Design and analysis of T-shape Microstrip antenna for WLAN and C band application.

A THESIS SUBMITTED IN PARTIAL FULFILLMENT

OF THE REQUIREMENTS FOR THE DEGREE OF

Bachelor of Science

In

Electrical and Electronic Engineering

By

Maul Jannat Fatema, Sharmin Sultana

ID: 181-33-591,181-33-627

Under the supervision of

Md. Ashraful Haque
Assistant professor

Department of Electrical and Electronic Engineering
Faculty of Engineering
Daffodil International University

Daffodil International University

Certification

This is to certify that the thesis entitled, “**Design and analysis of T-shape microstrip antenna for WLAN and C band application**” submitted by **Sharmin Sultana** & **Maul Jannat Fatema** in partial fulfillment of the requirements for the award of Bachelor of Science Degree in ELECTRICAL AND ELECTRONIC ENGINEERING at the Daffodil International university, Ashulia is an authentic work carried out by him under my supervision and guidance. To the best of my/our knowledge, the matter embodied in the thesis has not been submitted to any other University/ Institute for the award of any degree or diploma.

Ashraf

Md. Ashraful Haque
Assistant Professor, EEE Department
Department of EEE
Faculty of Science and Engineering
Daffodil International University

Jannat

Maul Jannat Fatema
ID: 181-33-591
Academic year: 2018-2021

Sharmin

Sharmin Sultana
ID: 181-33-627
Academic year: 2018-2021

BOARD OF EXAMINERS

Dedicated to

Our Parents

TABLE OF CONTENTS

LIST OF FIGURE

LIST OF TABLES

LIST OF ABBREVIATIONS

RMPA	Rectangular Microstrip Patch Antenna
MPA	Microstrip Patch Antenna
GHz	Giga Hertz
IE3D	Moment of Method Based EM Simulator
EM	Electro-Magnetic
GPS	Global Positioning System
Wi-Fi	Wireless Fidelity
WLAN	Wireless Local Area Network
RF	Radio Frequency
VSWR	Voltage Standing Wave Ratio
PCB	Printed Circuit Board
MP	Microstrip patch
WiMAX	Worldwide Interoperability for Microwave Access
RFID	Radio Frequency Identification
MIMO	Multiple-Input Multiple-Output
MHz	Mega Hertz
NASA	National Aeronautics and Space Administration
2D	Two Dimensional
3D	Three Dimensional
Dg	Directivity Gain
Rp	Radiation intensity for Particular angle of antenna
Ra	Average Radiation intensity
Bw	Bandwidth
Fu	Upper Frequency
Fl	Lower Frequency
Fc	Center Frequency
RL	Return Loss

LIST OF SYMBOLS

λ	Wavelength
π	Pie
f	Frequency
C	Speed of light
Γ	Reflection coefficient
ρ	Magnitude coefficient
R	Resistance
L	Inductance
C	Capacitance
G	Conductance
Z_0	Impedance
ω	Angular frequency
εr	Relative dielectric constant
ε_{eff}	Effective dielectric constant
$\tan\delta$	Loss tangent
h	Height
fr	Resonant frequency
V_0	Velocity of light
□□□□	Effective length
□	Angle

ACKNOWLEDGEMENT

I express our sincere gratitude and in debtedness to the thesis supervisor **Md. Ashraful Haque,** for his initiative in this field of research, for his valuable guidance, encouragement and affection for the successful completion of this work. His sincere sympathy and kind attitude always encouraged us to carry out the present work firmly. I express our thankfulness to **Professor Dr. M. Shamsul Alam**, Head of the Department of Electrical and Electronic Engineering, DIU, Ashulia for providing us with best facilities in the Department and his timely suggestions. I would also like to thank **Md. Ashraful Haque,** Assistant Professor, Department of Electrical and Electronic Engineering, DIU, Ashulia for his guidance and suggestions in our work. I would also like to thank Zeland Software for providing the simulation package. I am very grateful and thanks to **Abu Saleh** to helping me so much for teaching about CST software.

Last but not least we would like to thank all my friends and well-wishers who were involved directly or indirectly in successful completion of the present work.

Maul Jannat Fatema, Sharmin Sultana
Student ID: 181-33-591, 181-33-627

ABSTRACT

In this study, a new modified T shape simple Microstrip patch antenna (MPA) for Wi-Fi packages is proposed and studied. The suggested antenna runs between 4 and 8 GHz with a go back loss of less than -10 dB, practically covering the entire C band with the well-known benefit. In addition, the suggested antenna is designed to operate at C band and WLAN (802.11/a/b/g) frequency bands by feeding a coaxial probe, and the MPA is simulated on Zeland IE3D simulation software using an Arlon cu 217LX (lossy) substrate with a dielectric constant of 2.2 and a thickness of two.425mm. The antenna is 20 inches long and 20 inches wide. The dimension of designed antenna consists of 20 102.425 mm3 is the size of a tenth of a tenth of a tenth The suggested antenna resonates at 5.121 GHz for IE3D and 5.78 GHz for CST, and can be used in satellite packages, planes, spacecraft, and wireless communication, including WLAN, WiMAX, and Wi-Fi. For CST, the cited advantage and directivity are 5.42929 dB and 6.16506 dBi at 5.121 GHz, respectively, and gain and directivity are 4.47 dBi and 5.46 dBi at resonance frequency 5.78 GHz, respectively.Higher return loss and VSWR (2).

CHAPTER 1

OVERVIEW

1.1 Introduction

Wireless communication is a significant portion of the communication industry. It has become user-friendly in our society and indispensable in our daily lives. It gives us a new sense of agility and has revolutionized the way we do almost everything with great pleasure. Microstrip patch antennas (MPA) are widely used in ubiquitous industry and have piqued the interest of researchers due to various properties such as low profile, easy fabrication and integration with circuits, and easy mounting on vehicles, among many others [9, 22]. These magnificent properties of MPA contribute to military applications such as missiles, spacecraft, and aircraft, and commercial applications such as mobile cellular communications, mobile satellite system, and global positioning system. The proper antenna is chosen based on the application's requirements such as cost, size, gain, bandwidth, efficiency, radiation pattern, frequency band, and coverage, and it will reduce power consumption and improve transmission efficiency. Wi-Fi is the fastest growing component of modern wireless communication, providing users with the mobility, freedom, and flexibility to move around within a wide coverage area while remaining connected to the network [1]. The global electromagnetic radiation has been allocated for all types of electromagnetic (EM) radiation based on EM wave wavelengths and frequencies where antennas can operate for applications such as wireless local area network connections (WLAN), satellite, and so on. The material that can be used to make an antenna is determined in part by the operating frequency of the antenna. Many materials are used in antennas, including RT duroid, Arlon Cu, ceramic, steel plate, and new artificial materials known as meta-materials, which exhibit unusual properties not found in nature. By designing antennas with meta-materials, antenna performance can be improved. Antennas, on the other hand, are among the most complicated radio frequency (RF) design aspects The antenna has a significant impact on the range and performance of an RF link [24].

In this paper, a single band MPA is designed for WLAN application id designed.Designing MPA using various techniques allows for the enhancement of antenna characteristics such as antenna size, gain, bandwidth, directivity etc and so on.

1.2 Background

G.A. Deschamps [22] spearheaded the amalgamation of MPA in the 1950s. Following the evolution of printed circuit board (PCB) technology in the 1970s, many authors developed the first practical microstrip antenna and described the radiation of the patch antenna from the ground plane by a dielectric substrate for various aspects. As a consequence, Munson developed an antenna for rockets and missiles, which opens up a vast field of investigation all over the world [24].A microstrip antenna includes a very thin metal strip referred to as patch positioned on a ground plane. The engaging in patch and ground aircraft are separated by means of dielectric substrate [antenna theory pdf]. There are many radiating structures in geometry for MPA together with square, circular etc. That are widely discussed in bankruptcy 2. The low profile planar configuration of microstrip antennas may be fashioned conformal to host plane without any hassle. Many packages of microstrip antenna have drawn attention of researchers as they could work no longer most effective for civilian but also for army cause which includes cellular machine, radio frequency identification (RFID), global positioning machine (GPS), WLAN, Wi Max, Wi-Fi, satellite communique, radar gadget and missile control gadget and many others. [22-24].

Microstrip antennas allow for a wide range of design possibilities, which is an area of ongoing research. Modified MPA shapes, such as rectangular or circular dimensions of length (L) or radius (r), can aid in obtaining desired resonant frequencies [23]. The most common types of microstrip antennas are rectangular and circular patches. The gap between the conducting patch and the ground plane is known as the quality factor (Q), and it (Q) can be reduced by increasing the thickness of the dielectric substrate. However, there is a significant disadvantag

As the thickness of the material increases, the efficiency decreases, and it also indicates a low power gain, extra radiation from its feed and junction points [22]. The substrate permittivity (□□) also influences the bandwidth and gain.

1.3 Literature Review

In recent years, a technical trend has centered significant effort into the creation of microstrip patch antennas for advantages such as low cost, light weight, and the ability to sustain good performance over a wide frequency spectrum[5]-[9]. Patch antennas, on the other hand, have limited gain and a narrow bandwidth. Several strategies have been used to circumvent these limitations, including changing and combining patch shapes, cutting slots, increasing substrate thickness, and inserting parasitic elements [10]-[15]. Designing an E-shaped patch antenna [16], [17], or changing the ground plane [5], [7], or a U-slot patch antenna [18] or T shape patch antenna [19]- [22] are examples of patch shape modification. The authors of [16] say that a patch antenna can improve bandwidth by up to 30%, while an E-shaped microstrip antenna can improve bandwidth by more over 30% when compared to a standard MPA. The primary goal of this paper is to To improve bandwidth, build a T-shaped patch antenna.

[19] proposes a T-shape microstrip patch antenna with 37.2128.891.6 mm3 dimensions for broad bandwidth, which is essential for fourth generation wireless networks. The T shape antenna's operating frequency is 2.5 GHz, with a return loss of -13.63 dB, a VSWR of less than 2, a bandwidth of 123 MHz, and a dielectric constant and thickness of 4.2 and 1.6 mm, respectively. In [21], a wide Ku-band microstrip patch antenna with dimensions of 20201.625 mm3 was presented employing a FR-4 substrate slab backed by a PEC ground plane. Two rectangular patches ending in a T shape were introduced to improve the antenna's bandwidth and gain. The suggested antenna has a 7.5 GHz bandwidth and a gain of 5 dB. The suggested antenna has a return loss of -17 dB and resonates between 15.8 and 18.8 GHz. The proposed antenna in [14] is an exploration of an inset fed wideband circular slotted patch antenna appropriate for 5.2 GHz satellite C-band applications, with a diameter of 44 56.4 mm2. The antenna that has been proposed

have increased efficiency (97%) as well as gain (8.17 dB), directivity (8.22 dB), and return loss (8.22 dB) (-21.79). In the frequency range 3.94 to 3.98 GHz, the suggested antenna has a 92 percent impedance bandwidth.The author improved the bandwidth by using a folded-patch feed, U-shaped slot, one shorting pin on the edge of the aperture, and an E-shaped edge at 10.65 GHz. Using two shorting pins and a V-shaped slot patch, the antenna's size was lowered. The tiny wideband antenna was also obtained, working in the range of 4-14.4 GHz, while the patch's size was reduced from 18 to 16 mm.On a 7 mm thick air substrate, the basic antenna measures 15 mm2 to 15 mm2. Cos of their small size, low cost, and outstanding quality, UWB patch antennas [5] have been extensively used in different domains of communication in recent years. They're mostly used because of their various frequency capabilities. However, to accomplish dual band notch and a wide bandwidth of 2.98-10.76 GHz with two notched bands operating at 3.5 and 5.5 GHz, the projected antenna used a line-fed and a single tri-arm resonator below the patch. In [11], a tiny quad-band MPA with dimensions of 30 30 4.4 mm3 was proposed for S and C band applications. There are two rectangular notches on the quad band antenna. At -10 dB, the proposed antenna's simulated impedance bandwidths are 100 MHz (4.65-4.75 GHz), 170 MHz (5.04-5.21 GHz), 120 MHz (5.64-5.76 GHz), and 130 MHz (5.64-5.76 GHz) (6.24-6.37 GHz). The C-band is used for satellite communication, whether for full-time satellite TV networks or raw satellite feeds, and is particularly popular in tropical rainy locations because it is less susceptible to rain fade than the Ku-band. The frequency range of the C- band is 4-8 GHz.

1.4 Aim and Objectives

The objective of this study is to increase the MPA characteristics' performance in the C band. The objectives are listed below.

- Antenna return loss minimization (S11).
- Build an MPA with higher capacity to cover the entire C-band.
- The designed antenna's gain has indeed been improved.
- CST Studio Suite confirms.

1.5Methodology

The performance of the Microstrip patch antenna (MPA) has been improved in the C-band frequency domain. Adding two halves of plow to MPA yields a sufficient outcome. To achieve our eligible objectives, basic methods have been outlined step by step.

Step1: Defining the length (L) and fundamental construction of a simple rectangular MPA (W).

Step 2: Increasing the bandwidth of the antenna by using a T shape.

Step 3: For improved results, modify and add a plow-shape part to the T-shape patch.

Step 4: Evaluate the performance of each designed antenna in terms of antenna characteristics, particularly bandwidth, gain, and return loss.

Step 5: Evaluate the proposed antenna parameters in light of existing literature.

1.5 Thesis Organization

There are five primary chapters in this thesis, as well as a reference section.

Chapter 1 The introduction, background, literature review, aims, and scope of the thesis are all covered.

Chapter 2 the essential concepts of the MPA are explained through brief literature reviews. It also goes over the essential literature on slot-based C-band MPA design.

Chapter 3 describe the design procedure of proposed antenna using line feeding technique.

Chapter 4 The suggested T shape patch antenna is discussed with a comparison of the CST studio suite and the Zeland IE3D simulator, a return loss graph, bandwidth for all individual antennas, average and vector current distribution, and 2D and 3D radiation patterns. A quick comparison of current articles and the proposed antenna was also conducted.

Finally, **Chapter 5** concludes the work and discusses future work possibilities.

CHAPTER 2

Literature Studies

2.1 Antenna parameters:

An antenna, which functions as a transducer, turns electrical energy into electromagnetic energy and vice versa. It is necessary to understand several observable qualities in order to assess whether the antenna design is good or bad. It is necessary to comprehend the many antenna factors that aid in determining the design's strengths and weaknesses. These antenna characteristics are dependent on one another. Consequently, it should be make sure that all the parameters are optimized to the designing antenna. For example, if the Return loss is larger than -10 dB then the designed antenna doesn’t work and VSWR value will be than 2.

2.1.1 Antenna Field regions:

Antenna field regions are significant because an antenna begins to radiate after a fixed distance from the antenna. They are separated into three main areas:

- Regions that are reactive
- Near-field radiation / Fresnel area
- A large area

The far field areas are the most essential since they influence the antenna radiation pattern and most of the other parameters. Antennas On the other hand,are used utilized to establish long-distance communication. As a result, the antenna field regions are critical.

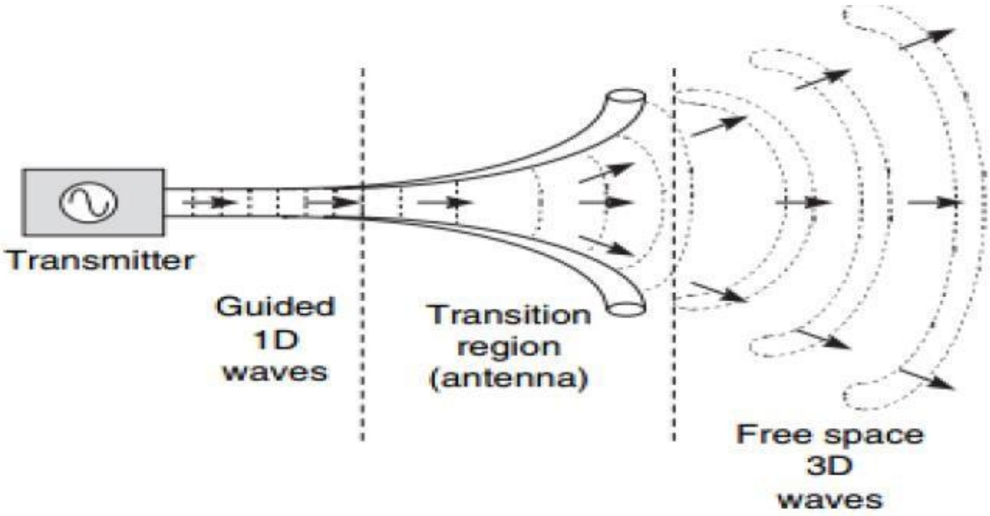


Figure 2.1 Antenna radiation

Antennas field components include electric and magnetic fields. These fields are referred to as radiative and reactive fields, respectively. The distance 'r' in the denominator equation of the reactive field component is of the order of two or higher. The radioactive component has a distance component with 'r' of the first order as well. As a result, as the distance between the two points grows, the reactive component of the field dies, but the reactive component remains. Near field areas are defined as reactive and radiating near field / Fresnel regions, respectively. Far field refers to the total range of two times the wave length to infinity.

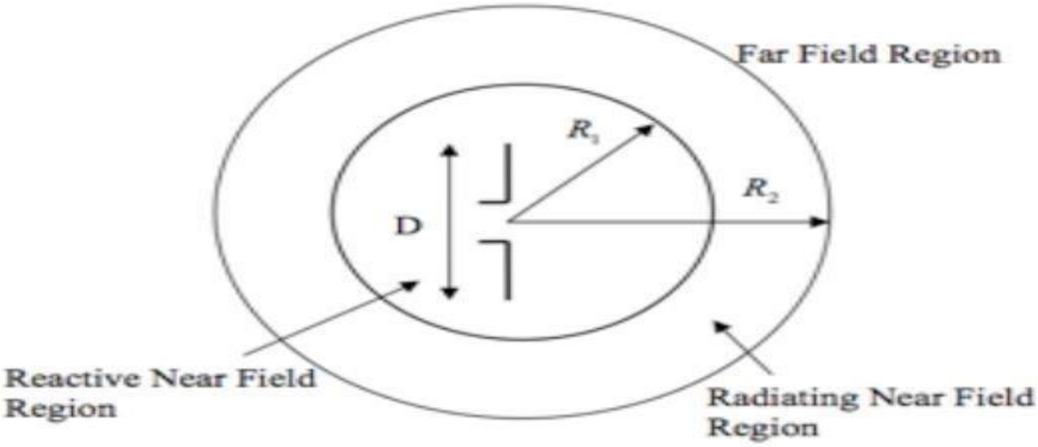


Figure 2.2 near field and far field regions.

2.1.2 Radiation pattern:

Mainly the radiation is produced when the flowing current feel sudden discontinuity. Radiation pattern is the delegation of antennas radiation intensity with respect to space co-ordinate system. According to the radiation pattern, antennas characteristics are normally directional or omnidirectional. When antenna radiate equally along azimuthal angle but varies with elevation of angle sinusoidal, the antenna called omnidirectional one. On the other hand, if an antenna radiates with higher directivity at any particular angle with respect to others angle. The antenna said to be directional. The directionality of antenna is known as directivity. The radiation pattern can be display as 2D plot, 3D plot or polar plot. Plots are given below.

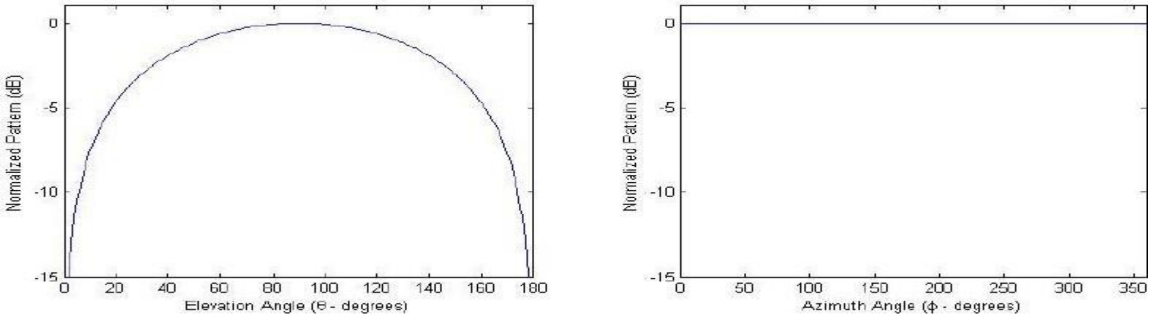


Figure 2. 3 Radiation pattern

2.1.3 Directive gain:

Another antenna that radiates differently at different angles is the directional antenna. Directive gain is the ratio of an antenna's radiation intensity at a specific angle to the average radiation intensity in all directions. It's written as dBi.

$$\text{Radiation intensity at that particular angle} = \frac{\text{Direction gain at that particular angle}}{\text{Average radiation intensity}}$$

2.1.4 Directivity:

An directional antenna that is dependent on a higher angle of radiation strength than all other directions. When the derectivity gain of directional antenna stays at a specific direction this is reffered to as directivity of directional gain.

2.1.5 Antenna Efficiency:

When applying power, the applied power may not be equal to the received power, resulting in loss in any system. Antenna, on the other hand, has two losses. One is due to an impedance mismatch between the antenna and the free space. Another reason is that because the antenna is made of a conducting substance, the input power is not radiated. Antenna efficiency is the ratio of an antenna's output power to its input power.

$$Antenna\ Efficiency = \frac{Output\ power}{Input\ Power} \times 100\%$$

2.1.6 Antenna gain:

An antenna gain is the antenna's directivity when the antenna efficiency is taken into account. The ideal case for an antenna is directivity, while the real scenario is gain. As a result, if all of the input power to an antenna is radiated, the gain and directivity will be the same. Because there are usually losses associated with antennas in practice, gain will be less than directivity.

Antenna Gain = Antenna Efficiency *Directivity

2.2 Matching and Reflection:

When power is applied to the structure, the function is to absorb the power. As a result, there is a significant discrepancy between applied and out power. If the system absorbs little power, part of it reflects back according to matching, whereas no reflection occurs due to mismatching of the transmission line with the antenna.

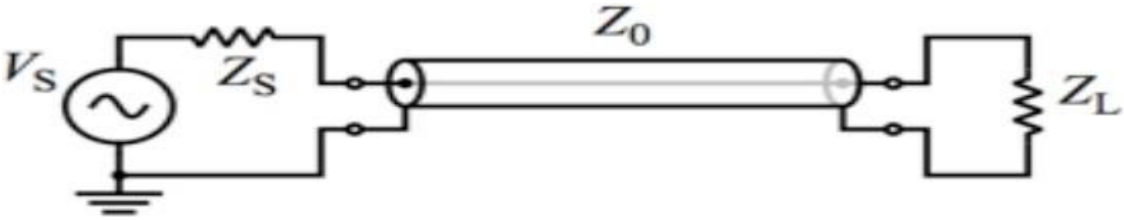


Figure 2. 4 Circuit Diagram of Load impedance, Source and Transmission line

The reflection can be measured by given equation. The reflection co-efficient is

$$\Gamma = \frac{Z_L - Z_S}{Z_L + Z_S}$$

The reflection co-efficient is complex number (a+jb). If the imaginary part is 0, then if

The reflection co-efficient = -1; the line is short circuited (maximum negative reflection).

The reflection co-Efficient = 0; the line is perfectly matched (No reflection occurs).

The reflection co-efficient = 1; the line is open circuited with antenna (positive reflection).

The reflection co-efficient is a complicated value that changes on a regular basis. The reflection coefficient can be graphically described using a smith chart, as seen in the figure.

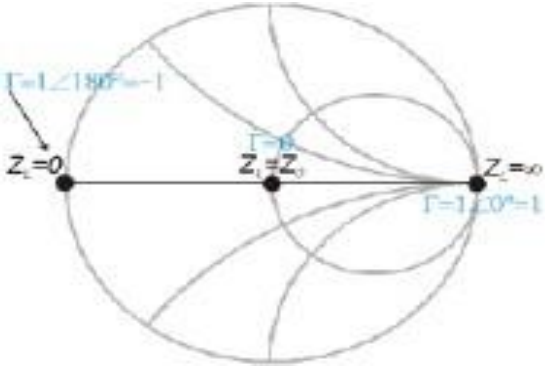


Figure 2. 5 Smith Chart

2.2.1 Voltage Standing Wave Ratio (VSWR):

There is no reflection created there due to a mismatch of transmission line with antenna, or there is a great amount of reflection produced there due to perfect matching of transmission line with antenna. By calculating VSWR, it is possible to determine how much load impedance reflection is mismatched. The ratio of maximum to minimum voltage is known as VSWR. It's possible to write it mathematically as,

$$VSWR = \frac{Maximum\ voltage\ of\ standing\ wave}{Minimum\ Voltage\ of\ standing\ wave}$$

The value of VSWR is 1, means perfectly matched transmission line with antenna. The value of VSWR 2 is accepted as good match.

2.2.2 Return loss/Sparameters:

Return loss or S-parameters is a power which is reflected in the transmission line. It’s also called as scattering parameter and the measuring units is dB. Mathematically written as

$$RL_{\mathrm{dB}} = -20\log_{10}|\Gamma|$$

The relationship between reflection co-efficient and VSWR is:

$$VSWR = \frac{1-\tau}{1+\tau}$$

By simplifying the equation written as

$$Return\ Loss = -20\log\frac{VSWR-1}{VSWR+1}\ dB$$

2.2.3 Bandwidth:

The space between the lowest and highest frequency ranges within an antenna's operating range is referred to as bandwidth. The S11 parameter bandwidth is the frequency range with a return loss of less than -10 dB. There are various types of bandwidth, each based on a distinct parameter. Impedance bandwidth is constant, while Affectivity and Directivity bandwidth are sometimes known as gain bandwidth. Impedance bandwidth is determined by a variety of factors, including dielectric materials and ground plane dimensions. Impedance bandwidth was measured at -6 dB return loss. The flowing equation can be used to compute the desired bandwidth;

$$\mathrm{BW}_{Broadband} = \frac{f_H}{f_L}$$

$$BW_{narrowband}(\%) = \left(\frac{f_H - f_L}{f_C}\right) \cdot 100$$

$Where,$

$f_H = The\ Upper\ Frequency,$

$f_L = The\ Lower\ Frequency,$

$f_C = The\ Center\ Frequency.$

2.3 Introduction of Microstrip patch antenna:

Microstrip patch antennas are becoming increasingly used in the millimeter-wave frequency band [24-26]. Patch materials, dielectric materials, and ground materials make up the microstrip patch antenna. The conducting materials that are placed on the dielectric materials make up the antenna patch. As shown in the diagram, Groundisa substance that is connected that is substrate materials and substrate is put between patch and ground .

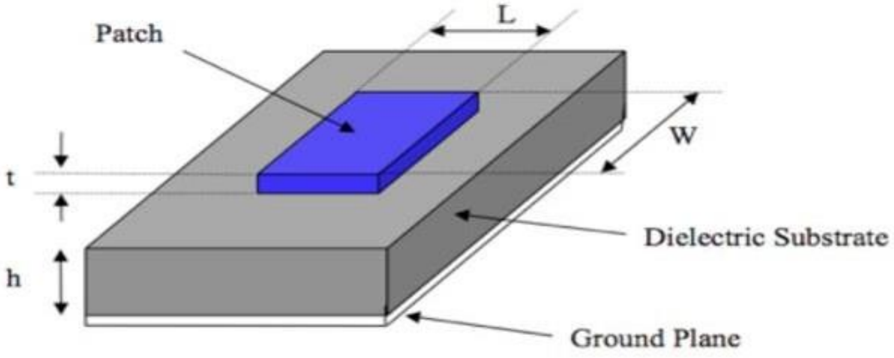


Figure 2.6 a microstrip patch antenna

Microstrip patch antennas come in a variety of shaps such as rectangular, square, circular, Triangular and Elliptical, as shown in the given diagram.

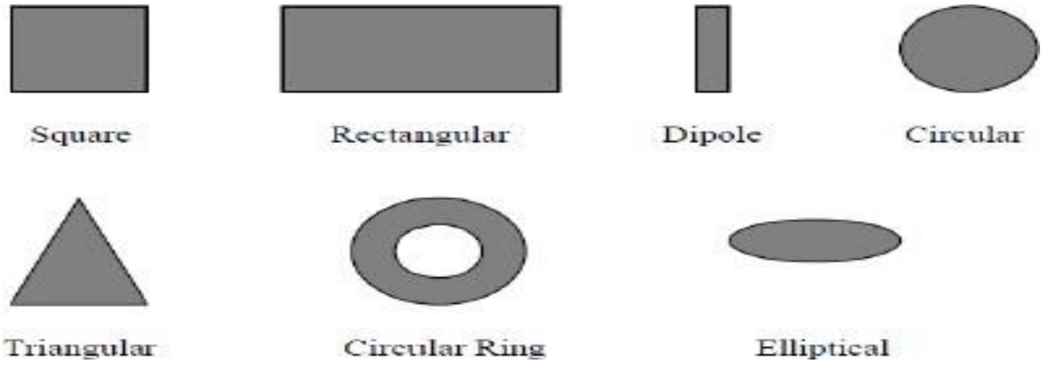


Figure 2.7 Different shape of Microstrip patch antenna

2.3.1 Advantage and Disadvantage:

Because of its various features, the microstrip patch antenna is becoming increasingly popular. The benefits of microstrip patch antennas are listed below [27].

- Low volume and light weight
- Low-profile design that can readily be made to fit to the host surface
- Because of the low cost of production, it can be produced in enormous quantities.
- Both linear and circular polarization are supported.
- It's simple to incorporate into a microwave integrated circuit (MICs)
- Dual and triple frequency functioning are possible.
- When installed on a hard surface, it is mechanically rohbust.

When compared to traditional antennas, microstrip patch antennas have more flaws. The following are some of the significant disadvantages by [27] and Garg at a [28]

- A limited bandwidth
- Ineffectiveness
- Gain is little.
- Radiation from feeds and connections that isn't needed
- Except for tapered slot antennas, poor end fire radiator
- Capacity to handle low power
- Excitation via surface waves.

Restricted transfer speed of Microstrip fix radio wire is the hindrance which is happens because of different explanation among them huge quality variable is rule reason. Enormous quality variable of Microstrip fix receiving wire address Narrow transmission capacity and low proficiency. Quality variable can be diminished by expanding thickness of the substrate layer. Be that as it may, expanding thickness of substrate layer made another issues, for example, lower gain and lower power taking care of limit. These issues are overwhelmed by involving a cluster design for the components.

2.4 Basic principle of operation:

The primary shape of antenna like as a given parent. In this parent, the center conductor of a coax serves as the feed probe to couple eletromagnetic strength in or out of the patch. After feeding to the p.C. Antenna is experience discontinuity then it produced electromagnetic field there. At center of the patch Electric area is 0,most at one side and bad at opposite. These are continously trade facet consistent with the instantenuos carried out sign.

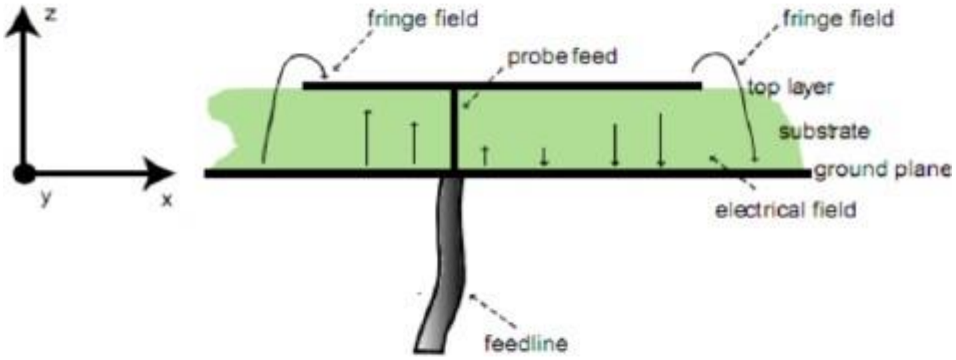


Figure 2.8 Side view of microstrip patch antenna

2.4.1 Feeding technique:

Antenna feeding is the manner by way of which patch of antenna is excited. Microstrip patch antennas are excited or feeding in diverse approaches. There are types of feeding strategies. One is contacting and every other is non-contacting feeding.

2.4.2 Contacting feeding:

The contacting feeding is the manner by which electricity is being feed at once to radiating patch thru the connecting elements which include microstrip line. Again, the contacting feeding techniques may be sub-divided into two strategies.

- Microstrip feedline
- Coaxial feedline

2.4.3 Microstrip feedline:

Feeding microstrip patch of antenna is immediately with transmission line like as figure .

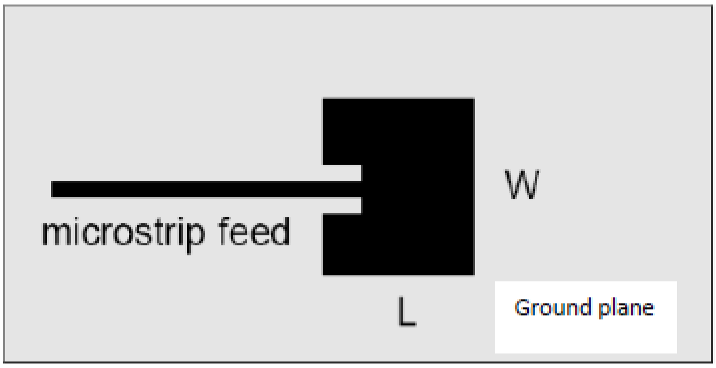


Figure 2.9 Microstrip feeding of patch antenna

There are numerous benefit and disadvantage of Microstrip feed lin approach.

Advantages:

- Easy to manufacture
- Easy to impedance matching
- Easy to model

Disadvantages of this method:

- Make surface wave
- Limited bandwidth
- Asymmetric shape that is responsible to go polarization

2.4.4 Coaxial feed:

In coaxial feeding approach, drilling a hollow in substrate and ground so that patch is happy or feed immediately contacting via the hollow like as the given determine:

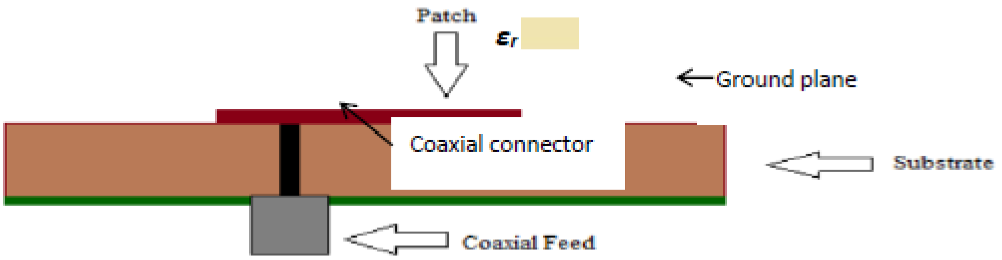


Figure 2.10 Coaxial feed

Advantages:

- It is Easy to healthy
- It is Easy to manufacture
- Low spurious radiation

Disadvantages:

- Difficult model when Epsilon r >0.02lamda
- Limited band width
- Cross polarization

2.4.5 Non-contacting:

The non-undertaking is the technique by means of which energy is being fed circuitously patch with transmission line is called non-contacting method.

The non-contacting technique sub-divided into techniques.

- Aperture-coupled feed: The aperture coupled is different structure in which two different substrate is used and these two substrate layer is separated by ground plate. The patch is placed on the top substrate layer and transmission line is connecting with last layer of substrate like as the given figure.

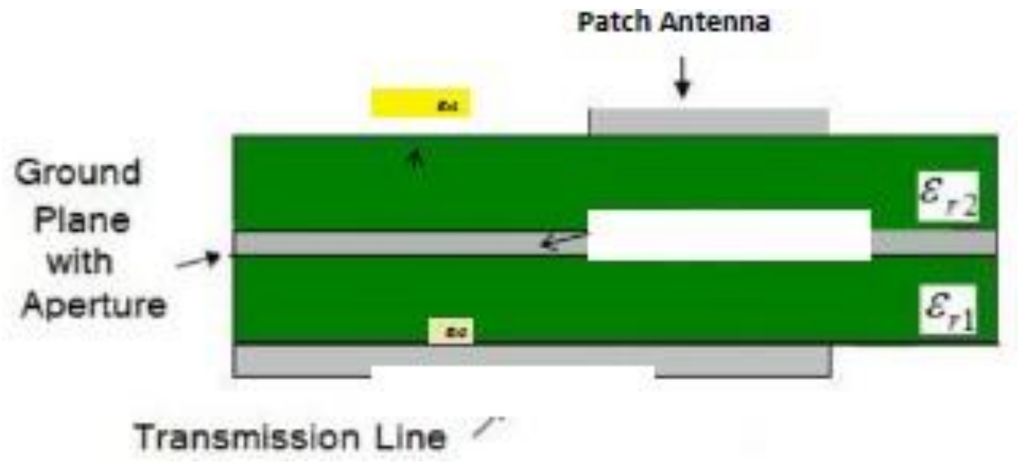


Figure 2.11 Aperture-coupled feed

- Proximity coupled feed: The proximity coupled feed is referred to as Electromagnetic coupling. In this approach substrate layer is used like as aperture coupled feed strategies but those are separated via transmission line like as the given determine.

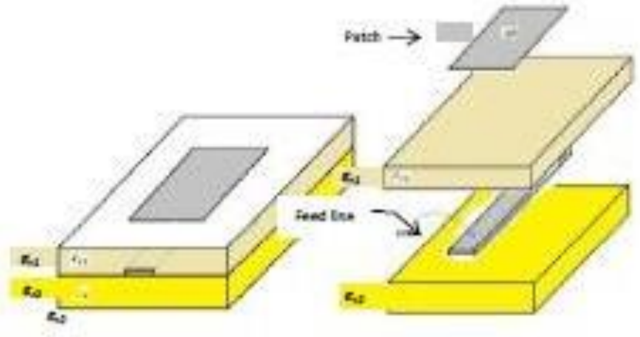


Figure 2.12 Proximity coupled feed

CHAPTER 3

DESIGN OF THE PROPOSED PATCH ANTENNA

In literature overview (Chapter 1) it's been audited that the antennas, functioning in C-band vicinity, advantage and bandwidth are systematically bad in some antenna. Therefore, the critical focus of this thesis is to design a MPA having stepped forward bandwidth and advantage in C-band vicinity. In this chapter antenna designs are validated in chronological order where bandwidth expansion of the proposed antenna are found inside the single patch antenna.

To design our favored proposed antenna Zeland IE3D simulator has been used. All the antennas are simple and feature the functionality to function for C-band utility.

3.1 Specifications

Our essential goals is to design a patch antenna that may accomplish all of the Hi-velocity WLAN standards available at some stage in the globe within the 5-6 GHz levels. More in particular our patch antenna must justify [23]:

- European 802.11a or 5.725-5.825 GHz band
- Middle-eastern WLAN or 5.47-5.825 GHz band
- USA 802.11a or 5.15-5.35 GHz band

- Currently approved IEEE 802.11j or 4.9-5.1 GHz band

Overall, our proposed antenna design need to provide at the least -10 dB return loss for the complete band of 4.05 GHz to 8.35 GHz and VSWR also ought to be less than 2. However, Arlon cu 217LX(lossy) substrate with dielectric consistent of two.2 has been decided on as dielectric cloth for our proposed antenna. As a beginning reference [19] we are going to use the T-form structure and its parameters to design a easy form of T-form patch antenna. Then optimization is done through converting various parameters to discover the most ideal antenna for our choice operation. After finding out the parameters which could produce a suitable go back loss for four GHz to 8 GHz variety, we proceed to observe radiation sample, contemporary distribution and vector distribution of the proposed antenna.

3.2 Microstrip Patch Antenna Dimension

Patch width has a minor impact on the resonant frequency and radiation pattern of the antenna and it also impacts the input resistance and bandwidth to a bigger volume. However, the radiation depends at the antenna width and period. The width of antenna is at once proportional to electricity radiation, bandwidth of antenna, and radiation efficiency and inversely proportional to resonant resistance. To determine micro-strip patch antenna’s duration by means of given equation.

$$\square = \frac{c}{2fr\sqrt{\square r}} \qquad (3.1)$$

Where speed of light is denoted by c, resonant frequency frand dielectric constant□r.

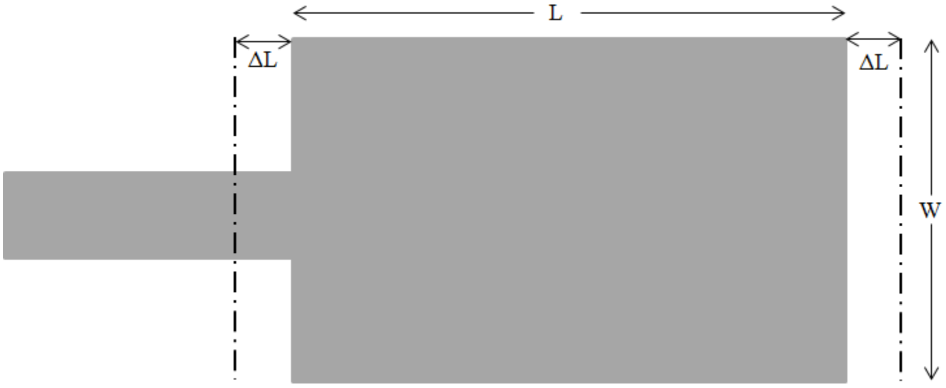


Figure 3.3(a) Microstrip Patch Antenna Dimension

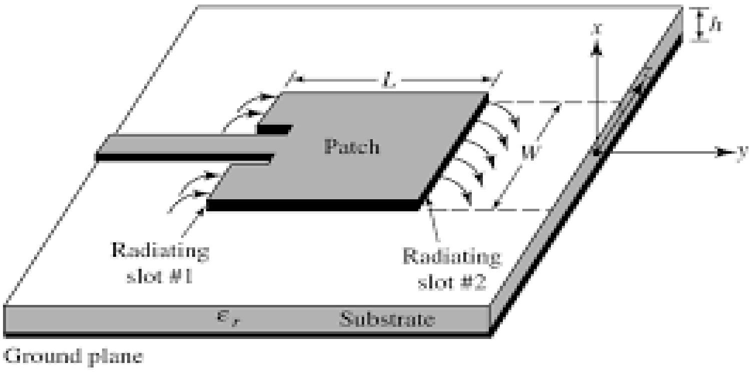


Figure 3.3(b) Radiation flow from patch to ground

For efficient radiation, width of patch is given by:

$$W = \frac{v_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} \qquad (3.2)$$

Here, V_0 = velocity of light = 299792458 m/sec, f_r= resonance frequency and ε_r =relative dielectric constant of substrate.

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{W}\right]^{-\frac{1}{2}} \qquad (3.3)$$

Where, ε_{eff} = Effective dielectric constant, h = Height of dielectric substrate. For a given resonance frequency f_r, the effective length of patch is given by [7]:

$$L_{eff}= \frac{1}{2 f_r \sqrt{\varepsilon_{eff}} \sqrt{\mu_o \varepsilon_o}} \qquad (3.4)$$

Now the actual length of patch can be expressed by

$$L= \frac{1}{2 f_r \sqrt{\varepsilon_{eff}} \sqrt{\mu_o \varepsilon_o}} -2\Delta L \qquad (3.5)$$

Where, length extension is as follows [22].

$$\Delta L =0.421h \frac{\left(\varepsilon_{eff} +0.3\right)\left(\frac{W}{h}+0.264\right)}{\left(\varepsilon_{eff} -0.258\right)\left(\frac{W}{h}+0.8\right)} \qquad (3.6)$$

The ground plane of the MPA is larger than the patch by approximately six times of the thickness of substrate all around the fringe which can be expressed as follows:

Lg = 6h+L (3.7)

Wg= 6h+W (3.8)

3.3 Design of MPA

The simulation result and the layout of the MPA are placed on this segment.The essential parameters of an antenna to check the operation of an antenna at desired band are return loss, VSWR, advantage and directivity as a consequence.We can noticed that the designed antenna resonates at 5.121 GHz with a maximum return loss of -31.3 dB.

To understand parametric analysis of microstrip patch antenna, a reference antenna deign is given under. In which a single band RMPA is designed in Figure 3.Three(c) and it can be visible in Figure 3.Three(d) that the designed antenna resonates at 1.7 GHz with a minimal return lack of -

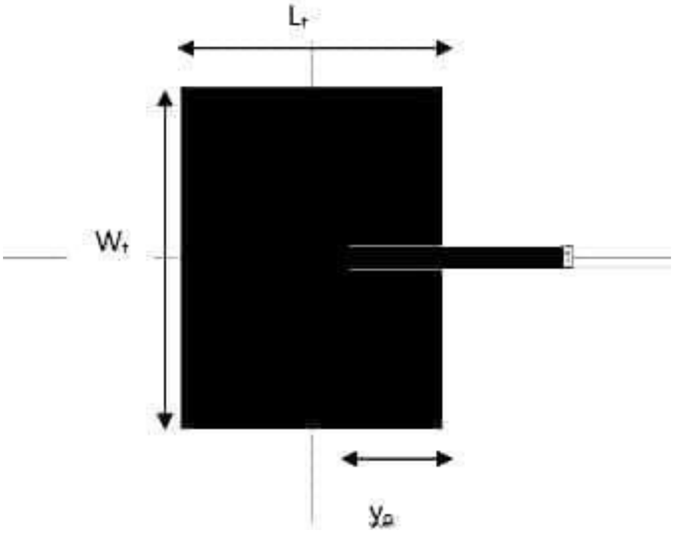
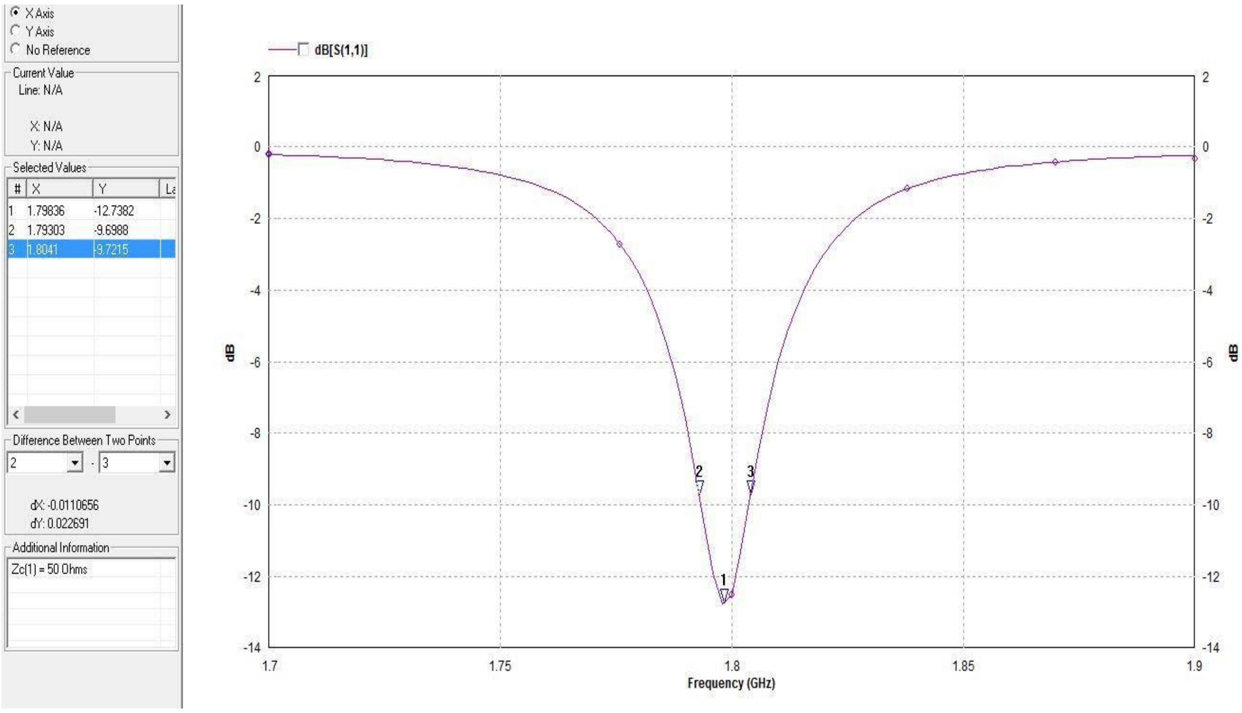


Figure 3.3(c) Design of the single band RMPA



● X Axis
○ Y Axis
○ No Reference

Current Value
Line: N/A
X: N/A
Y: N/A

Selected Values

#	X	Y
1	1.79836	-12.7382
2	1.79303	-9.6988
3	1.8041	-9.7215

Difference Between Two Points
2 - 3
dX: -0.0110656
dY: 0.022691

Additional Information
Zc(1) = 50 Ohms

Figure 3.3(d) Return loss of the single band RMPA

To acquire our preferred antenna and frequency band, we advanced T-form antenna with including more plow-shape inside the proposed antenna. The proposed antenna is proven in Figure three. Three(e) and the desire bandwidth and return loss graph is proven in Figure 3.Three(f). The measuring unit of measurement of proposed antenna is millimeter (mm).

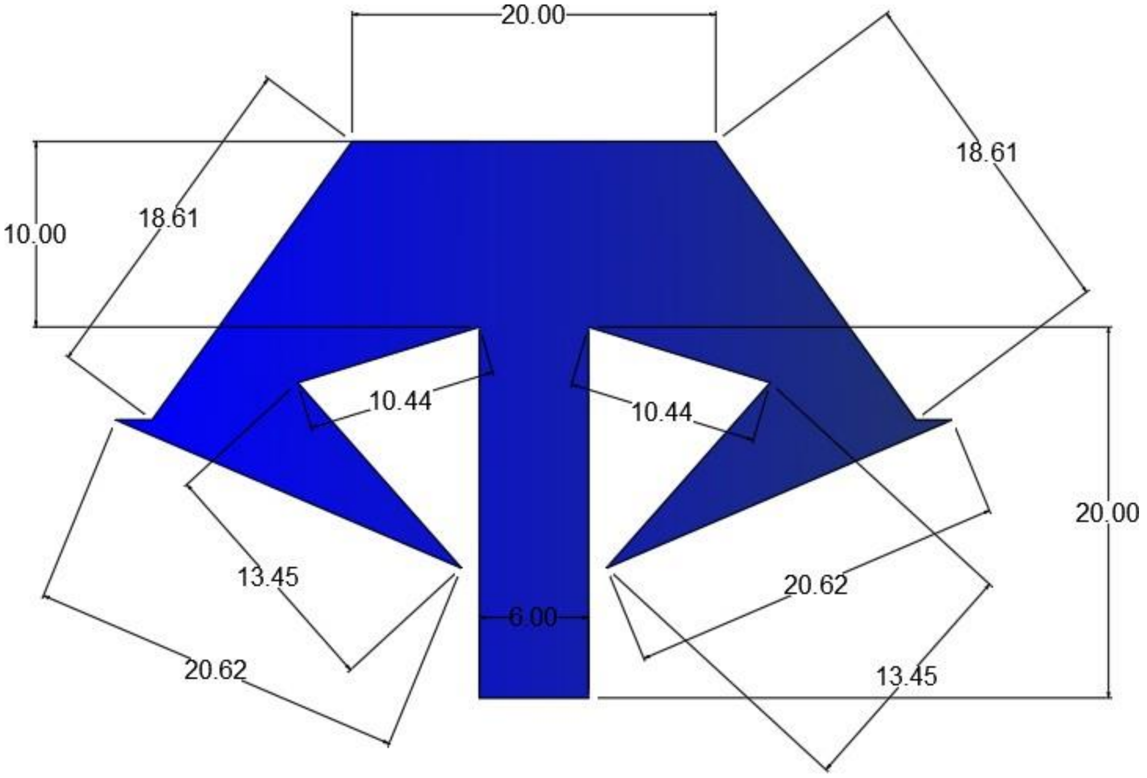
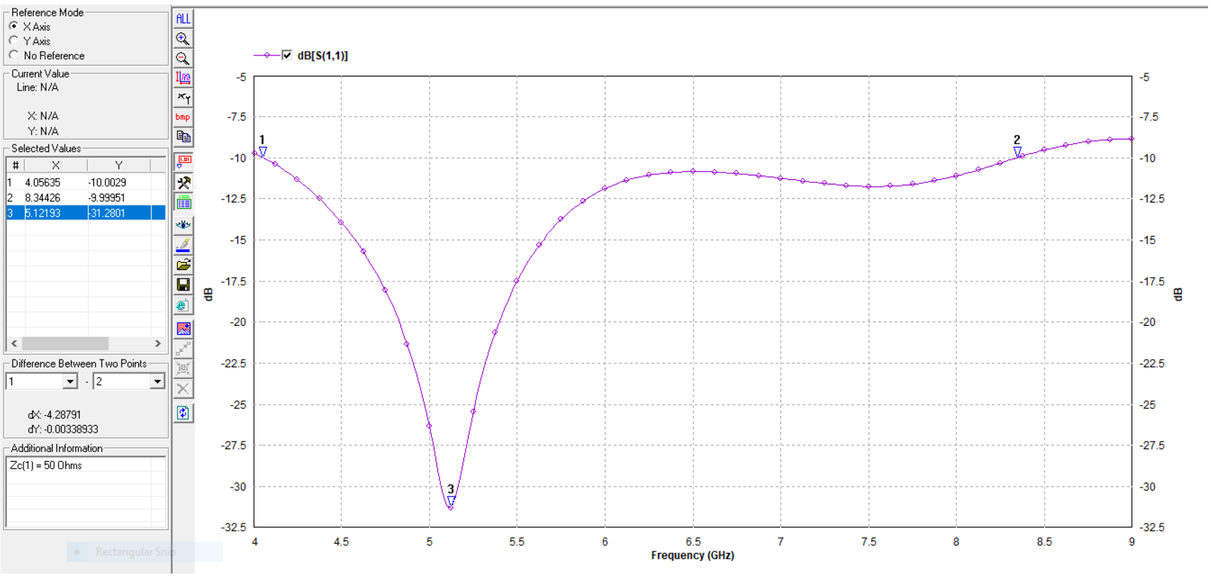


Figure 3.3(e): The design of the proposed antenna


Reference Mode
● X Axis
○ Y Axis
○ No Reference

Current Value
Line: N/A

X: N/A
Y: N/A

Selected Values

#	X	Y
1	4.05635	-10.0029
2	8.34426	-9.99951
3	5.12193	-31.2801

Difference Between Two Points
1 - 2

dX: -4.28791
dY: -0.00338933

Additional Information
Zc(1) = 50 Ohms

Figure 3.3(f): The desire return loss graph

CHAPTER 4

RESULTS AND ANALYSIS

4.1 Simulated Results of the Proposed Antenna using IE3DZeland

Zeland IE3D simulator, a full-wave electromagnetic simulator based on the method of moments that also analyzes 2D/3D and multilayer structures of ordinary shapes, was used to simulate the MPA. It can also plot S11 parameters and compute return loss, gain, VSWR, current and vector distributions, as well as radiation patterns. IE3D simulator is used to simulate the suggested antenna performance measures such as return loss, gain, directivity, bandwidth, average current distribution, vector current distribution, and 2D/3D radiation patterns. For comparative purposes, the same performance metrics are simulated using CST Studio Suite simulator software, which will be explained later in this chapter.

Acute simulation was used to obtain the desired antenna for C band use, which was the thesis's principal goal. A simple T shape patch with an extra section has been devised, resulting in a progressive increase in bandwidth. The suggested antenna's rectangular patch has been adjusted using a slot cutting approach for improved antenna performance, and the proposed antenna's bandwidth has been significantly expanded due to the features of slots. The suggested antenna has a 4 GHz bandwidth and can cover 100% of the C band frequency spectrum at a resonant frequency of 5.12 GHz. As a result, the suggested antenna may support WLAN applications, uplink and broadcast satellite service, GPS, fixed microwave, mobile satellite, and radio navigation.

An acute simulation was performed in the previous chapter to optimize the antenna for the frequency range of 4-8 GHz (bandwidth of 4 GHz), and as a result, we have fixed an antenna with an area of 20*10mm2 and a return loss of less than -10 dB, which is very effective for USA 802.11a or 5.15-5.35 GHz band and Middle-eastern WLAN or 5.47-5.825 GHz band.

standards. The design of the antenna is simple, resulting in reliable and useful operations for C band applications. Now that our simulated antenna covers all WLAN standards, we should evaluate our antenna operation in each of the standards using our antenna's average and vector current distributions, as well as 2D/3D radiation patterns for each band. The current distribution depicts the antenna form and aids in determining the density and direction of current movement inside the patch at specific frequencies. It also shows how different parts of the antenna react to different operating frequencies. A graphical illustration of a 2D/3D radiation pattern shows how an antenna radiates its output signal. However, a 2D radiation pattern can show the directivity and emission style of E-H fields, but a 3D radiation pattern can show the gain and directivity gain of E-H fields.

4.1.1 Average Current Distribution

The average current distribution primarily depicts which side of the antenna is radiating and which is not. As a result, we'll replicate our antenna at 5.12 GHz with 10 cells per wavelength and then look at the current distribution throughout the antenna surface.

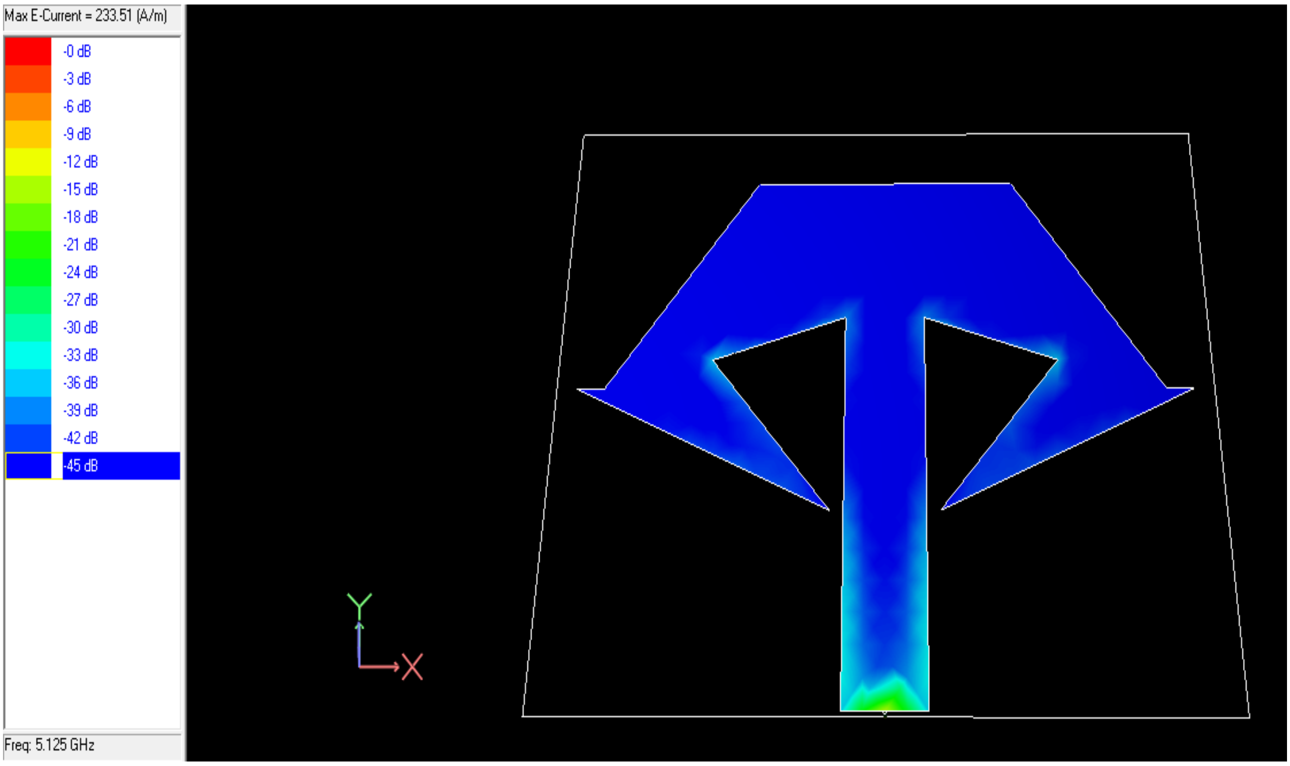


Figure 4.1 Average current distribution of proposed antenna at 5.125 GHz

At 5.125 GHz, the average current density on the surface of all antennas is shown in the diagram above . For all frequencies, the current distribution is predominantly green or blue, equivalent to an amplification of -30 dB to -45 dB, implying that our antenna can work as a transmitter or receiver at all frequencies in the 4-8 GHz range.

4.1.2 Vector Current Distribution

The vector current distribution depicts how current flows in the surface and how the antenna's current is spread. It also aids in determining the antenna's polarization and provides information on the path and movement of current at the resonant frequency over the patch surface. To further understand the frequency response, we will examine the vector current distribution on the surface of the patch at the same frequency.

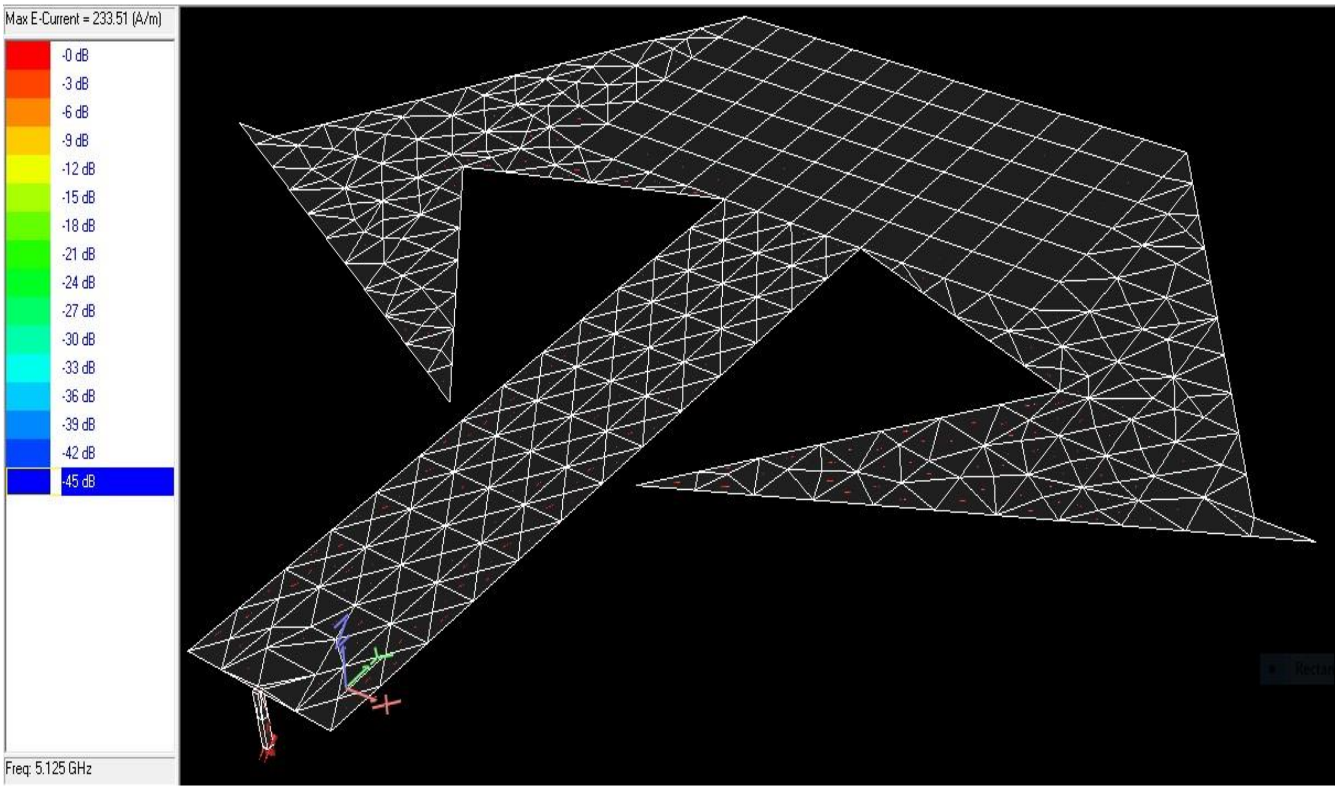


Figure 4.2 Average Vector current distribution of proposed antenna at 5.125 GHz

At a resonant frequency of 5.125 GHz, the vector current distribution over the surface of the patch antenna is shown in Figure 4.2(a). The magnitude of the current density at a certain moment and location is indicated by the size and direction of the vectors.

4.1.3 Radiation Pattern in two dimensions

Throughout the frequency range that it covers, a good antenna should maintain its polarization and emission pattern. n fact, the 2D radiation pattern aids in understanding how the antennas radiate in a 3D pattern. However, for analytical reasons, a 2D radiation pattern is used. The 2D polar plot of the planned antenna at 5.125 GHz is shown in figure 4.3.

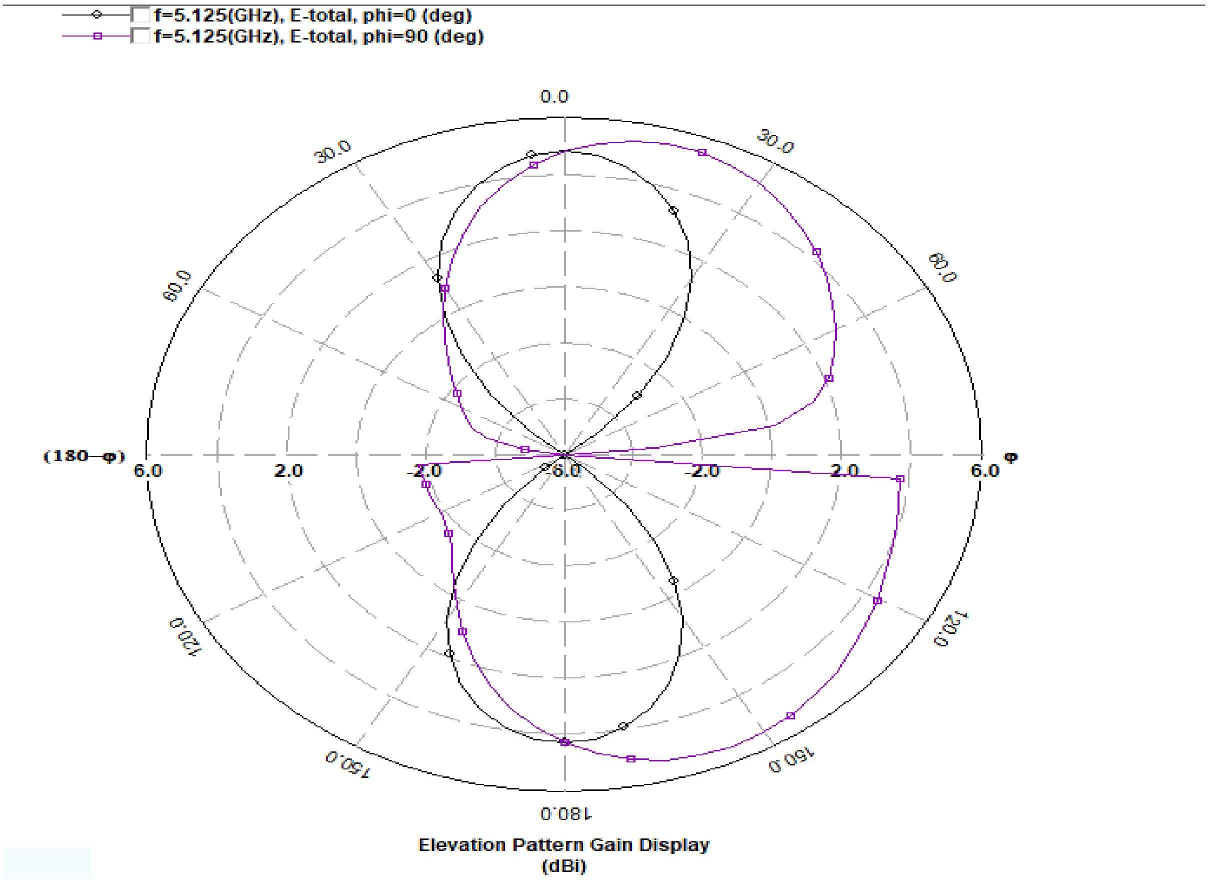


Figure 4.3 2D Radiation pattern of proposed antenna at 5.125 GHz

Figure 4.3 shows the proposed antenna's 2D radiation pattern at its resonance frequency of 5.125 GHz. Microstrip antennas, from the other hand, radiate normal to their patch surface, with elevation variations of = 0 and = 90 degrees. The suggested antenna's maximum gain is almost 6 dBi, and yet only 5.429 dBi at 5.125 GHz.

4.1.4 3D Radiation Pattern

A good antenna, like a 2D radiation pattern, should maintain its polarization and radiation pattern throughout the frequency range it covers. To better understand 2D patterns, a 3D radiation pattern has been utilized to represent the antenna's gain or directivity. Figure 4.4 shows an example of real 3D radiation pattern at the proposal antennas resonance of 5.125. The size of pattern in relation to the origin shows how strong the field is at given (theta, phi) angle.

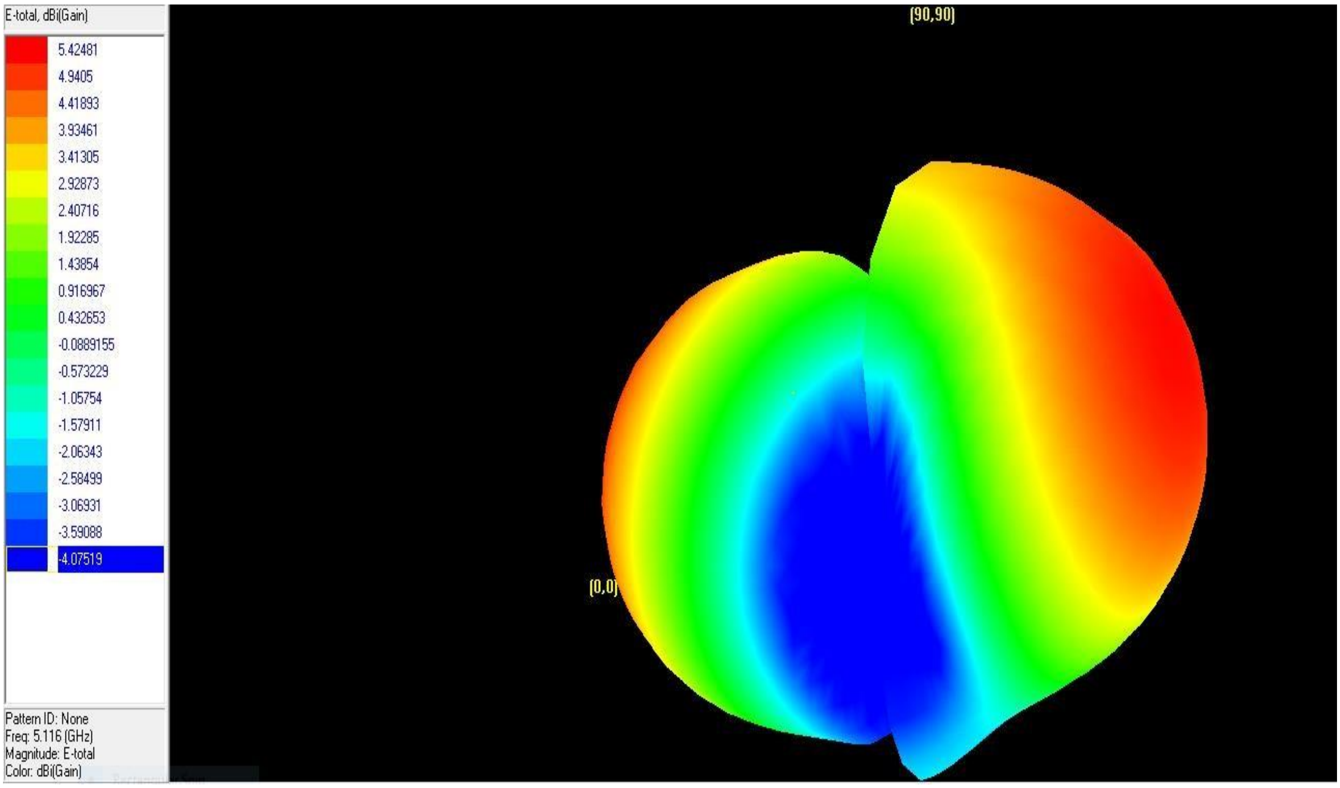


Figure 4.4 3D Radiation pattern of the proposed antenna at 5.125 GHz

The radiation pattern in 3D is achieved as follows in the Figure 4.4 from the different angles on the different axis. We can observe the gain on the left hand side of the Figure 4.4.

4.2 Simulated Results of the Proposed Antenna using CST Studio Suite

The suggested antenna is also intended for verification utilizing CST studio Suite software, which is equivalent to Zeland IE3D software in terms of dimension and materials. It can produce the same as long as IE3D's designed which is given in figure.

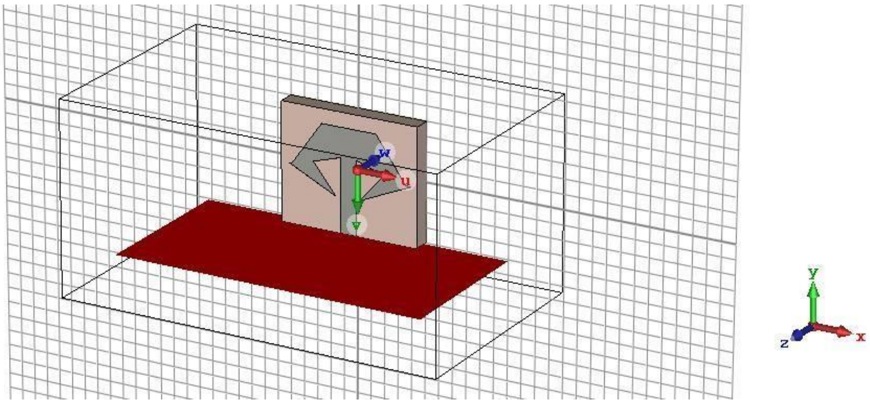


Figure 4.5 Proposed antenna by Using CST

The Following design is obtained by CST software and the return loss graph is similar to the previous result of IE3D.

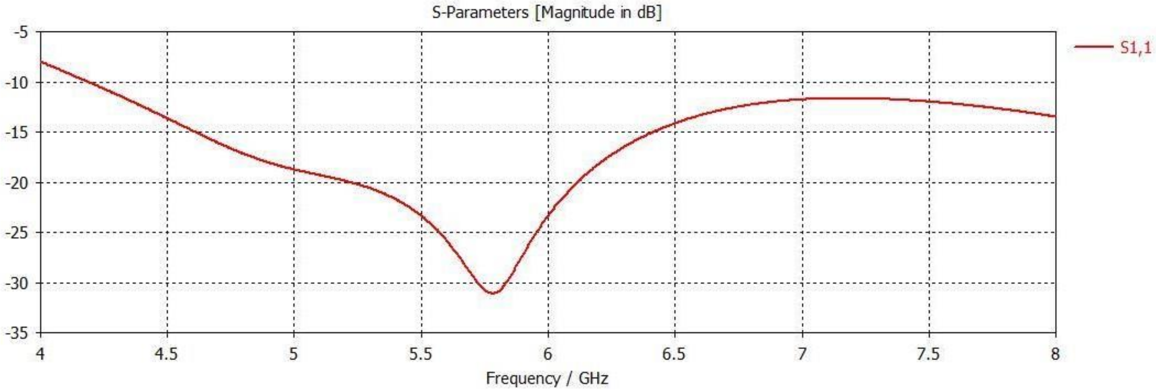
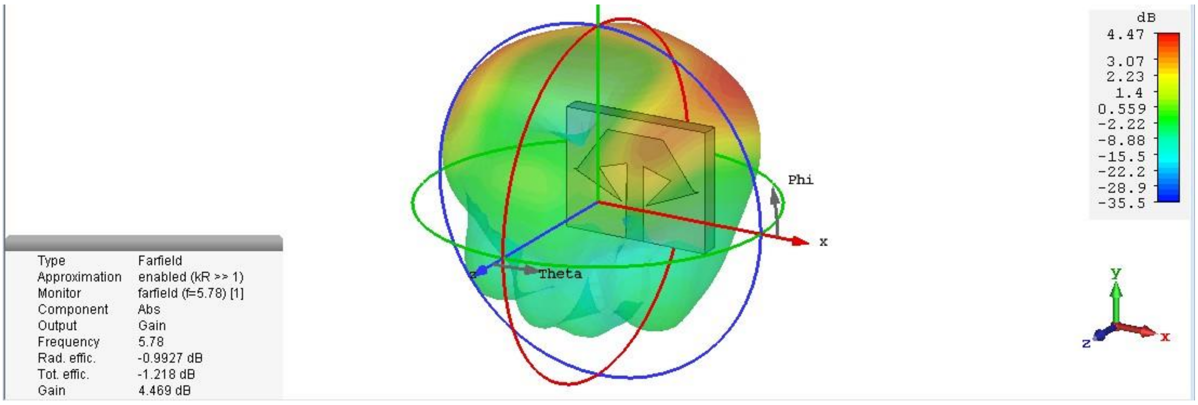


Figure 4.6 S-parameter got from CST

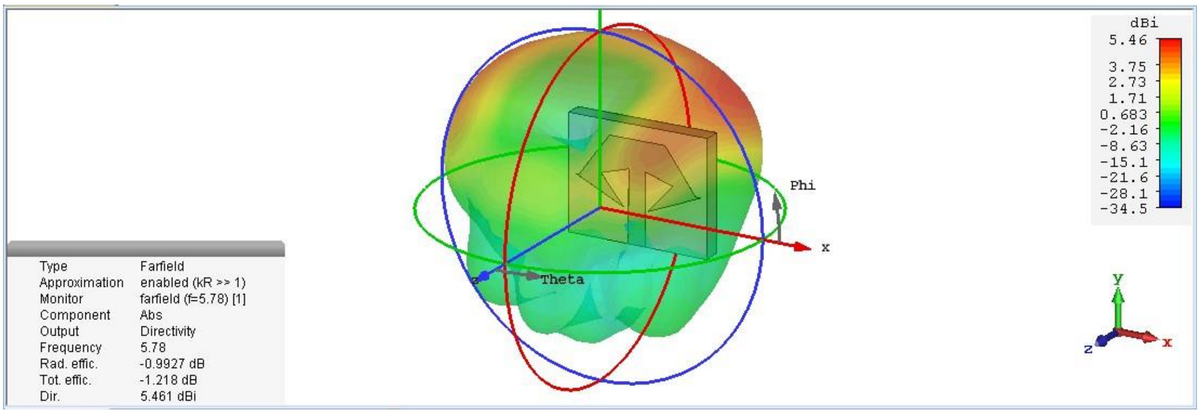
4.2.1 Simulated Radiation Pattern

In addition to 2D, 3D, and polar radiation patterns, CST's antenna design includes 2D, 3D, and polar radiation patterns. This design is used for the 5.78 GHz resonance frequency. Figures 4.5 and 4.6 show the 2D and 3D patterns at this resonance frequency, respectively.



Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (f=5.78) [1]
Component	Abs
Output	Gain
Frequency	5.78
Rad. effic.	-0.9927 dB
Tot. effic.	-1.218 dB
Gain	4.469 dB

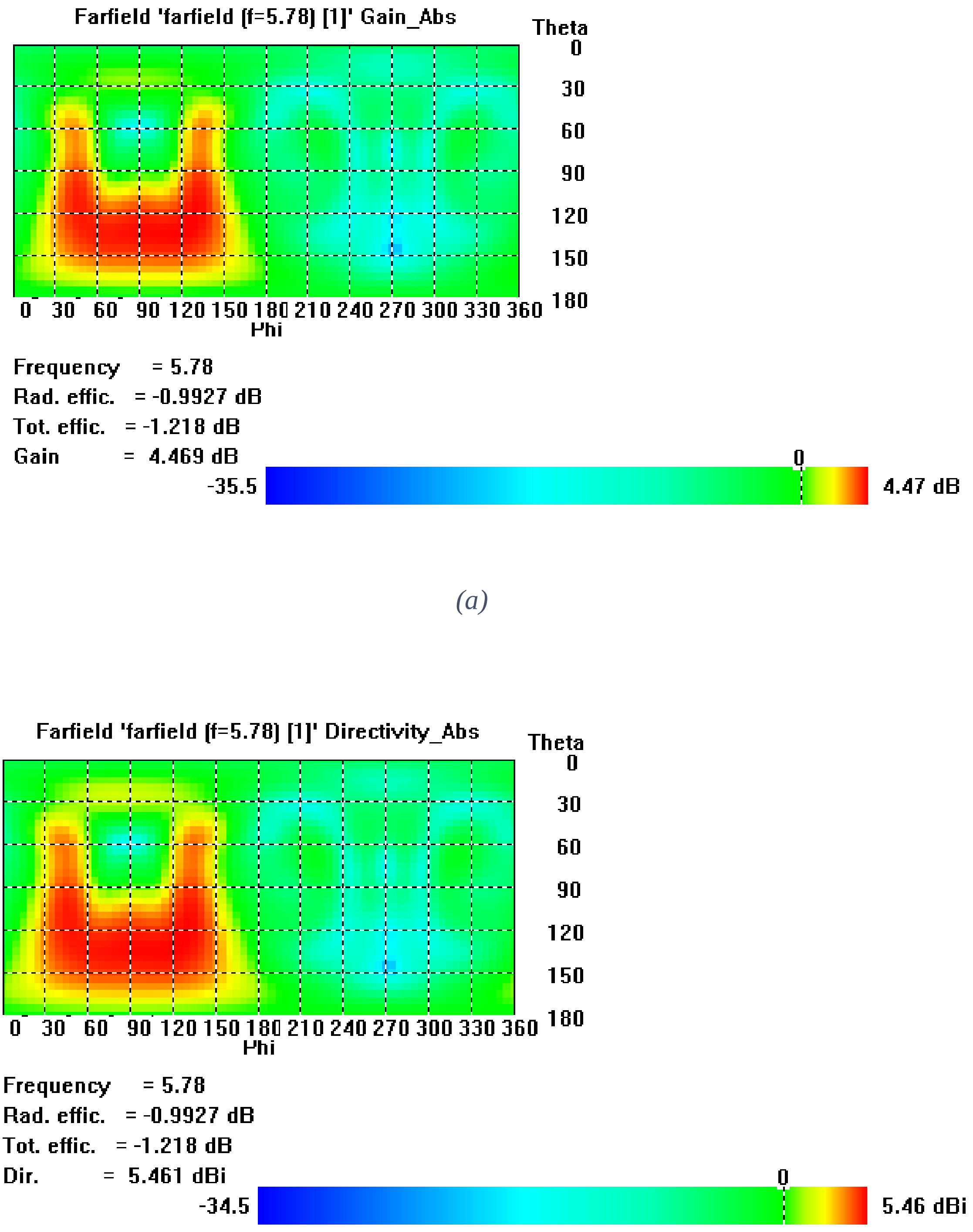
(a)



Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (f=5.78) [1]
Component	Abs
Output	Directivity
Frequency	5.78
Rad. effic.	-0.9927 dB
Tot. effic.	-1.218 dB
Dir.	5.461 dBi

(b)

Figure 4.7: 3D radiation pattern at 5.78 GHz (a) for Gain (b) for Directivity



Frequency = 5.78
Rad. effic. = -0.9927 dB
Tot. effic. = -1.218 dB
Gain = 4.469 dB

(a)

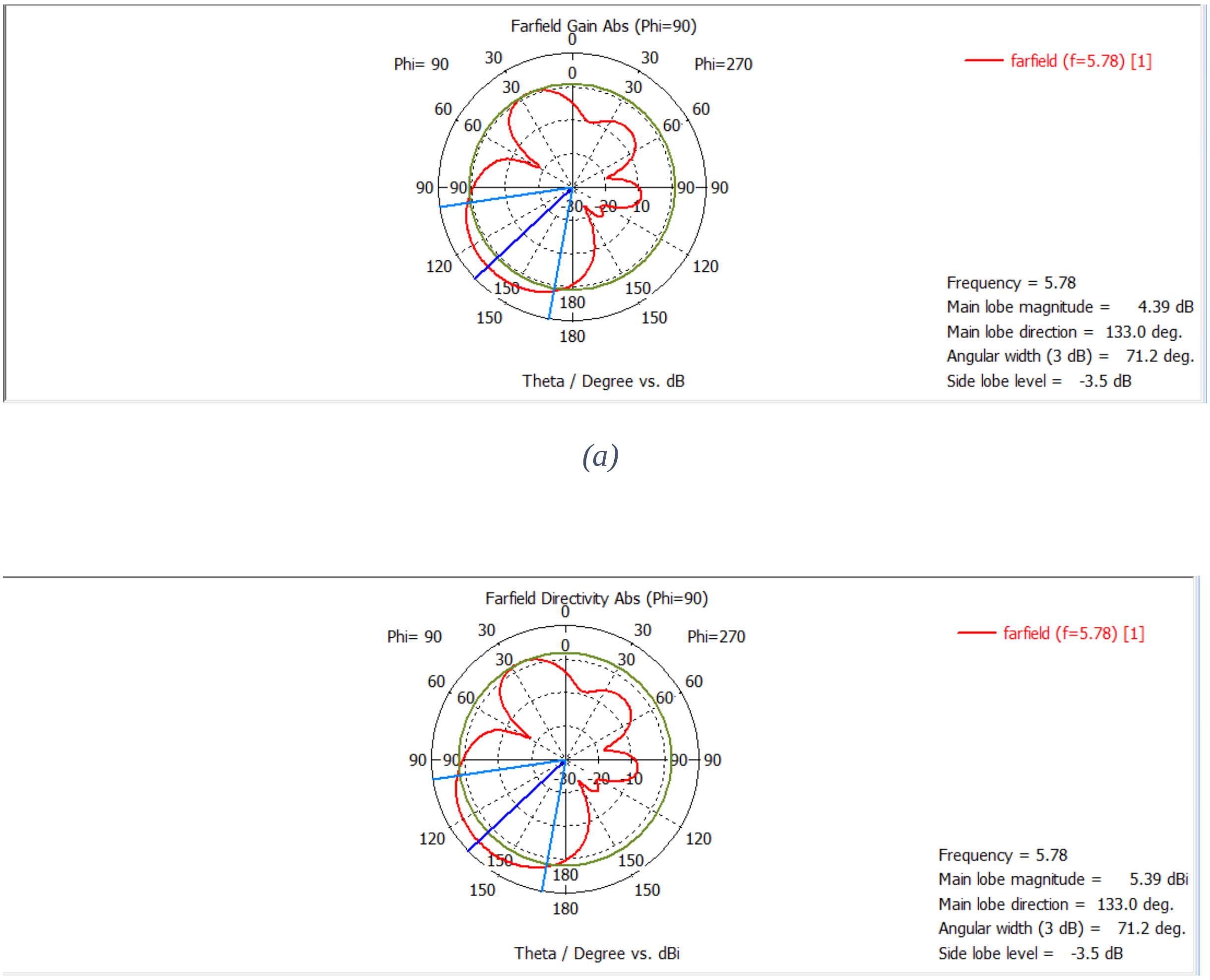
Frequency = 5.78
Rad. effic. = -0.9927 dB
Tot. effic. = -1.218 dB
Dir. = 5.461 dBi

(b)

Figure 4.8: 2D radiation pattern at 5.78 GHz (a) for gain (b) for directivity

Figures 4.5 and 4.6 show gain at the resonance frequency of 5.78 GHz, as shown in the a forementioned 2D and 3D radiation patterns. At the same resonant frequency, the simulated Directivity in CST is

In figure, a simulated 2D polar plot of the proposed antenna's radiation pattern is shown.The 3 dB beam width, side lobe level (SLL), main lobe direction, and main lobe magnitude are shown in the diagram. The proposed antennas 3dB beam witdh at it’s resonance frequency is 71.2^0.



Frequency = 5.78
Main lobe magnitude = 4.39 dB
Main lobe direction = 133.0 deg.
Angular width (3 dB) = 71.2 deg.
Side lobe level = -3.5 dB

(a)

Frequency = 5.78
Main lobe magnitude = 5.39 dBi
Main lobe direction = 133.0 deg.
Angular width (3 dB) = 71.2 deg.
Side lobe level = -3.5 dB

(b)

Figure 4.9: Polar plot of the proposed antenna at 5.78 GHz (a) for gain (b) for directivity

The SLL at the resonance frequency of 5.78 GHz is clearly -3.5 dB. The larger the negative magnitude of SLL, the less power is radiated by the antenna side lobe and the greatest power is generated by the main lobe.

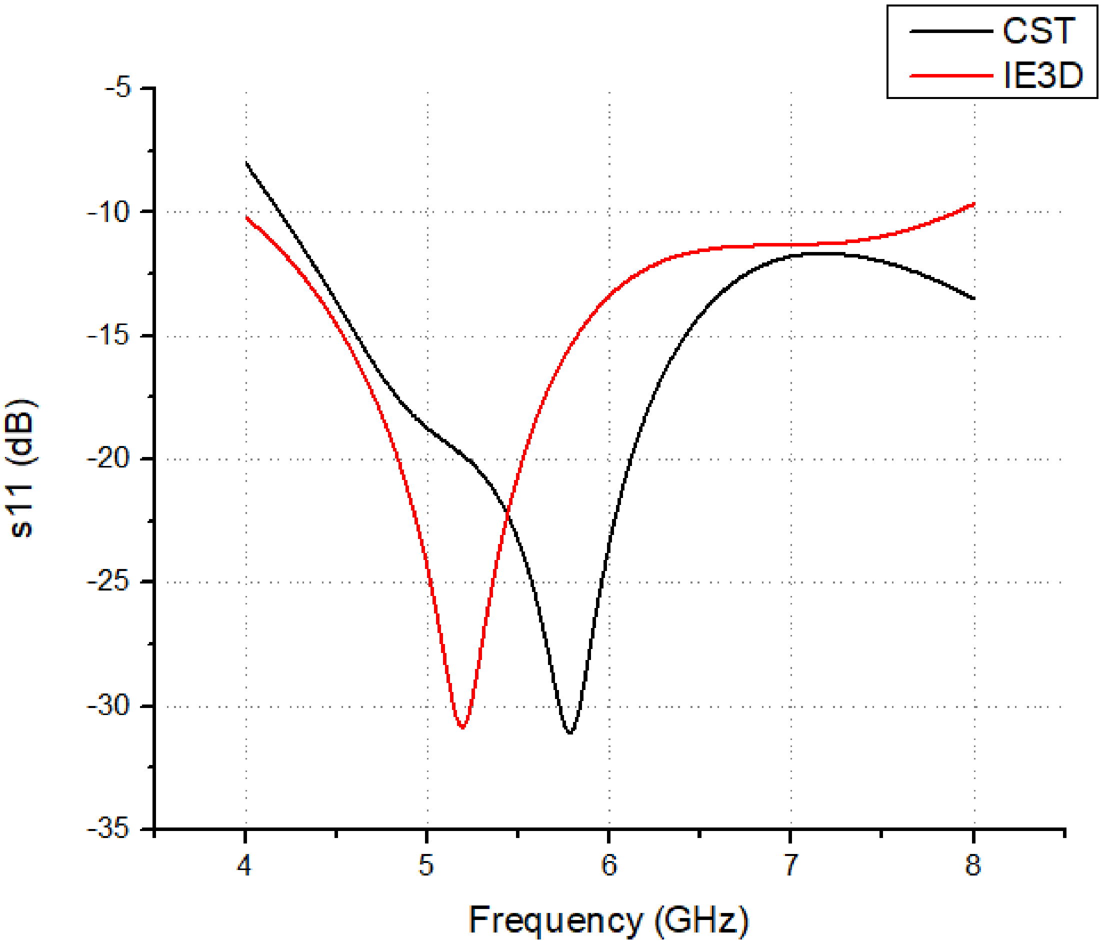


Figure 4.10: Comparative S-parameter of the proposed antenna using IE3D Zeland and CST

Comparative have a look at of the S parameter of the simulated end result using each IE3D Zeland and CST is show in parent 7.The attention of S parameter is that how antenna impedance matched with the reference transmission line impedance. In common, the antenna is simulated considering reference impedance Z0 =50 ohm. When the antenna impedance perfectly matched with the reference 50 ohm impedance than the much less electricity is pondered from the antenna port and maximum power is radiated with the aid of the antenna inside the direction of predominant lobe. Figure 7 shows that the IE3D and CST simulators both produce return losses of less than -10 dB over the frequency range of 4 to 8 GHz. This frequency spectrum encompasses the use of the C band in the wireless communication industry. It's also worth noting that the simulated result's lowest return loss within the coverage frequency range at resonant frequency 5.78 GHz is -31.09 dB.

for CST and almost similar return loss that is -31.29 dB for IE3D at resonant frequency 5.12 GHz.

Table 4.1: The results of proposed antenna after simulation.

Antenna Parameters	RMPA with modified T shape with extra portion as plow
Resonant Frequency	5.125 GHz
Return Loss	-31.29 dB
Bandwidth	4GHz
Gain	5.429 dB
Directivity	6.165 dBi
Efficiency (%)	84.629

TABLE 4.2: Comparison between proposed design and reference based on C band coverage.

Parameters	References					Proposed Antenna
	22	19	21	14	10	
Substrate Height (mm)	5	1.6	1.625	1.5784	8	2.425
Length (mm)	16.5	28.89	20	44	78	20
Width (mm)	34	37.21	20	56.4	100	10
Band Width	4 GHz	123 MHz	7.5 GHz	400 MHz	1.419 GHz	4 GHz
Return Loss	-24 dB	-13.63 dB	-17 dB	-21.79 dB	-53.94dB	-31.29 dB
Gain (dB)	5.34	N/A	3.2	8.044	3.64	5.429
Directivity (dBi)	7.8	N/A	NA	8.22	3.7	6.165

TABLE 4.3: Comparison of the simulated results using IE3D Zeland and CST

Parameter	IE3D Zeland	CST
Return Loss (dB)	-31.29	-31.09
Gain (dB)	5.429	4.469
Directivity (dBi)	6.165	5.461
Frequency (GHz)	5.125	5.78
Bandwidth (GHz)	4.29	5

CHAPTER 5

CONCLUSION AND FUTURE WORKS

5.1 Major Contributions of the Thesis

Although narrow bandwidth and occasional benefit are trouble of Microstrip patch antenna, Even after that Microstrip patch antenna constantly popular for Low cost, light weight and occasional profile nature.

In this thesis, the slender bandwidth and occasional benefit trouble for single band (C band) may be conquer in proposed plowing T shape antenna. By including plow-form with T-form, the bandwidth and gain of this designing antenna is advanced. So this thesis persuade enhancing signal the feature of rectangle microstrip route antenna including with plow form. The measurement of the Rectangle designing antenna is 20 × 10 mm2 with a substrate peak 6mm, also adding two plow form with this rectangle (20 × 10mm2) shape each aspect and transmission line (6 × 20mm2) is brought the center this rectangle shape. The proposed antennas have ability to provide provider, WLAN utility in addition to uplink and broadcasting, satellite tv for pc provider, GPS, Fixed microwave, mobile satellite tv for pc and radio navigation. The proposed antenna is cowl one hundred% C band frequency range and resonant frequency is five.12GHz. The reflection coefficient or go back loss at the resonant frequency is -31.29dB and the price of VSWR is much less than 2 for whole band. The maximum advantage and directivity respectively 5.429dBi and6.165dBi.

To verify the result got from Zeland IE3D is compared with famous software CST. The go back loss and gain nearly identical among IE3D and CST’s simulated end result. The fee of VSWR is between 1 and 2 for both software.

5.2 Future Scope of work

In this thesis, we experimented our Microstrip patch antenna and simulated end result to broaden the band width and antenna parameters. Besides, the essential paintings of this thesis is that fabrication may be carried out to observe real time performance of the antenna in future. Actually, the preference of fabrication of the proposed antenna may be manufacture commercially for C band application. In addition, slot slicing method, Array, optimization, Reducing the size and converting the antenna kind may be contain to improve performance of the proposed antenna. We can also use Metamaterials as a substrates.

REFERENCES

[1] D. R. K.Dinakaran, M.Vajikabanu, Piriyadharsini, “Design of Microstrip Patch Antenna For Wi-Fi Applications,” *Ijarece*, vol. 5, no. 1, pp. 38–41,2016.

[2] V. H. R. Keerthi, H. Khan, and P. Srinivasulu, “Design of C-Band Microstrip Patch Antenna for Radar Applications Using IE3D,” vol. 5, no. 3, pp. 49–58,2013.

[3] P. Gour, R. Mishra, A. S. Zadgaonkar, and P. K. Sahu, “Circular polarized broad band microstrip patch antenna for C band,” *Int. J. Control Theory Appl.*, vol. 9, no. 41, pp. 191–197,2016.

[4] S. K. Padhi, N. C. Karmakar, C. L. Law, and S. Aditya, “A Dual Polarized Aperture Coupled Circular Patch Antenna Using a C-Shaped Coupling Slot,” *IEEE Trans. Antennas Propag.*, vol. 51, no. 12, pp. 3295–3298, 2003, doi:10.1109/TAP.2003.820947.

[5] R. Azim, M. T. Islam, and A. T. Mobashsher, “Dual band-notch UWB antenna with single tri-arm resonator,” *IEEE Antennas Wirel. Propag. Lett.*, vol. 13, pp. 670–673, 2014, doi: 10.1109/LAWP.2014.2314486.

[6] V.S.Rao,D.R.Jahagirdar,andG.Kumar,“DesignanddevelopmentofBroadbandCircularlypolarized C-bandmicrostripantennaarray,”*11thIEEEIndiaConf.Emerg.TrendsInnov.Technol.INDICON2014*, pp. 6–9, 2015, doi:10.1109/INDICON.2014.7030582.

[7] U.Chakraborty,A.K.Biswas,A.Kundu,andS.K.Ram,“AWideBandMicrostripAntennaforWLAN, C Band Uplink and Wimax Applications,” *2017 IEEE Int. Conf. Comput. Intell. Comput. Res. ICCIC 2017*, vol. 1, pp. 1–3, 2018, doi:10.1109/ICCIC.2017.8524210.

[8] S. Rawat and K. K. Sharma, “A compact broadband microstrip patch antenna with defected ground structure for C-band applications,” *Cent. Eur. J. Eng.*, vol. 4, no. 3, pp. 287–292, 2014, doi: 10.2478/s13531-013-0162-1.

[9] W. Afzal, M. Z. Baig, and M. Z. Babar, “Optimization of Microstrip Patch Antenna for C-band and WLAN Applications,” no. July 2017, 2015.

[10] V. Singh, H. Bhatia, P. Kuchroo, and E. Sidhu, “Slotted rook shaped novel wide-band microstrip patch antennaforradaraltimeter,IMT,WiMAXandC-bandsatellitedownlinkapplications,”*Proc.-Int.Conf. Glob. Trends Signal Process. Inf. Comput. Commun. ICGTSPICC 2016*, pp. 334–337, 2017, doi: 10.1109/ICGTSPICC.2016.7955323.

[11] S. Perhirin and Y. Auffret, “A low consumption electronic system developed for a 10km long all-optical extension dedicated to sea floor observatories using power-over-fiber technology and SPI protocol.,” *Microw. Opt. Technol. Lett.*, vol. 55, no. 11, pp. 2562–2568, 2013, doi:10.1002/mop.

[12] Z.W.Yu,G.M.Wang,andC.X.Zhang,“AbroadbandplanarmonopulseantennaarrayofC-band,” *IEEE Antennas Wirel.Propag.Lett.*, vol. 8, pp. 1325–1328, 2009, doi: 10.1109/LAWP.2009.2038077.

[13] N. M. Thaker and V. Ramamoorthy, “A Review on Circular Microstrip Patch Antenna with Slots for C Band Applications,” *Int. J. Sci. Eng. Res.*, vol. 5, no. 12, pp. 1039–1043,2014.

[14] F.A.Dahri,R.A.Soomro,S.A.Memon,Z.Memon,andM.H.Memon,“Anoptimizedinsetfeedcircular cross strip antenna design for C-band satellite links,” *Int. J. Adv. Comput. Sci. Appl.*, vol. 9, no. 5, pp. 238–242, 2018, doi:10.14569/IJACSA.2018.090532.

[15] W. M. Khan and S. M. Gulhane, “Related review on microstrip patch antennas 1,” no. 1, pp. 9–15,2015.

[16] F. Yang, X. X. Zhang, X. Ye, and Y. Rahmat-Samii, “Wide-band E-shaped patch antennas for wireless communications,” *IEEE Trans. Antennas Propag.*, vol. 49, no. 7, pp. 1094–1100, 2001, doi: 10.1109/8.933489.

[17] A. M. Hadian, H.R. Hassani."Wideband rectangular microstrip patch antenna with U-slot.' Antenna propagation,2007.

[18] S. Weigand, G. H. Huff, K. H. Pan, and J. T. Bernhard, “Analysis and design of broad-band single-layer rectangular U-slot microstrip patch antennas,” *IEEE Trans. Antennas Propag.*, vol. 51, no. 3, pp. 457–468, 2003, doi:10.1109/TAP.2003.809836.

[19] S. S. Amit Kumar, “Designing and Analysis of T-Shape Microstrip Antenna for the 4G Systems,”*Glob. J. Comput. Sci. Technol.*, vol. 13, no. 8, 2013.

[20] M. Ismaeel, T. Jayanthy, and S. Sathyamurthy, “Comparison of rectangular and T-shaped microstrip antenna,” *Proc. 8th WSEAS Int. Conf. Electron. hardware, Wirel. Opt. Commun.*, pp. 185–189,2009.

[21] P. Singh and S. Singh, “Design and analysis of T shaped broad band micro strip patch antenna for Ku band application,” vol. 5, no. 2, pp. 44–49,2016.

[22] M. A. Haque, L. C. Paul, R. Azim, M. M. Mowla, A. Saleh, and M. N. Hossain, “A Modified E-Shaped Microstrip Patch Antenna for C Band Satellite Applications.” *IEEE*, 16 April 2020, doi: 10.1109/SPICSCON48833.2019.9065126.

[23] S. M. M. R. Al-Arif, “Design and Analysis of a Wideband Microstrip Antenna for High SpeedWLAN,” *Int. J. Comput. Appl.*, vol. 111, no. 12, pp. 16–23, 2015, doi: 10.5120/19590-1355.

[24] Khan, W.M. and S.M. Gulhane, Related review on microstrip patch antennas. International Journal of Industrial Electronics and ElectricalEngineering.

[25] Ge, Y.; Esselle, K.P.; Bird, T.S.; , ‘E-shaped patch antennas for highspeed wireless networks,’ Antennas and Propagation, IEEE Transactionson , vol.52, no.12, pp. 3213- 3219, Dec.2004.

[26] Ang.B.K.,&Chung,B.K.(2007).AwidebandE-shapedmicrostrippatchantennafor5-6GHzwireless communications. Progress in Electromagnetics Research, 75,397-407...

[27] Ge, Y., Esselle, K. P., & Bird, T. S. (2006). A compact E-shaped patch antenna with corrugated wings. IEEE transactions on antennas and propagation, 54(8),2411-2413.

[28] B. Z. Wang, S. Xiao, and J. Wang, “Reconfigurable patch-antenna design for wideband wireless communication systems," Microwaves, Antennas & Propagation, IET , vol.1, no.2, pp.414-419,