Design, Fabrication and Characterization of Circularly Polarized Patch Antenna

By

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ABSTRACT

A novel design for circularly polarized patch antenna with quadruple stubs embedded spider web shaped dual band circularly polarized patch with partial and defected ground structure is presented in this dissertation. The designed antenna is fed by a single feed. It is a dual band circularly polarized patch antenna for S and C band with quadruple stubs and partial ground. It comprises of four stubs with variable width and length alongside defected rectangular patch and partial and defected ground structure (DGS) constituting of 'rectangular tower' square shaped slots. The proposed antenna radiates a circularly polarized wave and covers the dual bands with a bandwidth of 2.69 - 2.75 GHz (Bluetooth, Wi-Max, W-LAN and LTE) and 4.7 - 5.5 GHz (Wi-Fi). The operating frequency and reflection coefficient is dependent on the length and width of the stubs whereas axial ratio of the circularly polarized wave is administered by the defects of the ground plane. The steepness of reflection coefficient is controlled by the defects in the central rectangular patch and the axial ratio is monitored by the slots in the ground plane. The prototype of circularly polarized patch antenna is designed and fabricated on Rogers RT DUROID (5880) resulting in a very compact and efficient design. The measured and simulated results of the circularly polarized patch antenna are observed to be in good accordance with each other.

CERTIFICATE

It is herewith certified that the constituents of this thesis entitled "Design, Fabrication and Characterization of Circularly Polarized Patch Antenna" articulated by Hira Afzal under the skilled support and guideline of Assoc Prof Dr. Farooq Ahmed Bhatti has been found adequately falling under the requirement of M.S Degree in Electrical Engineering.

Supervisor:

Assoc Prof Dr.Farooq Ahmed Bhatti

MCS, NUST

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Dated:

DECLARATION

It is pertinently declared that the contents presented in this treatise carries resemblance to none nor it is being submitted in support of any other award or qualification in the institution itself as well as anywhere outside.

DEDICATED TO

Allah Almighty, All Benevolent and Merciful

Faculty for their constant guidance

Family for their boundless encouragement

ACKNOWLEDGEMENT

With the sincere endeavour I would consider it obligatory to pay my heartiest gratitude towards my mentor Associate Prof Dr. Farooq Ahmed Bhatti who wisely dedicated his skilled efforts and willingly put his blessed hand in helping me bringing all the tasks to their final representation.

Moreover the fulfilment of this work is credited to my Parents and Husband who collectively ventured and supported me into the process of its completion and eventually giving it a sequential shape.

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INTRODUCTION

1.1 INTRODUCTION

An antenna is a transducer that converts electrical RF currents into electromagnetic waves in space and vice versa. It is used for radiating and receiving waves and acts as a transitional configuration between free space and a guiding structure. The antenna also serves as a directional device by optimizing the radiating energy in some directions and suppressing it in others. The introductory chapter of this thesis provides an immaculately structured explanation of the various antenna designing fundamentals, parameters and types of antenna.

1.2 Background Study

Man is a social animal who is dependent on communication for survival. The need for communication has always been a paramount factor for human beings to thrive in an era. Different modes of communication have been put to play throughout the history of mankind to convey a message from one place to another such as fire, light signals, birds, written messages delivered by humans etc. With the rapid advancements and technological inventions in the field of telecommunication various communication mechanisms came into subsistence. The domain of wireless communication came into existence with the revolutionary development of an antenna. The narrative of antennas dates back to 1800s when Heinrich Hertz created a wireless communication system to find electromagnetic waves by forcing an electrical spark through the gap of a transmitter dipole antenna and using a loop antenna as receiver. Subsequently the use of antennas for the purpose of communication increased tremendously and ever since their structure has undergone numerous modifications and improvements for improved communication. Wireless communication has observed a very expeditious progress in the previous decades. An essential and a crucial constituent of any wireless communication system is the, **'antenna'**. The antenna is a system part intended to broadcast and take delivery of waves. By characterization, an antenna could be called as an electrical transducer used to reorganize guided electromagnetic energy from a transmission line for the purpose of radiating electromagnetic energy into the free space. Antenna forms the main component of a communication system.

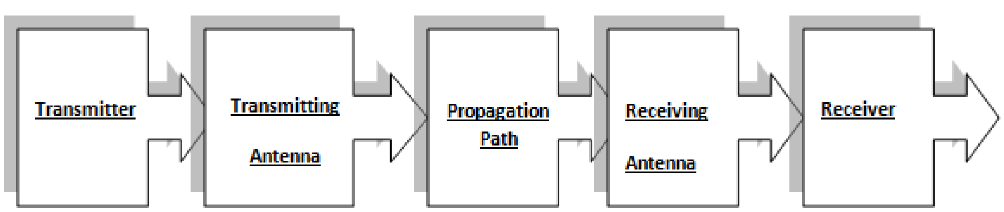


Figure 1: Radio communication link

1.3 Overview

The modern era stresses on the development of advanced and up to date technological mechanisms to cater the demands of the ever-growing and progressing telecommunication industry. This thesis envisages the creation and development of a circularly polarized microstrip patch antenna proficient of operating on multiple bands. Novelty of this editorial lies in designing a compact circularly polarized dual band patch antenna for S and C band with CP characteristics governable by varying the dimensions of width and length of stubs and slots.

1.4 Problem Statement

The communication systems call for efficient, low profile, cost effective and facile to use circularly polarized patch antennas which mitigate the effects of polarization mismatching, weather infiltration, immobility, multi path interference and Faraday rotation offering a flexible orientation of transmitter and receiver. For the purpose of including multiple bands of the frequency spectrum a circularly polarized patch antenna is proposed which is capable of being integrated with devices working on different frequencies. Moreover, the compactness of the designed antenna will make it an appropriate choice to be incorporated in the mainstream devices.

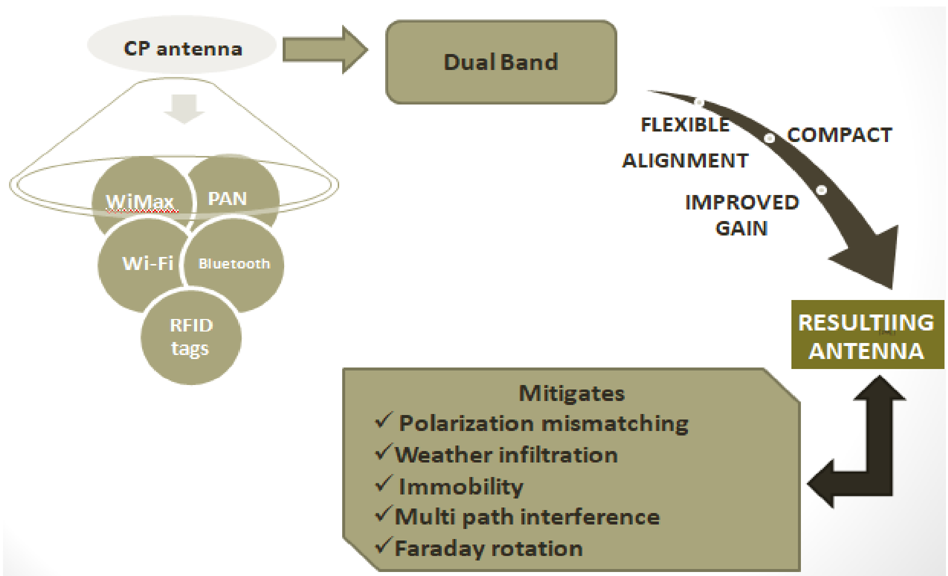
1.5 Project Approach

The quadruple stubs embedded spider web shaped circularly polarized dual band microstrip patch antenna with partial and defected ground structure is fed by a single feed. It operates for S and C band with quadruple stubs and partial ground. It comprises of four stubs with variable width and length alongside defected rectangular patch and partial and defected ground structure (DGS) constituting of 'rectangular tower' square shaped slots. The proposed antenna radiates a circularly polarized wave and covers the dual bands with a bandwidth of 2.69 - 2.75 GHz (Bluetooth, Wi-Max and LTE) and 4.7 - 5.5 GHz (Wi-Fi). The operating frequency is proportional to the length and width of the stubs whereas axial ratio of the circularly polarized wave is administered by the defects of the ground plane. The steepness of reflection coefficient is controlled by the defects in the central rectangular patch and the axial ratio is monitored by the slots made in the ground plane. The prototype of circularly polarized patch antenna is fabricated and designed on Rogers RT DUROID (5880) resulting in a very compact and efficient design.

1.6 Thesis Objective

This thesis is founded by using the concepts of antenna designing techniques particularly those related to the introduction of circular polarization and multi band operation. The proposed antenna aspires to work for two different bands along with executing a value of axial ratio in accordance to the literature. This antenna design aims to amalgamate theoretical knowledge with practicality.

1.7 Proposed Methodology



1.8 Prerequisites for Thesis

- ✓ Computer Simulation Technology Version 2020.
- ✓ High Frequency Structure Simulator Version 13.
- ✓ Apparatus used for result computation.
- ✓ VNA
- ✓ OriginLab.
- ✓ Excel.
- ✓ Advance Design System simulator
- ✓ Fabrication Tools.

1.9 Antenna Basics

1.9.1 Antenna Radiating Patch

Patch of an antenna is made up of a metal foil constituting numerous shapes fabricated on the plane of a pcb and works as a transmitter or receiver of the radio signals. The effective frequency bands attained are controlled by the dimensions of the patch. In a radio, antenna patch is the configuration that is used to transmit and receive the radio signals.

1.9.2 Antenna Transmission Line Structure

RF (Radio Frequency) energy is transported from one point to another by a transmission line that acts as a path between antenna and transmitter or receiver. The function of transmission line is to transport signals arrived at the antenna with least amount of alteration to the components. Transmission lines are classified in terms of impedance and are a function of per unit length of Capacitance (C), Inductance (L) and Resistance (R).

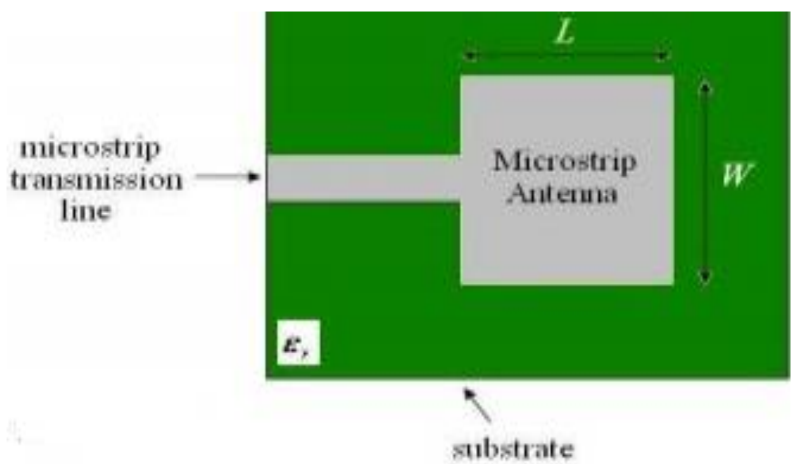


Figure 2: Overview of Transmission line attached to a Microstrip antenna

1.9.3 Antenna Substrate Structure

Substrate is a substantial component of micro strip patch antennas. The location of a substrate is among the patch and ground. The selection criterion for various substrates is dielectric constant and tangent loss. For obtaining optimum results of an antenna the right choice of substrate depending upon the efficiency, expense, accessibility and dimensions render an important part. Furthermore, the thickness of substrate directly affects the working of an antenna.

Table 1: Contrast of features among few substrates

Parameters	Bakelite	FR4 Glass Epoxy	RO4003	Taconic TLC	RT Duroid
Dielectric constant	4.7	4.36	3.4	3.2	2.2
Loss tangent	0.03045	0.013	0.002	0.002	0.0004
Water absorption	0.5-1.3%	<0.25%	0.06%	<0.02%	<0.05%
Tensile strength (MPa)	60	<310	141	-	450
Volume resistivity (MΩ.cm)	3x1015	8x107	14x109	1x107	2x107
Surface resistivity (MΩ)	5x1010	2x105	4.2x109	1x107	3x107
Breakdown voltage (kV)	20-28	55	-	-	>60
Peel Strength (N/mm)	-	9	1.05	12	5.5
Density (kg/m^3)	1810	1850	1790	-	2200

1.9.4 Antenna Ground Plane

The ground plane is a conducting surface which is attached to the transmitter's ground wire and does the function of a reflecting surface for radio waves. The shape of ground plane is flat or just about flat horizontal surface that constitutes as part of an antenna and mostly situated below the substrate. The utility of ground plane is to reflect the radio waves from the other antenna elements within an antenna structure. To fulfill the function of ground plane, the diameter of conducting surface must be at least ($\lambda/4$) i.e. a quarter of wavelength of the radio waves.

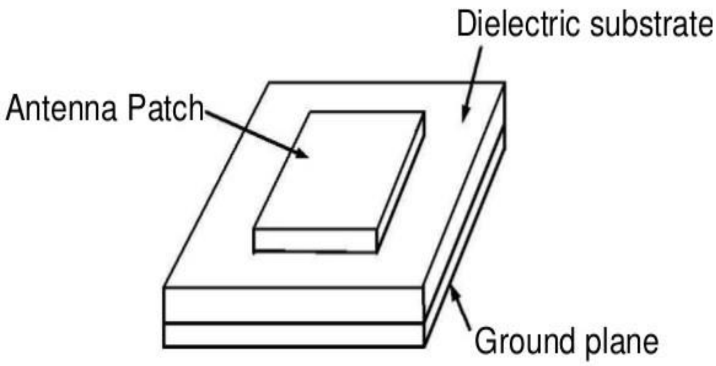


Figure 3: Substrate, Ground and Patch

1.9.5 Antenna Radiation Pattern

It is a pictographic depiction of the allocation of the power exuded from or received by the antenna. Radiation pattern uses a polar projection.It is usually donut shaped in three dimensional perspectives. The simulations of radiation pattern are mostly observed in the far field region. The plots of radiation patterns are propagated in CST and HFSS and give an insight about the directions of antenna radiation.

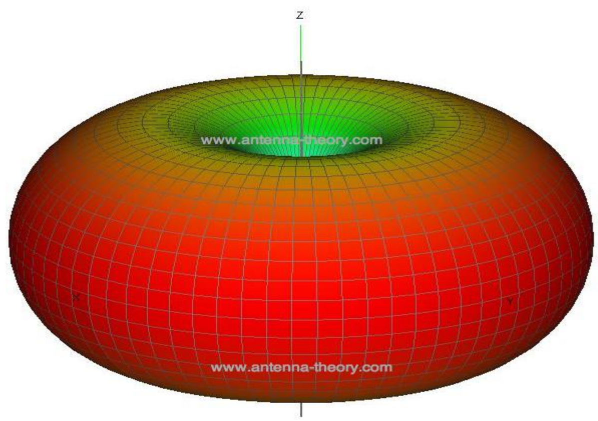


Figure 4: Illustration of Radiation Pattern of an antenna

1.9.6 Antenna Gain

The ratio of output power over input power defines gain of an antenna. Antenna gain is the capability of an antenna which specifies the radiation power in a specified direction. It is measured in decibels scale. A good-quality radiator antenna must extricate a positive gain with increased statistical value.

1.9.7 Antenna Efficiency

It is a fraction of power delivered over the radiated power. An antenna is said to possess high efficiency when maximum radiated power reaches the receiver, however, the said antenna will have low efficiency in the scenario where maximum value of the power is dissipated due to losses. High efficiency is one of key factor for the determination of a good performance antenna.

1.9.8 Antenna Return Loss

Return loss occurs when the signal fails to reach predefined destination subjected to mismatch of the transmission line, resulting into wastage of power. It is the reduction of electrical power observed in the returning or reflecting signal by an interruption or a break in the structure of a transmission line. In the software's HFSS and CST, S_{11} plot demonstrates power reflected from the antenna, therefore is identified as return loss. As per IEEE standards, this return loss is preferably to be less than -10 dB. In simple terms it is the magnitude of reflection coefficient given in dB.

1.9.9 Antenna Bandwidth

The collection of frequencies around which an antenna can operate, radiate and receive energy efficiently is termed as bandwidth of that particular antenna. Usually the desired bandwidth is one of the key parameters in designing of an antenna. It is measured in terms of Hertz (Hz). A broader bandwidth antenna will be capable of receiving a greater range of different radio waves. Different types and shapes of antennas have different bandwidth limitations.

1.9.10 Antenna Directivity

The Directivity factor ‘D’ measures how directional an antenna’s radiation pattern is towards a particular direction. Directional antennas radiate in a particular direction whereas omni directional antennas radiate in the same manner in all directions.

1.9.11 Antenna Beam Efficiency

Antenna beam efficiency is used to calculate the quantity of received or transmitted power by minor lobes in contrast to the major lobe. It is a fraction among the received or transmitted power by the cone angle to the power received or transmitted by the entire antenna. It is used as a marker to estimate the functioning of an antenna. It is also called as stray factor.

1.9.12 Antenna Voltage Standing Wave Ratio

It is the ratio of the maximum and minimum voltages of the waves formed in the structure of a transmission line. VSWR is used to measure the matching of the impedance of antenna with the connected transmission line. On a positive scale, the value of VSWR can vary from one to infinity.

1.9.13 Antenna Feed

An antenna feed is a part of the antenna which is used to deliver the RF electrical currents to the antenna from where the currents are radiated into the space.

1.9.14 Antenna Port

An antenna port can be characterized as the point through which an antenna is given feed. Every antenna port has one resource grid representing a specific channel mode.

1.9.15 Antenna Field

Field is termed as the area surrounding an antenna. It is furthermore differentiated in two more types.

1.9.15.1 Antenna near Field

The area of electromagnetic waves neighbouring an antenna owing to high frequency flow of current is termed as near field. Reactive near field area instantaneously environs the antenna structure. However, radiating near field region or Fresnel region is situated among the reactive near field and far field.

1.9.15.2 Antenna Far Field

The farthest area neighbouring an antenna is termed as far field. Far field region outstretches further than infinity where electromagnetic waves usually travel. Since the antennas are used to communicate wirelessly from long distances, they usually operate in far field. This is the region in which all antenna parameters are measured.

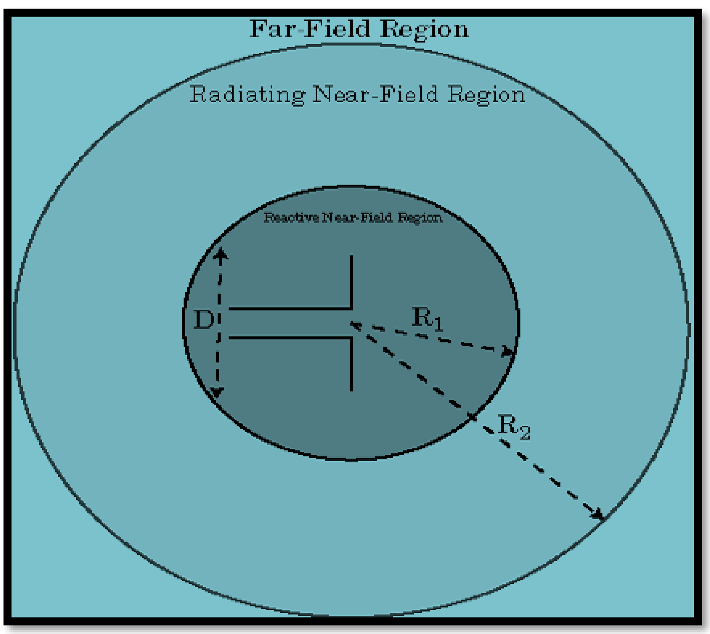


Figure 5: Far Field

1.9.16 Antenna Polarization

It is defined as the course of the electric field of the radio wave with reference to the Earth's surface which is regulated by the material construction of the antenna as well as its direction. It is basically the orientation of oscillations of electromagnetic waves in space. Polarization is the property which is used to define the time varying change in direction and magnitude of the electric field vector. The tip of electric field vector of a polarized wave creates a contour whose shape is known as the polarization ellipse. Polarization can be segregated into following types based on the polarization ellipse:-

A. Linear Polarization which is further characterized into two types as following:-
    i. Horizontal Polarization
    ii. Vertical Polarization

B. Circular Polarization

C. Elliptical Polarization

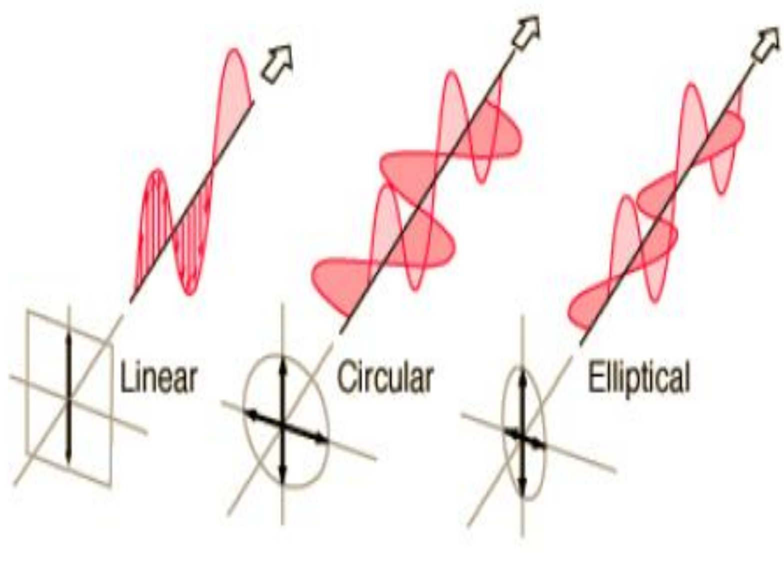


Figure 6: Different types of polarization

1.9.16.1 Linear Polarization

The time harmonic wave of the electric-field vector if oriented along the same line at a specific instant in space at each moment of time is said to be linearly polarized at that point.

In order to accomplish linear polarization, the electric field vector must possess the following attributes:-

1. The time harmonic wave must comprise a single component, or

2. A travelling wave can be called as linearly polarized if both of its linear components have no phase difference i.e. $\delta = 0^o$ or they are in time phase or 180^o (or multiples of 180^o) out-of-phase. The component's magnitudes decide that whether a horizontal or vertical linear polarized wave will be generated.

Linear polarization is very undemanding to generate and has various uses in the fields of mobile phones, radio applications and broadcasting.

1.9.16.2 Circular Polarization

When the contour of the electric-field vector marks out a circle as a function of time at a given instant in space the time-harmonic wave executes circular polarization.

In order to accomplish circular polarization, the electric field vector must possess the following characteristics:-

1. Both the components of electric field must be orthogonal to each other.
2. Both components must possess the same magnitude i.e. $E_1 = E_2$.
3. Both components of the electric field ought to acquire a time-phase difference of odd multiples of 90^0 i.e. $\delta = 90^o$.

When $\delta = +90^o$ the time harmonic wave is known to be RHCP and LHCP when $\delta = -90^o$.

These three characteristics must be fulfilled for a time harmonic wave to be circularly polarized.

1.9.16.3 Elliptical Polarization

The tip of time harmonic wave of the electric-field vector at a given moment in the space if traces an ellipse at each moment of time then the wave is termed as elliptically polarized at that instant. If a wave is not linearly or circularly polarized then it is said to be elliptically polarized.

For the purpose of achieving elliptical polarization the electric field vector should suffice the subsequent constraints:

1. Both the components of electric field must be linear to each other.

2. Both components can possess either of the following:-

(a) The same magnitude i.e. $E_1 = E_2$

In this scenario time phase difference among the two components should not be in odd multiples of 90^{o}otherwise it would be considered as circularly polarized.

(b) Varying magnitude i.e. E1 ≠ E2

In this setup, the time-phase difference among both the components must not be in terms of multiples of 180^o or 0, and then it would be cogitated as linear polarization.

1.9.17 Axial Ratio

Axial ratio is a very important parametric quantity that symbolizes shape of the polarization ellipse and in turn defines the polarization of an antenna.

The axial ratio of a linearly polarized wave inclines to reach the value of infinity i.e. AR = ∞ because either horizontal or vertical component of electric field has a zero measure.For an antenna that encompasses elliptical polarization, the axial ratio is a quantitative measure among the major and minor axes of the ellipse and it can acquire values greater than one and lesser than infinity.

$$1 \leq AR \leq \infty$$

An antenna can possess ideal circular polarization if the value of axial ratio is 1 (0 dB) i.e. AR = 1. In the case of circularly polarized antennas, both the electric field components have the same magnitude so the major and minor axes become equal.

$$AR = \frac{major\ axis}{minor\ axis}$$

1.9.18 Axial Ratio Bandwidth

The axial ratio bandwidth elaborates a frequency range in which the antenna axial ratio is kept below a certain level. Axial ratio tends to vary ± 30° away from the main beam for a circularly polarized antenna. Therefore, in the measurements of circularly polarized patch antennas, a frequency is considered to be within this bandwidth if the AR at bore sight is below 3 dB i.e. AR < 3 dB. This specifies that the deviation from circular polarization is less than 3 dB over the specified angular range.

1.10 Merits and Demerits of Microstrip Patch Antennas

These types of antennas are a first-rate choice for various appliances because of multiple advantages coupled with few shortcomings which can be dealt with using different techniques such as changing configuration of patch, implying diverse feeding methods, use of parasitic elements and increased thickness of substrate etc.

I. Merits

a) Low profile
b) Light weight
c) Low volume
d) Ease of fabrication
e) Cost effective
f) Ease of integration with other devices
g) Conformity to host surface
h) Compact size, making them facile to use with hand held devices and personal mobile communication
i) Allowance of multiple frequency operation by usage of stacked patches
j) Mechanically robust
k) Sustains dual polarization

.

II. Demerits

a) Decreased power gain
b) Limited use for low power applications

c) Narrow impedance and axial ratio bandwidth
d) Lesser power handling capacity
e) False radiations from feed and junctions
f) Increased antenna dimensions
g) Enlarged ground planes

1.11 Merits and Demerits of Circularly Polarized Patch Antennas

Circularly polarized patch antennas have gained wide popularity owing to numerous additional advantages. Similar to the former, this antenna also comes with certain drawbacks necessitating measures for improvements.

I. Merits

a) Decreased polarization mismatch due to misalignment and interference
b) Enhanced weather penetrability
c) Improved mobility
d) Immunity to Faraday rotation
e) Elimination of multipath propagation
f) Flexible orientation of transmitter and receiver

II. Demerits

a) Difficult to design
b) Complexity in maintenance of Omni directional radiation pattern
c) Decreased wideband radiation
d) Lack of miniaturization

Chapter 2

LITERATURE APPRAISAL

2.1 Introduction

A detailed literature review of the existing techniques for generation of circular polarization was carried out. This chapter provides background information on the existing circularly polarized antenna designs. Problems, challenges and complications faced in their designs were reviewed during investigation of these techniques. Every methodology has its own benefits and shortcomings. The important aspects and flaws of each antenna along with the background information are congregated in this dissertation. This literature survey was utilized for the designing of a circularly polarized dual band patch antenna.

2.2 Existent Methodology

Over the precedent years many trials, research and analysis have been done to invent new techniques and methods in order to create efficient, unfailing and topnotch microstrip patch antennas. A wide variety of circularly polarized patch antennas were studied.

Dechamps proposed the idea of microstrip patch antenna for the first time in 1953 [1].

The notion presented by Dechamps was patented in 1955 initially [2]. However, the foremost fabrication of antenna was done in the 1970’s when high-quality substrates became accessible. The microstrip antennas possess multiple distinctive and appealing benefits such as cost effectiveness, light weight, low volume and ease of fabrication by using printed circuit board technology which led to the design and invention of various antenna mechanisms. Advancement in technology has increased the demand for compact sized microstrip patch antenna because of its facile integration with hand held and personal mobile communication devices and conformity to host surface. The features such as allowance of multiple frequency operation and mechanical robustness bring microstrip patch antennas to the forefront and their application is found in the fields of terrestrial communication, direct broadcast satellite and global positioning system, military executions, commercial devices and remote sensing [3, 4, 5].

The demand and rapid development in microstrip antenna utilization consequently gave birth to an unremitting endeavor for evolving its characteristics [6].

This led to an intensive research and investigation of printed antennas or software-based antennas in order to take advantage of their benefits as compared to other radiating systems which include cost effectiveness, reduced weight, decreased complexity, facile integration and conformability with active and passive devices [7].

In the edition [8], David M.Pozar stated that for modern microwave systems, microstrip patch antennas have emerged as one of the most eminent antenna choice. The publication further elaborates that the performance of a classic communication arrangement can be improved by an increase in the gain of transmitting and receiving antennas. The salient feature in escalating gain is polarization matching of the antennas at the transmitter and receiver.

With advancement in technology, the obstacle faced was the creation of a system capable of working on multiple bands and the microstrip patch antennas acted as a solution for this challenge. Microstrip patch antennas incorporated the ability to work on multiple bands depending upon the need of the application [9]. Multiple frequency bands can be attained by making slots in the microstrip patch antenna [10]. Each slot shape has its own benefits and utilization; therefore a few of them are used to achieve the multi band operation whereas others are used for the function of increasing the bandwidth [11]. Defected ground structures techniques have also emerged as potential candidates in printed antennas for attaining multiband operation and reconfigurability [12].

The polarization of an antenna is termed as the course of the electric field of the radio wave with reference to the earth's surface which is regulated by the material construction of the antenna as well as its direction. Polarization matching achieves reduction in transmission loss by adjusting the direction of oscillations of electromagnetic waves in space collectively at transmitting and receiving antennas. In order to attain polarization matching, there exist a necessity which states that both the transmitter and receiver must have the same sense of polarization along with identical axial ratio and spatial orientation [13].

Wireless communication technologies that require mobility and portability, namely Wireless Local Area Network (WLAN), Global Positioning System (GPS) and UHF Radio Frequency Identification (RFID) make it challenging to attain polarization matching in these systems. Furthermore, various Air Traffic Control (ATC) radars and Synthetic Aperture Radar (SAR) systems utilize circularly polarized antennas making use of their polarization scattering characteristics [14].

Over the previous several decades, microstrip antenna technology has experienced many advances resulting in its emergence as a significant choice for the production of circularly polarized patch antennas [15]. The microstrip patch antennas are not self-sufficient for the generation of circular polarization; hence they can gain circular polarization by the introduction of a disconcerted segment to the basic microstrip antenna structure or by altering the antenna geometry [16]. The employment of circularly polarized patch antennas offers an appealing quick fix to procure polarization matching among the transmitting and receiving antenna [17]. An important element of antenna design industry is the use of circular polarization which is employed to remove the significance of antenna orientation. It offers additional adaptability to the antennas between the transmitter and receiver, and in addition, it improves weather infiltration and mobility [18]**.** In wireless communication, decreased multi path interference and reduced polarization loss factor make circularly polarized patch antennas an apposite choice [19, 20]. Circularly polarized (CP) micro strip patch antennas offer the complimentary merits of small size and weight, fittingness in confirm mounting and affinity with other devices [21]. For the applications of Global Positioning System circular polarization is a befitting feature [22, 23]. Circular polarization (CP) operation can be acquired by making few alterations to the basic antenna's geometric configuration or feed [24] and it can also be attained by making axial ratio equal to 1 (unity) or 0 dB [25].

The publications before 2010 for CP monopole antennas are very sparse. The first publicized paper is from the year 2008 [26] which incorporates a CPW fed monopole C shaped patch antenna along with a rectangle shaped ground plane. Moreover, a quasi-loop shaped antenna arrangement is formulated by the addition of an inverted L shaped structure on the ground plane in conjunction with the C shaped patch. The change in dimensions of quasi-loop structure results in optimization of the antenna which is used for GPS applications. The loop imitating structure has enlarged dimensions and increased complexity of fabrication. Furthermore, another resonant frequency can't be added without enhancement in perplexity of the antenna design.

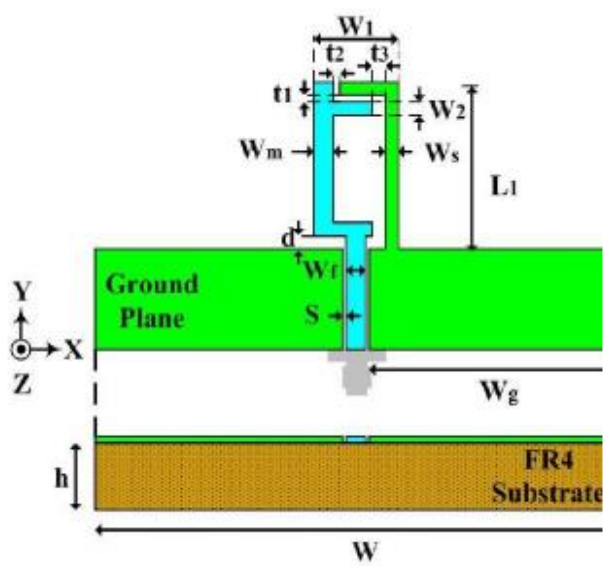


Figure 7: CP antenna with quasi-loop element

The circularly polarized (CP) antennas can be excited by two different techniques [27–29]. The CP characteristics can be acquired by two orthogonal linear components possessing same magnitude and a time phase difference of 90^{o} [30]. These antennas have two main classifications named as single feed and dual orthogonal feed, relying upon the number of feed points necessary to produce the CP waves [31]. Research concentrated on single feeding techniques [32-37] and dual orthogonal feeding techniques [38-40] were investigated.

In the recent past, work of [39] dual orthogonal feeding was presented. Dual feeding technique needs a supplementary power divider or phase shifters that increase complexity of antenna structure and implementation. But this arrangement turns out to be troublesome when integrated in a compact communication mechanism. The height of the antenna projected in this exposition solves the problem as its value doesn't exceed 7cm. A narrower impedance bandwidth and a decreased total efficiency is the consequence of a dual fed circularly polarized patch antennas [40]. Consequently, this makes the single feeding techniques preferable due to their benefits of simple implementation and low profile.

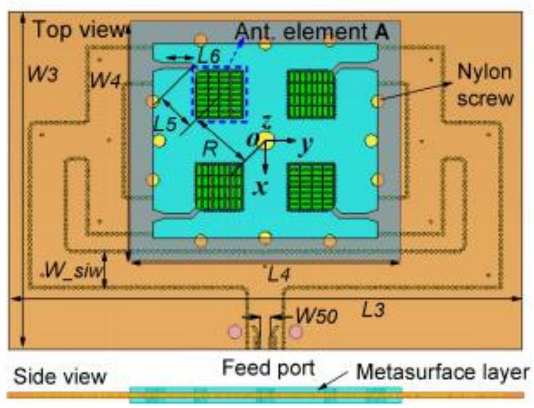


Figure 8: Dual orthogonal feed CP antenna

In 2020, a paper [41] published in MDPI which presented an arrangement of sequentially fed circularly polarized antennas, resulting in a wider AR bandwidth but at the cost of very complex antenna structure which is a significant downside in large as well as compact antenna arrays. Hence, single fed circularly polarized patch antennas offer more suitable substitutes in order to achieve easier implementation and size-oriented gains.

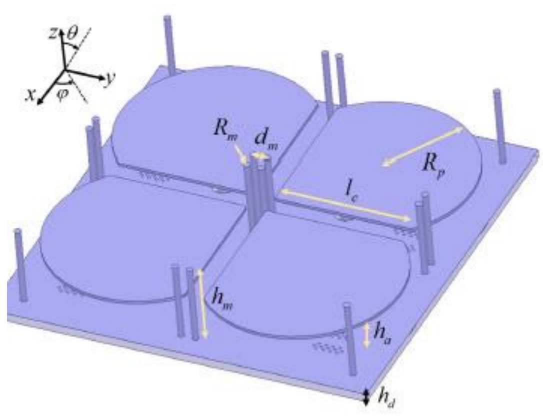


Figure 9: Sequentially fed dual band CP antenna

IEEE published a paper [42] in which an antenna comprising of a CPW fed halberd shaped printed circularly polarized square patch antenna with slots was articulated. The designed antenna depicted small sized slots and a miniaturized overall antenna dimensions. It exhibited up to the mark axial ratio having a value smaller than 3 dB lying in between 1545 MHz to 1605 MHz frequency band. However, the requisite of design was a comprehensive parametric study in order to fulfill the objective of miniaturization of the circularly polarized antenna resulting in its cost ineffectiveness.

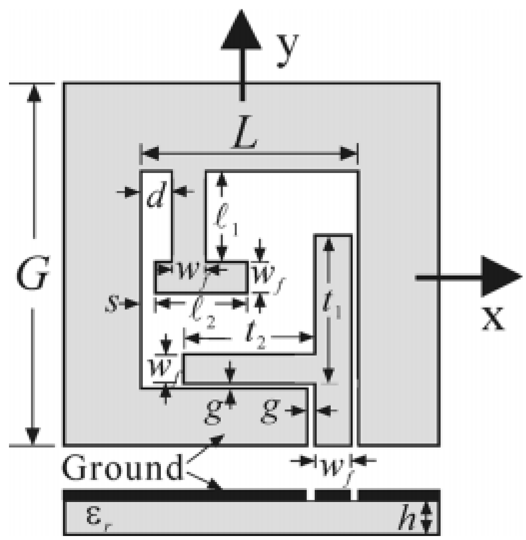


Figure 10: PSSA antenna with miniaturization configuration

For some circularly polarized antennas, the multiband coverage in contrast to single band coverage is a merit to experience decreased interference [43]. In literature, there are many approaches used to attain dual-band functionality. Slotted procedures are common by making a slot in the antenna geometry for the purpose of changing the path of flow of current and formation of two frequency bands. Based on these propositions, a surface opening cross-shaped patch in [44], U shaped perturbation slot in [45], Slotted patch antenna with an edge opening in [46], Slotted CP antenna with open ring structure in [47] and slotted antenna with asymmetrical opening [48] are proposed.

Recently in 2020, a paper [49] published in Springer brought into light a technique of defected ground structures to achieve circular polarization. However, the articulated antenna comprises of complicated ground plane structure and offset feeding which makes the design, complex from the prospects of fabrication. Moreover, increasing the resonant frequencies will require more oval shaped monopoles resulting in enlarged dimensions of the proposed antenna.

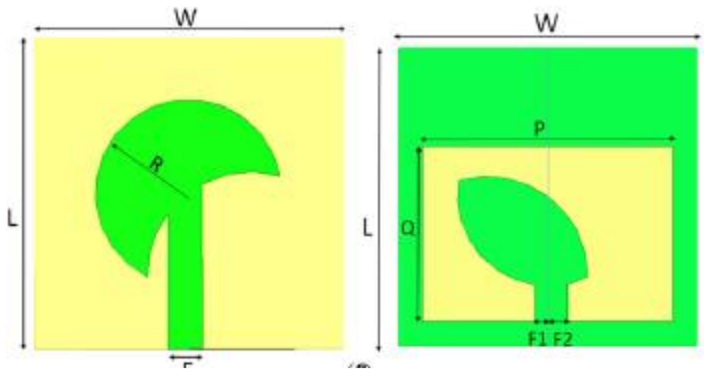
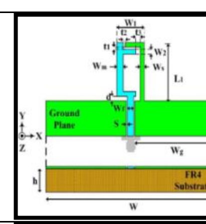
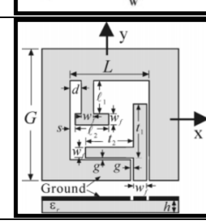


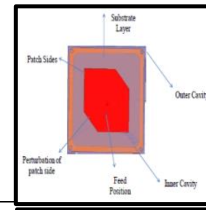
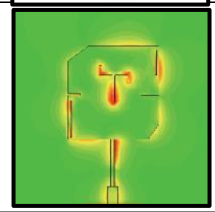
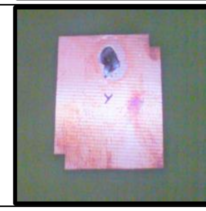
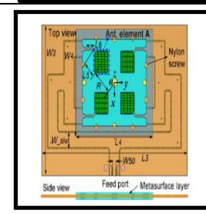
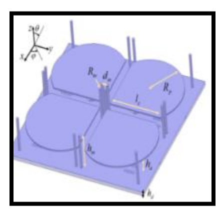
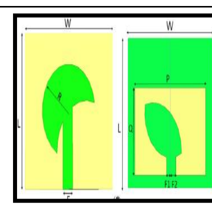
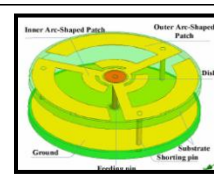
Figure 11: Oval shaped complex ground structure

A paper published by IEEE in 2021 [50] displays an antenna arrangement of sandwich shaped multiple arcs as patches along with a loaded capacitive coupled feeding pin capable of generating different resonant modes for the dual band functionality. By the addition of these bulky arcs, the sandwich shaped structure becomes much more complex to fabricate by an enormous increase in the antenna dimensions. Moreover, the introduction of another resonant frequency or band isn't possible without complicating the structure further.

A synopsis of few of the existing techniques is put forward in this table:-

Table 2: Comparative analysis of existing techniques

EXISTING CP ANTENNA TYPE	APPLICATIONS	DRAWBACKS	DESIGN
Quasi-Loop Element	GPS	➢ Complex fabrication ➢ Complicated design	
Miniaturized PSSA	GPS	➢ Cost ineffective ➢ Cumbersome parametric study	

Single Fed Patch with cavity	WLAN	➢ Limited Bandwidth	
T shaped slotted	Wi-Max	➢ Less control on CP orientation and larger size	
Y shaped slot	Wi-Max	➢ Decreased reduction in multipath effect and narrow bandwidth	
Dual orthogonal feeding	➢ Millimeter wave ➢ GNSS	➢ Complicated manufacturability ➢ Arduous design ➢ Narrow bandwidth ➢ Less efficiency	
Cross Dipole with slots	LTE	➢ Increased Dimensions and manufacturing complexity	
Sequential feeding	➢ Satellite ➢ Wireless	➢ Perplexing antenna geometry for compact array structure ➢ Enhanced bulkiness	
Dual band Offset feeding	➢ Satellite ➢ Wireless	➢ Enlarged dimensions ➢ Fabrication complexity due to oval shaped monopoles	
Sandwich shaped arcs	➢ ISM	➢ Bulky structure ➢ Complex fabrication	

2.3 Utilization of Previous Study

The credentials reviewed related to circularly polarized antennas gave an insight about the distinctive techniques and methods which can be employed to devise a compact circularly polarized dual band patch antenna with the intention of fulfilling the modern day needs of wireless communication systems. This appraisal investigation proved to be prolific for the optimization and parametric analysis of the proposed antenna.

Chapter 3

ANTENNA DESIGN

3.1 Introduction

This chapter focuses on the design of a novel compact dual band antenna executing circularly polarized performance, having dimensions of 70 mm x 60 mm x 1.57 mm. Rogers RT Duroid (dielectric constant= 2.20 and thickness= 1.57 mm) 5880 is used as substrate. Innovation of the antenna design mechanism lies in the employment of quadruple stubs with varying lengths embedded in a deformed square patch along with a defected ground structure, having slots for generation of commendable value of axial ratio of the CP waves. The antenna designing parameters, model for the antenna design and antenna design analysis using method of moments are summarized in this chapter.

3.2 Antenna Design Requisites

- ✓ Circularly polarized
- ✓ Compact size
- ✓ Dual band operation
- ✓ Enhanced gain
- ✓ Easy composition
- ✓ Cost effective
- ✓ Effortless fabrication
- ✓ Facile to assimilate with devices
- ✓ Improved impedance and axial ratio bandwidth

3.3 Antenna Design Parameters

In this thesis, a compact dual band circularly polarized patch antenna is put forward. The resultant antenna is facile to fabricate and integrate with modern world devices. The antenna executes improved parameters such as positive gain, enhanced impedance, axial ratio bandwidth, return loss having a value lesser than -10 dB for dual bands, directivity and radiation pattern. The calculated antenna designing parameters used for the designing of this antenna are stated beneath:

3.3.1 Width of Patch

The width of the dual band circularly polarized patch antenna helps in maximizing efficiency. It has been calculated by using the formula stated underneath:

$$\mathbf{Width} = \frac{\mathbf{c}}{\mathbf{2f}\sqrt{\frac{\epsilon\mathbf{r+1}}{\mathbf{2}}}} \ldots\ldots\ldots\ldots\ldots (1)$$

Where,

f = operating frequency of patch

$\epsilon_{\mathbf{r}}$= dielectric loss = 2.2

c = speed of light (c = 3 x 10^11 mm)

3.3.2 Length of Patch

The length of the designed antenna is calculated by using the following formula:

$$\mathbf{Length} = \frac{\mathbf{c}}{\mathbf{2f}\sqrt{\epsilon\mathbf{r}}} - \mathbf{0.824h}\ (\frac{(\epsilon\mathbf{r+0.3})(\mathbf{W}/_{\mathbf{h}}\mathbf{+0.264})}{(\epsilon\mathbf{r-0.258})(\mathbf{W}/_{\mathbf{h}}\mathbf{+0.8})} \ldots\ldots\ldots\ldots\ldots (2)$$

Where,

f = operating frequency of patch

$\epsilon_{\mathbf{r}}$ = dielectric loss = 2.2

h = height of substrate = 1.57 mm

c = speed of light = 3 x 10^11 mm

3.3.3 Length of Substrate

The length of substrate used i.e. ROGERS RT DUROID 5880 is calculated by using the formula stated underneath:

$$L_g = L + (6xh) \quad \ldots\ldots\ldots\ldots\ldots (3)$$

Where,

L_g = Length of substrate

L = Length of patch = 70 mm

h = height of substrate = 1.57 mm

3.3.4 Width of Substrate

The width of substrate used i.e. ROGERS RT DUROID 5880 is realized by making use of the following formula:

$$W_g = W + (6xh) \quad \ldots\ldots\ldots\ldots\ldots (4)$$

Where,

W_g = Width of substrate

W = Width of patch = 60 mm

h = height of substrate = 1.57 mm

3.3.5 Effective Relative Permittivity

The dielectric constant or relative permittivity of the microstrip line due to the non homogeneous nature of the structure (i.e., the structure is made up of two dielectric materials: air and the substrate material) that controls the resonance of the antenna is called as effective relative permittivity or dielectric constant and is given by the formula:

when $\left(\frac{\mathbf{W}}{\mathbf{H}}\right) < 1$

$$\epsilon_{\mathbf{e}} = \frac{\epsilon_{\mathbf{r}}+\mathbf{1}}{\mathbf{2}} + \frac{\epsilon_{\mathbf{r}}-\mathbf{1}}{\mathbf{2}}\left[\left(\mathbf{1}+\mathbf{12}\left(\frac{\mathbf{H}}{\mathbf{W}}\right)\right)^{-\mathbf{1/2}} + \mathbf{0.04}\left(\mathbf{1}-\left(\frac{\mathbf{W}}{\mathbf{H}}\right)\right)^{\mathbf{2}}\right] \ldots\ldots\ldots\ldots\ldots (5)$$

Where,

$\epsilon_{\mathbf{r}}$ = dielectric loss = 2.2

H = Height of microstrip transmission line = 22.3 mm

W = Width of microstrip transmission line = 0.7 mm

ϵr_{eff} = Effective relative permittivity = 1.653

Increase in effective relative permittivity of the substrate results in decrease in antenna size but bandwidth and gain of the antenna reduces with respect to the increase in the permittivity value.

3.3.6 Resonant frequency

The resonant frequency of the proposed antenna can be actualized by the formula stated underneath:

$$\mathbf{f} = \frac{\mathbf{c}}{\mathbf{2L}\sqrt{\epsilon_{\mathbf{r}}}} \ldots\ldots\ldots\ldots\ldots (6)$$

Where,

$\epsilon_{\mathbf{r}}$ = effective relative permittivity = 1.653

L = Length of patch = 70 mm

c = speed of light = 3 x 10^11 mm

3.3.7 Input impedance Microstrip feed line

The antenna is fed by a single feed microstrip feed line whose input impedance is calculated by making use of the formula as stated:

$$\mathbf{X_f} = \frac{\mathbf{L}}{\mathbf{2}\sqrt{\in_{\mathbf{r(eff)}}}} \ldots\ldots\ldots\ldots\ldots (7)$$

Where,

L = Length of patch = 70 mm

$\in_{\mathbf{r(eff)}}$ = Effective relative permittivity = 1.653

3.3.8 Bandwidth

The bandwidth of dual bands is actualized by using the formula:

$$\mathbf{Bandwidth} = \frac{\mathbf{h}}{\sqrt{\in_{\mathbf{r}}}} \ldots\ldots\ldots\ldots\ldots (8)$$

Where,

h = height of substrate = 1.57 mm

$\in_{\mathbf{r}}$= relative permittivity = 2.2

3.3.9 Wavelength

Wavelength is the required antenna length. The frequency of the electromagnetic waves is related to the wavelength by the equation stated as follows:

$$\lambda = c/f \text{..............} \quad (9)$$

Where,

c = speed of light = 3 x 10^11 mm

f = operating frequency = 3.3 GHz

3.3.10 Characteristic impedance

Characteristic impedance is defined as the input impedance of a transmission line. It is given by the following formula:

$$\mathbf{when}\left(\frac{\mathbf{W}}{\mathbf{H}}\right) < 1$$

$$\mathbf{Z_o} = \frac{\mathbf{60}}{\sqrt{\epsilon_{\mathbf{eff}}}} \mathbf{ln}\left(\mathbf{8}\frac{\mathbf{W}}{\mathbf{H}} + \mathbf{0.25}\ \frac{\mathbf{W}}{\mathbf{H}}\right) \mathbf{8}\ \frac{\mathbf{H}}{\mathbf{W}} (\mathbf{ohms}) \text{ ....} \quad (10)$$

Where,

H = Height of microstrip transmission line = 22.3 mm

W = Width of microstrip transmission line = 0.7 mm

$\epsilon_{\mathbf{r(eff)}}$ = Effective relative permittivity = 1.653

3.3.11 Return Loss

Return loss depends upon the scattering parameters. S_{11} is known as reflection coefficient. The magnitude of S_{11} can be expressed in decibels and the return losses can be estimated as

$$S_{11} = 20\log_{10}|S_{11}|\,dB \ldots\ldots\ldots\ldots\ldots (11)$$

3.3.12 Axial Ratio

Axial ratio is a very important parametric quantity that symbolizes shape of the polarization ellipse and in turn defines the polarization of an antenna.

$$\mathbf{AR} = \frac{\mathbf{major\ axis}}{\mathbf{minor\ axis}} \ldots\ldots\ldots\ldots\ldots (12)$$

The value of axial ratio is 1 for circularly polarized antennas but the electric waves deviate from the main bean with an angle of 30^o. So according to the standards of IEEE a value of lesser than 3 dB is selected to be accurate for circular polarization.

The LHCP and RHCP components can be calculated by using the following formulas:

$$\mathbf{E_{lhcp}} = \frac{1}{\sqrt{2}}(\mathbf{E_\theta} - \mathbf{jE_\varphi}) \ldots\ldots\ldots\ldots\ldots (13)$$

$$\mathbf{E_{rhcp}} = \frac{1}{\sqrt{2}}(\mathbf{E_\theta} + \mathbf{j\,E_\varphi}) \ldots\ldots\ldots\ldots\ldots (14)$$

$$\mathbf{AR_{cp}} = \frac{|\mathbf{E_{lhcp}}| + |\mathbf{E_{rhcp}}|}{|\mathbf{E_{lhcp}}| - |\,\mathbf{E_{rhcp}}|} \quad \ldots\ldots\ldots\ldots\ldots (15)$$

The formula stated as under is used for the analysis of axial ratio:

$$\mathbf{AR\ (dB) = 20\ log\ (A_V\ exp\ (Phi_V)\ /\ A_H\ exp\ (Phi_H)} \ldots\ldots\ldots\ldots\ldots (16)$$

3.4 Model for Antenna Design

High Frequency Structural Simulator (HFSS) is used for the initial design and simulation of the projected antenna. It is a proficient 3D electromagnetic simulator and complication solver. It is used for the designing of perplexing radio frequency elements. It is based on finite element method (FEM). It is smoothly operated software offering user friendly interface for antenna designing and testing. Many different types and shapes of antennas can be prepared using HFSS [51]. The design requisites were effectuated by employing a deformed rectangular monopole patch with quadruple stubs and partial defected ground plane having two vertical rectangular slots. The formulated design utilizes a quarter wave transformer having a length of λ/4, terminating with a 50 Ω transmission line for impedance matching. This feeding configuration optimizes the antenna to actualize different bandwidths. Stubs are administered inside the deformed rectangular monopole patch in order to obtain the dual band operation for the S and C band. The partial ground plane technique is materialized for achieving enhanced bandwidth of the dual circularly polarized bands. Defected slotted ground structure technique is implemented to procure circular polarization for both the bands. Below is the HFSS design of the dual band antenna

.

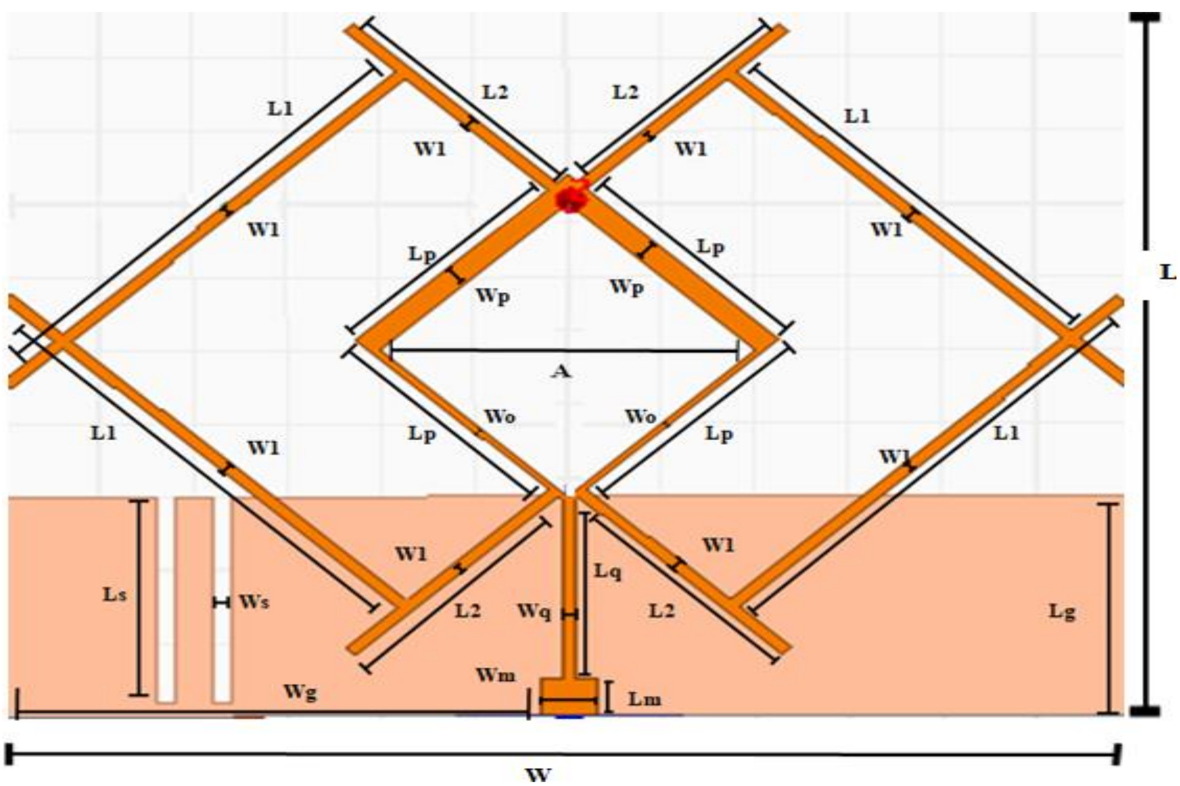


Figure 12: Antenna Geometry dimensions

The articulated antenna operates on the bands of **Bluetooth, Wi-Fi, Wi-Max and LTE (2.69 - 2.75 GHz) and Wi-Fi (4.7 - 5.5 GHz)**. The antenna design was attained by utilizing dimensions mentioned in the table below:

Table 3 : Dimensions of Antenna Design

LABEL	DIMENSIONS (mm)
L	70
W	60
L_g	15
W_g	28.5
Lq	22.3
Wq	0.7
Lm	2.5
Wm	3
Lp	16
Wp	5
A	10
Wo	1
L_1	30.5
W_1	0.7
L_2	15.5
Ls	15
Ws	1

3.5 Parametric study

The parametric study involves investigation of the influence of geometric parameters for the solution of the problem. By employing this approach, a dual band circularly polarized antenna's prototype is developed covering the bands of 2.69 - 2.75 GHz (Bluetooth, Wi-Fi, Wi-Max and LTE) and 4.7 - 5.5 GHz (Wi-Fi). The selected substrate is Rogers RT Duroid 5880 (dielectric constant = 2.20, h = 1.57 mm). Dimensions of the resultant patch are L = 70 mm and W = 60mm. The antenna makes use of a quarterwave transformer having a length of λ/4 terminating with a 50 Ω transmission line for impedance matching. Measurement of ground plane are L = 15mm and W = 60 mm. The quadruple stubs of the radiating patch have two lengths of L_1 = 30.5 mm and L_2 = 15.5 mm having a constant width of W_1 = 0.7 mm. A square whose length is equal to L_p = 16 mm is designed at the centre of the radiating patch. Quadruple stubs are attached to four of its corners. Another square of length A = 10 mm is subtracted from the square of L_p = 16 mm to generate a deformed rectangular radiating patch. CP characteristics of the dual band antenna are administered by varying the dimensions of width and length of stubs attached to the square patch and slots in the ground plane.

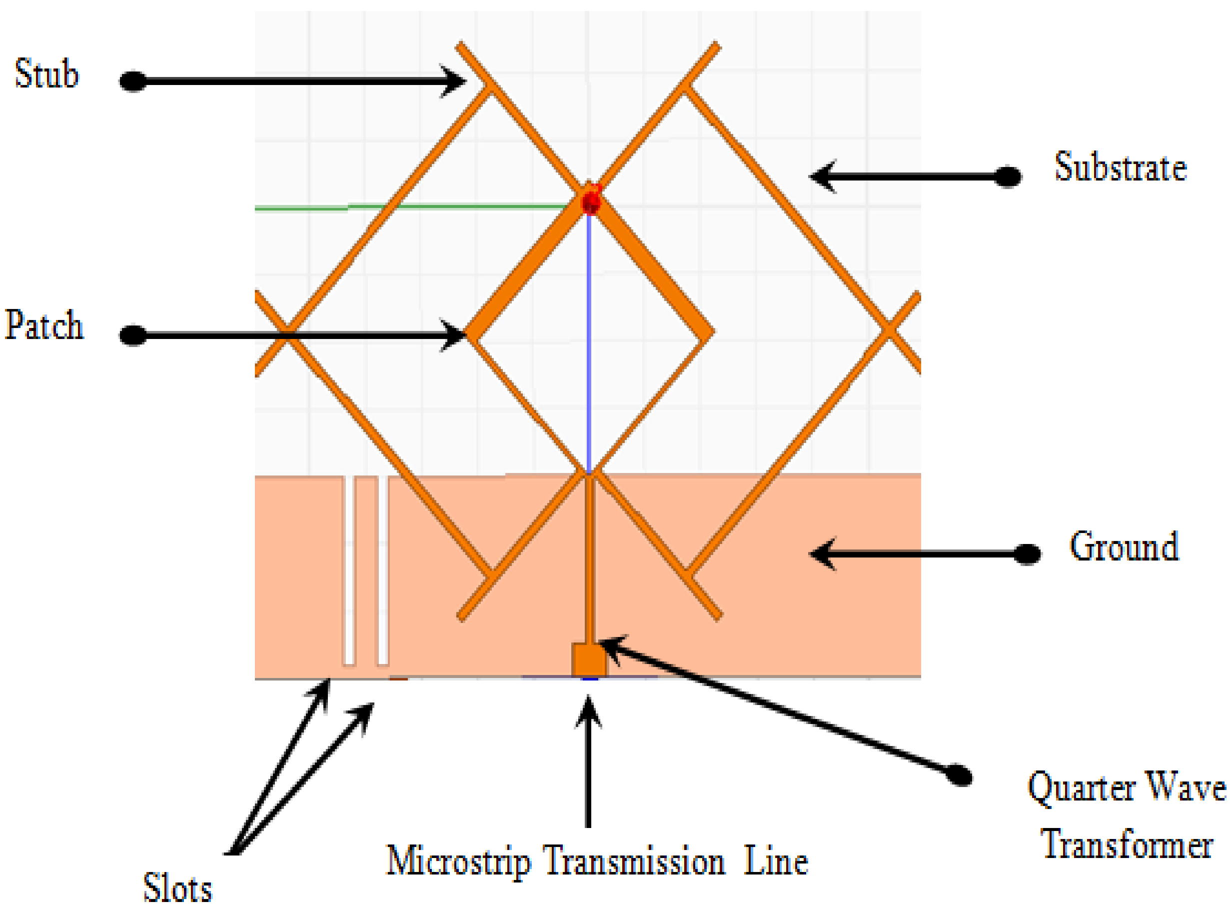


Figure 13: HFSS antenna design delineation

I. The effect of ground plane

The ground plane plays an important role in generation of circular polarization in an antenna.

- ***Partial Ground Plane***

A partial ground plane has been selected in order to increase back radiation. The back radiation produced by the partial ground plane reduces the energy stored in the substrate of RT Duroid Rogers 5880. This reduction in energy leads to decrease in Quality factor Q of the antenna which in return increases the axial ratio bandwidth.

- ***Length and width of ground plane***

The length of the ground plane is selected as L = 15 mm and width as W = 60 mm for the production of two circularly polarized waves.

- ***Defected Ground Structure (DGS)***

A defected Ground structure is selected for the generation of circular polarization

- ***Slots***

The slots in the midst of ground plane have dimensions of width Ws = 1 mm and length Ls = 15 mm each. These slots are responsible for the generation of circular polarization.

- ***Gap between slots***

A small gap of 4 mm is designed between the two slots on the ground plane for generation of circular polarization**.** Increasing the gap leads to degradation in the value of axial ratio.

II. The effect of radiating patch

In the proposed design the radiating patch plays an imminent role for governing the reflection coefficient, bandwidth and ensuring phase difference among the electric field components. Phase difference among the electric field components is an important characteristic for the generation of circularly polarized waves.

➢ *Deformed Rectangular central patch*

It is used to govern the reflection coefficient and impedance bandwidth of the proposed antenna.

➢ *Stubs*

The stubs with different lengths are employed in order to form an LC circuit. This LC circuit is used for the generation of phase difference among the electric field components.

Longer Stubs

S band (2.69 - 2.75 GHz) is generated by the longer stubs at 2.7 GHz resonant frequency. The longer stub with length L_1 is short circuited and is placed parallel to the central rectangular patch. The longer stubs act as an inductor. These stubs generate a CP wave which is leading in phase.

Shorter Stubs

C band (4.7 – 5.5 GHz) is generated by shorter stubs at 5 GHz resonant frequency. The shorter stubs with length L_2 is open circuited and are placed directly attached to the central patch. The shorter stubs act as a capacitor. These stubs generate a CP wave which is lagging in phase.

➢ *Feed point*

For production of circularly polarized wave, two feed points are given in practice to the antenna to feed the two equal magnitude electric field components and to generate a phase difference of 90^0 between them. In the proposed antenna, the radiating patch is fed by a single feed point so the stubs of variable lengths are attached to the patch for providing the necessary 90° phase shift to the radiated field components.

III. Quarter wave Transfomer and Feed line

- The antenna is fed by a 50 Ω transmission line along with a quarter wave transformer.
- This geometry is used to actualize bandwidth at two different frequency ranges in the frequency spectrum.
- Both of these components also help in performing impedance matching.

3.6 Optimization

Axial Ratio

i. By altering the **width, length and location** of the slots on the ground plane, a shift and optimization of the axial ratio bandwidth of the dual bands is observed.

ii. **Increasing the size of ground** plane will reallocate the axial ratio bandwidth downwards in frequency range **whereas decrease in size of ground plane** will transfer the axial ratio bandwidth upwards in the frequency range.

iii. **Widening the gap** among slots degrades the value of axial ratio. Characteristically, the difference in slots must be kept small for good value of axial ratio.

Reflection Coefficient

Increasing the **width of stubs** improves the value of reflection coefficient.

➢ Impedance Bandwidth

i. **Squared defect** of A = 10mm at the centre of the rectangular patch helps in enhancing the impedance bandwidth.

ii. Increasing the **length of stubs** improves the value of impedance bandwidth.

The S_{11} parameters show critical reliance on the length and width of the radiating patch and stubs.

3.7 Antenna Design Analysis

The circular polarization characteristics of a circularly polarized antenna fed by a single feed are analyzed by using **Method of moments.**

- It is a numerical technique used to solve integral equations changing them into simultaneous linear equations.
- It is used to calculate current distribution along the antenna.
- Green's functions and the reaction integral equation for the patch currents are formulated in the spectral domain by utilizing an impedance model.
- Galerkin's method is employed to determine the input impedance, far-field patterns, impedance bandwidth, beamwidth, and axial-ratio bandwidth.
- The possibility of improving the axial-ratio bandwidth of the microstrip antenna is demonstrated.
- The patch surface current density is decomposed into entire basis functions with unknown amplitudes. The entire basis function can mode any current with the same accuracy as one would achieve Nth value of current for the basis function.
- To improve the ARBW of the dual band CP antenna, the effect of the substrate is also examined.

3.7.1 Surface current density

The impedance of the patch is computed by modeling the orthogonal currents on the patch. The patch is excited by single feed microstrip feed line. For the purpose of analysis it can be replaced by an equivalent current source given by equation (17).

$$\vec{J}_s = \frac{\check{z}Io}{s} \quad \text{…………… (17)}$$

3.7.2 Green's Function

Green's function is used to find electric field of the electric current elements located on the patch. Greens function demonstrates the antenna's electromagnetic response in space. The electric field on the patch is produced by the excitation currents $\vec{J}_1$ and $\vec{J}_2$ of the stubs. The integral equation is formulated as follows

$$\vec{E}(\vec{J}_{s1}) + \vec{E}(\vec{J}_{s2}) + \vec{E}(\vec{J}_i) = 0 \quad \text{…………… (18)}$$

3.7.3 Sub domain basis function

Sub domain basis function is used because it sub divides the geometry of rectangular patch into smaller segments and model the current distribution for each segment.

The unknown surface current densities on the patch are extended into sets of basis function:

$$\vec{J}_{si} = \sum_{m=1}^{N_i} I_{mi}^{x} J_{mi}^{x} \hat{x} + \sum_{n=1}^{N_{i+2}} I_{ni}^{y} J_{ni}^{y} \hat{y}, \quad \text{…………… (19)}$$

Where $I_m^{x,y}$ is the unknown amplitude of the expansion coefficient current of the basis function $J_{mi}^{x,y}$.

3.7.4 Galerkin's Method

Galerkin's procedure is employed to solve for the unknowns. Galerkins method defines the testing function to be same as basis function. Using Galerkin's approach, substituting (18) into equation (3), the following integral equations are achieved

$$\underset{N_t \times N_t}{[Z]}\ \underset{N_t \times 1}{[I]} = \underset{N_t \times 1}{[V]},\ N_t = \sum_{i=1}^{4} N_i \qquad \ldots\ldots\ldots\ldots\ldots (20)$$

The input impedance Zin, of the microstrip antenna can be obtained from the formula

$$Z_{in} = -\sum_{i=1}^{2}\left[\sum_{m=1}^{N_i} I_{mi}^{x} V_{mi}^{x} + \sum_{n=1}^{N_{i+2}} I_{ni}^{y} V_{ni}^{y}\right] \qquad \ldots\ldots\ldots\ldots\ldots (21)$$

3.7.5 Sub domain function as Fourier Transform

The sub domain basis function is analogous to Fourier transform and it exists over the entire domain of the unknown coefficients. So the equation (18) can be rewritten as:

$$\vec{J}_{si}(x, y) = \left\{\sum_{m=1}^{N_i} \frac{I_{mi}^{x}}{2w_i} \sin\left(\frac{m\pi}{2a_i}x\right)\hat{x} + \sum_{n=1}^{N_{i+2}} \frac{I_{ni}^{y}}{2a_i} \sin\left(\frac{n\pi}{2w_i}y\right)\hat{y}\right. \qquad \ldots\ldots\ldots\ldots (22)$$

3.7.6 Analysis wrapping up:

A full wave analysis is employed to evaluate the characteristics of a circularly polarized dual band antenna. The substrate effect is taken into account by the rigorous Green's function formulation of electric field patterns in the far field. The value of analytical electric current density calculated by the method of moments can be compared with the simulated and measured electric current density of the proposed circularly polarized patch antenna.

Chapter 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the design verification of the proposed antenna. A comparison between simulated and measured results is shown. It can be observed that the simulated and measured S parameters are found to be in good accordance with each other. The fabricated dual resonance circularly polarized antenna exhibits good matching (S_{11} < -10 dB) for both the frequency bands. The first circularly polarized band corresponds to 2.2 % bandwidth with operating frequency of 2.7 GHz exhibiting reflection coefficient of -19 dB. For the second circularly polarized operating band antenna is well matched from (4.7 - 5.5 GHz) corresponding to 16 % bandwidth with operating frequency of 5 GHz having reflection coefficient of -14.5 dB. The first CP band is well matched from (2.69 - 2.75 GHz) and corresponds to 2.2 % impedance bandwidth with operating frequency of 2.7 GHz exhibiting reflection coefficient of -19 dB and the second CP operating band is well matched from (4.7 - 5.5 GHz) corresponding to 16 % bandwidth with operating frequency of 5 GHz having reflection coefficient of -14.5 dB. The gains of the designed antenna are 2.3570 dB and 5.4248 dB at the first and second band. The measured AR bandwidth (< 3dB) of the antenna is 60 MHz (2.69 - 2.75 GHz) at the first band and 300 MHz at the second band (5 - 5.3 GHz). The realized antenna executes improved parameters and is capable of effectively working on the Wi-Max, Bluetooth, W-LAN and LTE applications fulfilling the need of circularly polarized double resonance.

4.2 HFSS optimized results

After designing and optimization of the antenna, favorable results were obtained. Achieving desired gain and axial ratio posed as a great challenge. Simulated results are summarized beneath.

4.2.1 Simulated results

4.2.1.1 Dual band return Loss

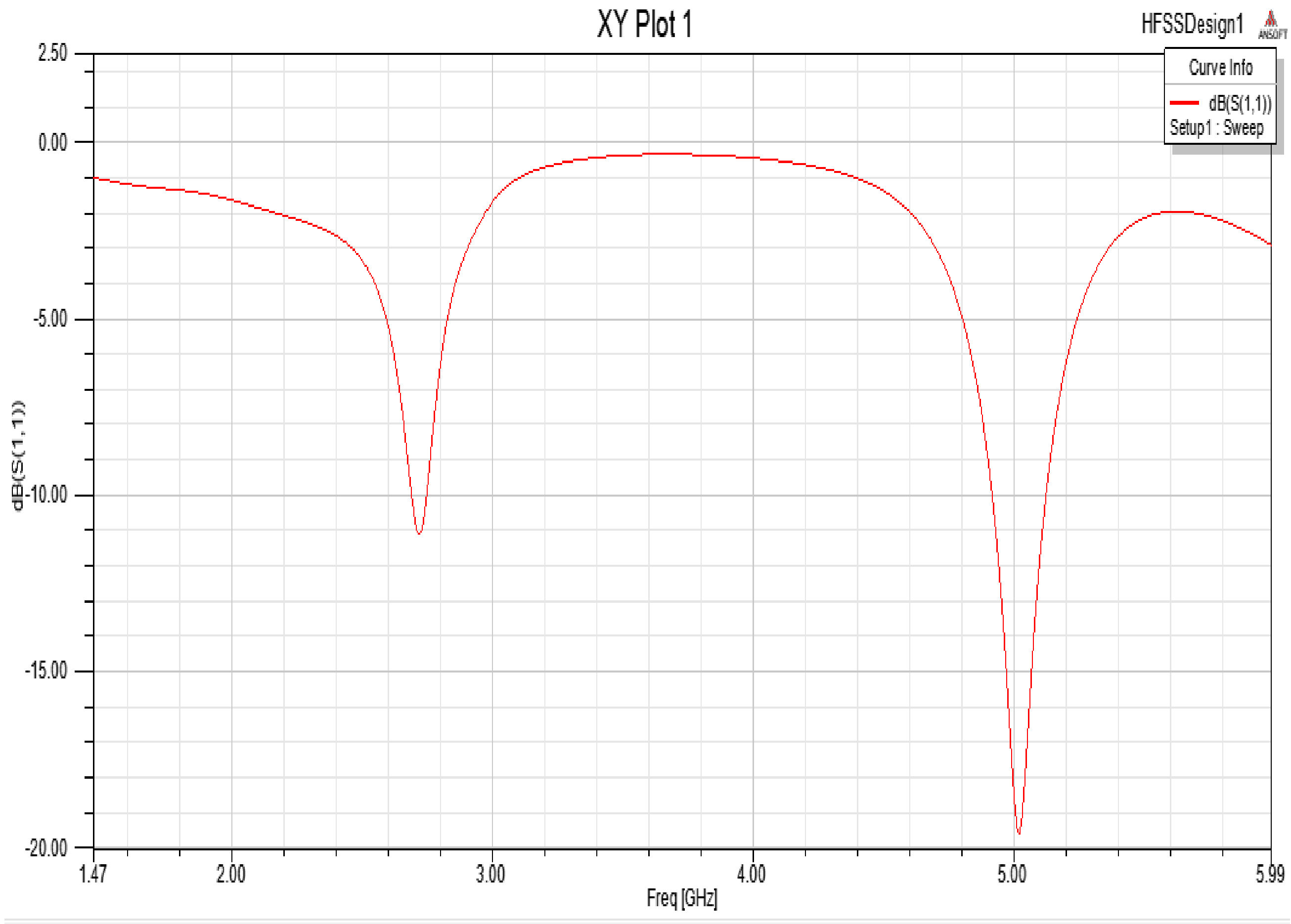


Figure 14: Simulated return loss (S11) Plot for dual band operation

It is observed from the acquired results that the value of return loss for both the bands is less than -10 dB i.e. -11.14 dB and -19.6 dB for the first and second band.

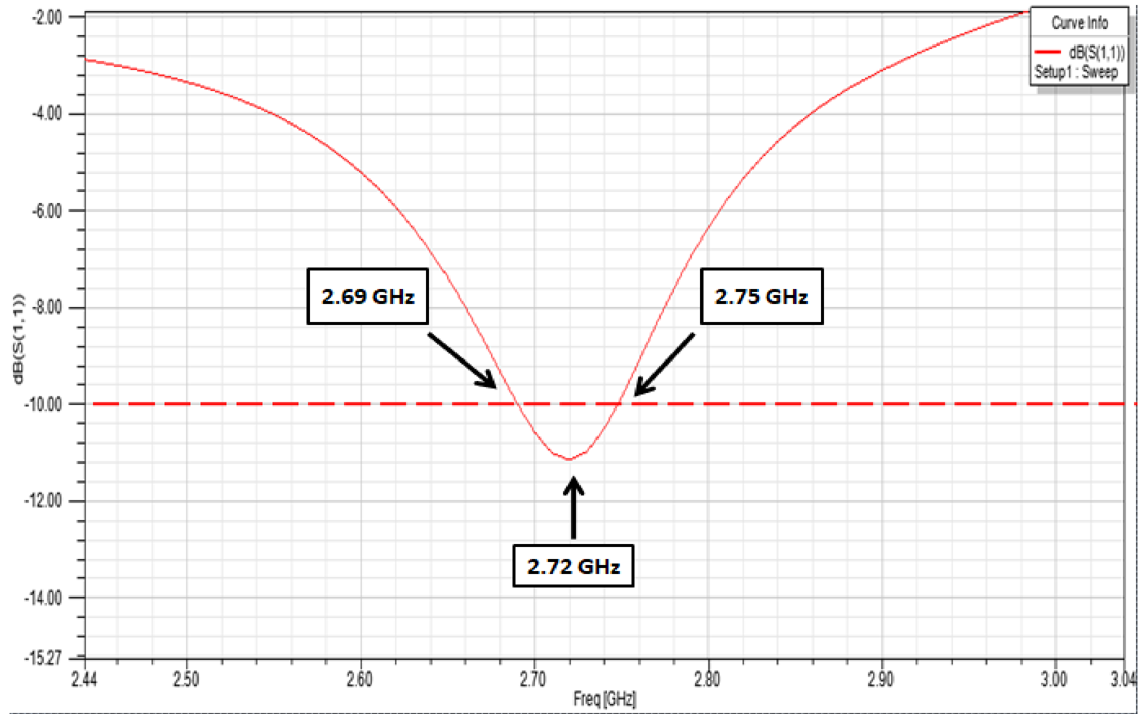


Figure 15: Simulated S11 plot for first band

The first band (2.69 - 2.75 GHz) has a bandwith of 2.2 %

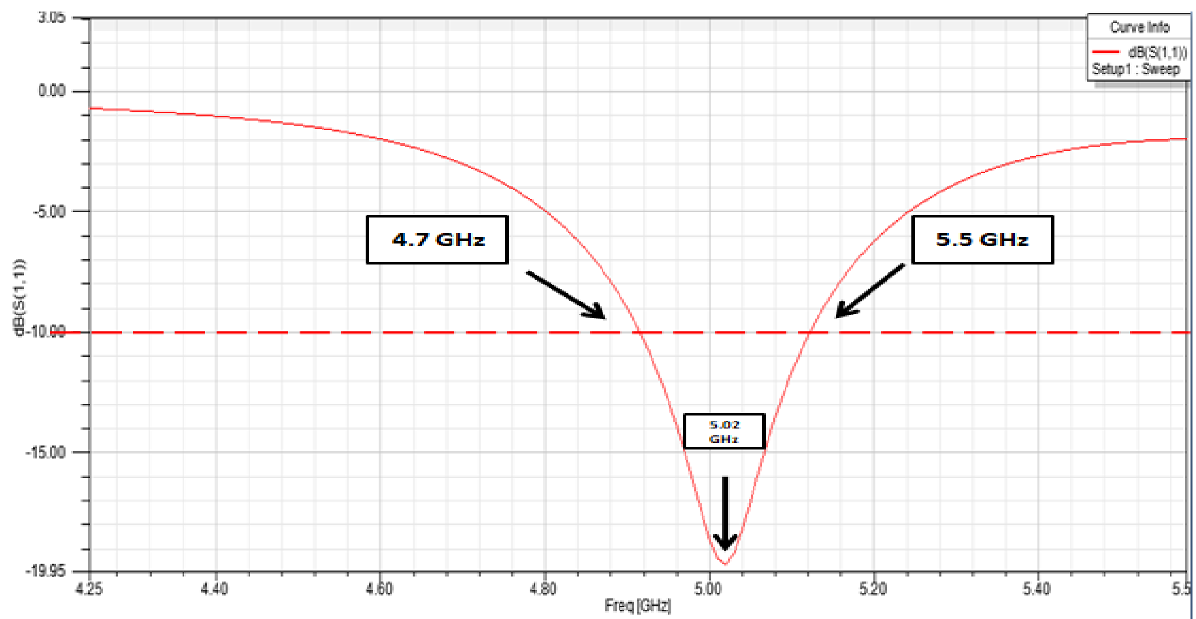


Figure 16: Simulated S11 plot for second band

The second band (4.7 - 5.5 GHz) has a bandwidth of 16 %

4.2.1.2 3D Polar Plots for gain of dual bands

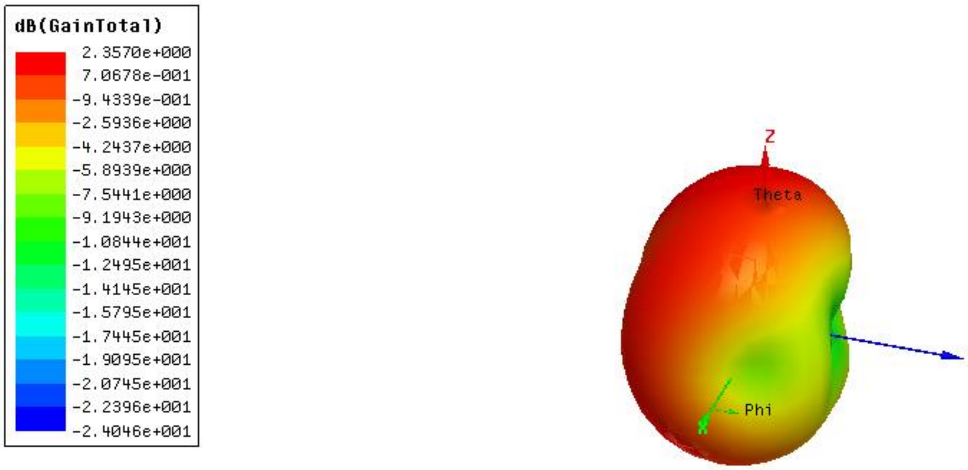


Figure 17: 3D polar plot for max and min gain at first band (2.69 - 2.75 GHz)

The attained gain of the band of **Bluetooth, Wi-Fi, Wi-Max and LTE (2.69 - 2.75 GHz)** is **2.3570 dBi**

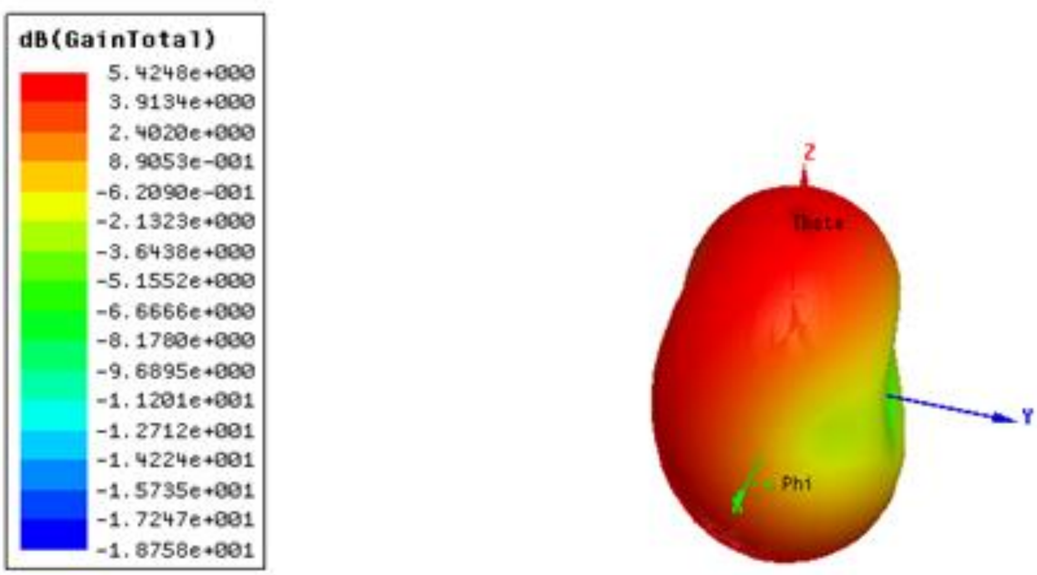


Figure 18: 3D polar plot for max and min gain at second band (4.7 - 5.5 GHz)

The attained gain of the band of **Wi-Fi (4.7 - 5.5 GHz)** is **5.4248 dBi**

4.2.1.3 Surface Current Distribution Plots

The surface current distribution plots for the realized antenna are demonstrated in fig 19 and 20 at 2.7 GHz and 5.00 GHz to understand the behavior of resonance. The red area illustrates the areas of maximum current distribution. Fig 19 and Fig 20 depicts the surface current distribution plot at 2.7 GHz and 5.00 GHz resonant frequency respectively. It can be observed that the length, width and location of quadruple stubs alongside the quarter-wavelength transformer contribute in attaining the desired frequency band. The longer stubs tune 2.7 GHz resonant frequency whereas 5.00 GHz resonant frequency is tuned by shorter stubs,

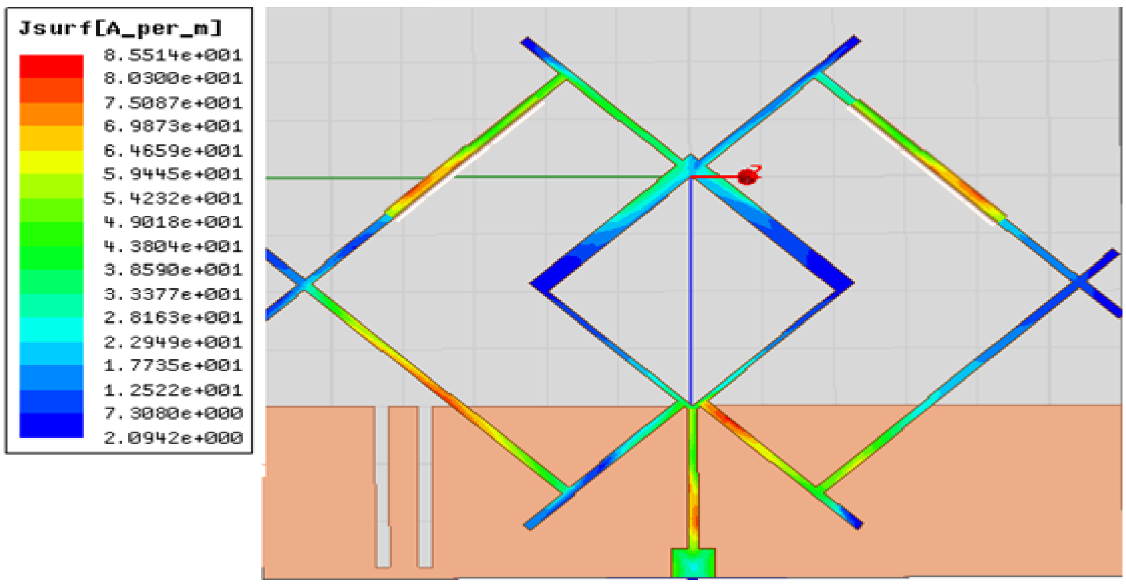


Figure 19: Surface current Density at 2.7 GHz resonance frequency

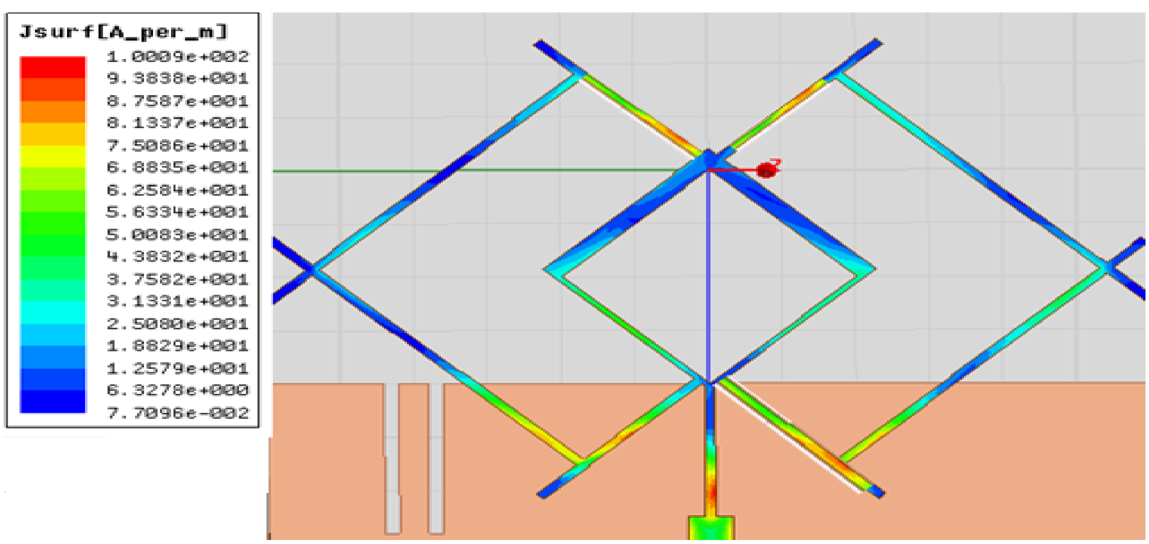


Figure 20: Surface Current Density at 5.00 GHz resonant frequency

4.2.1.4 Vector Surface Current Distribution Plots

Vector surface current density plots are animated in order to observe the direction of electric current. At phi = 0º the right side of the antenna design has electric current towards the +x axis whereas the left side of the antenna design has electric current towards the +y direction. This leads to the generation of a LHCP wave in the +z direction. At phi = 90º the left side of the proposed CP antenna has electric current towards the –x axis whereas the left side of the antenna has electric current towards the –y direction. This results in the generation of a RHCP wave towards –z direction. Both the resonant frequencies execute the same behavior. This behavior of the vector current distribution confirms the circular polarization performance of the proposed antennas for both the bands**.**

First band (Resonant Frequency =2.7 GHz)

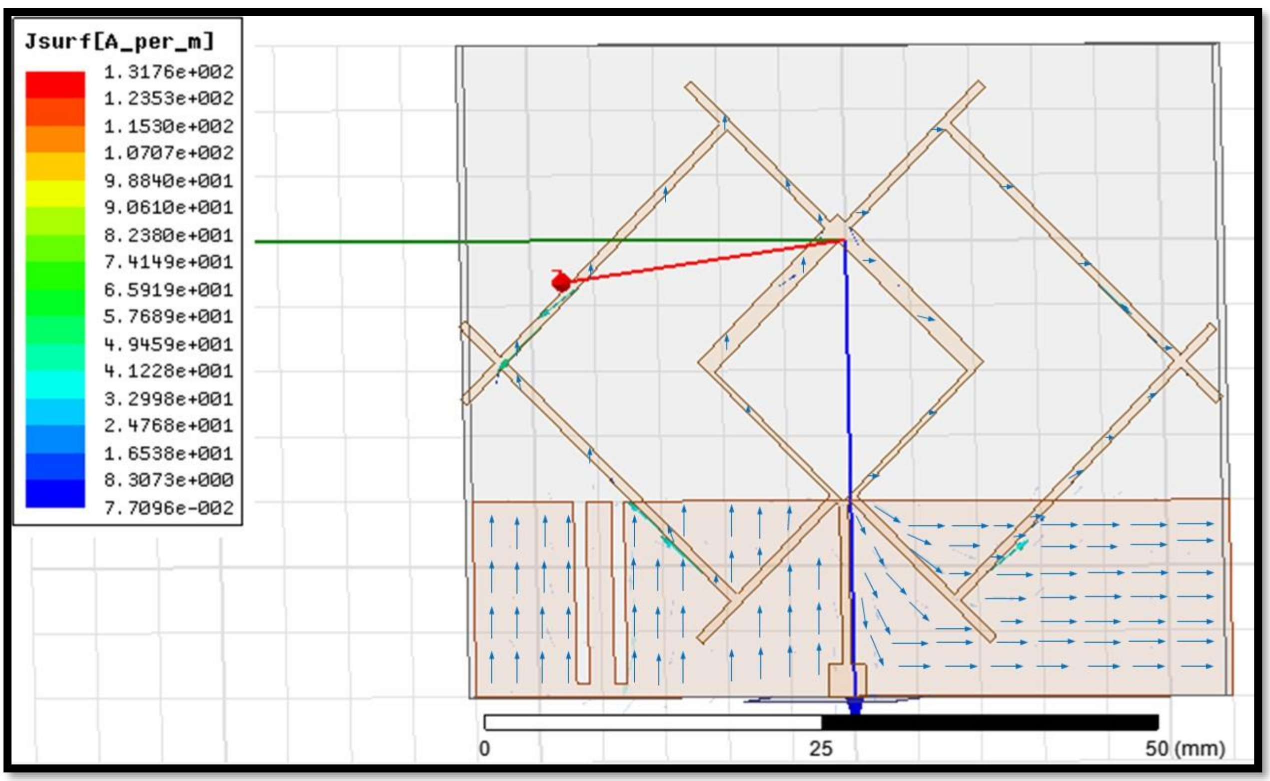


Figure 21: Vector Current Distribution at Phi=0º

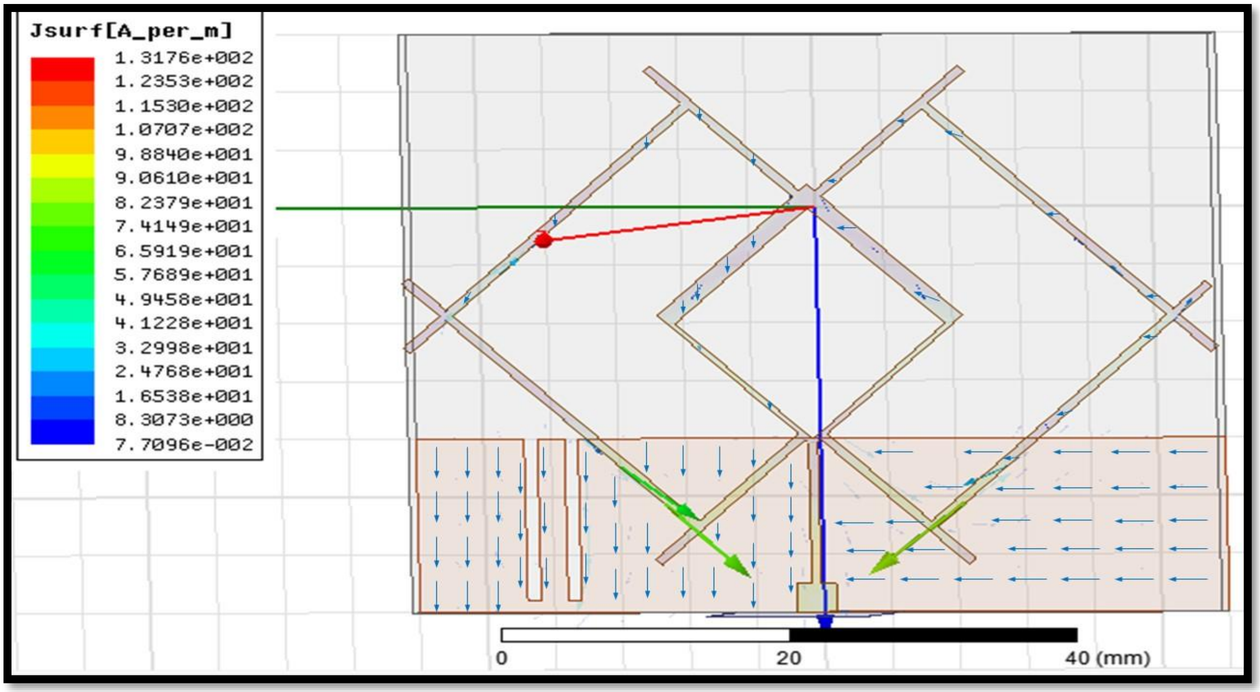


Figure 22: Vector Current Distribution at Phi=90º

Second band (Resonant Frequency =5 GHz)

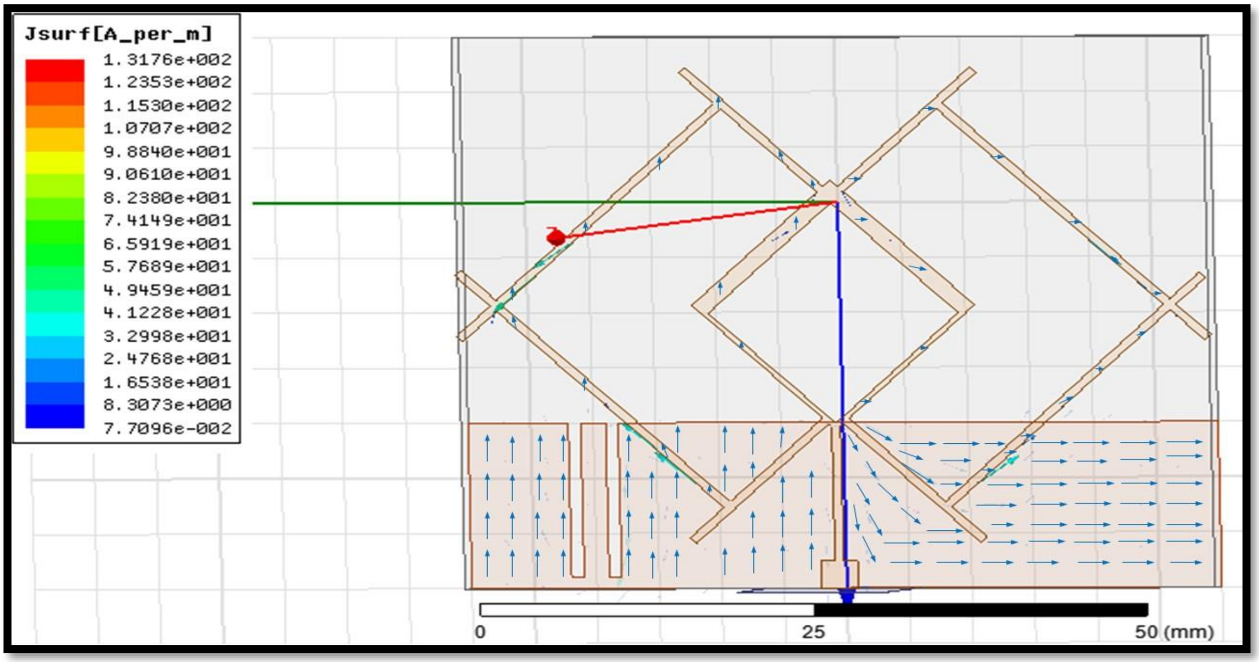


Figure 23: Vector Current Distribution at Phi=0º

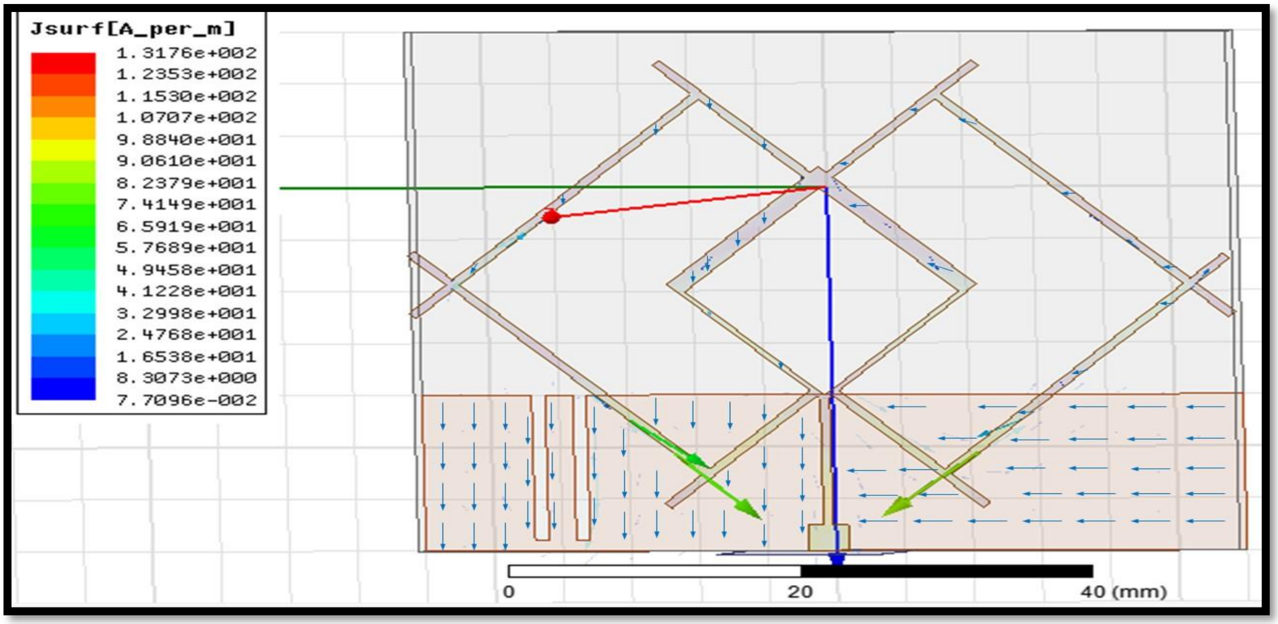


Figure 24: Vector Current Distribution at Phi=90º

4.2.1.5 Radiation Pattern

The 3D simulated radiation pattern portrays the power radiated by the antenna as a function of direction moving away from the CP antenna with dual bands. The cross polarization levels of the simulated radiation patterns is higher that confirms the circular polarization performance of the antenna.

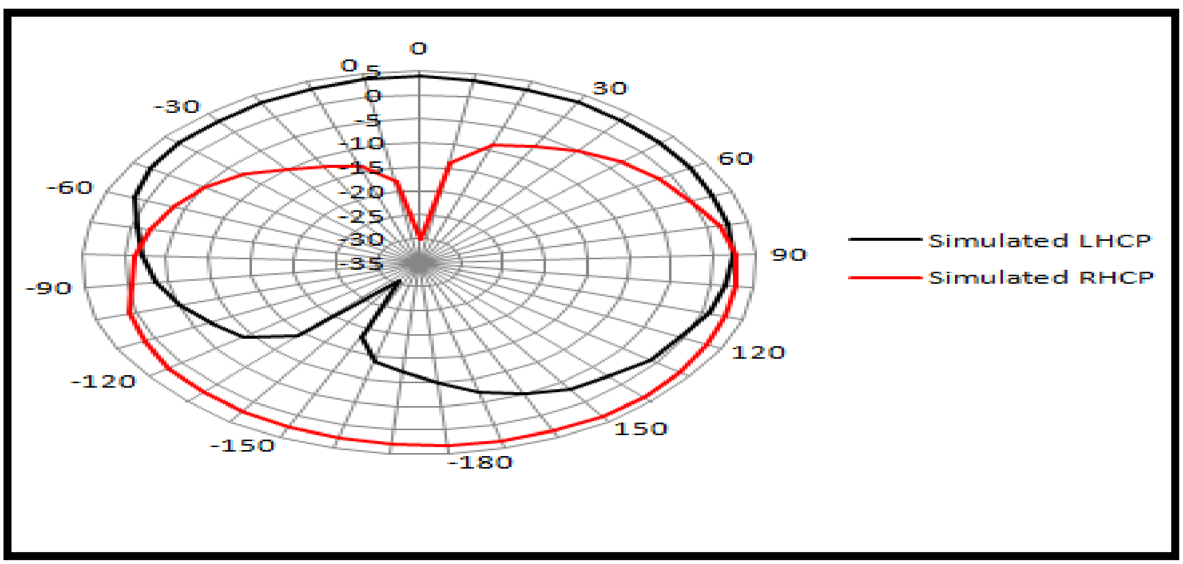


Figure 25: Simulated LHCP and RHCP radiation pattern at 2.7 GHz in xz-plane

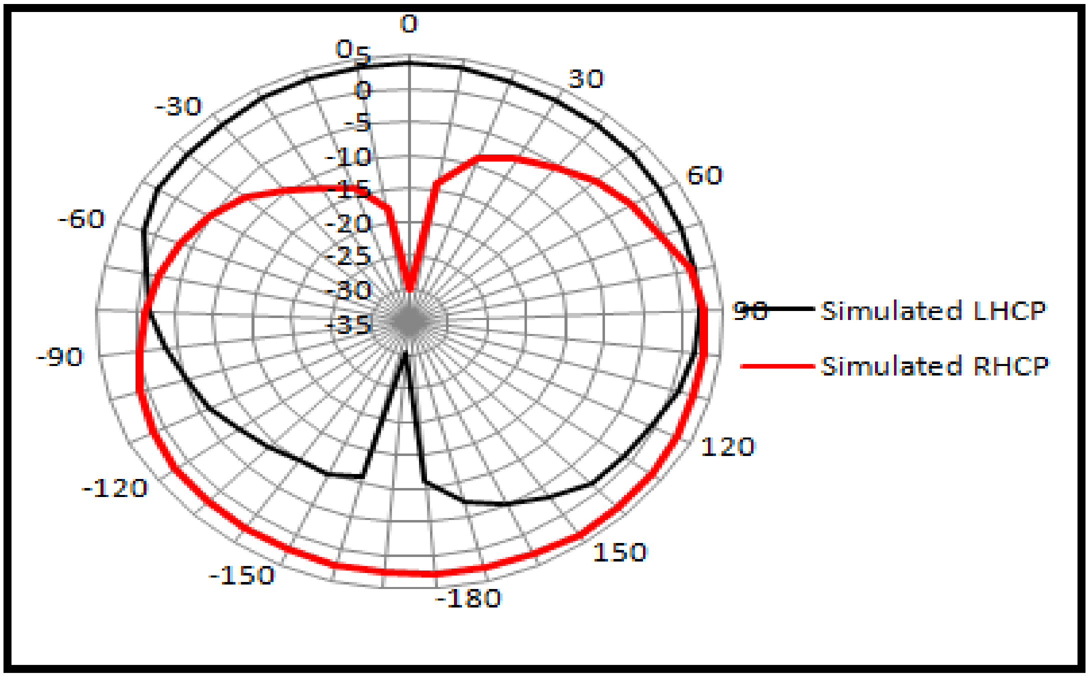


Figure 26: Simulated LHCP and RHCP radiation pattern at 2.7 GHz in yz-plane

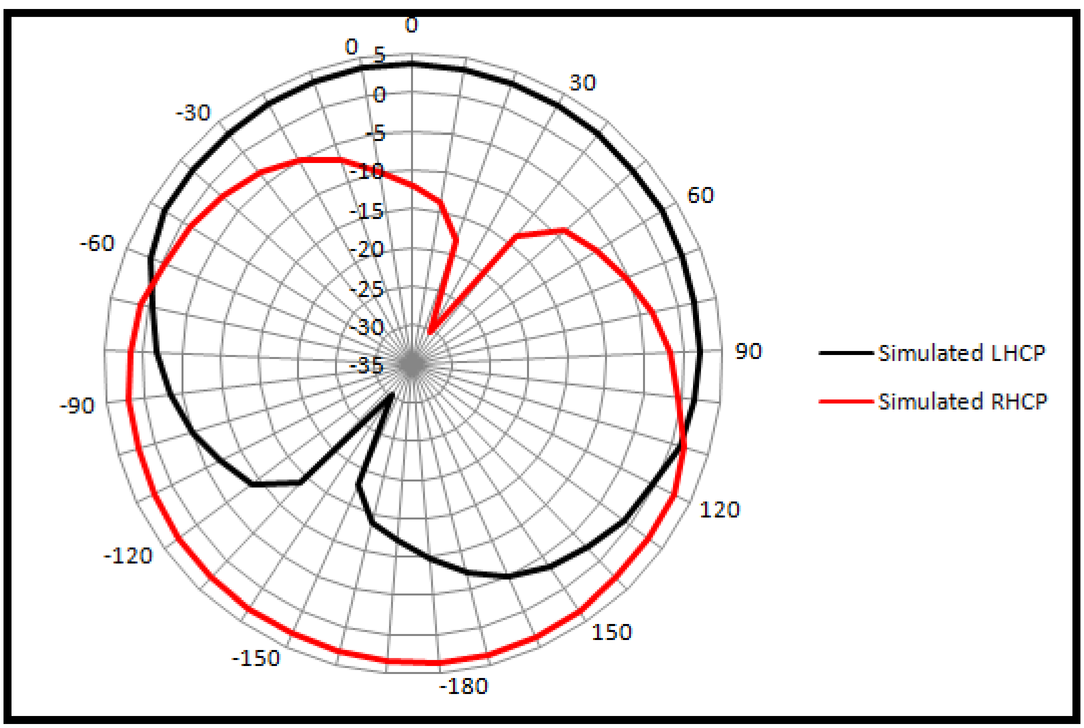


Figure 27: Simulated LHCP and RHCP radiation pattern at 5 GHz in xz-plane

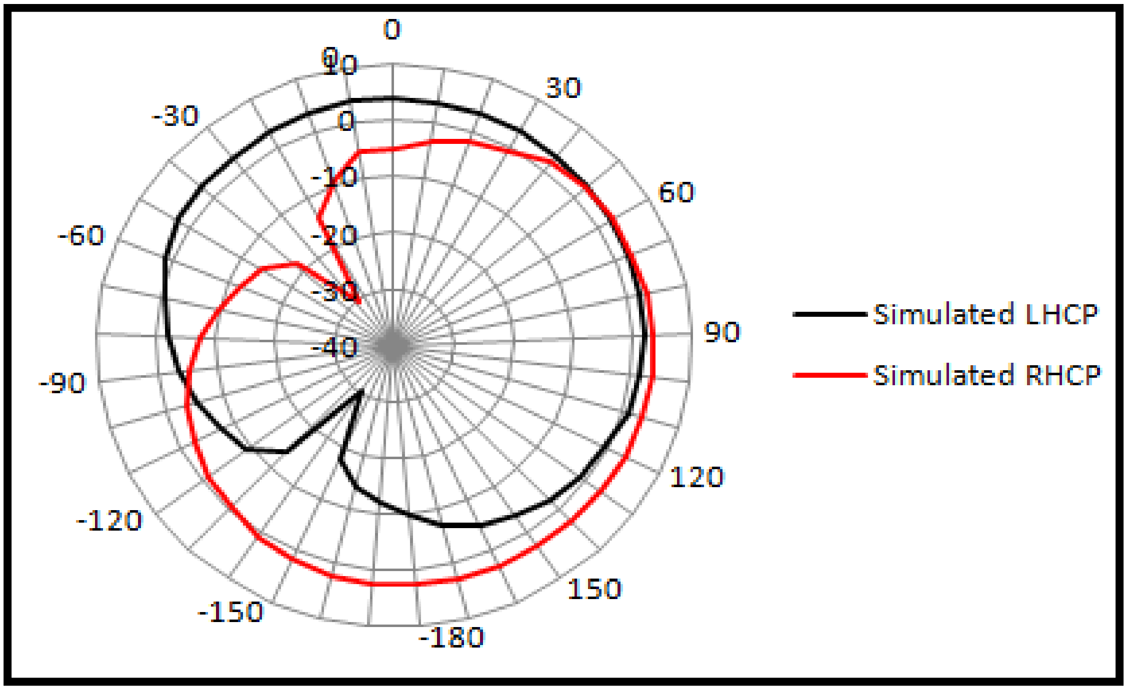


Figure 28: Simulated LHCP and RHCP radiation pattern at 5 GHZ in yz-plane

4.2.1.6 Simulated Axial Ratio

The designed antenna uses dual slots of same length in the ground plane to control axial ratio at both the frequencies.

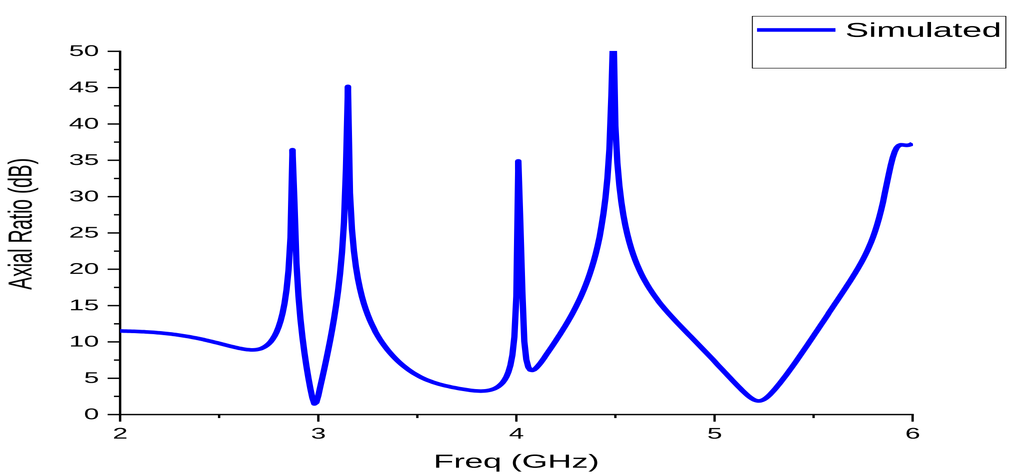


Figure 29: Simulated axial ratio

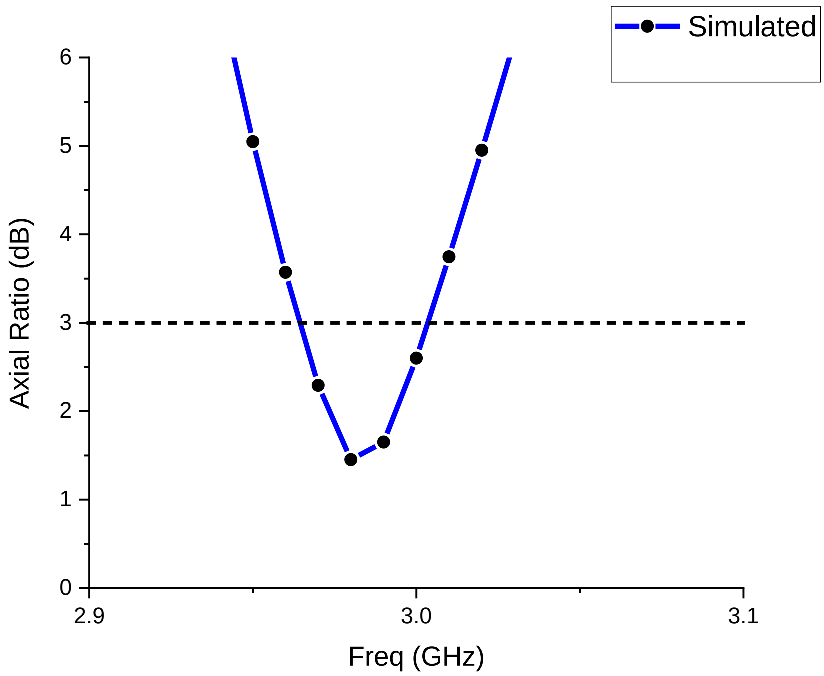


Figure 30: Simulated axial ratio for the first band

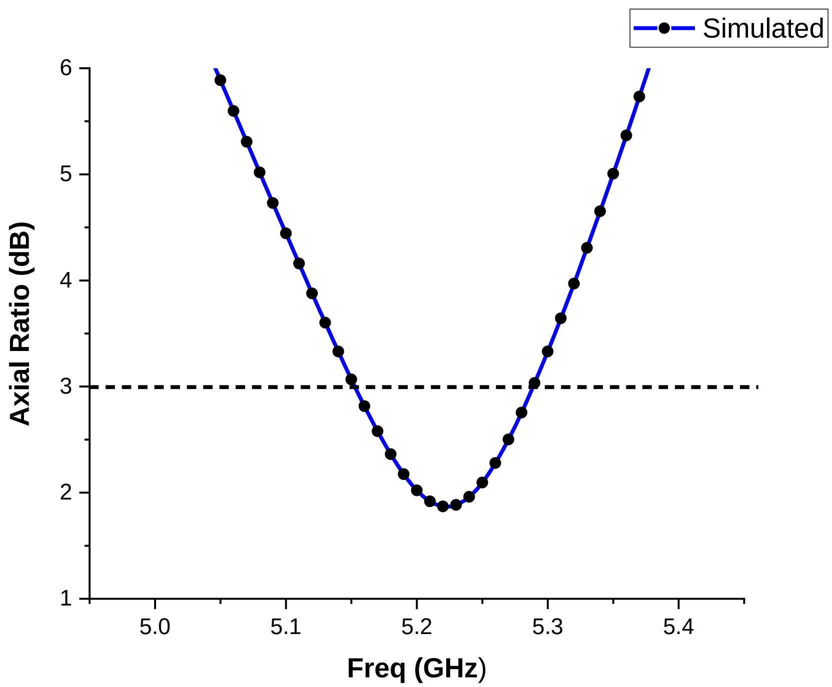


Figure 31: Simulated axial ratio for the second band

4.3 Substrate preference

Rogers RT DUROID 5880 was selected as substrate for antenna fabrication. It possesses incredible mechanical properties rendering it appropriate for a large variety of electrical applications. It has a lesser value of dielectric constant making it suitable for broadband devices. The antenna was fabricated using a substrate thickness of 1.57 mm.

4.4 Relative Permittivity or Dielectric constant

The relative permittivity of chosen substrate for the antenna designing i.e., ROGERS RT DUROID 5880 is 2.20.

4.5 Fabricated Antenna

The simulated results of the antenna from HFSS were exported to Agilent ADS software for the creation of gerber file type. The gerber file of antenna design was sent to NIE (National Institute of Electronics) and fabricated on a sheet of Rogers RT Duroid 5880. Beneath is the figure of the fabricated dual band circularly polarized antenna.

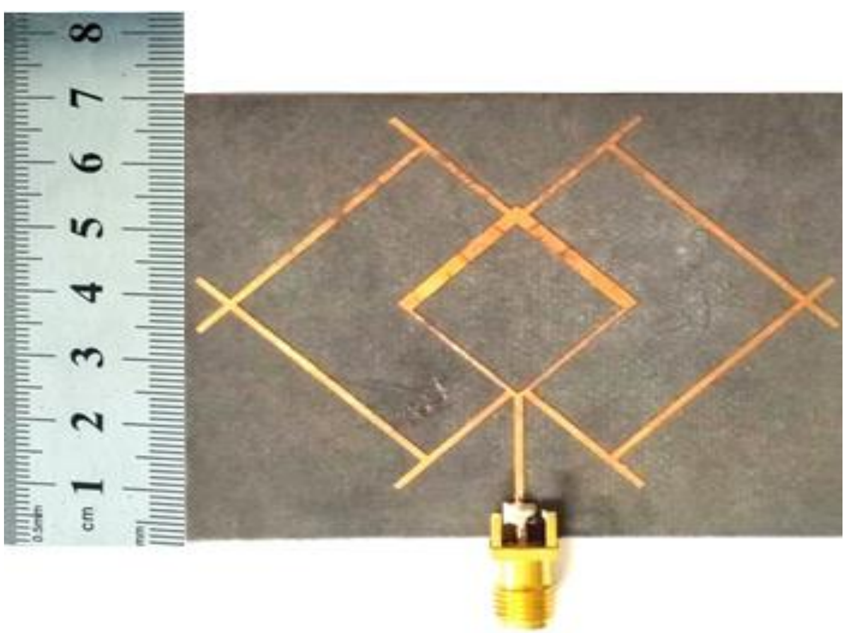


Figure 32 : Front view

Figure 33: Rear view

4.6 Measurement Setup

The fabricated antenna was sent to RIMMS (Research Institute for Microwave and Millimeter-Wave Studies) NUST, Islamabad for the measurement of results. The measurement setup included an anechoic chamber, the dual band CP antenna under the test (as receiver) and a standard gain testing Horn antenna having a range of 0.8 - 18 GHz (as transmitter). Both the antennas are connected to the Rohde & Schwarz Vector Network Analyzer (VNA) and computer for obtaining measured results.

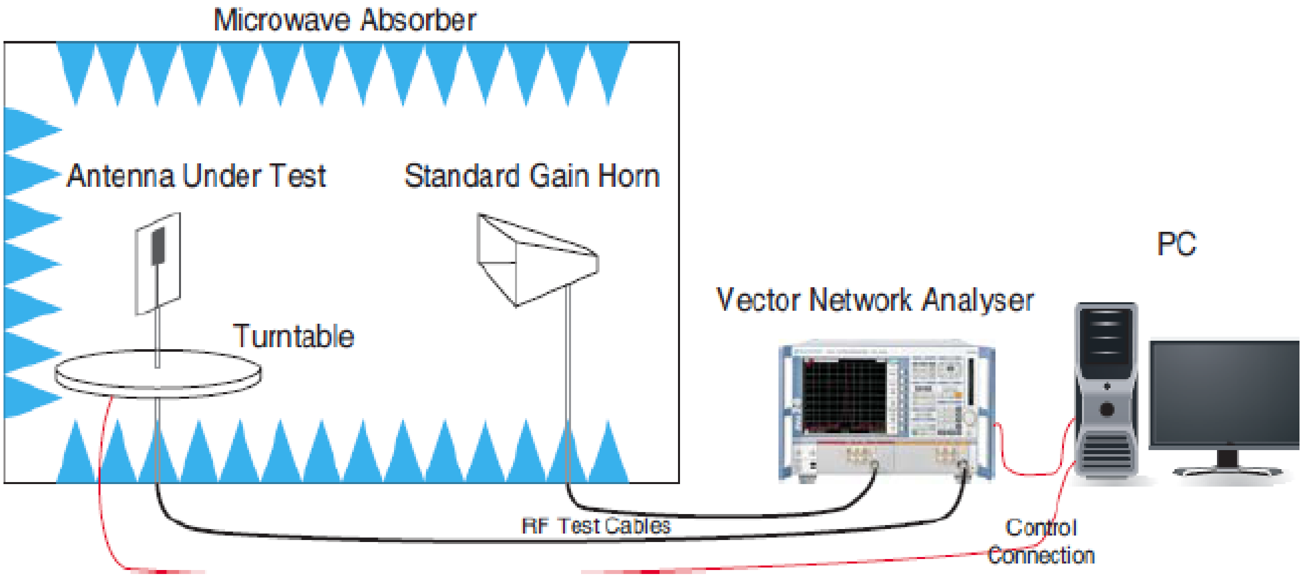


Figure 34: Measurement Setup

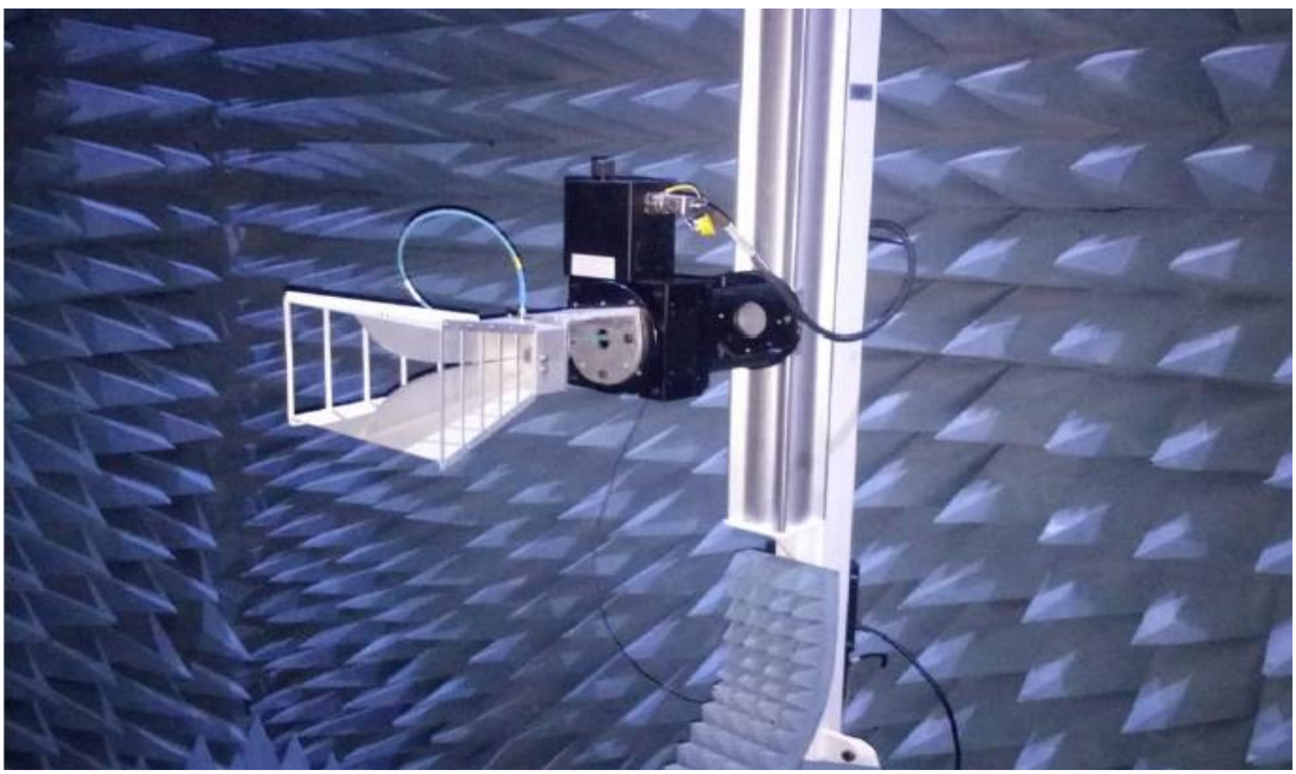


Figure 35: Standard Gain Transmitting Horn Antenna (0.8 - 18 GHz)

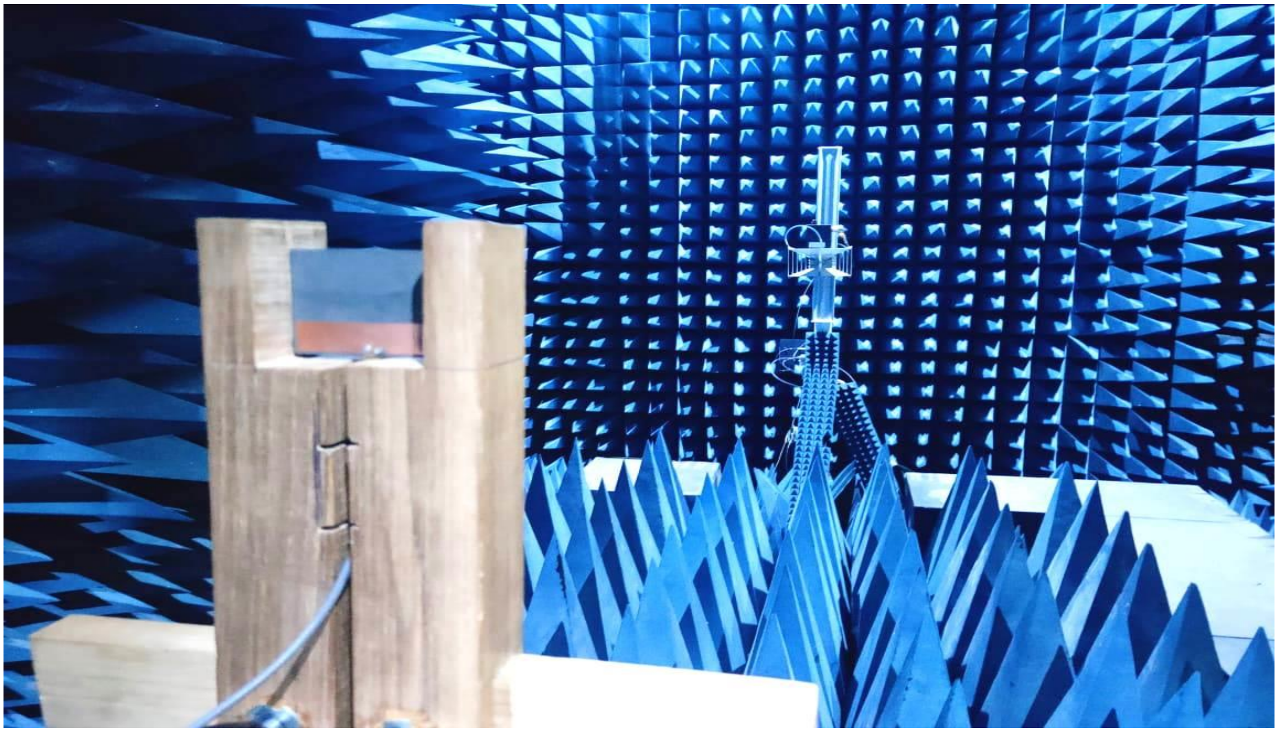


Figure 36: Rear Side of Dual Band CP performance antenna under test

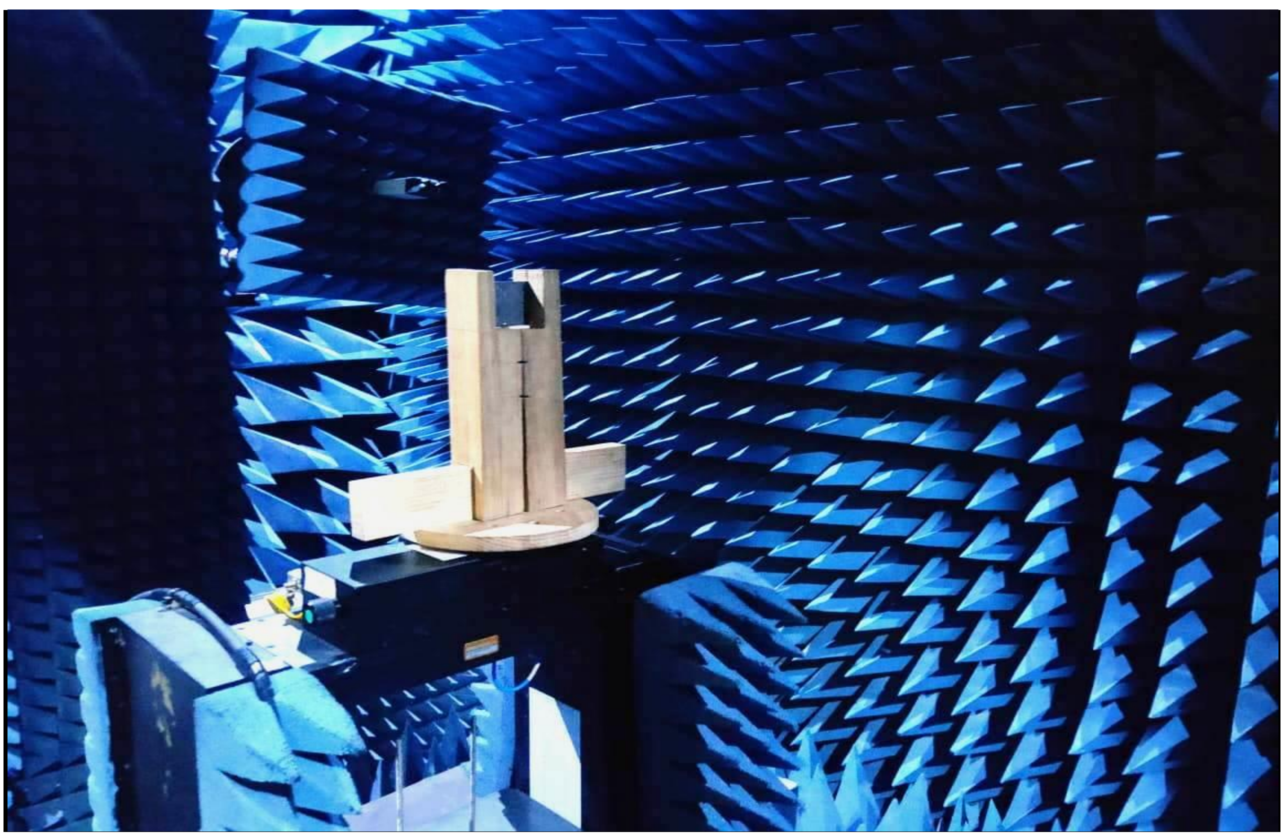


Figure 37: Front Side of Dual Band CP performance antenna under test

4.7 Measured results of the fabricated antenna

4.7.1 Measured Return Loss Plot

The reflection coefficient results were measured using Rohde & Schwarz Vector Network Analyzer. Comparison among the results is summarized in the graph for the simulated and measured S_{11} plots of the dual band CP antenna.

Frequency vs. Return loss

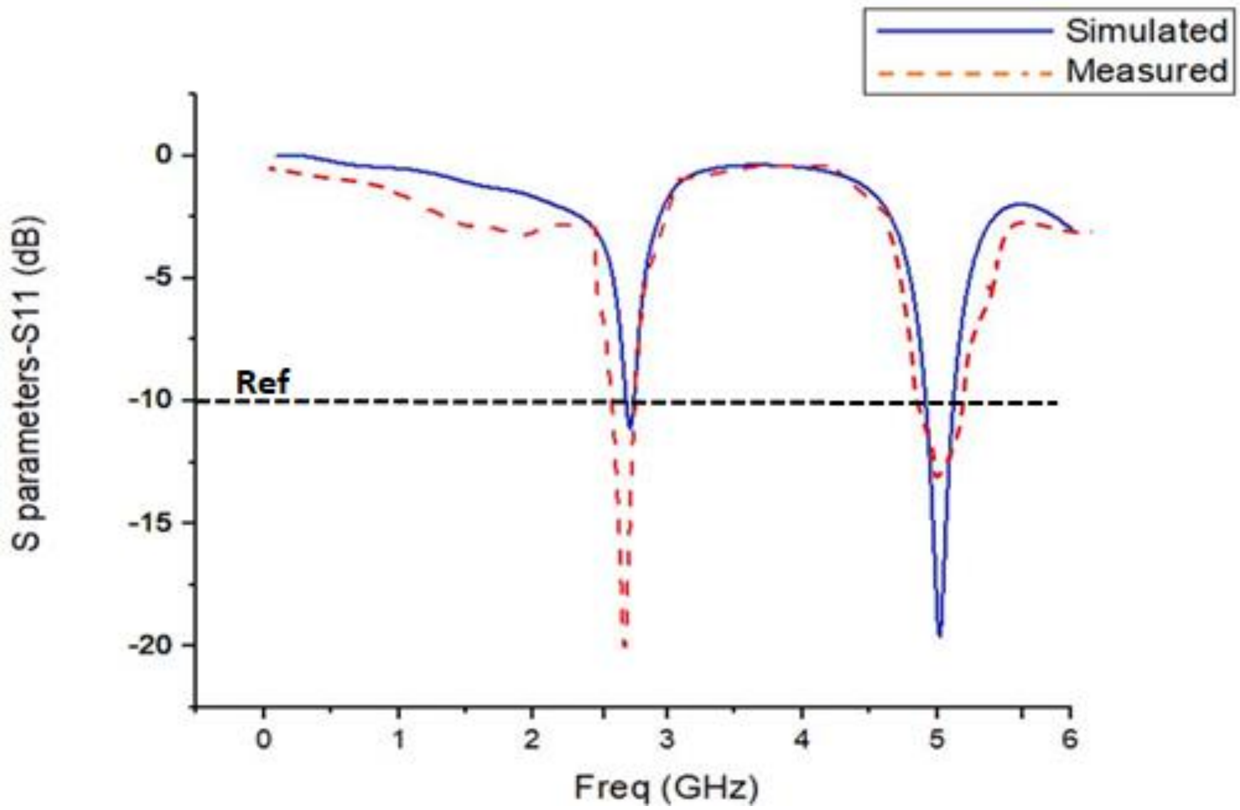


Figure 38: Comparison of Measured and Simulated S_{11} plots

The inference can be made by observing the Fig: 38 that the simulated and measured S parameters (S_{11} plot) are in accordance with each other and exhibit a commendable dual band response. The red line indicates measured S_{11} plot of the fabricated antenna and the blue line indicates simulated S_{11} plot in HFSS. Both the circularly polarized bands are executing return loss lesser than -10 dB which is up to the mark and in agreement with the standards of IEEE. The first circularly polarized band corresponds to 2.2 % bandwidth with operating frequency of 2.7 GHz exhibiting reflection coefficient of -19 dB. For the second circularly polarized operating band antenna is well matched from 4.7 - 5.5 GHz corresponding to 16 % bandwidth with operating frequency of 5 GHz having reflection coefficient of -14.5 dB. The table shows the summary of the results.

Table 4: Comparison of Simulated and Measured results

Parameters		First band (2.69 - 2.75 GHz)	Second band (4.7 - 5.5 GHz)
Bandwidth		**2.2 %**	**16 %**
S_{11}	**Measured**	**-19 dB**	**14.5 dB**
	Simulated	**-12.5 dB**	**-19.95 dB**

4.7.2 Axial Ratio analysis and Results

The LHCP and RHCP components can be calculated by using the following formulas:

$$\mathbf{E_{lhcp}} = \frac{1}{\sqrt{2}}(\mathbf{E_\theta} - \mathbf{j}\mathbf{E_\varphi})$$

$$\mathbf{E_{rhcp}} = \frac{1}{\sqrt{2}}(\mathbf{E_\theta} + \mathbf{j}\ \mathbf{E_\varphi})$$

$$\mathbf{AR_{cp}} = \frac{|\mathbf{E_{lhcp}}| + |\mathbf{E_{rhcp}}|}{|\mathbf{E_{lhcp}}| - |\mathbf{E_{rhcp}}|}$$

The formula stated as under is used for the analysis of axial ratio:

$$\mathbf{AR\ (dB) = 20\ log\ (A_V\ exp\ (Phi_V)\ /\ A_H\ exp\ (Phi_H))}$$

The critical parameter for characterizing performance of a circularly polarized antenna is axial ratio. The measured AR bandwidth (< 3 dB) of the antenna is 60 MHz (2.69 - 2.75 GHz) at the first band and 140 MHz at the second band (5.15 - 5.29 GHz).

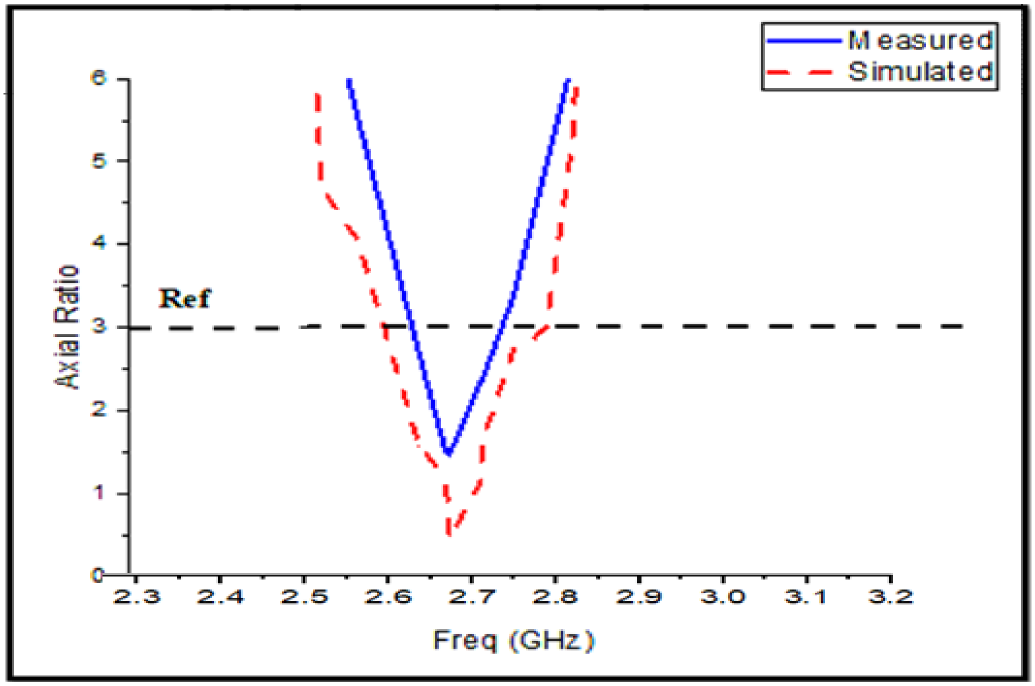


Figure 39: (a) First band

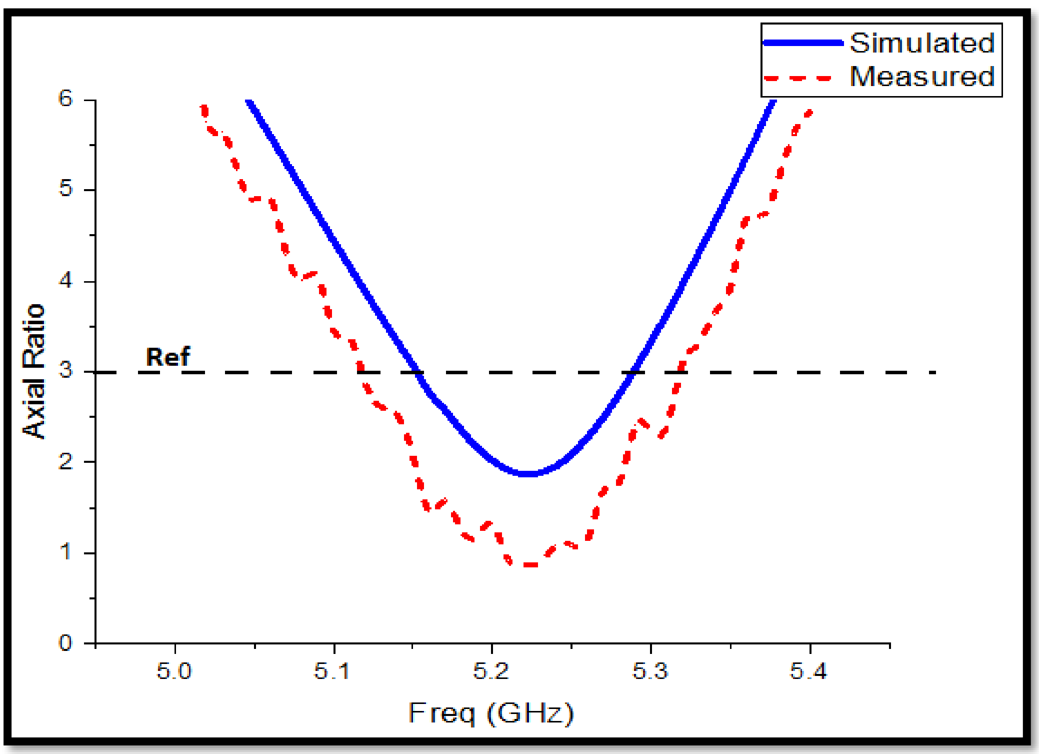


Figure 40: (b) Second band

Relative investigation of simulated axial ratio and measured axial ratio

(a) First band (b) Second band

4.7.3 Measured Radiation Pattern

The 3D simulated and measured radiation pattern portrays the power radiated by the antenna as a function of direction moving away from the CP antenna with dual bands. The cross polarization levels of the simulated and measured radiation patterns is higher that confirms the circular polarization performance of the antenna.

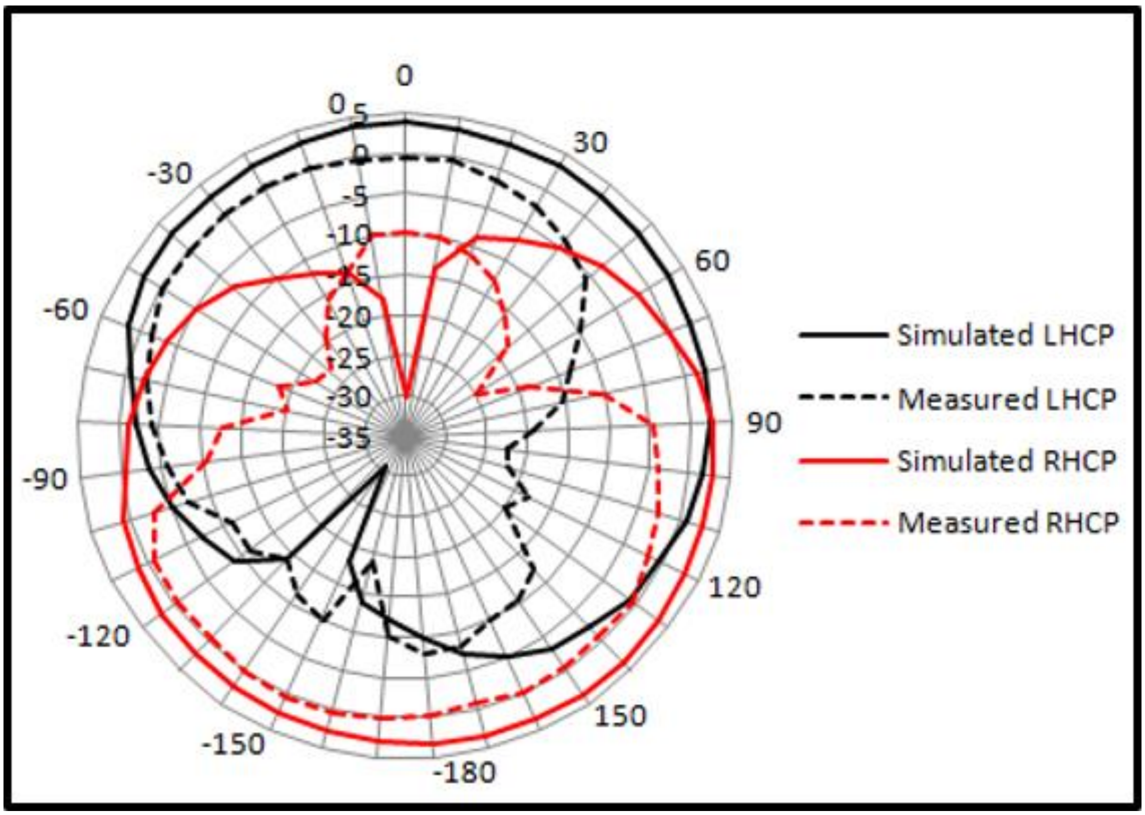


Figure 41: Simulated and Measured LHCP and RHCP radiation pattern at 2.7 GHz in xz-plane

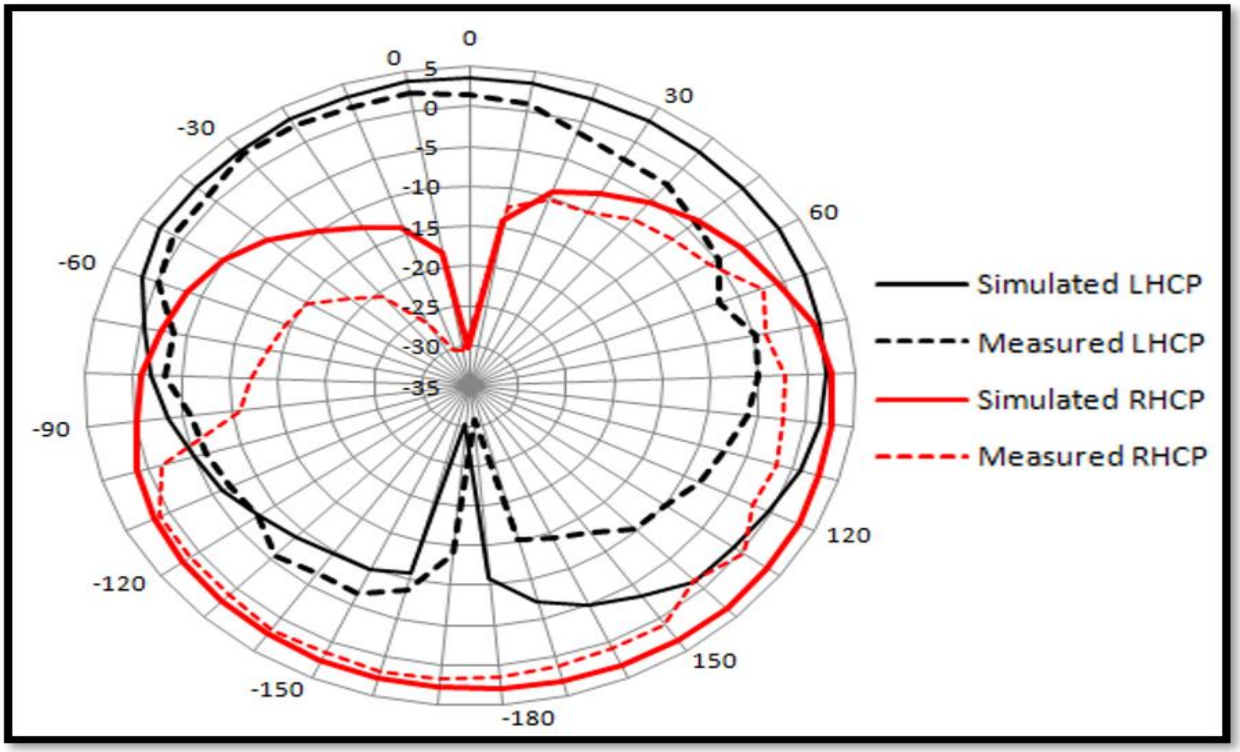


Figure 42: Simulated and Measured LHCP and RHCP radiation pattern at 2.7 GHz in yz-plane

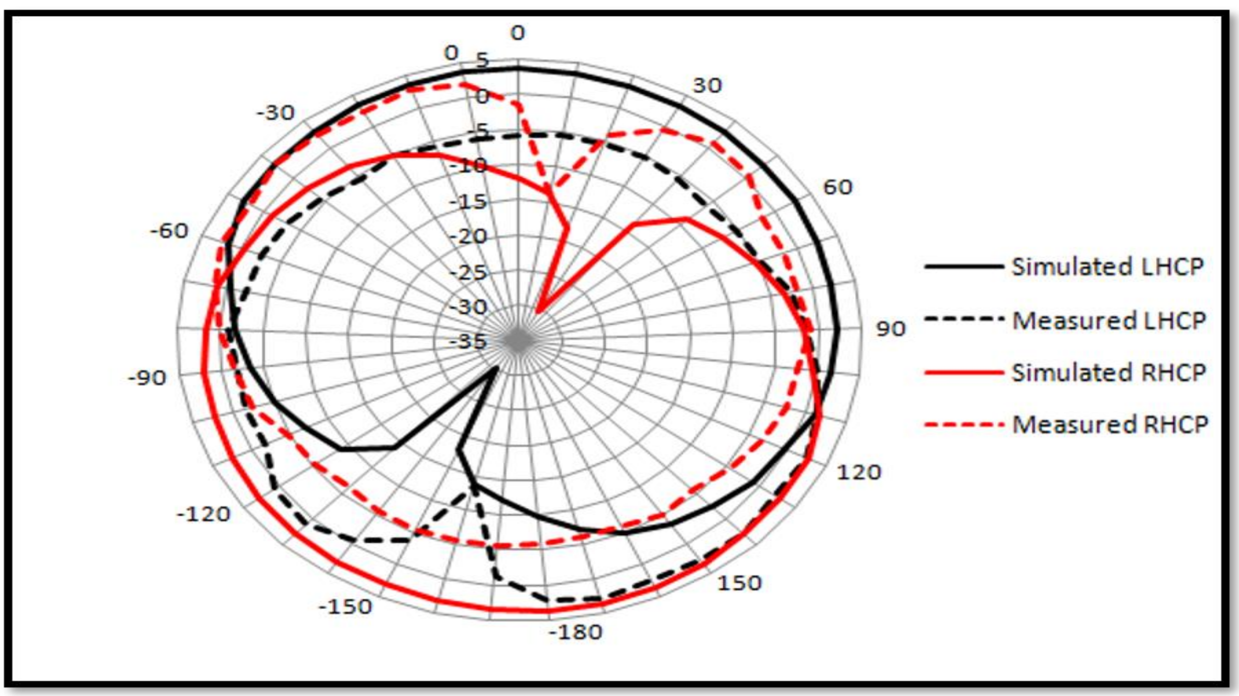


Figure 43: Simulated and Measured LHCP and RHCP radiation pattern at 5 GHz in xz-plane

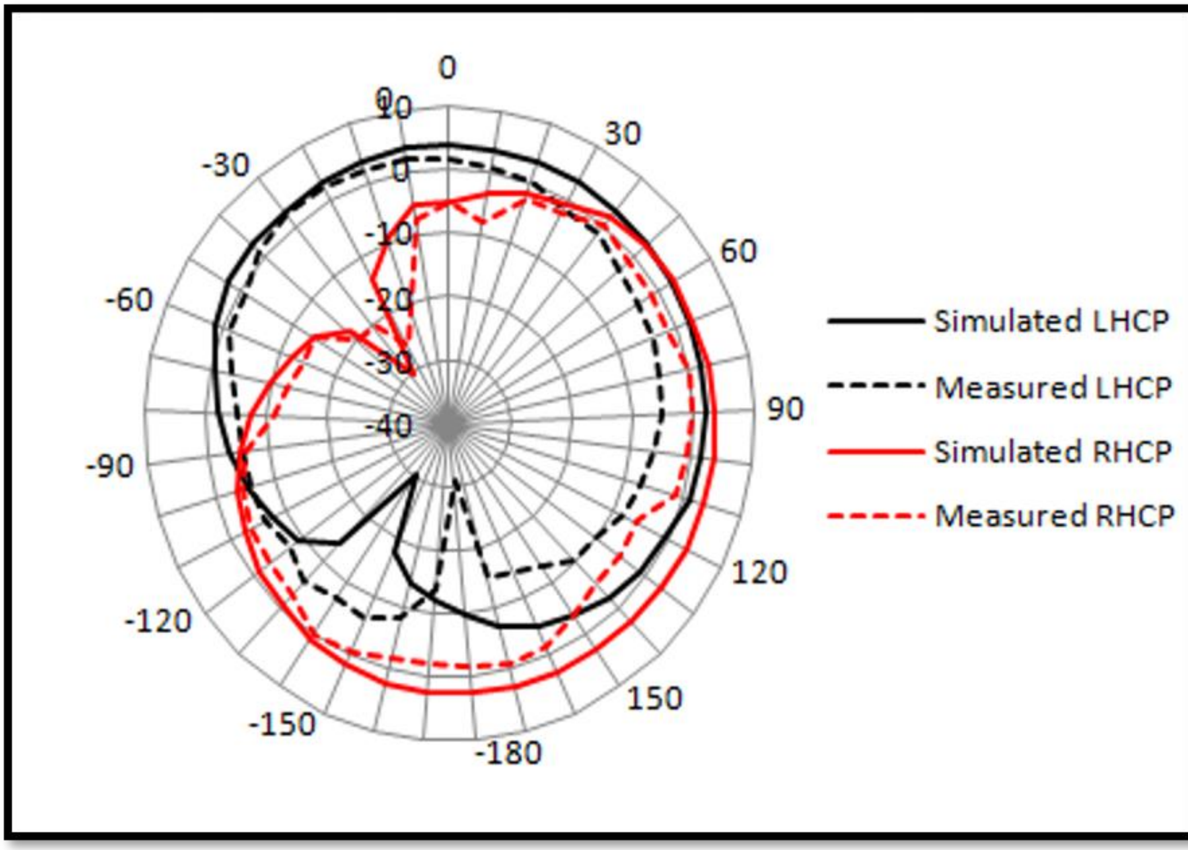


Figure 44: Simulated and Measured LHCP and RHCP radiation pattern at 5 GHZ in yz-plane

Chapter 5

CONCLUSION AND COMMENDATION FOR FUTURE PROSPECTS

5.1 Conclusion

In this research, a novel compact dual band antenna executing circularly polarized performance, having dimensions of 70 mm x 60 mm x 1.57 mm has been reported. A detailed literature appraisal of existing CP techniques and description of the improvements projected in the proposed antenna is summarized. Innovation of the antenna design mechanism lies in the employment of quadruple stubs with varying lengths embedded in a deformed square patch along with a defected ground structure, having slots for generation of commendable value of axial ratio of the CP waves. The measurement setup for measuring the fabricated results is demonstrated and the obtained results are observed to be in accordance with the simulated results. The first CP band (2.69 - 2.75 GHz) corresponds to 2.2 % bandwidth with operating frequency of 2.7 GHz exhibiting reflection coefficient of -19 dB and the second CP operating band is well matched from (4.7 - 5.5 GHz) corresponding to 16 % bandwidth with operating frequency of 5 GHz having reflection coefficient of -14.5 dB. The gains of the designed antenna are 2.3570 dB and 5.4248 dB at the first and second band. The measured AR bandwidth (< 3dB) of the antenna is 60 MHz (2.69 - 2.75 GHz) at the first band and 300 MHz at the second band (5 - 5.3GHz). The three-dimensional (3D) simulated and measured radiation patterns of the proposed dual band circularly polarized patch antenna are investigated; both of them show high cross polarization levels. Therefore, confirming the CP performance of the antenna. The CP performance is further confirmed by observing vector current distribution plots, at 2.7 GHz and 5 GHz the antenna generates right-hand circular polarization (RHCP) in the -z-direction and left hand circular polarization (LHCP) in the +z-direction respectively. The realized antenna executes improved parameters and is capable of effectively working on the Wi-Max, Bluetooth, W-LAN and LTE applications fulfilling the need of circularly polarized double resonance.

5.2 Future Prospects

The antenna projected in this dissertation can be turned into an array configuration, utilized in polarizer for maintaining an Omni directional radiation pattern or can be switched into a reconfigurable antenna by dynamically regulating the antenna parameters such as frequency, radiation pattern and polarization types and sense which in turn helps the antenna to adjust in varying arrangements and environments. Reconfigurable antennas have built in mechanisms for reconfiguration instead of external networks which decrease antenna designing complexity and provide optimized performance for changing operating conditions.

5.2.1 Array Production

This single fed circularly polarized dual band antenna can be used for generating array structure. An extension in this design can be made by examining designs which require circularly polarized array mechanism. By arranging the antenna in multiple arrangements, an array of CP antennas can be obtained.

5.2.2 Omni Directional Radiation Pattern

It is very convenient to obtain Omni directional radiation pattern in linearly polarized antennas but it is cumbersome in CP antennas. The generation of a circularly polarized wave requires two equal in magnitude and orthogonal i.e. (having phase shift of 90^o) electric field components. Polarizer structure can be made employing the designed CP antenna to maintain the Omni directional pattern.

5.2.3 Radiation Pattern Reconfigurability

The adjustment of spherical allocation of radiation pattern to maximize antenna gain is used to attain radiation pattern reconfiguration. Antenna arrays utilizing CP antenna can be employed to maneuver the CP beam. Literature review depicts that pin diodes can be used to control the radiation direction or a change in feeding direction of the antenna can also accomplish reconfiguration of radiation pattern.

5.2.4 Polarization Reconfiguration

Polarization reconfigurable antennas are capable of adjusting themselves among different polarization modes. The designed antenna can be altered to switch between left hand circular polarization and right hand circular polarization in order to diminish polarization mismatch. The antenna can also be used for switching between circular and linear polarization by introducing switches.

5.2.5 Frequency Reconfiguration

The developed dual band CP performing antenna can be made reconfigurable by varying the operating frequency as per the requirement of various applications. A single CP antenna can be used for coverage of multiple bands by frequency reconfiguration. Switching among frequency bands can be attained by making use of various RF switches.

5.2.6 Numerical Analysis

Different numerical analysis techniques like method of moments can be employed to compare the analytical, simulated and measured results of the proposed dual band circularly polarized antenna.

5.3 Applications

The designed and fabricated antenna executing dual band CP performance aims to pave way for compact and flexible antennas capable of being incorporated in small sized modern day devices. It can be used for following applications:

- Wi-Max Devices
- Bluetooth Devices
- W-LAN Devices
- LTE

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1 APPENDIX A

APPROVED TH-1 FORM
National University of Sciences & Technology

MASTER'S THESIS WORK

1. Name: NS Hira Afzal **2. Reg. No:** 00000205336 **3**. **Department/ Discipline:** Electrical Engineering **4**.**Institute:** Military College of Signals, NUST
5. Thesis Topic: Design, Fabrication and Characterization of Circularly Polarized Patch Antenna
6.Brief Description/Abstract: The objective is to design, fabricate and characterize a circularly polarized microstrip patch antenna. The resultant antenna will be compact in size, facile to use, cost effective and easy to integrate with modern technology devices. The use of circularly polarized patch antennas improves the overall performance of mobile communication system and presents an efficient solution to achieve polarization mismatching, reduction in the effects of multipath reflections, enhancement in weather penetration and allowance for flexible orientation of both the transmitter and receiver antennas.
7. Level of Research Already Carried out on the Proposed Topic: The need for wireless broadband communications has increased rapidly in recent years demanding quality of service, security, handover and increased throughput for the Wireless Local Area Networks (WLANs). The main aim of future wireless communication is high speed networking services for multimedia communication [1]. In the last few years printed antennas or software based antennas have been largely researched and studied due to their advantages over other radiating systems, namely, decreased weight and complexity, less expensiveness, reduced size , conformability and possibility of integration with both active and passive devices [2]. Over the past several decades, there have been significant advances in circular polarization (CP) micro strip antenna technology [3]. The CP antennas are classified as a single feed type or dual feeds depending on the number of feed point necessary to generate the CP waves [4]. Circular Polarized antennas are increasingly gaining importance in wireless communications since they allow signal reception irrespective of the orientation of the receiver antenna with respect to the

transmitter antenna [5]. The use of circularly polarized antenna is an attractive solution to achieve polarization matching between the transmitting and receiving antenna [6]. Circularly polarized micro strip antennas have the additional advantage of small size and weight, suitability in confirm mounting and compatibility with microwave and millimeter wave integrated circuits, and monolithic microwave integrated circuits (MMICS) [7]. Circular polarization (CP) operation may be obtained by certain modifications to the basic antenna either in geometry and/or feed [8]. Circulation polarization (CP) can be achieved by making axial ratio equal to one [9]. The CP characteristics can also be acquired by an unequal cross-slot embedded in the circular patch and two orthogonal linear stubs spurred from the annular-ring with small frequency ratio [10].

8. Reason/Justification for the selection of the topic:

Antenna is a major element required in all the modern wireless communication systems especially in High speed mobile communication. The work done will be able to cater the demand of ever growing wireless communications industry. The designed circularly polarized microstrip patch antenna can be used in devices operating on multiple bands for communication. Also the compactness of antenna will allow it to fit in majority of the existing devices. Circular polarization is preferred over linear polarization because it gives less polarization loss, decreased interference and lessened faraday rotation.

9. Objectives:

Following are the objectives of this research.

- To design, fabricate and characterize a circularly polarized microstrip patch antenna.
- Analysis of the design of circularly polarized patch antenna.
- Comparison of proposed antenna with existing antennas.

10.Relevance to National needs:

Circular polarization is beneficial because current and future commercial and military applications require the additional design freedom of not requiring alignment of the electric field vector at the receiving and transmitting locations. Circularly polarized antenna proposed in this research is intended to lay the foundation for more advanced radio systems, especially those embedded into small devices. The CP antenna is based on the microstrip patch antenna concept. This has a great manufacturing advantage, as the technology is very efficient, low cost and suitable for mass production.

11.Advantages:

The research will be paved useful in many perspectives, such as the proposed circular patch antenna can be made reconfigurable by dynamically adjusting the antenna parameters namely frequency, radiation pattern and polarization. Such antennas have reconfiguration mechanism built inside rather than in an external network, which optimizes the antenna performance to satisfy varying operating requirements. The resultant antenna is also low profile, which simplifies its integration with radio devices. The developed antenna features allows multiple new applications.

12. Area of Application:

- Wireless Communication.
- Suitable for handling mobile video and data streaming.
- Military applications.

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