results that are obtain from the software simulation for the single element rectangular micro-strip patch antenna. They observe that by decreasing the return

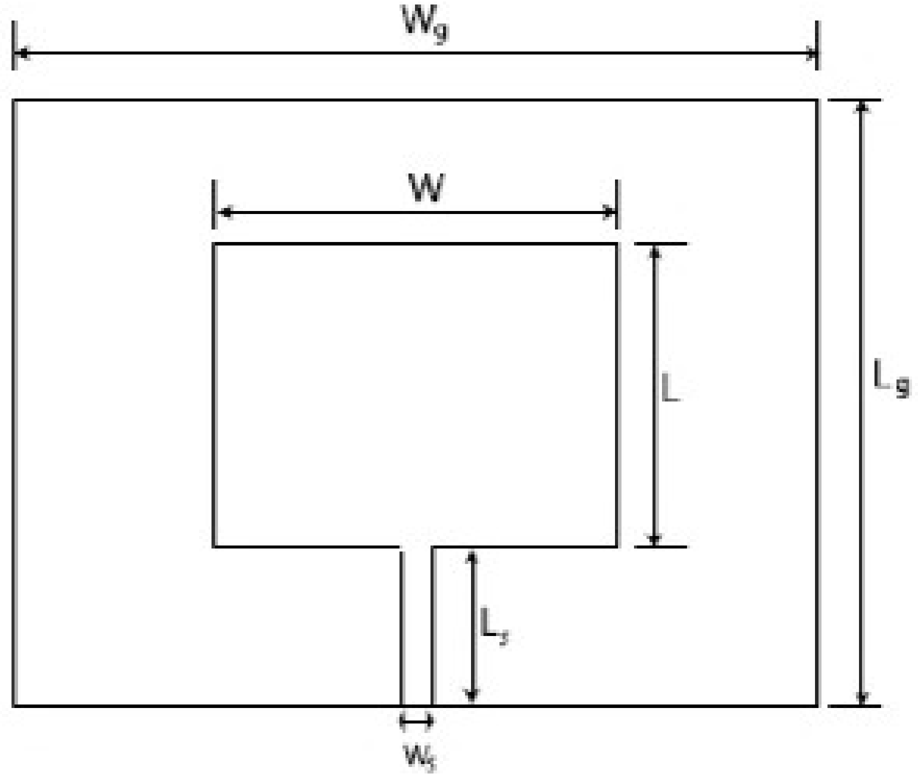


FIGURE 4.8: Antenna design on CST software [14]

loss of the antenna is -38.5 dB at 2.45 GHz. It has a -10 dB bandwidth of 59 MHz . The far-field radiation pattern picturize that the directivity and gain of the antenna is 7.48 dBi and 5.49 dB respectively. The total antenna efficiency can be calculated as 73.40%. The gain pattern shows that, main lobe magnitude is 5.5 dB, main lobe direction is 0.0 degree, 3dB angular beam width (i.e. HPBW) is 90.2 degree and side lobe level is -15.0 dB . [14]

4.3.3 Third Research Paper

The research paper named "Performance Analysis of MPA using Different Shapes of Patch at 2.4 GHz [13]". The parameters that they have used for designing their patch antennas are shown in table 4.3 By using these parameters, they design a micro-strip patch antenna on CST microwave studio software, which is shown in figure 4.12 and simulate it and then check their different graphs gain (figure 4.13),return losses(figure 4.14) and directivity etc. The figure shows the radiation pattern of this micro-strip patch antenna at 2.4GHz.

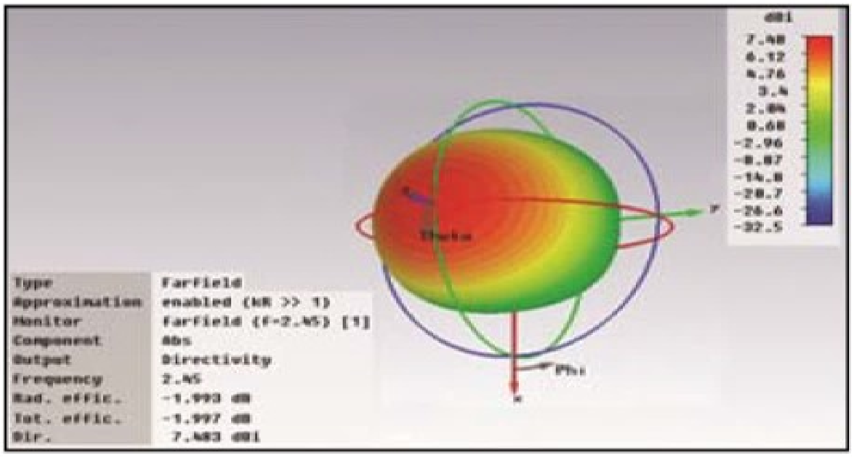


FIGURE 4.9: 3-D polar plot [14]

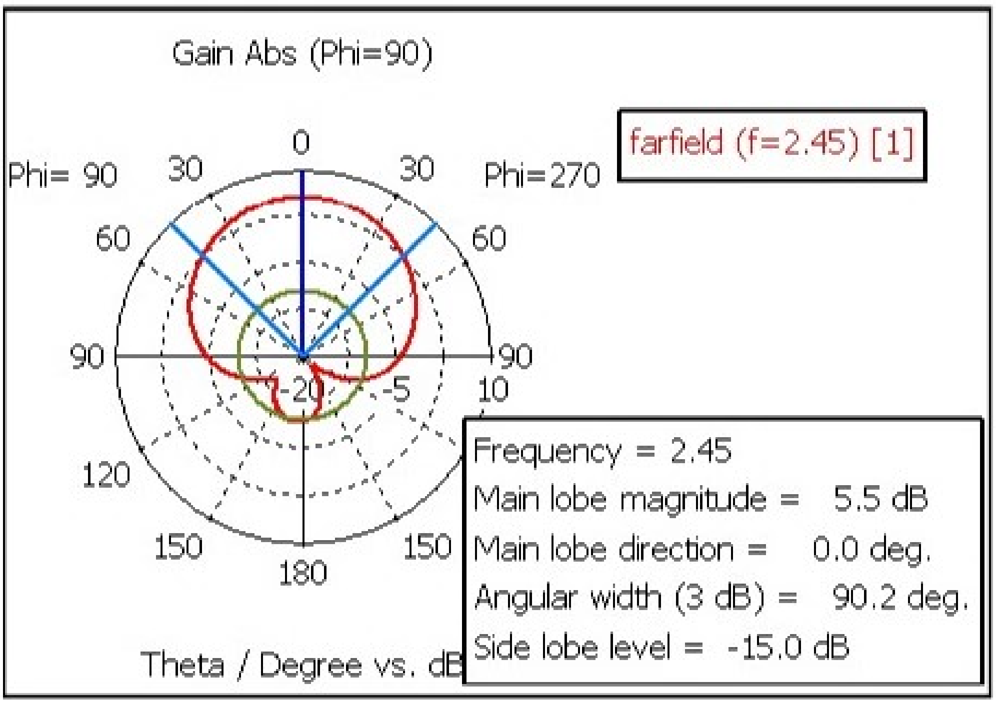


FIGURE 4.10: Far field radiation pattern [14]

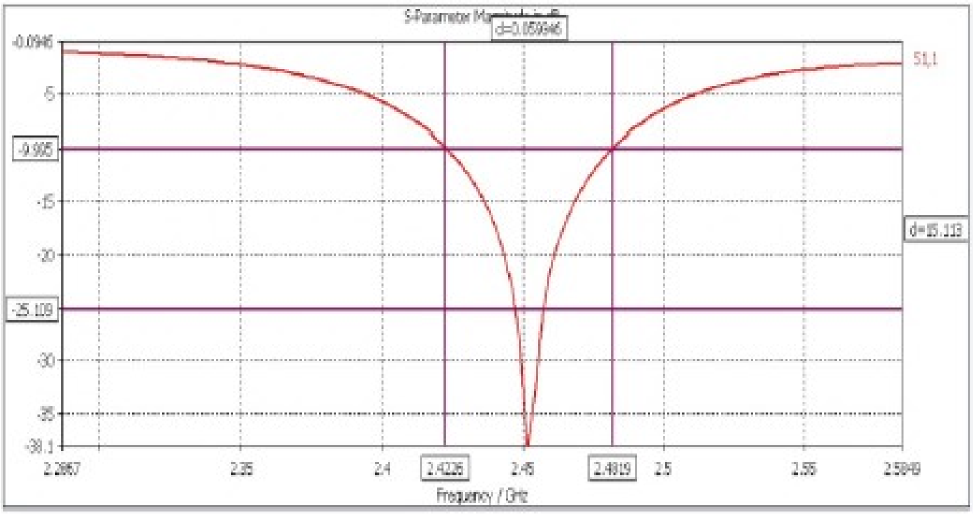


FIGURE 4.11: Return loss [14]

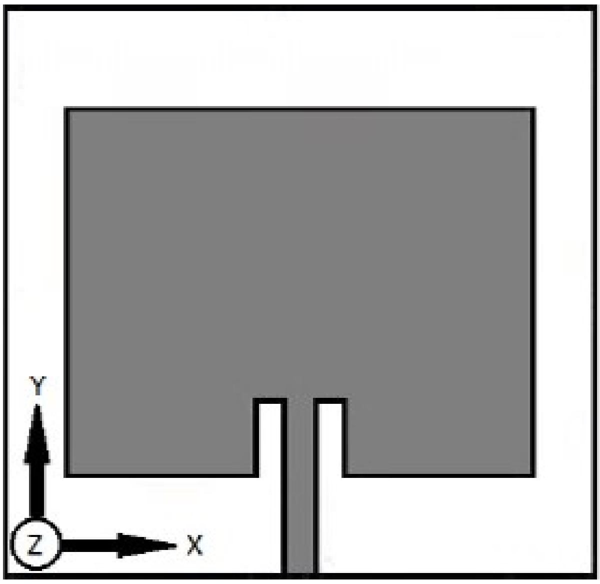


FIGURE 4.12: Antenna design on CST software [13]

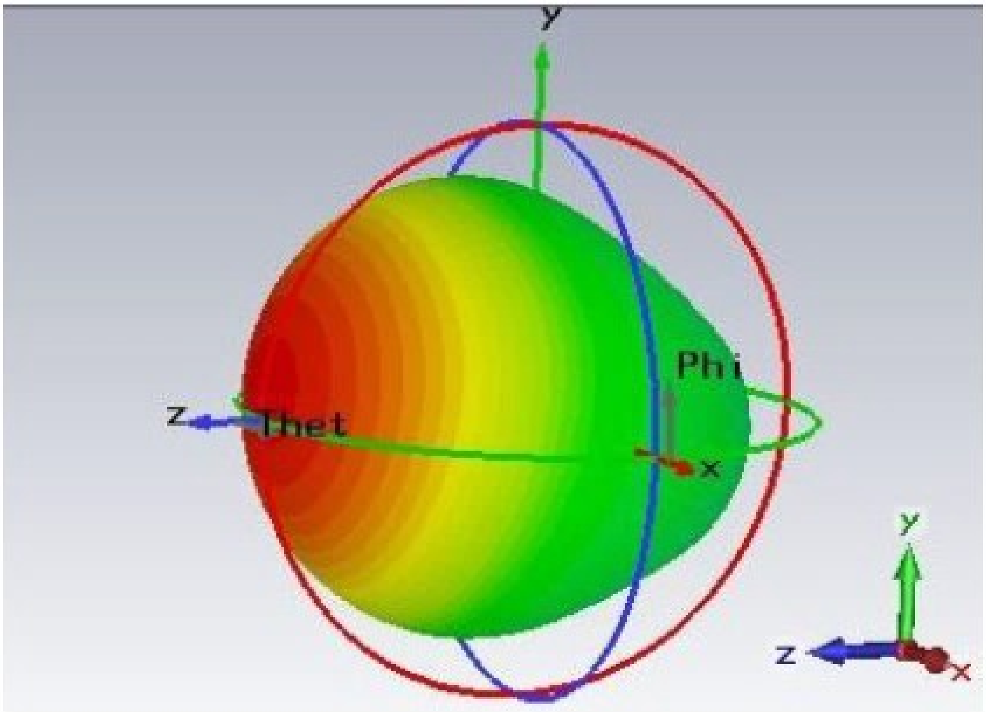


FIGURE 4.13: 3-D polar plot [13]

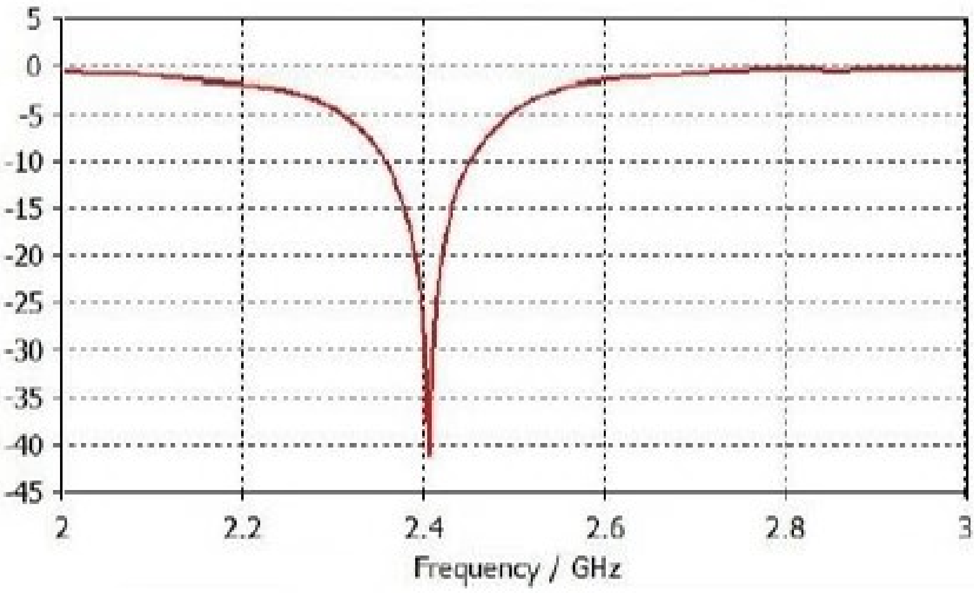


FIGURE 4.14: Return loss [13]

TABLE 4.3: Antenna parameters from 3^{rd} research paper [13]

Parameters	Dimensions (mm)	Optimized Dimensions (mm)
Length of Patch	28.4	28.84
Width of Patch	37.02	37.46
Height of Patch	0.1	0.1
Length of Substrate	38	45
Width of Substrate	46.6	46.6
Height of Substrate	1.6	1.6
Feed Length	11.4	14
Feed width	3	3

4.4 Comparison

By comparing these research paper results with our antenna results we get the following comparison that are described 4.4 in table. This table show that how by changing the substrate dielectric and permittivity our gain return loss and directivity changes.

TABLE 4.4: Comparative analysis

No.	Substrate	Permitivity	Thickness	Gain	Directivity	Return Loss
Paper [1]	Roger-RT5870	2.33	0.787	6.65	8.01	-22.5
Paper [14]	FR-4	3.8	1.5	5.49	7.48	-38.5
Paper [9]	FR-4	3.32	1.6	3.69	5.548	-40
Proposed	FR-4	4.4	1.6	2.92	6.15	-15.45

4.5 Summary

In this chapter final fabricated antenna design is completed for hardware purposes. And the results of our final design is compared with the results of different research paper to show that how by varying different factors gain can be improved .

Chapter 5

Conclusion and Scope for Improvement

5.1 Conclusion

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 Beam width) that affect design and applications were studied and their implications understood. The constructed microstrip rectangular patch antennas operated at the desired frequency and power levels. Also, patch antennas were simulated (using HFSS) and the desired level of optimization was obtained. It was concluded that the hardware and software results we obtained matched the theoretically predicted results.

5.2 Scope for Improvement

There were some areas we felt we did not address. They were

- The experimental radiation patterns of the constructed antennas could not be obtained and compared with the theoretical patterns

- A more complete study of different field solvers and simulators (such as Sonnet, AWR, IE3D etc.) could not be made. We were only able to focus on HFSS and MATLAB.

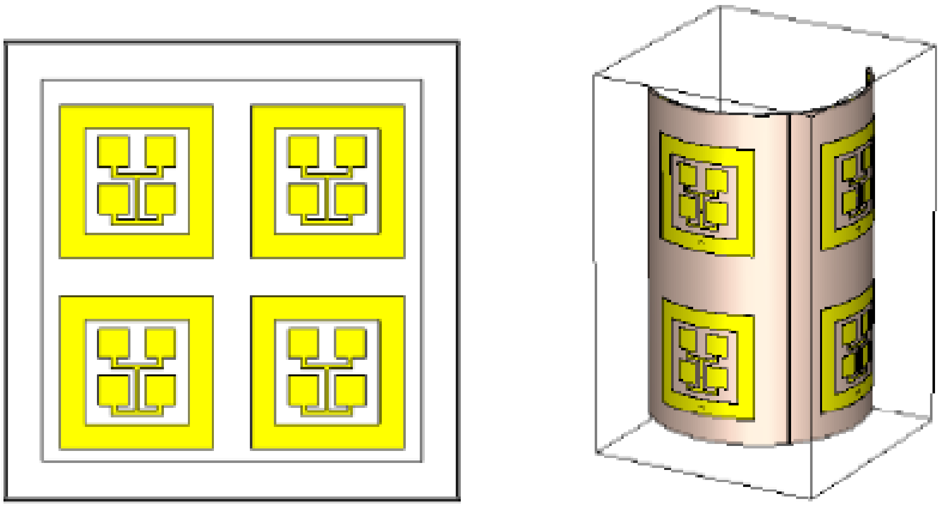
5.2.1 Future Scope

Presently, Wireless Communication is the fastest growing field of the communication field. There are many government and commercial applications where weight, size, cost, performance, ease of installation, aerodynamic profiles are the major constraints. In the last few years, the development of 5G technology represented one of the principle interests in the information and Communication field. Also, in today's environment, technology demands antennas which can operate on different wireless bands and should have different features like low cost, minimal weight, low profile and are capable of maintaining high performance over the operating frequency ranges.

The technological developments in the communication and biomedical fields have increased the demand for wearable devices such as smart watches, smart bands, On-body health monitoring devices etc. This has led to the idea of flexible electronics where the devices are designed in order to comfortably fit on various body parts. In order to satisfy the demand for wearable devices, conformal antennas are also required. The developed conformal antenna design can be employed for wearable devices that work in 5G communication band.

The objective of the work is to develop an antenna for 5G communication. The upcoming 5G communication systems are designed to work in mmwave frequencies like 28 GHz, 37 GHz, 38 GHz and 60 GHz. The attenuation due to water molecules in atmosphere is significant for signals at 38 GHz since water molecules absorb these signals. Similarly attenuation due to absorption of signal by atmospheric oxygen is high at 60 GHz. Thus both these frequencies can be used together to increase the signal strength to a better level compared to that obtained using one single frequency band.

To achieve that purpose, future research is aimed at developing a conformal shared aperture micro-strip 2 x 2 array antenna designed for dual-band operation at 38 and 60 GHz frequencies on a flexible substrate (Rogers RO4003c). Two different radiators, viz. window shaped slot and square patch antenna share a common aperture. Thus, the proposed antenna operates at both 38 GHz and 60 GHz frequencies which will aid in the increased signal strength required for 5G communication systems shown in figure 5.1. [15]



(a) (b)

FIGURE 5.1: Proposed shared aperture antenna [15]

5.3 Summary

In this chapter, we discussed scope of improvement in our project. We also discussed a possible approach for 5G communication using micro-strip patch antenna due to their ease of installation, low cost,profile and weight.

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