Addis Ababa University

Addis Ababa Institute of Technology

School of Electrical and Computer Engineering

Performance Comparison of Linearly and Circularly Polarized Micro strip Antenna for L-Band

A thesis submitted to Addis Ababa Institute of Technology, School of Graduate Studies, Addis Ababa university

In partial fulfillment of the requirement for the **Degree of Master of Science in Electrical Engineering (communication Engineering).**

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Addis Ababa, Ethiopia

June, 2018

Addis Ababa University

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Acknowledgment

First of all, I was most grateful to Almighty GOD for blessing me with good health and ideas for completing this thesis successfully. I would like to show my highest gratitude to my adviser, Professor Mohammed Abdo for his invaluable support, patience, assistance and especially his encouragement to do this thesis. I truly have learned a lot and all this would not be without his guidance. I also would like to thank all my fellow friends for their contribution in giving to me a moral support throughout my thesis development period. My sincere appreciation extends to my mother, father, sister and brother for their moral support.

Declaration

I declare that this thesis is my work and that all source materials used for this thesis have been properly acknowledged. This thesis has been submitted in partial fulfillment of the requirements for M.Sc. degree in communication Engineering at Addis Ababa University. I earnestly declare that this thesis is not submitted to any other institution any where for the award of any academic degree, diploma, or certificate.

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Abstract

In recent years, the devices in communication systems require the development of low cost, minimal weight, compact and low profile antennas that are capable of maintaining high performance over a wide spectrum of frequencies. This technological development has focused much effort in the design of micro strip patch antennas because of its inherent characteristics that fits the requirements of modern communication devices. This thesis presents the performance of linearly and circularly polarized micro strip antenna for L-band at 1.575GHz frequency operation and using the inset feed technique. The simulation of the design was done with the aid of computer simulation technology (CST) studio version 16 software and matlabR2015a which will be used to calculate the parameters. To design it, standard formulas are used to calculate different parameters of the antenna. After design the antenna, some parameters are varied during simulation to get good performances. The analysis for return loss, gain, directivity and radiation pattern were carried out. The proposed antenna shows return loss -14.692dB for right hand circular polarization (RHCP), -10.02dB for left hand circular polarization (LHCP) and -3.64dB for horizontal polarization (LP) and -21.41dB for vertical polarization which implies good result. The impedance matching is good at desired frequency with VSWR < 2 respectively. Another parameters which used to evaluate the performance of an antenna for different polarization are gain, directivity and bandwidth efficiency. In terms of these parameters one can compare the performance. Simulation results show that, right hand circularly polarized micro strip antenna offers high directivity (6.49dB) and high gain (as high as 5.22dB), minimum return loss and moderate bandwidth efficiency and has more suitable voltage standing wave ratio. This is a fairly high through directivity increase and minimize loss could have been studied through use of different substrate material and thickness. Therefore, RHCP are more preferable for selected application /system. The antenna can be designed on the substrate type RT/Doruid 6006 with dielectric constant of 6.15 and thickness of 1.6mm.

Keywords:- Micro strip antenna, Polarization, L-band, Return loss and Micro strip feed line.

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List of Symbols

ϵ_r	dielectric constant of substrate
f	operating frequency
ϵ_{eff}	effective dielectric constant
c	free space velocity of light, which is 3x108 m/s
h	height of dielectric substrate
W	width of the patch
L	length of the patch
Δ	patch length extension
λ	lambda
δ_{eff}	effective loss tangent
Q_T	total antenna quality factor
Q_d	dielectric quality factor
ω_r	angular resonant frequency
Q_c	conductor quality factor
Q_r	radiation quality factor
P_r	power radiated from the patch
λ_0	free-space wavelength
G	gain
L_{eff}	effective length of the patch
η	radiation efficiency
D	directivity of the patch antenna
k	wave vector
β	phase difference
h	dielectric thickness (mm)
e	efficiency
σ	conductivity of the conductor

List of Abbreviations

AGC	Automatic Gain Controller
CP	Circular Polarization
CST	Computer Simulation Technology
DGS	Defected Ground Structure
EBG	Electromagnetic Band Gap
GPS	Global positioning systems
HP	Horizontal polarization
HPBW	Half Power Beam Width
IEEE 802.11	International Electrical and Electronics 802.11
LHCP	Left hand circular polarization
RF	Radio Frequency
RFID	Radio frequency identification
RHCP	Right hand circular polarization
RL	Return Loss
RMA	Rectangular Micro stripe Antenna
SMA	Surface mount adapter
VSWR	Voltage Standing Wave Ratio
VP	Vertical polarization
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless local Area Networks

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Chapter 1

INTRODUCTION

1.1 Background of the Study

In high-performance aircraft, spacecraft, satellite, and missile applications, where size, weight, cost, performance, ease of installation, aerodynamic profile are constraints, and low-profile antennas may be required. Presently there are many other government and commercial applications, such as mobile radio and wireless communications, which have similar specifications. To meet these requirements, micro strip antennas [1-3] can be used.

With rapid development of wireless and satellite communication system, an antenna became inseparable from a transmission line and to radiate more efficiently, its matching with the transmission line needs more attention. In microwave frequencies, proper polarization enable to reduce multi-path effects. It also allows a more flexible reciprocal orientation between the transmitting and the receiving antennas. This thesis work focuses on the performance comparison of linearly and circularly polarized micro strip antenna for L-Band. Satellite communication and Wireless communication have been developing rapidly in the past decade and it has already had a visible effect on human life. In the last few years, the development of wireless local area networks (WLAN) represented one of the principal interests in the information and communication field. Thus, the current trend in commercial and government communication systems has been to develop low cost, minimal weight, low profile antennas that are capable of maintaining high performance over a large spectrum of frequencies. This technological trend has focused much effort into the design of micro strip antennas.

Conventional micro strip antennas in general have a conducting patch printed on a grounded microwave substrate, and have the attractive features of low profile, light weight, easy fabrication, and conformability to mounting host. However, micro strip antennas inherently have a narrow bandwidth, and bandwidth enhancement is usually demanded for practical applications. In addition, applications in present-day mobile communication systems usually require smaller antenna size in order to meet the miniaturization requirements of mobile units.

Thus, size reduction and bandwidth enhancement are becoming major design considerations for practical applications of micro strip antennas. For this reason, studies to achieve compact and broadband operations of micro strip antennas have greatly increased. Much significant progress in the design of compact micro strip antennas with broadband, dual-frequency, dual polarized circularly polarized, and gain-enhanced operations have been reported over the past several years[22].

With a simple geometry, patch antennas offer many advantages not commonly exhibited in other antenna configurations. For example, they are extremely low profile, lightweight, simple and inexpensive to fabricate using modern day printed circuit board technology, compatible with microwave and millimeter-wave integrated circuits (MMIC), and have the ability to conform to planar and non-planar surfaces. In addition, once the shape and operating mode of the patch are selected, designs become very versatile in terms of operating frequency, polarization, pattern, and impedance.

1.2 Statements of the Problem

Although much progress has been made in the polarization of micro strip antenna for different applications, it is still great challenges to select the appropriate polarization for the system. To do so, it is necessary to identify the particular and applicable polarization for desired signal /system to have a suitable set of the antenna. In order to be successful in that task, it is essential to have a complete understanding of modern technology. Failure to adequately understand the technology leads to the selection of an unsuitable polarization for a system. Due to this effective performance comparison is needed to understand the effect of polarization in modern satellite communication particularly for L-band applications.

1.3 Objective of the Study

1.3.1 General objective of the study

The main aim of this thesis is to do the performance comparison of linearly and circularly polarized micro strip antenna for L-band.

1.3.2 Specific objectives of the study

* To select the suitable polarization for L-band applications.
* To study performance of linear and circular polarization with software simulation.
* To compare the performance of linear and circular polarization and to select more applicable polarization for the system.

1.4 Methodology

The first phase is research phase at the beginning and gathering basic knowledge on the topic, and arrangement of collecting data. The methodology used in this thesis is shown below by means of flow chart. Based on an idea, the proposed antenna would be designed, numerical analysis for different radiation parameters such as return loss, gain, pattern and VSWR.

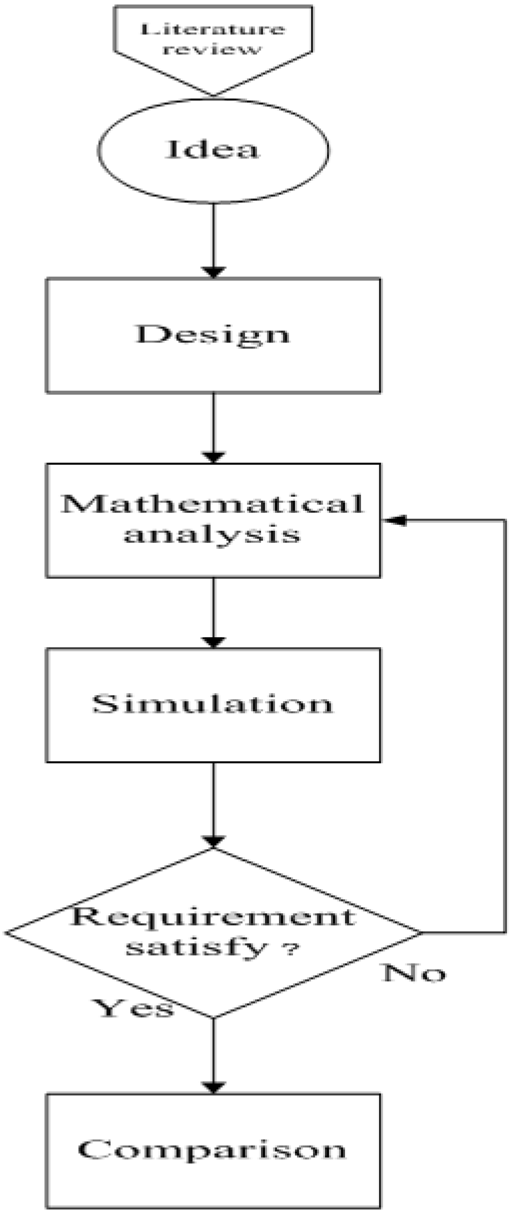


Figure 1.1: Methodology flow chart

Finally, software based simulation and comparison between requirements like axial ratio, performance enhancement, and economical benefit are conducted. If the simulation results does not satisfy the requirements, the design goes back to analysis and simulation stage. During this phase it is attempt to identify possible difference between the simulated and analyzed value.

1.5 Literature Review

Dual-Band Dual-Polarized Perforated Micro strip Antennas for synthetic aperture radar (SAR) Applications design and analysis was done in the year 2000, by Lotfollah L. et al [4]. For dual-band dual-polarized SAR applications a compact low-profile design is investigated by the authors. The operating frequencies are at the L and C-bands. Since the C-band frequency is larger by a factor of four, its array elements and inter element separations are smaller by the same ratio. The L-band elements selected as perforated patches to enable the placement of C-band elements within them. Stacked-patch configurations were used to meet the bandwidth requirements, especially in the L-band.

Broad-Band Single-Patch Circularly Polarized Micro strip Antenna with dual capacitive coupled feeds design was done in the same year by Kin-Lu Wong and Tzung-Wern Chiou [5]. The dual feeds are with a small top-loaded disk and are connected to Wilkinson power divider with a 90 phase shift between its two output feed lines. The radiating circular patch, printed on a thin substrate, is supported by non-conducting posts on a conducting ground plane and is excited capacitive through the dual feeds.

Small circular micro strip patch antenna was designed by LUAN Xiu-hen et al in the year 2002[6]. They should that,the probe-fed circular micro strip patch antennas incorporating a single shorting post can significantly reduce the overall size of the antenna. These kinds of antennas were seen as promising candidates for miniaturized telecommunication handsets.

In [7] Steven (Shichang) Gao, and Alistair Sambell, discussed about the dual-polarized broad-band micro strip antennas fed by proximity coupling in the year 2005. They presented a novel broad-band dual-polarized micro strip patch antenna, which is fed by proximity coupling. The micro strip line with slotted ground plane is used at two ports to feed the patch antenna. By using only one patch, the prototype antenna yielded a bandwidth of 22% and 21.3% at the input port 1 and 2, respectively. The isolation between two input ports is below 34 dB across the bandwidth. They also observed the good broadside radiation patterns and the cross-polar levels are below 21 dB at both E and H planes. Due to its simple structure, it is easy to form arrays by using this antenna as an element.

In the same year the FDTD analysis of a dual-frequency micro strip patch antenna was studied by S. Gao,et al [8]. They analyzed the characteristics of a single-layer, dual-frequency micro strip patch antenna, which uses a T-strip loaded rectangular micro strip patch. This antenna easily achieved good impedance matching at both frequencies by tuning the feed position and other design parameters. Another advantageous aspect is that it has high polarization purity.

They also performed a detailed parameter study and the theoretical analysis is based on the finite-difference time-domain (FDTD) method.
In [9] X. L. Bao, M. J. Amman, Studied dual-frequency circularly-polarized patch antenna with compact Size and small frequency ratio in the year 2007. A novel probe-fed single-layer annular-ring patch antenna for dual-frequency circular polarization is evaluated numerically and experimentally verified. The proposed antenna consists of a small circular patch surrounded by two concentric annular-rings, which is loaded by an unequal lateral cross-slot ground plane. The circularly-polarized frequency ratio of the two resonant modes is tunable to a small value, suitable for wireless communications systems.
In the year 2008, Mariano Barba studied the high-isolation, wide band and dual-linear polarization patch antenna [10]. The design of a dual-polarization stacked patch antenna to be used in GSM-UMTS base station arrays was presented. The patch showed a high matching level in a broadband and isolation between elements that make it a suitable radiating element for base station arrays. Moreover, the most relevant achievement of this element is the isolation between the two polarization ports of the same element in the antenna operating bandwidth.

Broadband circularly polarized annular-ring micro strip antenna was presented in the year 2009[11]. A wide-band circularly polarized (CP) annular-ring patch antenna with two proximity-coupled L-probe feeds orientated to have phases of 0 and 90, using a broadband 90 hybrid feed, was proposed. In this study,it was found that the current distribution for CP operation can be improved by cutting a smaller concentric circular slot on the original larger circular patch to form an annular-ring patch. With such an arrangement, the proposed antenna delivered a wider axial ratio (AR) bandwidth than that of the conventional circular patch with the identical feeding technique.
A dual-feed dual-polarized patch antenna with low cross polarization and high isolation was also designed in the year 2009[12]. Two different feed mechanisms are designed to excite a dual orthogonal linearly- polarized mode from a single radiating patch.One of the two modes is excited by an aperture-coupled feed, which is comprised of a compact resonant annular-ring slot and a T- shaped micro strip feed line; while the other is excited by a pair of meandering strips with a 180 phase differences. Both the linearly-polarized modes were designed to operate at 2400 MHz frequency.
Inset feed square micro strip patch antenna for S-band application was designed and studied by Priya Upadhyay and Richa Sharma in the year 2013[13]. In this paper, parallel Micro strip Inset feed Square patch antenna was designed for S-Band various wireless applications.

The Antenna is fed by Inset feed feeding technique. The advantage of Inset feed is that it can be easily fabricated. These antennas are designed using dielectric substrate with the permittivity of $\epsilon = 4.2$. In this analysis, they have compared the antenna parameters such as gain, impedance, Radiation Pattern, Polar Plot, VSWR and further the performance of these inset feed techniques are discussed. The antenna has been designed for the range 2.4 GHz; hence this antenna is highly suitable for S-band applications such as satellite communication, Radar, Medical applications, and other Wireless systems.

The high gain multi-band micro strip patch antenna using Hybrid substrates was designed and analyzed in the same year by Sudarshan Kumar Jain and Sandeep Toshniwal [15]. A design that is used to generate various frequency bands for the different applications was proposed. Every multi-band antenna has different bandwidth. Here multi-band is achieved by using hybrid substrates. It was also observed that the gain of the designed antenna is greater than the conventional patch antenna. The designed antenna was energized by using the micro strip feeding.

In the same year, A Circularly Polarized Multi Band Stub Loaded Slot Antenna for GPS by Satya Prakash Sinha and Kapil Bhushan [16].A single feed low profile and easy to fabricate circularly polarized slot antenna for four frequency band i.e. Global Positioning System, (GPS), World Wide interoperability microwave access (WiMAX) and Wireless Local Area Network (WLAN) has been developed. A CP multi band stub loaded antenna is designed and studied using Ansoft HFSS V 14.0 designer on the substrate of 3.5 relative permittivity, height of 0.8 mm and delta factor of 0.004. The design uses single feed with edge or micro strip line feed technique to generate the circular polarize signal since the different radiating elements of the multi band stub loaded circularly polarized antenna oscillates for the different frequency, so the change in their dimensions affect the particular resonant frequency of the antenna.

This thesis is concerned with design of linearly and circularly polarized micro strip antenna that would operate in the 1.575 GHz range and comparison performed. The chooses is commonly used as standard resonate frequency by military service for global positioning system and it also categorized as L-band of frequency range for satellite communication. The substrate used for the proposed antenna are FR-4 and RT/Duroid 6006 with a dielectric constant of 4.4 and 6.15 respectively. A thickness of 1.6mm and the loss tangent of the substrate is 0.019 both substrate are selected for comparison purpose. In this work thickness of substrate material are varying for the same dielectric constant to compute the performance parameters. Due to their numerous advantages single feed techniques and rectangular micro strip patch antenna are selected.

1.6 Outline of the Thesis

This thesis is organized into six chapters. **Chapter 1** presents the introductory part of the thesis by describing an overview of antenna, the motivation of the work, the methodology of the thesis and the literature review are included in this introductory chapter.

Chapter 2 consists of basics of micro strip antenna. It includes performance of micro strip antenna, radiation mechanism, advantage and disadvantage, major applications, various feeding techniques are used with advantage and disadvantage of each technique. Most popular rectangular micro strip antenna are discussed with various modeling techniques and summary of antenna parameters are included.

Chapter 3 deals with polarization of an antenna and radiating wave. It consist of various polarization techniques like linear polarization, circular polarization and elliptical polarization. This chapter describes conditions for various polarizations with polarization curve.

In **Chapter 4** design of rectangular micro strip antenna,design specification and design procedure are discussed.

Finally, **chapter 5** summarizes the work done and discusses results obtained. Conclusion and Recommendations for future work are presented in **chapter 6**.

Chapter 2

Micro strip Patch Antenna

2.1 Introduction

In this chapter, a detailed theory of micro strip patch antenna and different types of polarization would be discussed. In the part of proposed antenna theory covered numerous feeding techniques and the basic geometry of the micro strip antenna illustrated, followed by an analysis of the micro strip electromagnetic field pattern. Other topics discussed in this chapter includes the applications, advantages and disadvantages of micro strip antenna.

2.2 Micro strip Antenna Theory

The micro strip antenna concept was first proposed by Deschamps in 1953.However this concept was undeveloped until 1970 when the revolution in electronic circuit miniaturization and large-scale integration helped to build practical antennas .The antennas developed by Munson were used as low-profile flush-mounted antennas on rockets and missiles, this work showed that micro strip antenna was a practical thought for use in many systems problems. [1] The micro strip antennas have many unique and attractive advantages, such as its low profile, light weight, small volume, and ease of fabrication using printed-circuit technology that led to the design of several configurations for various applications. Nowadays with increasing requirements for personal and mobile communications, the demand for smaller and low-profile antennas has brought the micro strip antennas to the forefront, because they are being use not only in military applications but also in commercial areas such as mobile satellite communications, terrestrial cellular communications, direct broadcast satellite (DBS) system, GPS, remote sensing, and hypothermia. [1, 20, 21]

2.3 Basic Structure of Micro strip Antenna

In its most fundamental form, a Microstrip Patch antenna consists of a radiating patch on one side of a dielectric substrate which has a ground plane on the other side as shown in Figure 2.1. The patch is generally made of conducting material such as copper or gold and can take any possible shape. The radiating patch and the feed lines are usually photo etched on the dielectric substrate.

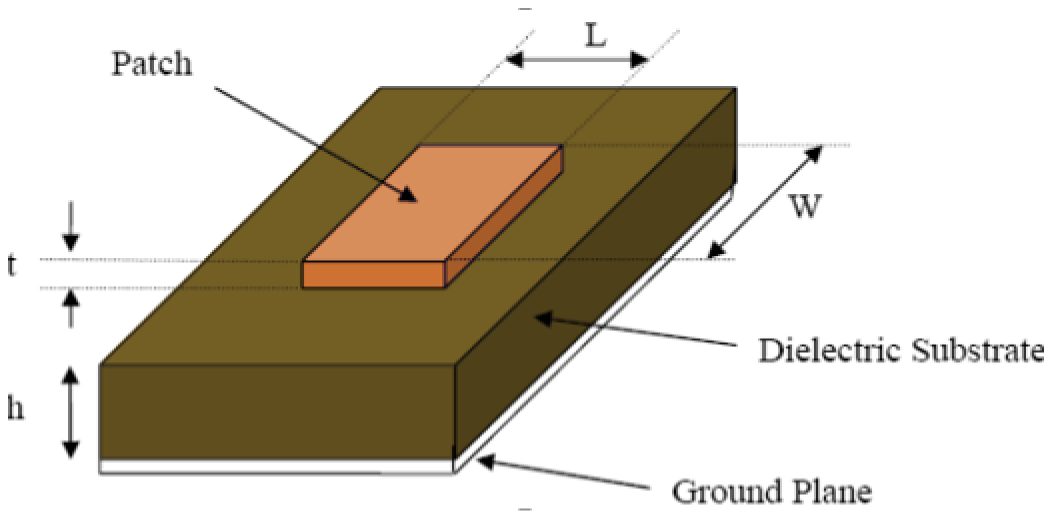


Figure 2.1: Rectangular Patch Antenna [1][21][22]

In order to simplify the analysis and performance prediction, the patch is generally square, rectangular, circular, triangular, and elliptical or some other common shape as shown in Figure 2.2 below. For a rectangular patch, the length L of the patch is usually $0.3333\lambda_0 < L < 0.5\Lambda_0$, where λ_0 is the wavelength of free space. The patch is selected to be very thin such that t≤ λ_0, where t is the thickness of patch. The height of dielectric substrate is usually $0.003\lambda_0 \le 0.05\lambda_0$. The dielectric constant of the substrate (ϵ_r) is typically in the range $2.2 \le \epsilon_r \le 12$.

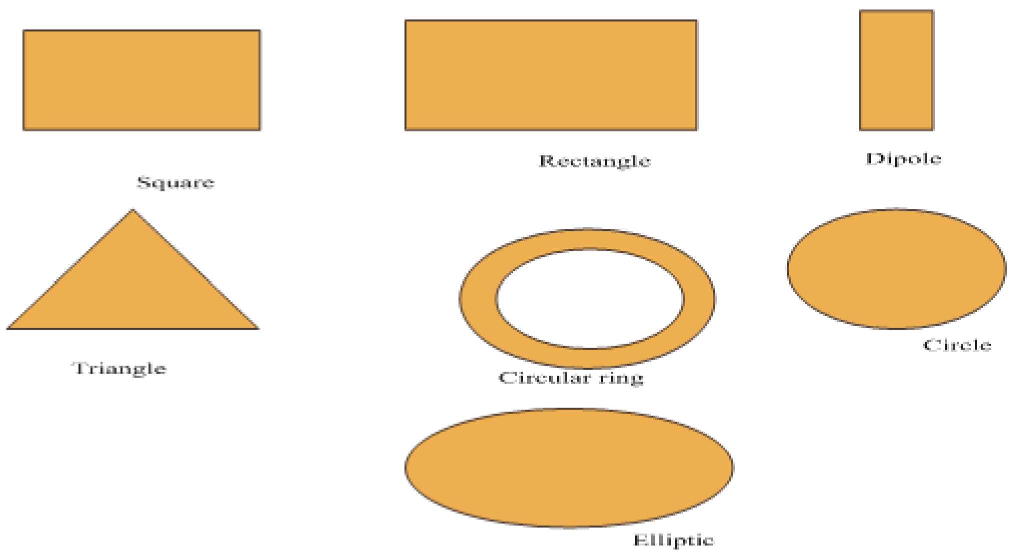


Figure 2.2: Common Available Shape of Micro strip Antenna [1][21]

Micro strip patch antennas radiate primarily because of the fringing fields between the patch edge and the ground plane. For good antenna performance, a thick dielectric substrate having a low dielectric constant is desirable since this provides better efficiency, larger bandwidth and better radiation. However, such a configuration leads to a larger antenna size.

In order to design a compact Micro strip patch antenna, substrates with higher dielectric constants must be used which are less efficient and result in narrower bandwidth. Hence a trade-off must be realized between the antenna dimensions and antenna performance. Linear and circular polarizations can be achieved with either single elements or arrays of micro strip antennas. Arrays of micro strip elements, with single or multiple feeds, may also be used to introduce scanning capabilities and achieve greater directives.

2.4 Feeding Techniques

There are many methods to feed the patch and all have their advantages and disadvantages. These feeding methods can be classified into two groups, contacting and non-contacting. For the contacting methods, the patch antenna feeds directly to the patch and for the non-conducting method electromagnetic field coupling is used to transfer the power to the patch.

2.4.1 Micro strip feeding line

The micro strip line consists of a conducting strip connected to the patch. The micro strip line has often the same thickness as the patch but the width is smaller. To obtain good impedance matching an inset cut can be made. The length of the inset controls the impedance matching [1]. Figure 2.3 shows how to use micro strip as feed techniques.

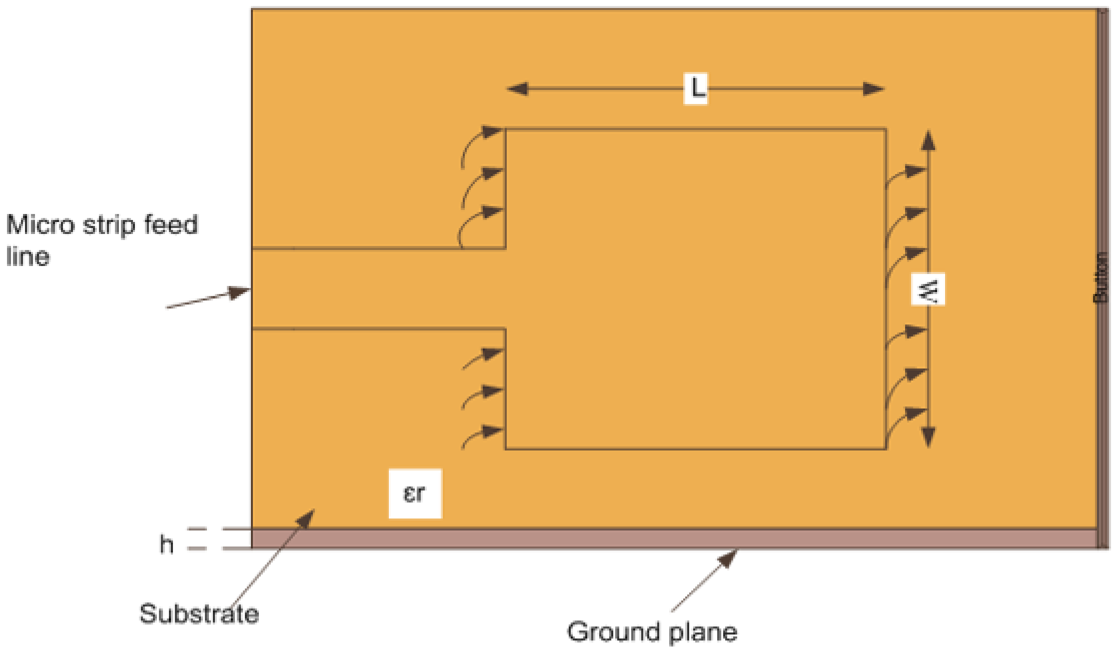


Figure 2.3: Micro strip Line Feeding Method[1][22]

Advantages of micro strip feed lines are [1]:

- One of the easiest method to fabricate

- Simple to match by controlling the inset position and rather simple to model

Disadvantages of micro strip feed line are [1]:

- Give undesirable cross polarization effects
- Make the patch larger
- Bandwidth decreases when the thickness of the substrate increases

2.4.2 Coaxial Feeding Method

The coaxial feed method is one of the most common feed techniques. The inner conductor of the coaxial goes through the substrate from ground to the patch and the outer conductor are connected to the ground plane [19]. Figure 2.4 shows how to use coaxial probe as feed technique.

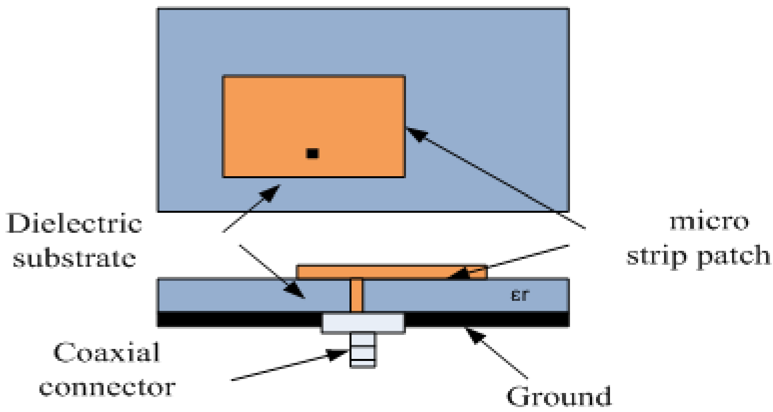


Figure 2.4: Coaxial Feeding Method[1][21]

Advantages with coaxial probe feed are [1]:

- Easy to fabricate
  - Easy to match because the feed position can be placed anywhere to the patch impedance matching
  - It has low spurious radiation

  Disadvantages with coaxial probe feed are [1]:

  - Narrow bandwidth
  - For thicker substrates, the increased probe length makes the input impedance more inductive which lead to matching problem.

– Difficult to model specially for thick substrate

Both the micro strip feed line and the probe possess inherent asymmetries which generate higher order modes which produce cross-polarized radiation. To overcome some of these problems, non-contacting aperture-coupling feeds and Proximity-coupled feed have been introduce below.

2.4.3 Aperture-coupling Feeding Method

In aperture coupling as shown in Figure 2.5 the radiating micro strip patch element is etched on the top of the antenna substrate, and the micro strip feed line is etched on the bottom of the feed substrate in order to obtain aperture coupling. The thickness and dielectric constants of these two substrates may thus be chosen independently to optimize the distinct electrical functions of radiation and circuitry. The coupling aperture is usually centered under the patch, leading to lower cross-polarization due to symmetry of the configuration. The amount of coupling from the feed line to the patch is determined by the shape, size and location of the aperture. Since the ground plane separates the patch and the feed line, spurious radiation is minimized. Generally, a high dielectric material is used for bottom substrate and a thick, low dielectric constant material is used for the top substrate to optimize radiation from the patch.

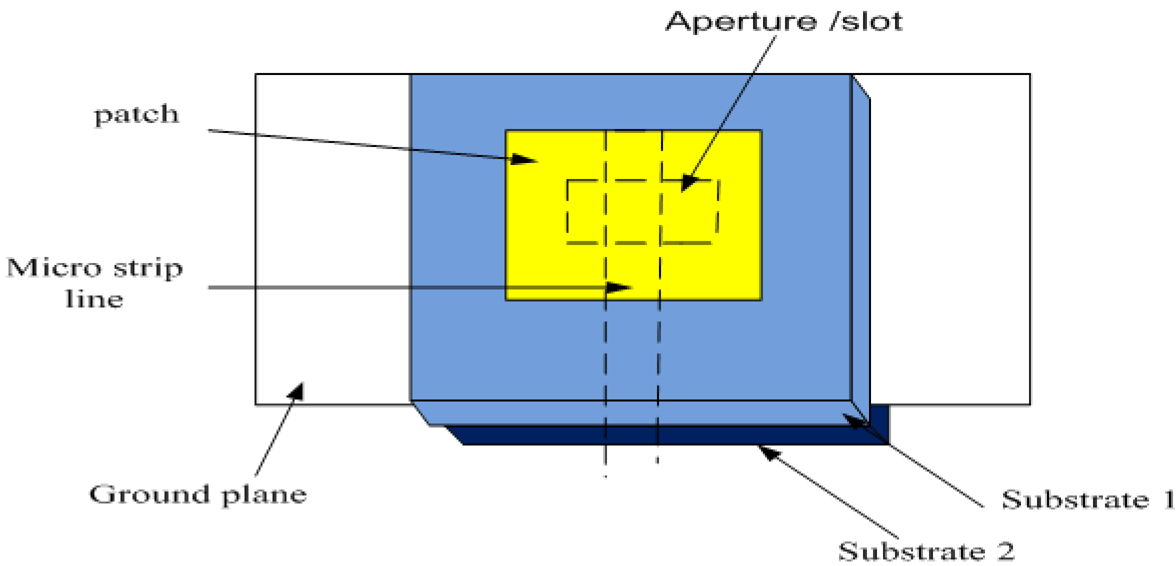


Figure 2.5: Aperture Coupling Method[1]

Advantages with the aperture-coupled patch feed are [1]:

– Many parameters to choose between to match the antenna as height of substrate, width, length and position of the slot.

– Purifier polarization since the feed is isolated by the ground plane between the substrates.

Disadvantages with the aperture-coupled patch feed are [1]:

– Difficult to fabricate

– Narrow bandwidth

2.4.4 Proximity-couple Feed Method

This type of feed technique is also called as the electromagnetic coupling scheme. As shown in Figure 2.6, two dielectric substrates are used such that the feed line is between the two substrates and the radiating patch is on top of the upper substrate. This scheme also provides choices between two different dielectric media, one for the patch and one for the feed line to optimize the individual performances.

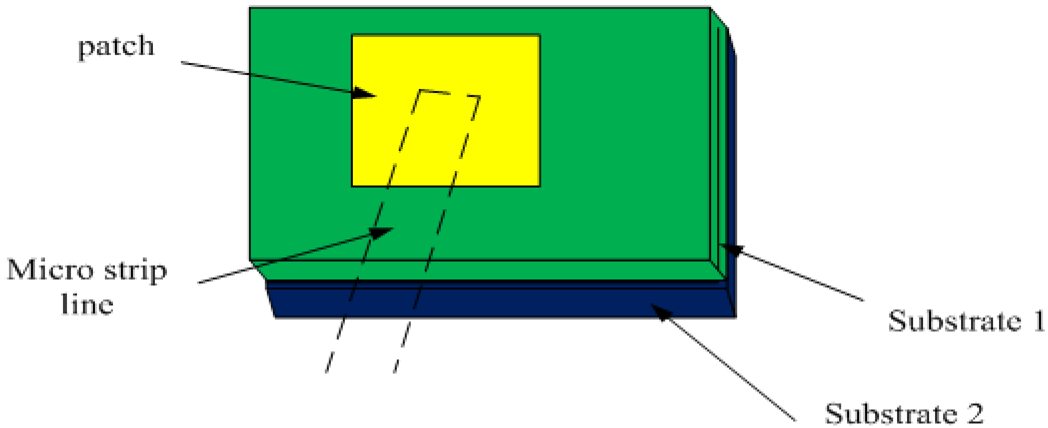


Figure 2.6: Proximity-couple Feed Method [1][22]

Advantages with the proximity-coupled patch feed are [1][22]:

– Easy to model and has low spurious radiation

– Due to increase in the electrical thickness of the micro strip patch antenna, it provides high bandwidth

Disadvantages with the proximity-coupled patch feed are [1][22]:

– It is difficult to fabricate because of the two dielectric layers that need proper alignment

Table 2.1: Comparison of different feeding techniques

characteristic	strip line	Coaxial feed	Aperture feed	Proximity feed
Spurious feed radiation	More	more	less	minimum
Reliability	Better	Poor	Good	Good
Easy to fabrication	Easy	Soldering need	Alignment required	Alignment required
Impedance matching	Easy	Easy	Easy	Easy
Bandwidth	$2-5\%$	$2-5\%$	21%	13%

– It is increasing in the overall thickness of the antenna

The rapid progress in wireless communications promises to make interactive voice, data, and video services available anytime and anyplace. Wireless communication systems come in a variety of different sizes ranging from small hand-held devices to wireless local area networks. The desirable features of micro strip antennas, such as performance, flexibility, simplicity, high gain and low fabrication cost, make them very popular for many applications. The slot in the radiating element gives a more compact design for the antenna and, thus, space-volume is saved. Since then these methods, aperture coupling and proximity coupling have helped overcome several of the performance burdens associated with direct contact excitation procedures (probe and edge feeding). These include the inherent narrow bandwidth of direct contact fed patches and also the spurious radiation associated with the current discontinuity where the feed and the patch join. Despite overcoming these detrimental attributes, proximity coupled patches have received little attention in the literature. This may be because the original form required an external impedance matching circuit to achieve a reasonable impedance bandwidth. In a stacked proximity coupled patch was developed that displayed a broad impedance bandwidth of approximately 25%, however this was achieved with the assistance of slots within the patch radiators. In wireless communication, much efforts has been devoted to reducing the size of micro strip antenna, with a lot of methods proposed recently, such as cutting slots on the patch, winding the lateral edge of patch, using stacked patch, and adopting the substrate with high permittivity, etc. DGS is then used in the design of a proximity coupled antenna for its miniaturization. Defected ground structure (DGS) is a convenient way to realize the slow wave effect. It has been widely used in the development of miniaturized antennas.

2.5 Radiation Mechanism

Consider the Figure 2.7 shown below, when a micro strip patch is provided the power, a charge distribution is seen on the upper and lower surfaces of the patch and at the bottom of the ground plane. This charge distribution is controlled by two mechanisms- an attractive mechanism and a repulsive mechanism. The attractive mechanism is between the opposite charges on the bottom side of the patch and the ground plane, which helps in keeping the charge concentration intact at the bottom of the patch. The repul-

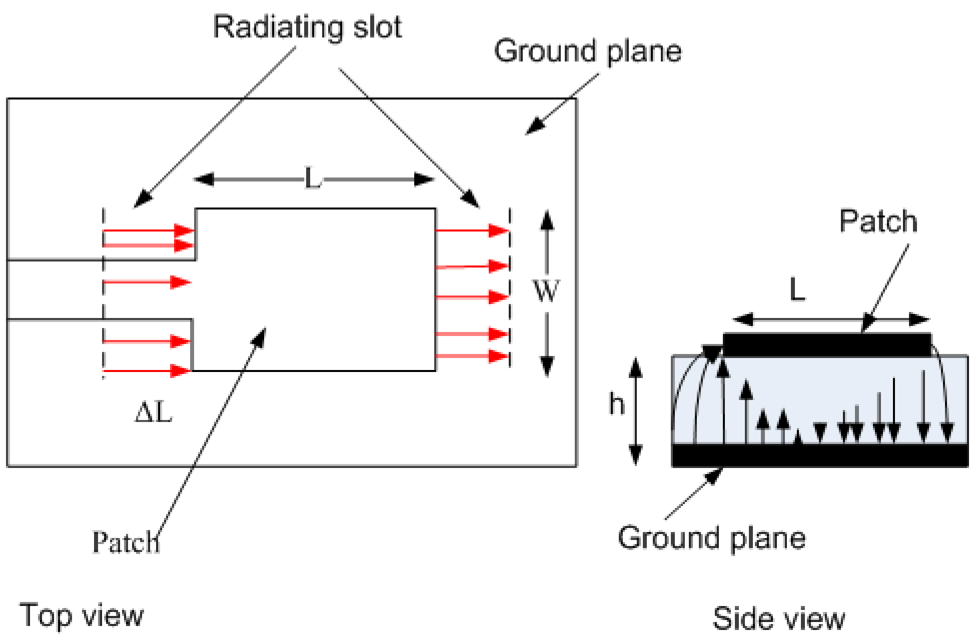


Figure 2.7: Radiation Mechanism[1][22]

sive mechanism is between the like charges on the bottom surface of the patch, which causes pushing of some charges from the bottom, to the top of the patch. As a result of this charge movement, currents flow at the top and bottom surface of the patch. In the Figure 2.7 the micro strip patch antenna is represented by two slots, separated by a transmission line of length L and open circuited at both the ends. Along the width of the patch, the voltage is maximum and current is minimum due to the open ends. The fields at the edges can be resolved into normal and tangential components with respect to the ground plane.

However the normal components of the electric field at the two edges along the width are in opposite directions and thus out of phase since the patch is $\frac{\lambda}{2}$ long and hence they cancel each other in the broadside direction. The tangential components, which are in phase, means that the resulting fields combine to give maximum radiated field normal to the surface of the structure. Hence the edges along the width can be represented as two radiating slots, which are $\frac{\lambda}{2}$ apart and excited in phase and radiating in the half space above the ground plane. The fringing fields along the width can be modeled as radiating slots and electrically the patch micro strip patch antenna looks greater than its physical dimensions.

The cavity model assumes that the height to width ratio (i.e. height of substrate and width of the patch) is very small and as a result of this the attractive mechanism dominates and causes most of the charge concentration and the current to be below the patch surface and much less current would flow on the top surface of the patch and as the height to width ratio further decreases, the current on the top surface of the patch would be almost equal to zero. It would not allow the creation of any tangential magnetic field components to the patch edges.

A loss cavity would now represent an antenna and the loss is taken into account by the effective loss tangent δ_{eff} which is given as [2];

$$\delta_{eff} = \frac{1}{Q_T} \tag{2.1}$$

where Q_T is the total quality factor of antenna and has been expressed in the form

$$\frac{1}{Q_t} = \frac{1}{Q_d} + \frac{1}{Q_c} + \frac{1}{Q_r} \tag{2.2}$$

where Q_d represent the quality factor of dielectric and is given by

$$Q_d = \frac{W_t \omega_r}{P_d} = \frac{1}{tan\delta} \tag{2.3}$$

where

ω_r=angular resonant frequency

W_t=total energy stored in the patch at resonance

P_d=dielectric loss

tanδ =loss tangent of the dielectric substrate

Q_c=quality factor of conductor and given as:

$$Q_c = \frac{W_t}{P_c} = \frac{h}{\Delta} \tag{2.4}$$

where P_c= conductor loss

Δ = skin depth of the conductor

h =height of dielectric substrate and

Q_r =represents the quality factor for radiation and is given as:

$$Q_r = \frac{W_t \omega r}{P_r} \tag{2.5}$$

where P_r is the power radiated from the patch

$$\delta eff = tan\delta + \frac{\Delta}{h} + \frac{P_r}{W_t \omega_r} \tag{2.6}$$

Thus, equation describes the total effective loss tangent for the micro strip patch antenna.

2.6 Methods of Analysis

The desired models for the analysis of micro strip patch antennas are the transmission line model, cavity model and full wave model (which include primarily integral equations/Moment Method). The transmission line model is the simplest of all and it gives good physical insight but it is less accurate. The cavity model is more accurate and gives good physical insight but is complex in nature. The full wave models are extremely accurate, versatile and can treat single elements, finite and infinite arrays, stacked elements, arbitrary shaped elements and coupling. These give less insight as compared to the two models mentioned above and are far more complex in nature.

2.6.1 Transmission line model

The transmission line model, as shown in the Figure 2.8 , represents the micro strip antenna by two slots, separated by susceptance B and conductance G of length L patch. Due to the dimensions of the patch are finite (or shorter than the base plate) along in length and width, the fields at the edges of the patch undergo fringing. The fringing fields act to extend the effective length of the patch. Thus, the length of a half-wave patch is slightly less than a half wavelength in the dielectric material

The amount of fringing of the antenna is a function of the dimensions of the patch and height of the substrate. Due to fringing electric field lines travels in non-homogeneous

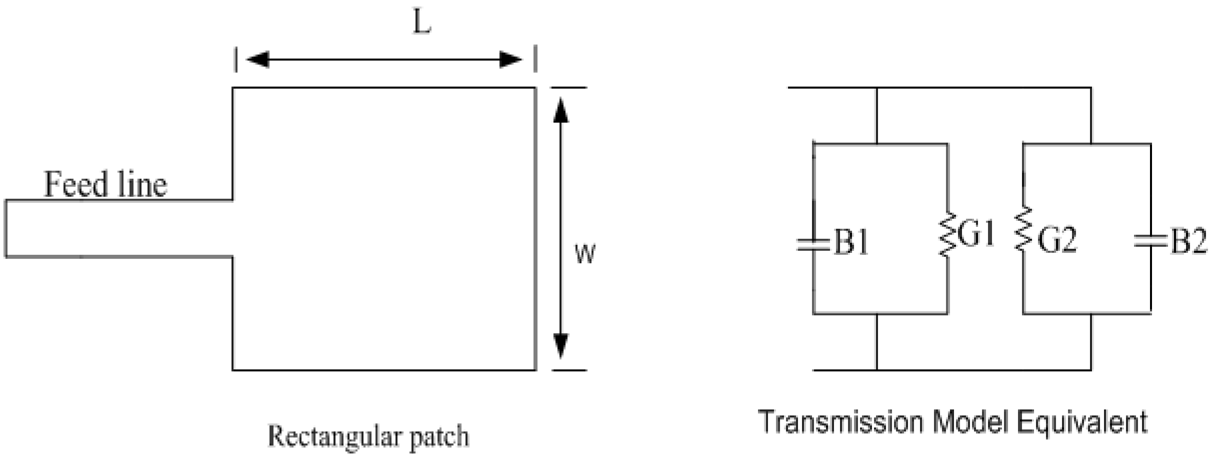


Figure 2.8: Transmission Line Model[1]

material, typically substrate and air, an effective dielectric constant ϵ_{reff} is introduced. For electric line with air above the substrate, the effective dielectric constant has values in the range of 1<ϵ_{rff} <ϵ_r. The dielectric constant for most applications is much greater than unity. The effective dielectric constant is expressed by the function of frequency. As the frequency of operation increases, most of the electric field concentrates in the substrate, and therefore, the micro strip behaves more like a homogeneous electric line of one dielectric, and the effective dielectric constant approaches the value of dielectric constant of the substrate.

Generally, the relationship of width (W) height (h) effective dielectric constant and relative dielectric constant of the substrate are related as follow:

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left[1 + \frac{12h}{w}\right]^{-1/2} \tag{2.7}$$

where

ϵ_r= relative dielectric constant.

ϵ_{eff}= effective dielectric constant

h = dielectric thickness (mm)

w = Width of the patch

A very popular and practical approximation relation for normalized extension of the length is obtained from below equation:

$$\Delta L = 0.412h\frac{(\epsilon_r + 0.3)\left(\frac{W}{h} + 0.264\right)}{\left(\epsilon_{eff} - 0.258\right)\left(\frac{W}{h} + 0.8\right)} \tag{2.8}$$

Substrate thickness should be chosen as large as possible to maximize bandwidth, but not so large to minimize the risk of surface wave excitation. The substrate should also has low dielectric constant in order to achieve high efficiency. Since the effective length of the patch has been extended by ΔL on each side, the effective length of the patch is expressed as

$$L_{eff} = L + 2\Delta L \tag{2.9}$$

After analyzing and determining the physical nature of the Micro strip antenna with reference of resonant frequency, f_r relative dielectric constant, ϵ_r, height of the substrate h; it is possible to design rectangular micro strip antenna dimension, width W and Length L, of patch as follow

$$W = \frac{C}{2f_r\sqrt{\frac{\epsilon_r+1}{2}}} \tag{2.10}$$

$$L = \frac{C}{2f_r\sqrt{\epsilon_e}} - 2\Delta L \tag{2.11}$$

As shown in Figure 2.8, a Micro strip antenna is represented by an equivalent circuit with two slots having conductance, G, and susceptance, B. The total admittance at slot one (input admittance) is obtained by transferring the admittance of slot two from the output terminal to input terminals using the admittance transformation equation of transmission lines. Ideally two slots are separated by $\lambda/2$ where λ is the wavelength in the dielectric (substrate). However, because of the fringing the length of the patch is electrically longer than the actual length. Therefore the actual separation of the two slots is slightly less than $\lambda/2$.

If the reduction of the length is properly chosen using equation 3.2, the transformed admittance of the slot two becomes.

$Y_1 = Y_2, G_1 = G_2 and B_1 = -B_2$

Therefore the total resonant input admittance is real and is given by:-

$Y_{in} = Y_1 + Y_2 = 2G_1$

Since the total input admittance is real, the resonant input impedance is also real

$Z_{in} = 1/Y_{in} = R_{in} = 1/2G_1$ Considering the mutual effects between the slots, the above equation will be modified as

$$R_i n = \frac{1}{2(G_1 \pm G_2)} \tag{2.12}$$

where the plus (+) sign is used for modes with odd (anti-symmetric) resonant voltage distribution beneath the patch and the slots while minus (-) sign is used for modes with even (Symmetric) resonant voltage distribution.

However, the mutual conductance of Micro strip antenna is defined as

$$G_{12} = \frac{1}{|V_o|}\Re\int\int E_1 \times H_2^{*}.ds \tag{2.13}$$

where E_1 is the electric field radiated by slot one, H_2 is magnetic field radiated by slot two, V_0 is the voltage across the slot.

2.6.2 Inset Feed

The resonant input resistance of the Micro strip antenna obtained by equation 2.12 can be changed to appropriate value using inset feed or other alternative technique in order to achieve maximum power transfer.The inset technique changes the resonant input resistance by introducing a physical notch, which in turn introduces a junction capacitance. The physical notch and its corresponding junction capacitance influence slightly the resonant frequency. The maximum resonant input resistance value occurs at the edge of the slot ($Yo = 0$) where the voltage is maximum and current is minimum. However, the minimum resonant input resistance value occurs at the center of the patch ($Yo = L/2$). As the inset feed point moves from edge toward the center of the patch the resonant input impedance decreases monotonically and reaches zero at the center. When the value of the inset feed-point reaches the center of the patch ($Yo = L/2$), the $\cos^2(\frac{\Pi}{L}y_o)$ function varies very rapidly; therefore the input resistance also changes rapidly with the position of the feed point. Analytically, the input resistance for inset feed is given approximately by [1] and [16]

$$R_{in} = \frac{1}{G_1 + G_2}\cos^2(\frac{\Pi}{L}y_o) \tag{2.14}$$

Similarly the characteristics impedance of Micro strip line feed is given by [4]

$$Z_c = \begin{cases} \frac{60}{\sqrt{\epsilon_{eff}}}\ln[\frac{8h}{W_f} + \frac{W_f}{4h}], & \frac{W_f}{h} \leq 1; \\ \frac{120\pi}{\sqrt{\epsilon_{eff}}[\frac{W_f}{h}+1.393+0.667\ln(\frac{W_f}{h}+1.44)]}, & \frac{W_f}{h} \geq 1 \end{cases} \tag{2.15}$$

where:W_f is width of micro stripe line and h is height of substrate

For TM_{010} the resonant frequency is given by

$$(fr)_{010} = \frac{1}{2L\sqrt{\epsilon_r}\sqrt{\epsilon_0 v_0}} = \frac{V_0}{2L\sqrt{\epsilon_r}} \tag{2.16}$$

where V_0 is speed of light in free space

2.6.3 Cavity model

Micro strip antenna resembles dielectric loaded cavities, and exhibit higher order resonances. The normalized fields within the dielectric substrate can be found more accurately by treating that region as a cavity bounded by electric conductors (above and below) and by magnetic wall along the perimeter of the patch. The bases for this assumption are the following points (for height of substrate h < < wave length of the field)

- The fields in the interior region do not vary with z-axis because the substrate is very thin, $h << \lambda$
- The electric field is z-axis directed only, and the magnetic field has only the transverse components in the region bounded by the patch metallization and the ground plane. This observation provides for the electric walls at the top and bottom.
- The electric current in the patch has no component normal to the edge of the patch metallization, which implies that the tangential component of magnetic field along the edge is negligible, and a magnetic wall can be placed along the periphery. This approximation model leads to reactive input impedance, and it does not radiate any power. However, the actual fields can be approximated to the generated field of the model and is possible to analyze radiation pattern, input admittance, and resonant frequency.

When the micro strip patch is provided power, a charge distribution is seen on the upper and lower surfaces of the patch and at the bottom of the ground plane. This charge distribution is controlled by two mechanisms-an attractive mechanism and a repulsive mechanism as discussed by Richards [21]. The attractive mechanism is between the opposite charges on the bottom side of the patch and the ground plane, which helps in keeping the charge concentration complete at the bottom of the patch. The repulsive mechanism is between the like charges on the bottom surface of the patch, which causes pushing of some charges from the bottom, to the top of the patch. As a result of this charge movement, currents flow at the top and bottom surface of the patch.

The cavity model assumes that the height to width ratio (i.e. height of substrate and width of the patch) is very small and as a result of this the attractive mechanism dominates and causes most of the charge concentration and the current to be below the patch surface. Much less current would flow on the top surface of the patch and as the height to width ratio further decreases, the current on the top surface of the patch would be almost equal to zero, which would not allow the creation of any tangential magnetic field components to the patch edges [1][5].

2.7 Advantages and Disadvantage of Micro strip Antenna

Micro strip antenna is a low profile antenna that has light weight and is very easy to installation due to which it is very popular in hand held wireless devices such as cell phones, pagers and in some high performance communication systems such as in satellite, missile, spacecraft, aircraft etc. Some of the major advantages of micro strip antenna as discussed [1] are given below:

- Inexpensive and easy to fabricate.
- Can be planted easily on any surface.
- Can easily get reconfigurable characteristics.
- Can easily design antenna with desired polarization.
- Mechanically robust, Resistant against vibration and shock.
- It can be realized in a very compact form, desirable for personal and mobile communication hand held devices.
- It allow for dual and triple band operations.
- For high gain and directive Array of antennas can be easily formed

Conversely micro strip antennas also have a number of disadvantages and limitations when compared to other antennas. Some of the major disadvantages of micro strip antennas are written below:

- High quality factor
- Low gain and power handling capability
- Suffers from spurious feed radiation
- Poor polarization efficiency
- Suffers from surface wave when high dielectric constant material is used.
- Sensitive to environment conditions like temperature and humidity

There are various methods to overcome this limitations, bandwidth of micro strip antenna can be increase by using some special methods like defected ground plane strategy, stacked patches, slotted patches, parasitic patch. Gain and the power handling ability of antenna can be improved by making an antenna array. Use of Electromagnetic Band Gap (EBG) structure and Meta material also results in the improvement of the antenna characteristics.

2.8 Application of micro strip antenna

After a number of limitations due to the several advantages micro strip antenna found very useful in different applications. Micro strip antenna widely used in the defense systems like missiles, aircraft, satellites and rockets. Now a day's micro strip antenna is used in commercial sectors due to its inexpensiveness and easy to manufacture benefit by advanced printed circuit technology. Some of the major applications of micro strip antennas are listed below:

- Mobile Communication
- Aircraft, Spacecraft and Missiles
- Direct Broad cast Television (DBS)
- GPS system
- Telemetry and Telemedicine
- Radar Application

2.9 Basic Parameters of the Antenna

To explain the performance and characteristics of an antenna, various fundamental parameters are required. Some of the parameters are linked and not all of them need be specified for complete explanation of the antenna performance. Parameter definitions will be given in this part. Gain and directivity, polarization, input impedance, VSWR, bandwidth, quality factor and beam width etc. some of basic or fundamental parameters of an antenna.

2.9.1 Directivity and Gain

Directivity is the ability of an antenna to focus energy in a particular direction. The definition of the directivity according to IEEE Standard 145-1983: "Directivity (of an antenna) (in a given direction) is the ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged over all directions". Note that the radiation intensity is equal to the total power radiated by the antenna divided by 4π. Directivity is always greater than one [2]

$$D = 1/2 \frac{Re(E_\theta H'_\varphi - E_\varphi H'_\theta)(\theta = 0)}{P_{rad}/4\Pi} \tag{2.17}$$

where:P_{rad} is radiated power

A good approximation of equation (2.18) for the directivity D of a rectangular patch antenna is given by [8 and 1]. Note that $(\theta = 0)$ in this approximation.

$$D \approx \frac{4(K_o W)^2}{\pi \eta G_{rad}} \tag{2.18}$$

where: G_{rad} = radiation conductance of the patch

The directive gain (according to IEEE Standard 145-1983) is "'the ratio of the radiation intensity, in a given direction to the radiation intensity that would be obtained if the power accepted by the antenna were radiated isotropically".We can obtain gain from directivity of the antenna:

$$G = eD \tag{2.19}$$

e is the efficiency of the antenna. Gain is always less than directivity because efficiency is between 0 and 1. The directivity increases with increase in substrate thickness h and patch width W. Conversely the beam width is expected to decrease with increasing of h and W

2.9.2 Input impedance

There are three different kinds of impedance relevant to antennas. One is the terminal impedance of the antenna, another is the characteristic impedance of a transmission line, and the third is wave impedance. Terminal impedance is defined as the ratio of voltage to current at the connections of the antenna (the point where the transmission line is connected). The complex form of Ohm's law defines impedance as the ratio of voltage across a device to the current flowing through it.

The most efficient coupling of energy between an antenna and its transmission line occurs when the characteristic impedance of the transmission line and the terminal impedance of the antenna are the same and have no reactive component. When this is the case, the antenna is considered to be matched to the line. Matching usually requires that the antenna be designed so that it has a terminal impedance of about 50Ω or 75Ω to match the

common values of available coaxial cable.
The input impedance of patch antenna is in general complex and it includes resonant and non-resonant part. Both real and imaginary parts of the impedance vary as a function of frequency. Ideally, both the resistance and reactance exhibit symmetry about the resonant frequency. Typically, the feed reactance is very small, compared to the resonant resistance for thin substrates.

2.9.3 Voltage Standing Wave Ratio

The standing wave ratio (SWR), also known as the voltage standing wave ratio (VSWR), is not strictly an antenna characteristic, but is used to describe the performance of an antenna when attached to a transmission line. It is a measure of how well the antenna terminal impedance is matched to the characteristic impedance of the transmission line. Specifically, the VSWR is the ratio of the maximum to the minimum RF voltage along the transmission line. The maxim and minim along the lines are caused by partial reinforcement and cancellation of a forward moving RF signal on the transmission line and its reflection from the antenna terminals.
If the antenna terminal impedance exhibits no reactive (imaginary) part and the resistive (real) part is equal to the characteristic impedance of the transmission line, then the antenna and transmission line are said to be matched. It indicates that none of the RF signal sent to the antenna will be reflected at its terminals. There is no standing wave on the transmission line and the VSWR has a value of one. However, if the antenna and transmission line are not matched, then some fraction of the RF signal sent to the antenna is reflected back along the transmission line. This causes a standing wave, characterized by maxima and minima, to exist on the line. In this case, the VSWR has a value greater than one. The VSWR is easily measured with a device and VSWR of 1.5 is considered excellent, while values of 1.5 to 2.0 is considered good, and values higher than 2.0 may be unacceptable.

2.9.4 Bandwidth

The bandwidth of an antenna is defined as the range of frequency within the performance of the antenna. In other words, characteristics of antenna (gain, radiation pattern, terminal impedance) have acceptable values within the bandwidth limits. For most antennas, gain and radiation pattern do not change as rapidly with frequency as the terminal impedance does. Since the transmission line characteristic impedance hardly changes with frequency, VSWR is a useful, practical way to describe the effects of terminal impedance and to specify an antenna's bandwidth. For broadband antennas, the bandwidth is usually expressed as the ratio of the upper to lower frequencies of acceptable operation. However, for narrow band antennas, the bandwidth is expressed as a percentage of the bandwidth. [1]

2.9.5 Return Loss

In telecommunications, return loss is the loss of signal power resulting from the reflection caused at a discontinuity in a transmission line. This discontinuity can be a mismatch with the terminating load or with a device inserted in the line. The return loss is related to both standing wave ratio (VSWR) and reflection coefficient (Γ). The increase of return loss corresponds to lower VSWR. An ideal transmission line would have a VSWR of 1:1, with all the power reaching the destination and no reflected power. As for the reflection coefficient (Γ), it is the ratio of the amplitude of the reflected wave V_0^- to the amplitude of the incident wave v_0^+. In another word, return loss is the measurement of how well devices or lines are matched and a match is good if the return loss is high. A high return loss is desirable and results in a lower insertion loss. Using return loss we can provide the best and most convenient method to calculate the input and output of the signal sources. The Return Loss is determined in dB as follows [1]:

$$RL(dB) = -20\log|\Gamma| \tag{2.20}$$

or

$$RL(dB) = -20\log|S_{11}| \tag{2.21}$$

where:

$$|\Gamma| = \frac{V_0^-}{V_0^+} = \frac{Z_L - Z_0}{Z_L + Z_0}$$

Here,S_{11} S-parameters Γ reflection coefficient,V_0^-incident wave, V_0^+ reflected wave, Z_L and Z_0 are the load and characteristic impedance. During the development of designing the rectangular patch antenna there is a response taken from the magnitude of S_{11}parameter versus frequency. This is known as the return loss. To have a perfect matching between the antenna and the transmitter,$\Gamma = 0$ and $RL = \infty$, this indicates that there is no power that is returned or reflected but when$\Gamma = 0$ and RL = 0 dB, this indicated that the power that is sent is all reflected back. It is said that for the practical applications VSWR = 2 is acceptable as the return loss would be - 9.54dB [2].

2.9.6 S-parameters

The S-parameters are very important in microwave design for describing the behavior of electrical devices. Most of the electrical properties i.e. gain, return loss, power, VSWR etc. relates to the S parameters. The S-parameters can be observed by sending a signal through an input port and observing the response on an output port. The term impedance is of great importance while calculating the S-parameters because the system should be matched properly, otherwise reflection which will give rise to standing waves and the system will not produce the desired output. The S-parameters S_{11} and S_{22} represent input and output reflection while S_{21} is the forward transmission coefficient (gain) and S_{12} are the reverse transmission coefficient (isolation)[20].

2.9.7 Impedance Matching

Impedance matching is the process of removing mismatch loss. That is, we want to minimize the reflection coefficient, to reduce the power reflected from the load (the antenna), and maximize the power delivered to the antenna. This is one of the fundamental tasks in getting antenna to radiate, and hence is one of the more important topics in antenna theory. To achieve perfect matching, the antenna or load impedance to match the transmission line. Thus $Z_L = Z_0$(or $Z_{in} = Z_0$)[21].

2.9.8 Radiation Efficiency and Quality Factor

For a micro strip patch antenna, efficiency can be defined as the power radiated from the micro strip element divided by the power received by the input to the element. Factors that affect the efficiency of the antenna and make it high or low are the dielectric loss, the conductor loss, the reflected power (Voltage Standing Wave Ratio VSWR), the cross polarized loss, and power dissipated in any loads in the element. General expression of the radiation efficiency can be found in most books of antennas including references of my research:[21]

$$e = \frac{p_{rad}}{p_{rec}} \tag{2.22}$$

where:

P_{rad}= Power radiated by the antenna

P_{rec}= Power accepted by the antenna.

Efficiency can also be expressed in terms of the quality factor as follows:[21]

$$e = \frac{\frac{1}{Q_{rad}}}{\frac{1}{Q_t}} \tag{2.23}$$

where:

Q_t =total quality factor

Q_{rad}= quality factor due to radiation (space wave) losses.

$$\frac{1}{Q_t} = \frac{1}{Q_{rad}} + \frac{1}{Q_c} + \frac{1}{Q_d} + \frac{1}{Q_{sw}} \tag{2.24}$$

where:

Q_C= quality factor due to conduction losses (ohmic).

Q_d = quality factor due to dielectric losses.

Q_{sw} = quality factor due to surface waves.

Most micro strip antennas have efficiency of between 80 to 90 percent. For a very thin antenna $h << \lambda_0; t << \lambda_0$ There are approximate formulas to calculate the quality factor:[21]

$$Q_c = h\sqrt{\pi f \delta \mu} \tag{2.25}$$

$$Q_d = \frac{1}{\tan\delta} \tag{2.26}$$

$$Q_{rad} = \left[\frac{2\omega\epsilon_r}{\frac{hG_t}{l}}\right] K \tag{2.27}$$

where:

$\tan\delta$= loss tangent of the substrate.

ω= conductivity of the conductor.

$\frac{hG_t}{l}$= the total conductance per unit length.

2.9.9 Radiation Intensity (U)

The radiation intensity is far field parameter[2].

$$U = r^2 P_{rad} \tag{2.28}$$

where: U=Radiation Intensity The radiation intensity is power per unit solid angle. P_{rad}=Average power radiated by an antenna (watts/m^2)

$$U = \frac{1}{2}\frac{E^2}{\eta^2 r^2} \tag{2.29}$$

An other way:

$$U = r^2 P_{avg} \tag{2.30}$$

where:

$$P_{avg} = \frac{1}{2}\frac{E^2}{\eta} \tag{2.31}$$

Radiation intensity will indicate about the energy of an antenna. Radiation intensity in a given direction will be defined as the power radiated from an antenna per unit solid angle.

Chapter 3

Polarization of antenna

3.1 Introduction

Polarization of an antenna can be defined like polarization of electromagnetic wave in given direction of radiation. If direction is not given then we consider in the maximum gain direction. Polarization of radiated electromagnetic wave can be changed by changing the points in the radiating sphere i.e. polarization can be changed by changing with direction from antenna [1].

Polarization is the study of relative orientation of two planar component of electric field component of radiated electromagnetic wave. Another way, one can define polarization is, the orientation of magnitude of electric field with direction. Here the direction is the time varying direction. Therefore, one can say polarization is a function of time, direction and magnitude also. Figure 3.1 shows trace of EMW as the function of time. At any point in radiation sphere of a far field the wave is to be characterized by plane wave whose strength of E-field is same like radiated wave and propagation direction is radial outward from antenna.

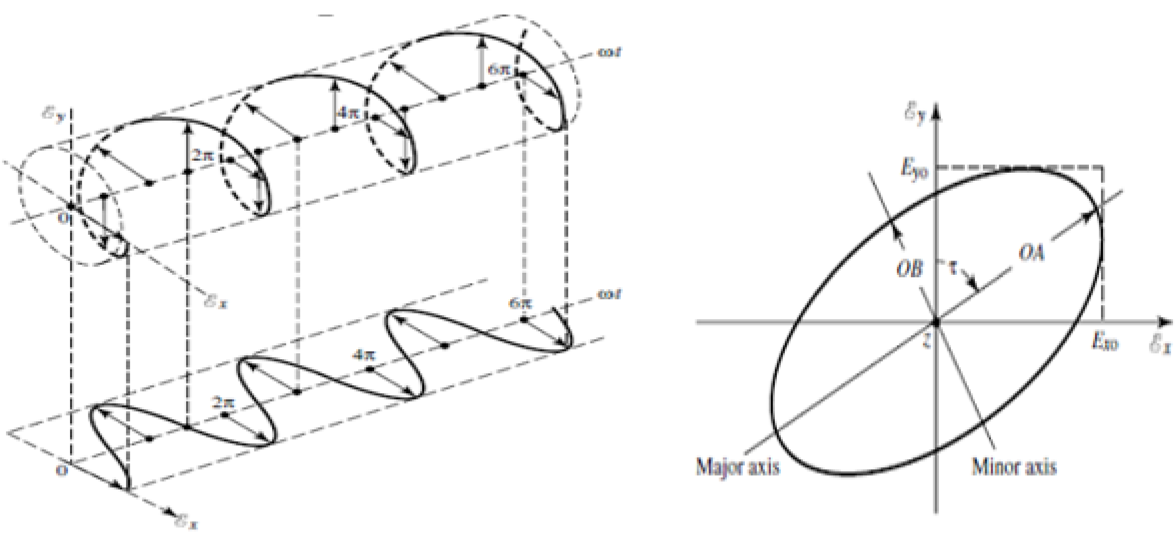


Figure 3.1: (a) Rotation of wave and (b) polarization ellipse [1][21]

As the distance from antenna increases up to infinity, radius of radiation sphere also increases to infinity and strength decreases. The propagated wave always appears like a plane wave. In any direction from antenna, at any point of radiation sphere polarization is the combination of two orthogonal polarizations known as co-polarization and cross-polarization. Co-polarization characterizes the polarization of wave the antenna wants to radiate, while cross- polarization is the polarization orthogonal to radiated polarization and it is an unwanted component.

3.2 Linear, Circular, and Elliptical Polarization

Polarization of radiated wave can be classified as Linear, Circular and Elliptical Polarization. Electric field component of a plane wave propagating towards negative z direction can be represented [1], [21] as

$$E(z;t) = E_x(z;t)\,a_x + E_y(z;t)\,a_y \tag{3.1}$$

where ,

$$E_x(z;t) \begin{array}{l} = Re[E_x \exp - j(\omega\text{t+Kz})] \\ = Re[E_{x0} \exp - j(\omega\text{t+Kz+}\phi_x)] \end{array} \tag{3.2}$$

and

$$E_y(z;t) \begin{array}{l} = Re[E_y \exp - j(\omega\text{t+Kz})] \\ = Re[E_{y0} \exp - j(\omega\text{t+Kz+}\phi_y)] \end{array} \tag{3.3}$$

where,E_{x0} and E_{y0} are maximum amplitude of X and Y component of electric field component.

3.3 Linear Polarization

Antenna Polarization is a very important parameter when choosing and installing an antenna. Most communications systems use either vertical, horizontal or circular polarization. Knowing the difference between polarizations and how to maximize their benefit is very important to the antenna user.

Figure 3.2 shows linearly polarized curve, a linear polarized antenna radiates wholly in one plane containing the direction of propagation. An antenna is said to be vertically polarized (linear) when its electric field is perpendicular to the Earth's surface. A circular polarized wave radiates energy in both the horizontal and vertical planes and all planes

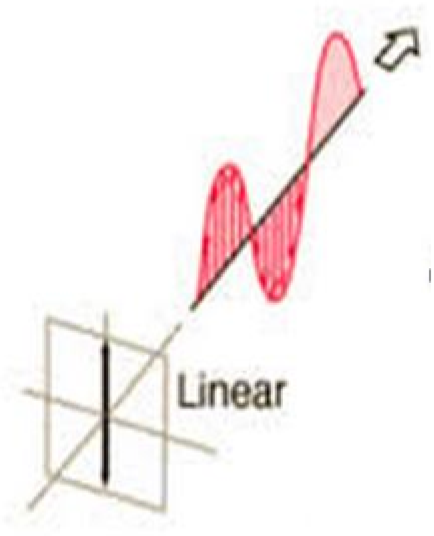


Figure 3.2: linearly polarizad curve [21]

in between. The difference, if any, between the maximum and the minimum peaks as the antenna is rotated through all angles, is called the axial ratio or elliptical and is usually specified in decibels (dB). If the axial ratio is near 0 dB, the antenna is said to be circular polarized. If the axial ratio is greater than 1-2 dB, the polarization is often referred to as elliptical.In linear polarized wave, two planar component of electric field component of equal or unequal amplitude are in phase

$\Delta\phi = \phi_y - \phi_x = n\pi, n = 0, 1, 2..........$

where, ϕ_y and ϕ_x are phase angle of electric field in y and x component

$\Delta\phi$ is quadrature phase difference between electric field X and Y component.

In case of linear polarization, if out of the two planar component of electric field of radiated wave only vertical component exist and there is no any horizontal component i.e.

$E_{x0} = 0$

Then polarization is called vertical linear polarization. In this case polarization curve is along y-axis only. Similarly, if there is only horizontal component exist and there is no any vertical component i.e.

$E_{y0} = 0$

Then polarization is called horizontal polarization. In this case polarization curve is along x-axis only.

3.3.1 Basic Considerations

Polarization is an important design consideration. The polarization of each antenna in a system should be properly aligned. Maximum signal strength between stations occurs when both stations are using identical polarization. On line-of-sight (LOS) paths, it is most important that the polarization of the antennas at both ends of the path use the same polarization. In a linearly polarized system, a misalignment of polarization of 45 degrees will reduce the signal up to 3 dB and if misaligned 90 degrees the attenuation can be 20 dB or more. Likewise, in a circular polarized system, both antennas must have the same sense. If not, an additional loss of 20 dB or more will be suffered.

Linearly polarized antennas will work with circularly polarized antennas and vice verse. However, there will be up to a 3 dB loss in signal strength. In weak signal situations, this loss of signal may impair communications. Cross polarization is another consideration. It happens when unwanted radiation is present from a polarization which is different from the polarization in which the antenna was intended to radiate. For example, a vertical antenna may radiate some horizontal polarization and vice verse. However, this is seldom a problem unless there is noise or strong signals nearby.

If ones antenna is to be located on an existing tower or building with other antennas in the area, it is need to separate the antennas as far as possible from each other. In the UHF range, increasing separation even a few extra feet may significantly improve performance from problems such as desensitization. When setting up ones exclusive communications link, it may be wise to first test the link with vertical and then horizontal polarization to see which yields the best performance (if any). If there are any reflections in the area, especially from structures or towers, one polarization may outperform the other.

Another point to note is when radio waves strike a smooth reflective surface, they may incur a 180 degree phase shift, a phenomenon known as specular or mirror image reflection. The reflected signal may then destructively or constructively affect the direct LOS signal. Circular polarization has been used to an advantage in these situations since the reflected wave would have a different sense than the direct wave and block the fading from these reflections.

3.4 Circular polarization

Micro strip antennas are widely used as an efficient radiator in many communication systems. One of the most interesting applications is their use for transmitting or receiving systems, required for circular polarization. A circularly polarized micro strip antenna can be classified into two categories, e.g. single- or dual-fed types. The classification of an antenna is based upon the number of feeding points required for circularly polarized waves. The singly-fed antenna is useful, because it can excite circular polarization without using an external polarizer. The other is a dual-feed CP antenna with an external polarizer such as 3dB hybrid. Therefore, it is important to understand the radiation mechanism of the antenna. However, one of the most serious problem in such an antenna is the considerable narrowness of the bandwidth compared to ordinary microwave antennas. Figure 3.3 shows circularly polarized curve,circularly polarized wave will radiate energy in the horizontal and vertical plane, as well as every plane in between. There are two directions of propagation that come with circular polarization: Right-Hand-Circular (RHC) which follows a clockwise pattern, and Left Hand-Circular (LHC) which follows a counterclockwise pattern.

Nowadays circular polarization is very important in the antenna design industry, it eliminates the importance of antenna orientation in the plane perpendicular to the propagation direction, it gives much more flexibility to the angle between transmitting / receiving antennas, also it enhances weather penetration and mobility [21, 22]. It is used in a group of commercial and militarily applications. However it is difficult to build good circularly polarized antenna [2]. For circular polarization to be generated in micro strip antenna two modes equal in magnitude and 90 out of phase are required [23-24]. Micro strip antenna on its own doesn't generate circular polarization; subsequently some changes should be done to the patch antenna to be able to generate the circular polarization [21]. The circular micro strip patch antenna's lowest mode is the TM11, the next higher order mode is the TM21 which can be driven to produce circularly polarized radiation. In circular polarized wave, two planar component of electric field component of equal amplitude are in odd multiple of 90 phase difference. That is $E_{x0} = E_{y0}$ and

$$\Delta\phi = \phi_y - \phi_x = \begin{cases} \left\{+(\frac{1}{2}) + n\right\}, & n = 0,1,2....CW \\ \left\{-(\frac{1}{2}) + n\right\}, & n = 0,1,2....CCW \end{cases} \tag{3.4}$$

where , CW is clockwise and CCW is counter clockwise

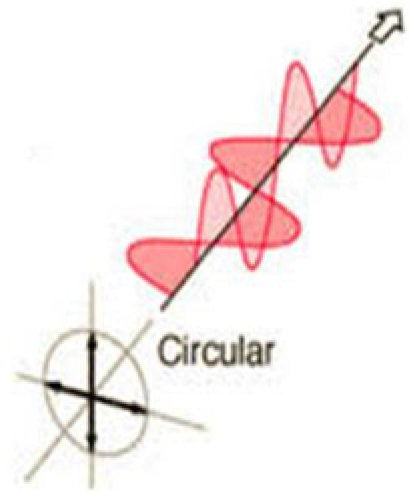


Figure 3.3: circularly polarized curve [21]

3.4.1 Dual feed circularly polarized micro strip antenna

As 90 degree phase shift between the fields in the micro strip antenna is a perquisite for having circular polarization, dual feed is an easy way to generate circular polarization in micro strip antenna. With the help of external polarizer the micro strip patch antenna is fed by equal in magnitude and orthogonal feed. Dual feed can be carried out using quadrature hybrid, ring hybrid, Wilkinson power divider, T-junction power splitter or two coaxial feeds with physical phase shift 90 degree [22].

3.4.2 Single feed circularly polarized micro strip antenna

Single fed micro strip antennas are simple, easy to manufacture, low cost and compact in structure as shown in Figure 3.5. The major advantage of single-feed, circularly polarized micro strip antennas is their simple structure, which does not require an external polarizer. They can, therefore, be realized more compactly by using less board space than do dual-feed, circularly polarized micro strip antennas. It eliminates the use of complex hybrid polarizer, which is very complicated to be used in antenna array [24, 28]. Single fed circularly polarized micro strip antennas are considered to be one of the simplest antennas that can produce circular polarization [7]. In order to achieve circular polarization using only single feed two degenerate modes should be exited with equal amplitude and 90 degree difference. Since basic shapes micro strip antenna produce linear polarization there must be some changes in the patch design to produce circular polarization.Perturbation segments are used to split the field into two orthogonal modes with equal magnitude and 90 degree phase shift. Therefore the circular polarization requirements are met.There are many methods to achieve this, with the most commonly used shown in Figure 3.4 below For the almost square patch technique (Figure 3.4a) the feed is

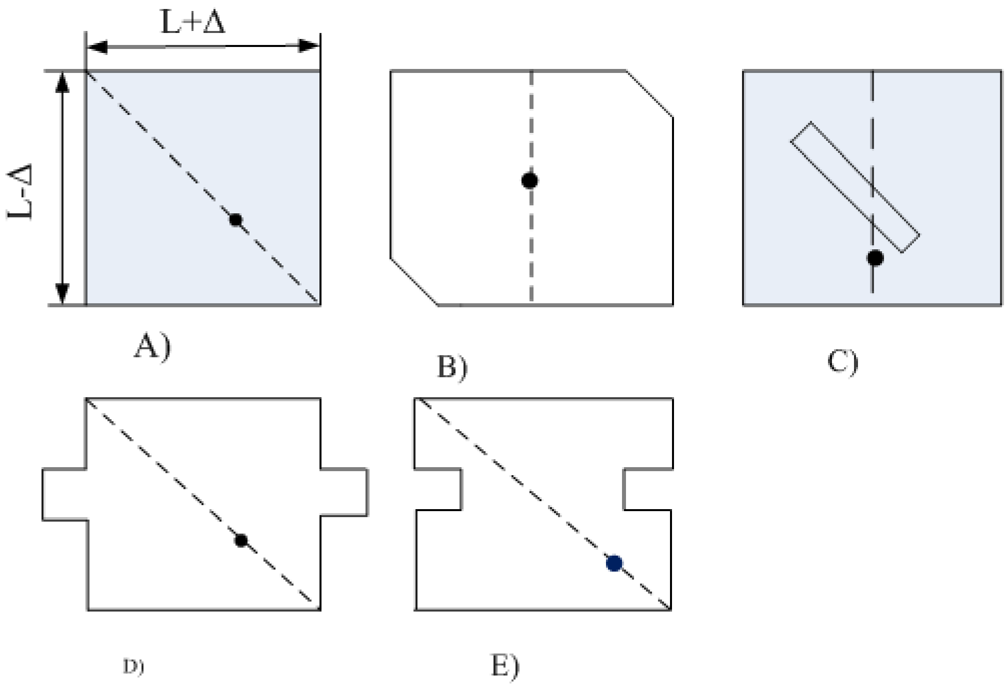


Figure 3.4: Geometries of various circularly polarize patches. Dashed line shows the line along which the feed point is located [22] [25]

located on the diagonal of the patch in order to excite two modes. The phase difference is achieved by introducing a small difference between the length and width of the patch, making the two modes resonate at slightly different frequencies be obtained. Around resonant frequency, the antennas performance switches from capacitive reactance (lower half of the Smith chart) to inductive reactance (upper part of the Smith chart). Therefore in the frequency range between the two resonances, one mode will have positive and the other - negative reactance. By adjusting this values, a 90 degree phase shift can be obtained. This is made by introducing a small difference Δ between patch length and width (see Fig. 3.4a). The difference should be inversely proportional to antenna quality factor (Q), i.e. lower Q requires greater Δ. This method results in an impedance bandwidth much wider than that of equivalent linearly polarized patch, however the axial-ratio bandwidth is narrow and also inversely proportional to Q.

The truncated corner technique (Fig. 3.4B) employs cutting off two corners on the rectangular patch, located across a diagonal. The feed is located at the middle of one of the edges. It therefore directly excites one mode and the other is excited by the irregularity in the square geometry of the patch. The sense of polarization depends on which two corners are truncated, therefore solutions for polarization reconfigurability have been proposed by covering and uncovering the truncation [26]. For these antenna types is can be difficult to achieve a good impedance match, when feeding the patch directly from a 50Ω micro strip line. For linearly polarized antennas an inset feed can be employed. However the two slots introduced into the patch by this technique will perturb the current for the orthogonal mode and as a consequence degrade circular polarization. In [25] propose a solution to this problem, where the impact of the inset feed is balanced by additional slots cut along other edges of the patch. This provides good AR performance while feeding the patch directly from a 50Ω micro strip line. Alternatively to the truncated corners, a diagonal slot can be introduced into the patch (Fig.3.4C). This acts similarly to the truncated corner, with the narrow slot splitting the energy into two orthogonal modes with appropriate phase shift. It was also demonstrated in [27] that a set of circular slots can be implemented, as long as there is an asymmetry in the structure to excite two orthogonal modes.

Alternatively, the slot can be located parallel to the edge of the patch and the feed located on the diagonal. In principle this work is similar to the almost-square patch, but the difference in resonant frequency is generated not by the longer patch, but by the fact that the current flows around the slot. This method is also very convenient to introduce polarization reconfigurable; by introducing a pin diode, MEMS switch or other suitable component the slot can be short circuited or not, switching between the RHCP and LHCP, as in [25].

An interesting method for a patch antenna fed by a coplanar waveguide (CPW) was proposed by S.H Hsu and K.chang in [26]. In this method the mode perturbation was made by a 45 degree inclined slot in a ground plane, protruding on both sides of CPW feed. The patch used is a regular square and both the perturbing and feed structures are located on the ground plane layer.Confirmed the same performance for the circular patch. Last, but not least, a stub protruding from the edge (Fig. 3.4D) or a section removed from the edge (Fig. 3.4E), or the combination of both can be used to generate 90 degree phase shift. Such structures - when properly designed introduce inductance and capacitance, which generates the phase shift.

3.5 Elliptical Polarization

In any given point of radiation sphere, if the electric field component of radiated wave traces a ellipse with advancing of time then the wave is said to be elliptical polarized. Figure 3.6 shows elliptical polarization curve,in elliptical polarized wave, two planar component of electric field component have unequal amplitude and in odd multiple of 90 degree phase difference or when phase difference is not equal to integer multiple of 90 degree.

$E_{x0} \neq E_{y0}$

And

$$\Delta\phi = \phi_y - \phi_x = \begin{cases} \{+(\frac{1}{2}) + n\}, & n = 0, 1, 2....CW \\ \{-(\frac{1}{2}) + n\}, & n = 0, 1, 2....CCW \end{cases}$$

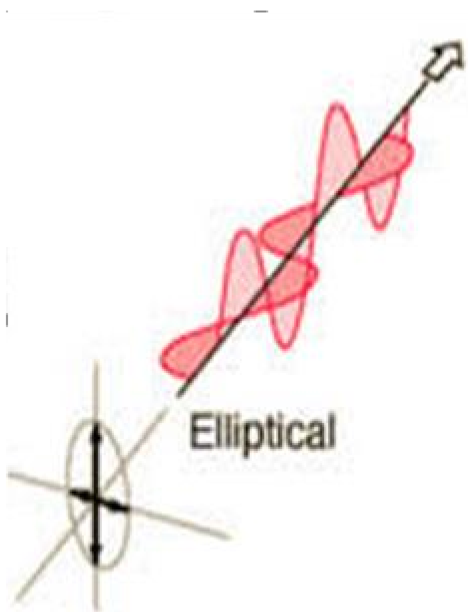


Figure 3.5: Elliptical polarization curve [21]

Chapter 4

Design of Rectangular Micro strip Antenna

4.1 Physical Design Parameter of Antenna

There are three important parameters which are to be considered carefully when the designing a rectangular micro strip patch antenna for various communication application. These are listed below,

4.1.1 choice of substrate

While designing MSA substrate selection is as decisive as the design itself. Radiating properties of MSAs depend on the substrate used for the antenna design. Dielectric constant, thickness, stiffness as well as loss tangent are important factors for substrate selection. To encourage fringing and hence radiation dielectric constant should be as low as possible. A use of thicker substrate can increase the impedance bandwidth but it suffers a loss in accuracy. For the approximation in the analysis a thin substrate is used in most MSA models [1]. For comparison purpose the dielectric material chosen for this design is FR-4 and RT/Duroid 6006 which has dielectric constant of 4.4 and 6.15 loss tangent 0.019 respectively. The reason for choice is due to its considerable properties, such as, low surface wave excitation, low moisture absorption, lowest electrical loss, uniform electrical properties over frequency, excellent chemical resistance and relative low cost.

4.1.2 Patch Parameters

The dimensions of a rectangular patch, as well as bandwidth and gain, are determined by the operating frequency of the antenna, the relative dielectric constant, and thickness of the substrate material. The following formulas are based on the transmission line model. The width and length of a rectangular micro strip patch are given at equation (2.10) and (2.11) respectively by [1][21]:

$$W = \frac{C}{2f_r\sqrt{\frac{\epsilon_r+1}{2}}}$$

$$L = \frac{C}{2f_r\sqrt{\epsilon_e}} - 2\Delta L$$

where:

C = speed of light (m/s).

f_r = operating frequency (MHz).

ϵ_r = relative dielectric constant.

ϵ_{eff}= effective dielectric constant.

where:

ϵ_{eff} from equation(2.7)

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left[1 + \frac{12h}{w}\right]^{-1/2}$$

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

where

h = dielectric thickness (mm)

4.2 Design specification

Before designing the antenna, the first step is to consider the specification of the antenna based on its application. The various parameters that are used for the design are taken from the data sheet of $FR4$ and listed in Table 4.1 . The frequency of 1.575 GHz is chosen because

Table 4.1: micro strip Antenna Design Specifications.

Parameters	Specification
Frequency	1.575 GHz
Substrate	FR4
Dielectric constant ,ϵ_r	4.4
Loss tangent	0.019
Substrate height	1.6 mm
Conductor thickness	$35\mu m$

this frequency is suitable to test with the L-Band application. This frequency also is widely use in the Mobile Communication Systems since L-band application uses the frequency range from 1000 – 2000 MHz, the designed antenna must be able to operate in this desired frequency range. As for the substrate selection, the major consideration will be the dielectric constant and loss tangent.A high dielectric constant will result in a smaller patch size but this will generally reduce bandwidth efficiency and might have difficulty in fabricating a very small patch size antenna. A high loss tangent will reduce the antenna efficiency [1].

4.3 Design procedure

Step 1: Calculation of width of micro strip patch antenna

The width of the RMSA is calculated from equation (2.10) i.e

$$W = \frac{3*10^8}{2x1.575*10^9\sqrt{\frac{4.4+1}{2}}}$$

W = 58mm for ϵ_r = 4.4 and 50.4mm for ϵ_r = 6.15

Step 2: Determination of the effective dielectric constant (ϵ_{reff})

This is computed from equation (2.7) is given as following

$$\epsilon_{reff} = \frac{4.4+1}{2} + \frac{4.4-1}{2}\left[1+\frac{12h}{w}\right]^{-1/2}$$

ϵ_{reff}= 4.1734 for ϵ_r = 4.4 and 5.7661 for ϵ_r = 6.15

Step 3: Determination of the length extension (ΔL)

The length of extension can be determined from equation (2.8) as,

$$\Delta L = 0.412h\frac{(4.1734+0.3)\left(\frac{58*^{-3}}{1.6*10^{-3}}+0.264\right)}{(4.1734-0.258)\left(\frac{58*^{-3}}{1.6*10^{-3}}+0.8\right)} = 0.74224mm$$

ΔL = 0.74224mm for ϵ_r = 4.4 and 0.71393mm for ϵ_r = 6.15

Step 4: Defining the effective length (L_{eff})

The effective length is given by

$$L_{eff} = \frac{3*10^8}{2*1.575*10^9*\sqrt{\epsilon_{eff}}}$$

L_{eff} = 46.6mm for ϵ_r = 4.4 and 39.7mm for ϵ_r = 6.15

Step 5: Determination of actual length of top patch (L)

The actual length of top patch is obtained from the expression

$$L = L_{eff} - 2\Delta$$

L = 45.1mm for ϵ_r = 4.4 and 38.2mm for ϵ_r = 6.15

Step 6: Determination of ground width and length

Most of models are applicable,Only for infinite ground planes. However, for practical considerations finite ground plane is required. If the ground plane around the periphery is greater than the patch dimensions by six times substrate thickness. Hence, for proposed design reformulate dimensions of ground plane would be given as:

$$L_g = 6 * h + L = 6 * 1.6 + 45.1$$

L_g = 54.7mm for ϵ_r = 4.4 and 47.8mm for ϵ_r = 6.15

$$W_g = 6 * h + W = 6 * 1.6 + 58$$

W_g = 67.6mm for ϵ_r = 4.4 and 60mm for ϵ_r = 6.15

step 7: Determination of Inset feed depth (y_o):

An inset-fed type feed is to be used in this design. The feed depth is given by y_0. The feed point must be located at that point on the patch, where the input impedance is 50 ohms at the resonant frequency. Hence, a trial and error method is used to locate the feed point. In this case one mat lab is used to obtain the exact optimum feed depth, where the return loss (R.L) is most negative (i.e. the least value). According to [5] there exists a point along the length of the patch which gives the minimum return loss. Analytically, the input resistance for inset feed is given approximately by equation(2.14) as

$$R_{in} = \frac{1}{G_1 + G_2} \cos^2\left(\frac{\Pi}{L} y_o\right)$$

Similarly the characteristics impedance of Micro strip line feed is determined from equation(2.15)

$$Z_c = \begin{cases} \frac{60}{\sqrt{\epsilon_{eff}}} \ln\left[\frac{8h}{W_f} + \frac{W_f}{4h}\right], & \frac{W_f}{h} \leq 1; \\ \frac{120\pi}{\sqrt{\epsilon_{eff}}\left[\frac{W_f}{h} + 1.393 + 0.667 \ln\left(\frac{W_f}{h} + 1.44\right)\right]}, & \frac{W_f}{h} \geq 1 \end{cases}$$

where

$$G_1 = \begin{cases} \frac{1}{90}\left(\frac{W}{\lambda_0}\right), & W << \lambda_0; \\ \frac{1}{120}\left(\frac{W}{\lambda_0}\right), & W >> \lambda_0 \end{cases}$$

Using the equation 2.14 (assuming that Z_c in the equation 2.15 which has a condition $\frac{W_f}{h} \geq 1$ is 50(Ω) where $Rin(y = y0)$ =50(Ω),by using mat lab software we can get $y_0 = 13.9mm$ for ϵ_r = 4.4

and 13.2mm for $\epsilon_r = 6.15$ and $W_f = 3mm$.

Below is the summary of the design parameter

Table 4.2: Dimension of Rectangular micro strip Antenna on FR-4 substrate material.

Design of rectangular micro strip antenna	Values
Width of patch (W)	58 mm
Length of patch (L)	45.1 mm
Effective dielectric constant of the patch	4.1734
Input resistance of the patch (R_{in})	50Ω
Inset depth of the patch (y_0)	13.9 mm
Width of micro strip line (W_f)	3 mm
length of ground (L_g)	54.7 mm
width of ground (W_g)	67.6 mm

Table 4.3: Dimension of Rectangular micro strip Antenna on RT/Duroid 600 substrate material.

Design of rectangular micro strip antenna	values
Width of patch (W)	50.4 mm
Length of patch (L)	38.2 mm
Effective dielectric constant of the patch	5.7661
Input resistance of the patch (R_{in})	50Ω
Inset depth of the patch (y_0)	13.2 mm
Width of micro strip line (W_f)	3 mm
length of ground (L_g)	47.8 mm
width of ground (W_g)	60mm

Chapter 5

Result and Discussion

5.1 Introduction

In this chapter, the numerical parameters that are used for evaluating the performance of the designed 1.575GHz linearly and circularly polarized micro strip antenna for L-Band applications are introduced. The design procedure will be based on what was explained in the previous chapter. The antenna structure that is supposed to be designed are shown in Figure 5.1 and 5.2. This structure is going be simulated in CST studio version 16.0 and the parameters are going to be calculated using matlabR2015a. The results of the performed computer simulations are presented in the form of tables and graphs. Finally, the results will be discussed and compared in term of the selected parameters.

5.2 Design 1 : Single feed circularly polarized micro strip antenna

The design consists of nearly square metallic radiating patch with corner truncated perturbation and single feed network. Because of corner truncation an antenna radiate circular polarized wave. Antenna feeds power by micro strip line feeding techniques particularly by inset feed line.

Antenna geometry

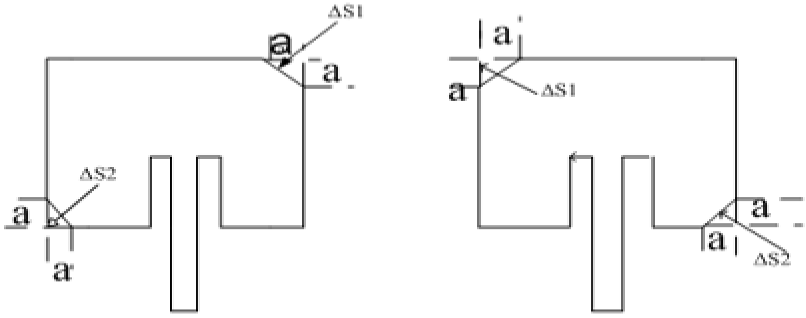


Figure 5.1: (a) RHCP and (b) LHCP

Design procedure for CP patch with single feed point are;

- Determining the unloaded factor Q_o of the patch, which depends on dimensions of a substrate thickness, and the substrate dielectric constant ϵ_r.
- Determining the amount of perturbation $\frac{\Delta s}{s}$ for the patch
- further more,the location of the feed point on the axis can be selected to provide a good match

To get the length of truncation "a" one can use [28],the following equation

$$a = L\sqrt{\frac{\Delta s}{s}} \tag{5.1}$$

- $$\frac{\Delta s}{s} = \frac{1}{2Q_o} \tag{5.2}$$

$$Q_o = \frac{c\sqrt{\epsilon_r}}{4fh} \tag{5.3}$$

where

a= length of truncating

$\frac{\Delta s}{s}$= Truncating ratio

Q_o= unloaded quality factor

L= actual length of the patch

c= speed of light

by substituting the value for L=45.1mm, f=1.575GHz, ϵ_r=4.4 and C=3 $*$ 10 exp 8

we get Q_o = 62.5, $\frac{\Delta s}{s}$=0.008 and a=4.032mm. For substrate material RT/Duroid 6006 which has dielectric constant ϵ_r=6.15 and length of patch L = 38.2mm. The length of truncation is a = 3.15mm

5.3 Design 2 : Linearly Polarized Micro strip Patch Antenna

For this design a rectangular polarized micro strip antenna is proposed. The antenna can radiate either horizontal or vertical polarized wave. Radiating patch is excited by feed-line through micro strip line specifically by inset micro strip feed-line techniques. The antenna is designed to compared the performance using a dielectric substrate of permittivity 4.4(i.e.FR4 substrate) and 6.15 (i.e. RT/Doruid 6006). Figure 5.2 shows the antenna geometry.

Antenna Geometry

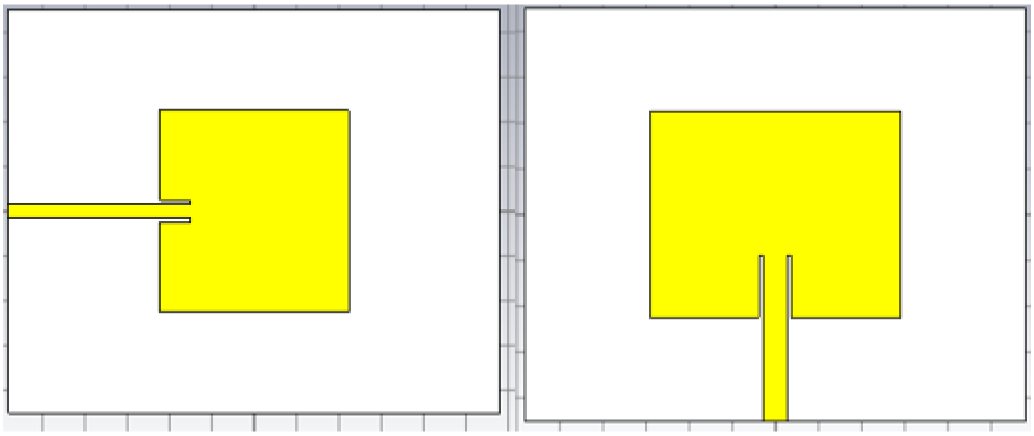


Figure 5.2: Schematic diagram for Horizontal and vertical polarization of micro strip antenna

5.4 Simulation Result and Discussion

After selecting the substrate parameter, calculating some model parameter and designing rectangular micros strip antenna, the computer simulations are carried out by using CST MW studio 16.0 for all the configurations and scenarios are defined in previous chapter. Performing the relevant computer simulations for each of these situations separately, the corresponding directivity, bandwidth efficiency, return loss, gain and VSWR of polarized rectangular micro strip antenna are computed by varying the thickness of the substrate material. Circular and linear polarization have two main categories these are; right hand circular polarization (RHCP) and left hand circular polarization (LHCP), and vertical and horizontal polarization respectively. Therefore, simulation will be done based on these categories. The simulation results presented below:

5.4.1 Return Loss

It is a parameter that is used to measure the power reflected by the antenna due to the mismatch of the antenna. If the return loss is 0dB there is nothing to radiate by the antenna because the power provided to the antenna is completely absorbed by the antenna or this means that the power input equal to the power reflected. The return loss performance of RHCP, LHCP, horizontally and vertically polarized micro strip antenna are shown in Figure 5.3-5.5 by varying the thickness of substrate material: During the development of designing polarized rectangular micro strip antenna there is a response taken from the magnitude of S_{11} (dB) versus frequency. This is known as the return loss. To have a perfect matching between the antenna and the transmitter, $\Gamma = 0$ and $RL = \infty$, this indicates that there is no power that is returned or reflected but when $\Gamma = \infty$ and RL = 0 dB, this indicated that the power that sent is all reflected back. It is said that for the practical applications VSWR = 2 is acceptable as the return loss

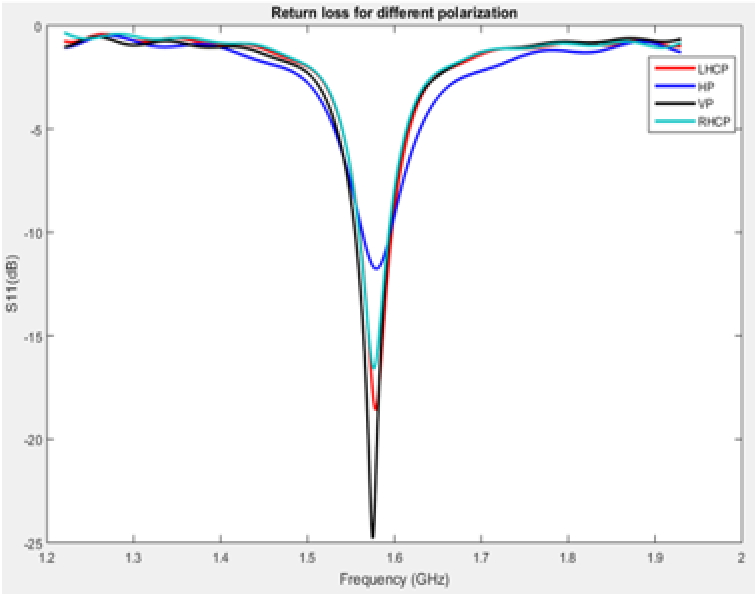


Figure 5.3: S_{11}(Return loss) parameter plot for different polarization at h =1.6mm

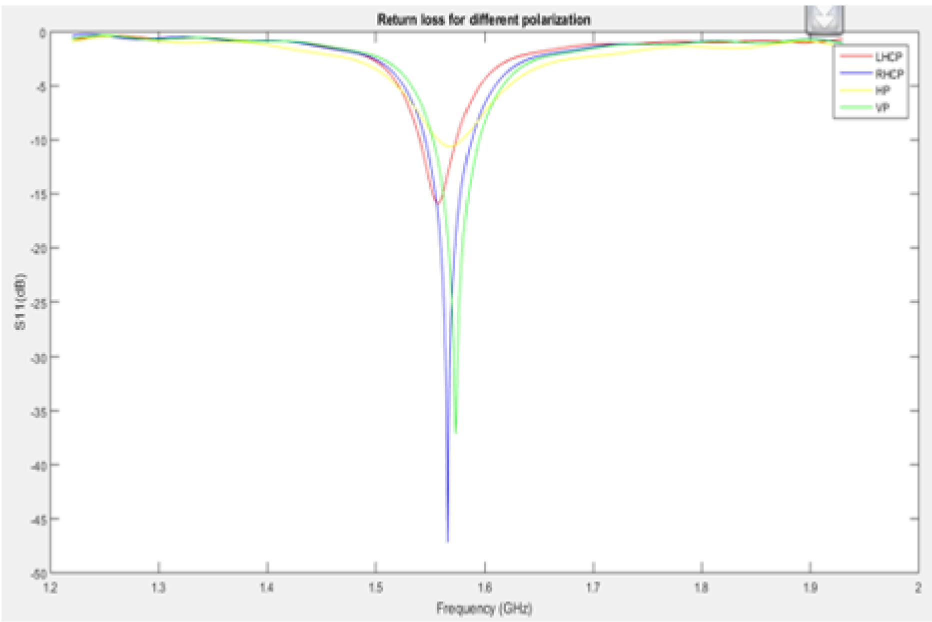


Figure 5.4: S_{11} (Return loss) parameter plot for different polarization at h =1.8mm

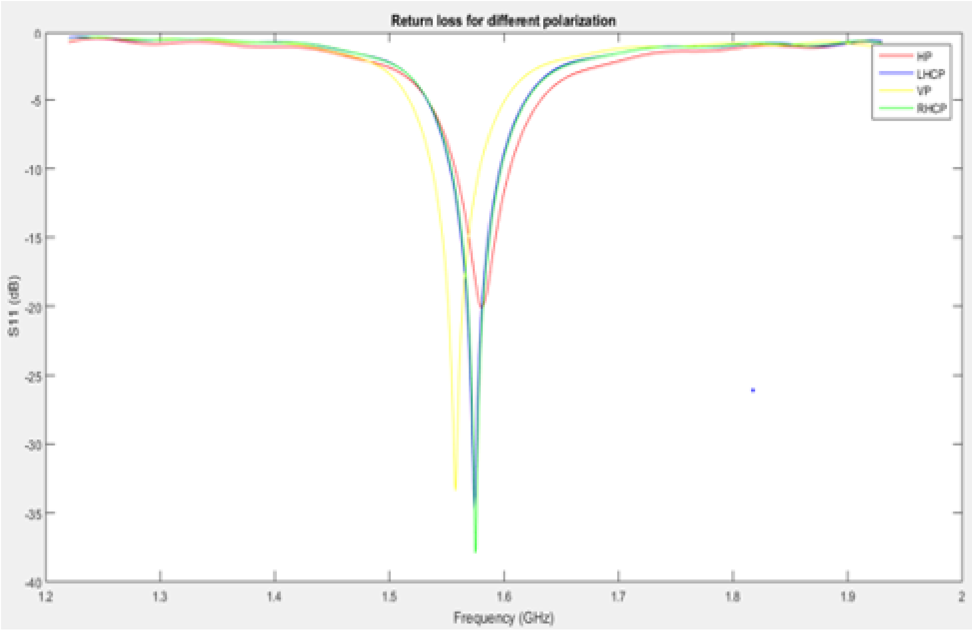
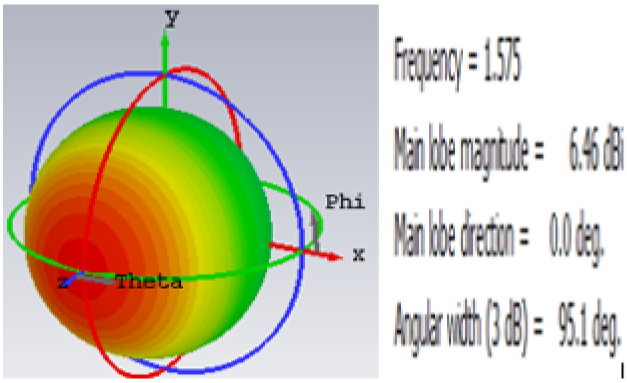


Figure 5.5: S_{11} (Return loss) parameter plot for different polarization at h =2mm

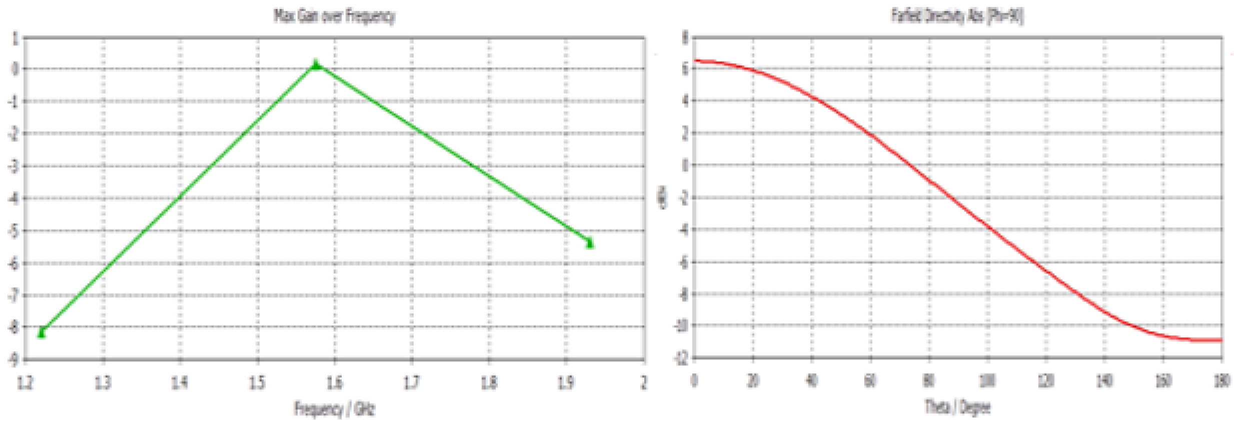
would be - 9.54dB. The reflection coefficient of the patch to confirm a good impedance match in this thesis design is VSWR =1.35. It is typical to consider the value $S_{11} = -10dB$ as a threshold value for determining the antenna bandwidth.

5.4.2 Radiation Pattern

The radiation pattern is the spatial distribution of a quantity that characterizes the electromagnetic field generated by an antenna. This distribution can be expressed as a mathematical function or as graphical representation [1]. Most of the time, the radiation pattern, is determined in the far-field region and is usually represented with the spherical coordinate system [1][22].The corresponding far field radiation pattern are simulated and measured. The obtained result are present below :



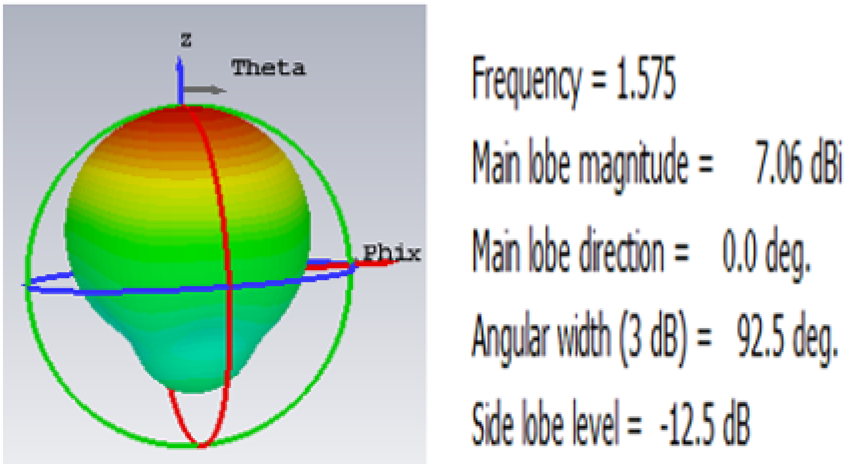
a)



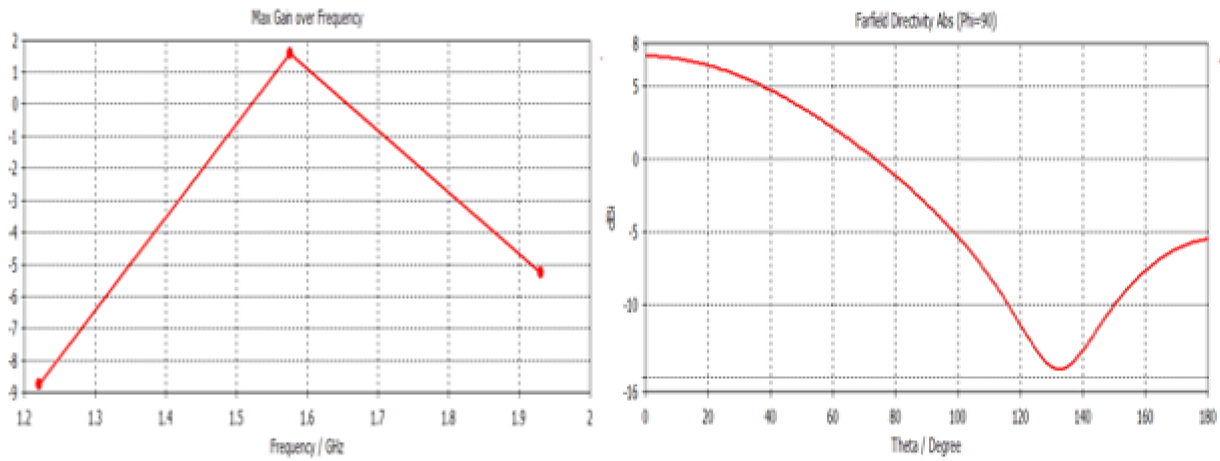
b)

Figure 5.6: a) 3-D Radiation Pattern b) Gain and directivity plot of HP at h = 1.6mm

Figure 5.6a shows radiation pattern of horizontally polarized micro strip antenna. One can observe that antenna is directional antenna and its direction is zero degree. The main lobe magnitude indicates the far field directivity of the antenna. The angular width (i.e. 3dB) bandwidth or half power beam width is 95.1 degree. From Figure 5.6b plot at operating frequency (i.e. 1.575 GHz) one can read the maximum gain value that is 0.155 dB and the main lobe direction directivity 6.46dBi



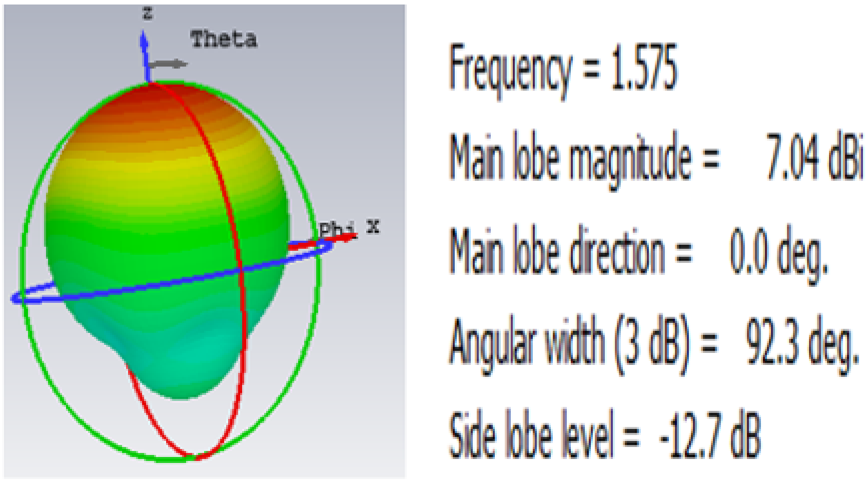
a)



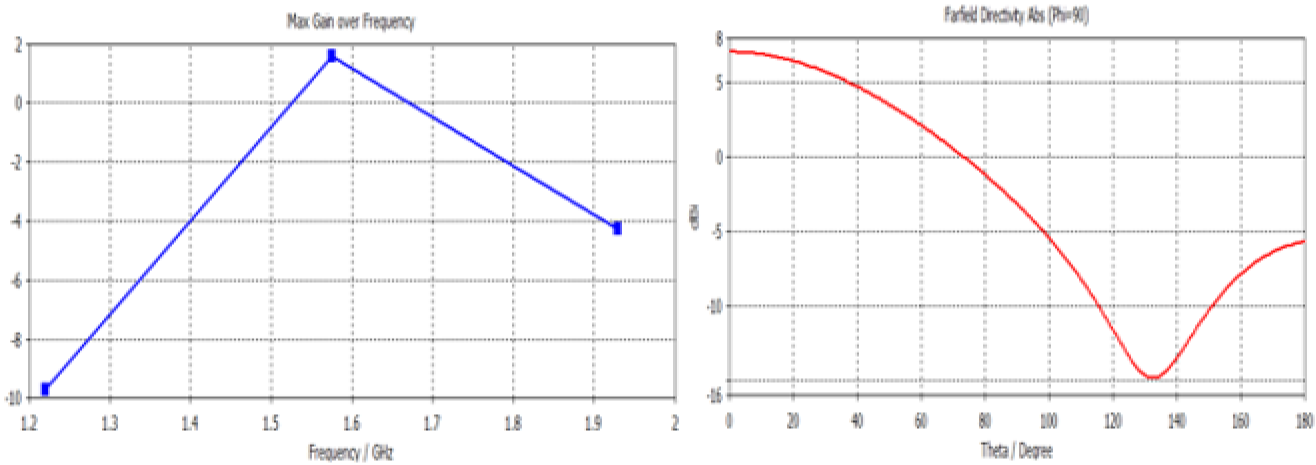
b)

Figure 5.7: a) 3-D Radiation Pattern b) Gain and directivity plot of LHCP at h = 1.6mm

The above Figure 5.7a shows the radiation pattern plot of LHC polarized micro strip antenna. From this one can observe that an antenna is a directional antenna. In this case at resonant frequency the main lobe magnitude is 7 dBi and its direction is zero degree. Figure 5.7b plot shows the maximum gain and far field directivity of the antenna. The maximum gain at operating frequency (i.e. 1.575 GHz) is 1.59 dB and the main lobe direction directivity is 7 dBi.



a)



b)

Figure 5.8: a) 3-D Radiation Pattern b) Gain and directivity plot of VP at h = 1.6mm

The above Figure 5.8a shows the radiation pattern plot of vertically polarized micro strip antenna. From this one can observe an antenna is a directional antenna. In this case at resonant frequency the main lobe magnitude is 7.04 dBi and its direction is zero degree. Figure 5.8b plot shows the maximum gain and far field directivity of the antenna. The maximum gain at operating frequency (i.e. 1.575 GHz) is 1.57 dB and the main lobe direction directivity is 7.04 dBi.

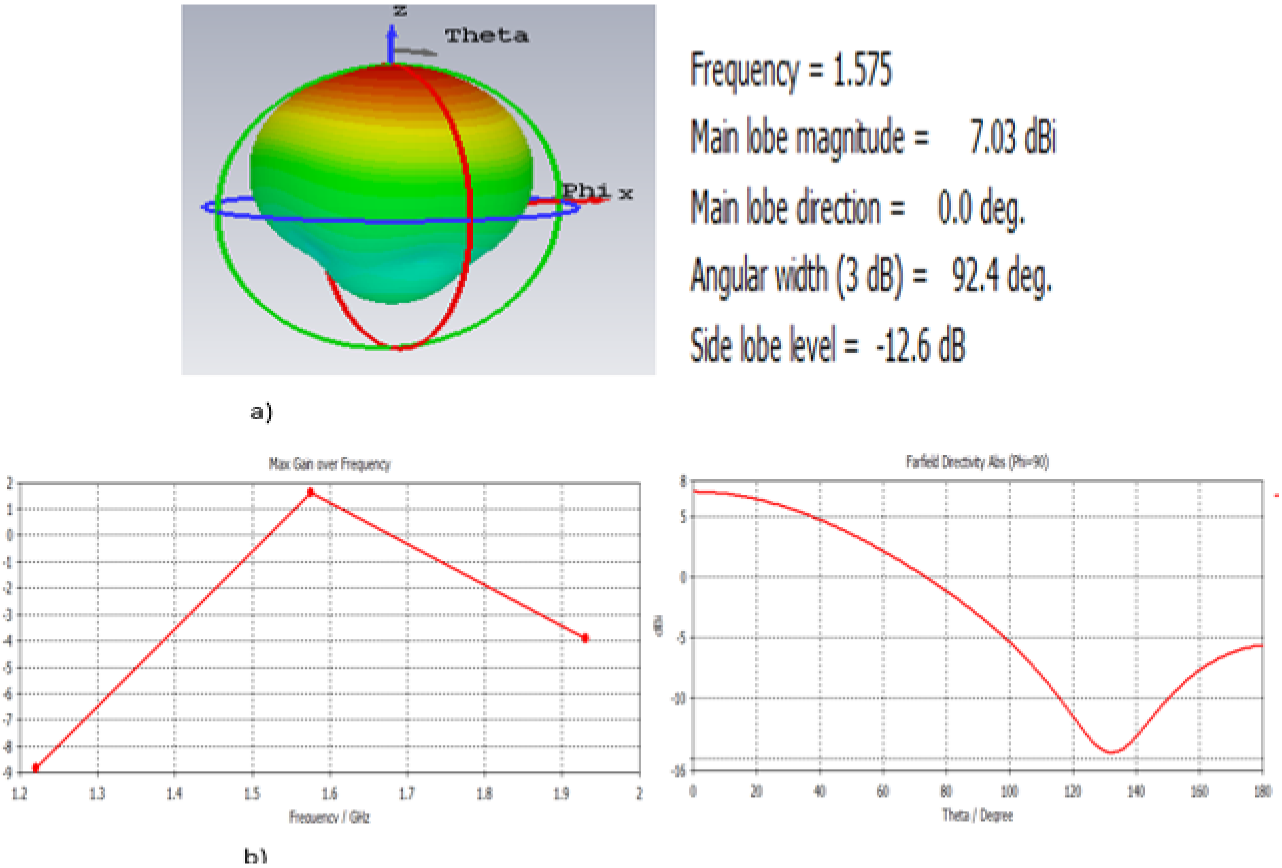
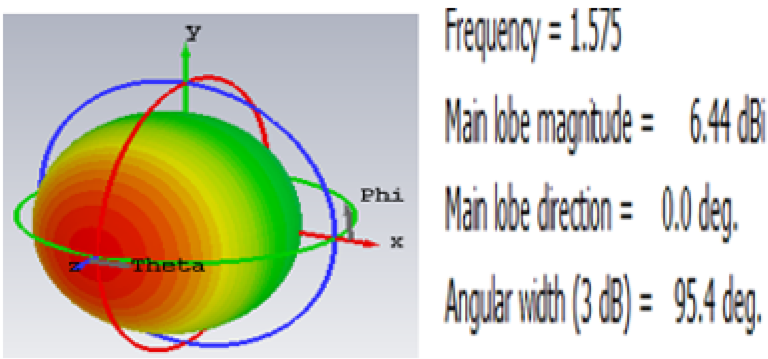


Figure 5.9: a) 3-D Radiation Pattern b) Gain and Directivity plot of RHCP at h = 1.6mm

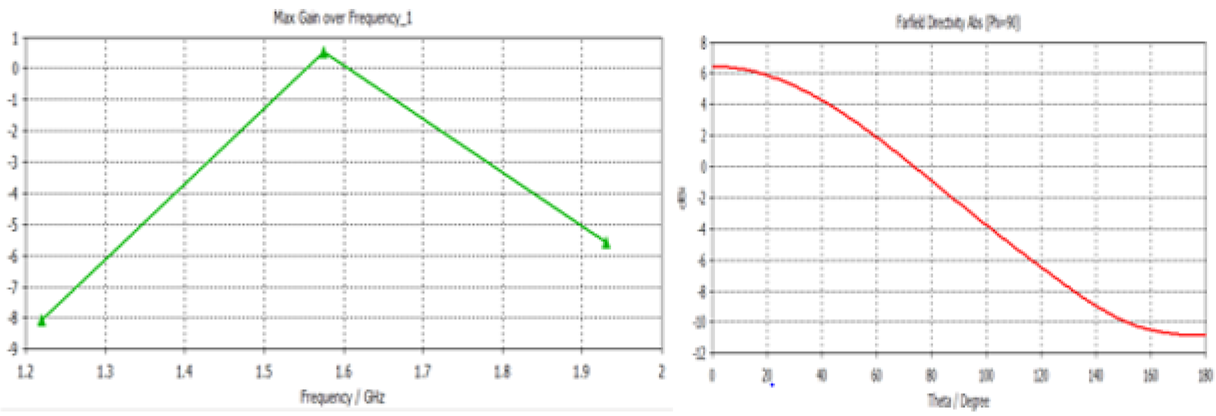
The above Figure 5.9a shows the radiation pattern plot of RHC polarized micro strip antenna. From this one can observe an antenna is a directional antenna. In this case at resonant frequency the main lobe magnitude is 7.03 dBi and its direction is zero degree. Figure 5.9b plot shows the maximum gain and far field directivity of the antenna. The maximum gain at operating frequency (i.e. 1.575 GHz) is 1.62 dB and the main lobe direction directivity is 7.03 dBi.

Table 5.1: Performance comparison and Results summary of different polarization at h =1.6mm

Quantity	RHCP	LHCP	HP	VP
Return loss(dB)	−16.492	−17.695	−11.621	−24.878
Directivity(dBi)	7.03	7.06	6.46	7.04
Gain(dB)	1.62	1.59	0.155	1.57
Bandwidth efficiency(%)	3.33	3.75	3.17	3.99
Beam-width(degree)	92.5	92.5	95.1	92.3
VSWR	1.35	1.3	1.711	1.12



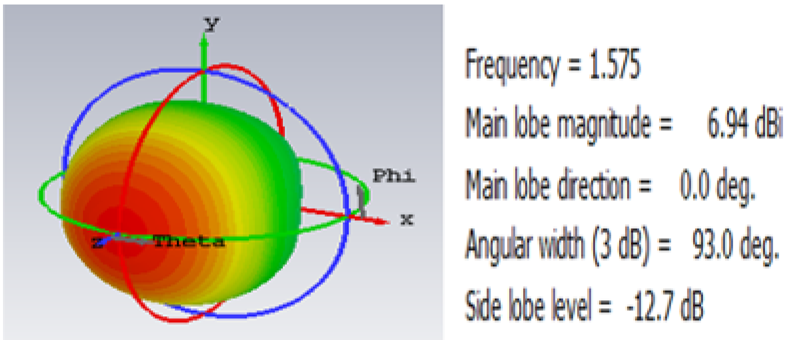
a)



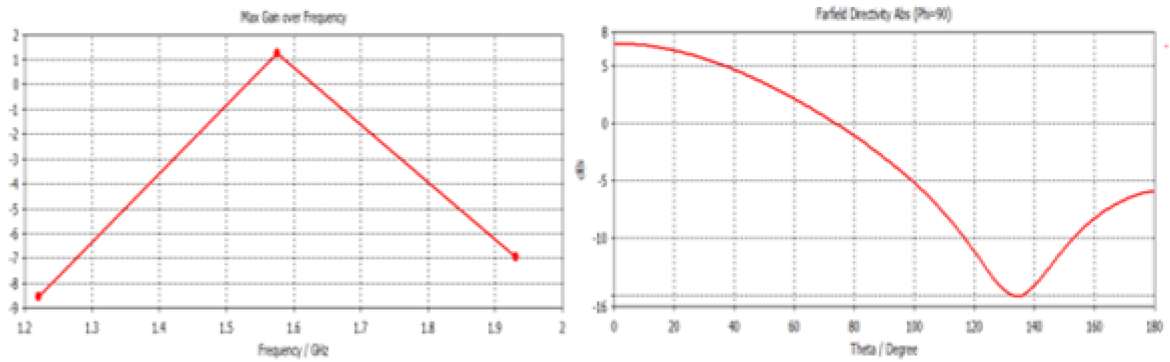
b)

Figure 5.10: a) 3-D Radiation Pattern and b) Gain and directivity plot of HP at h = 1.8mm

The above Figure 5.10a shows the radiation pattern plot of horizontally polarized micro strip antenna. From this one can observe that an antenna is a directional antenna. In this case at resonant frequency the main lobe magnitude is 6.44 dBi and its direction is zero degree. Figure 5.10b plot shows the maximum gain and far field directivity of the antenna. The maximum gain at operating frequency (i.e. 1.575 GHz) is 0.543 dB and the main lobe direction directivity is 6.44 dBi.



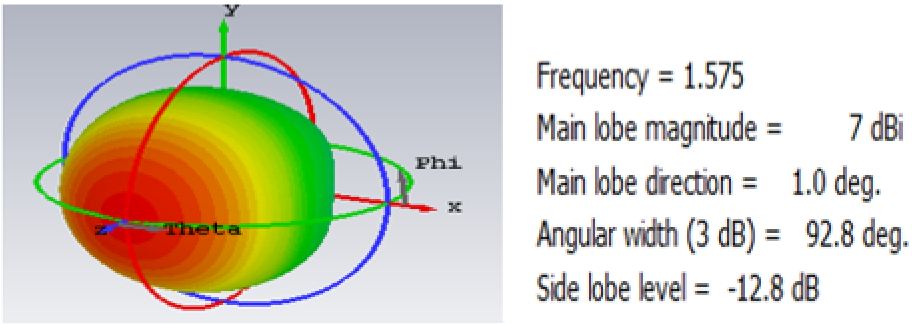
a)



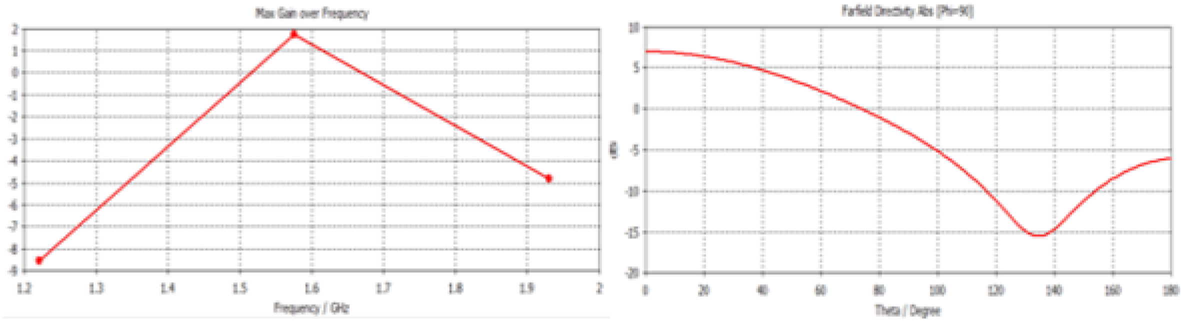
b)

Figure 5.11: a) 3-D Radiation Pattern and b) Gain and directivity plot of VP at h = 1.8mm

The above Figure 5.11a shows the radiation pattern plot of vertically polarized micro strip antenna. From this one can observe an antenna is a directional antenna. In this case at resonant frequency the main lobe magnitude is 6.93 dBi and its direction is zero degree. Figure 5.11b plot shows the maximum gain and far field directivity of the antenna. The maximum gain at operating frequency (i.e. 1.575 GHz) is 1.24 dB and the main lobe direction directivity is 6.93 dBi.



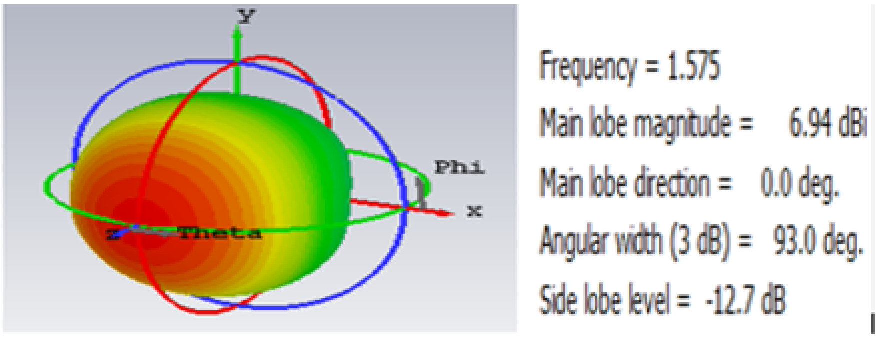
a)



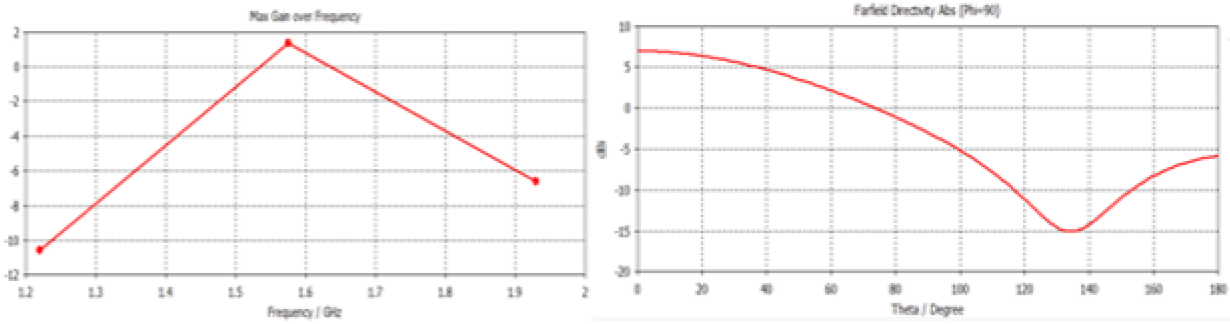
b)

Figure 5.12: a) 3-D Radiation Pattern and b) Gain and directivity plot of LHCP at h = 1.8mm

The above Figure 5.12a shows the radiation pattern plot of LHC polarized micro strip antenna. From this one can observe an antenna is a directional antenna. In this case at resonant frequency the main lobe magnitude is 7 dBi and its direction is zero degree. Figure 5.12b plot shows the maximum gain and far field directivity of the antenna. The maximum gain at operating frequency (i.e. 1.575 GHz) is 1.59 dB and the main lobe direction directivity is 7 dBi.



a)



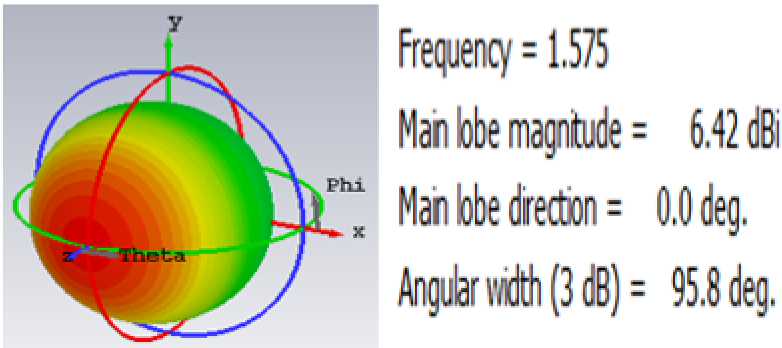
b)

Figure 5.13: a) 3-D Radiation Pattern and b) Gain and directivity plot of RHCP at h = 1.8m

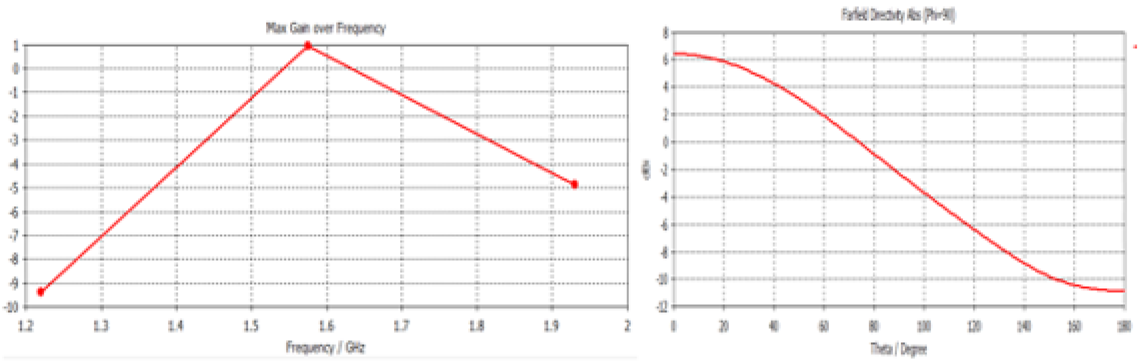
The above Figure 5.13a shows the radiation pattern plot of RHC polarized micro strip antenna. From this one can observe that an antenna is a directional antenna. In this case at resonant frequency the main lobe magnitude is 6.94 dBi and its direction is zero degree. Figure 5.13b plot shows the maximum gain and far field directivity of the antenna. The maximum gain at operating frequency (i.e. 1.575 GHz) is 1.35 dB and the main lobe direction directivity is 6.94 dBi.

Table 5.2: Performance comparison and Results summary of different polarization at h =1.8mm

Quantity	RHCP	LHCP	HP	VP
Return loss(dB)	−32	−15.87	−10.576	−17.6
Directivity(dBi)	6.94	7	6.44	6.93
Gain(dB)	1.35	1.59	0.534	1.24
Bandwidth efficiency(%)	4.12	3.39	2.19	4.19
Beam-width(degree)	93	92.8	95.4	93
VSWR	1.0526	1.383	1.84	1.3047



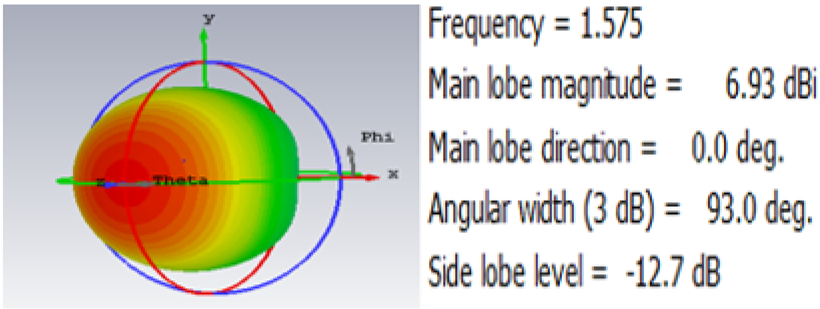
a)



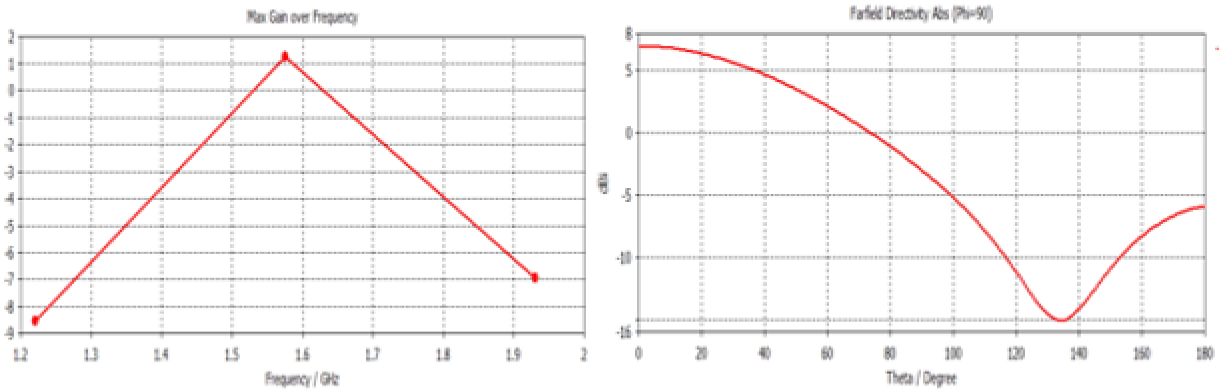
b)

Figure 5.14: a) 3-D Radiation Pattern and b) Gain and directivity plot of HP at h = 2mm

The above Figure 5.14a shows the radiation pattern plot of horizontally polarized micro strip antenna. From this one can observe an antenna is a directional antenna. In this case at resonant frequency the main lobe magnitude is 6.42 dBi and its direction is zero degree. Figure 5.14b plot shows the maximum gain and far field directivity of the antenna. The maximum gain at operating frequency (i.e. 1.575 GHz) is 0.534 dB and the main lobe direction directivity is 6.42 dBi.



a)



b)

Figure 5.15: a) 3-D Radiation Pattern and b) Gain and directivity plot of VP at h = 2mm

The above Figure 5.15a shows the radiation pattern plot of vertically polarized micro strip antenna. From this one can observe an antenna is a directional antenna. In this case at resonant frequency the main lobe magnitude is 6.92 dBi and its direction is zero degree. Figure 5.15b plot shows the maximum gain and far field directivity of the antenna. The maximum gain at operating frequency (i.e. 1.575 GHz) is 1.74 dB and the main lobe direction directivity is 6.92 dBi.

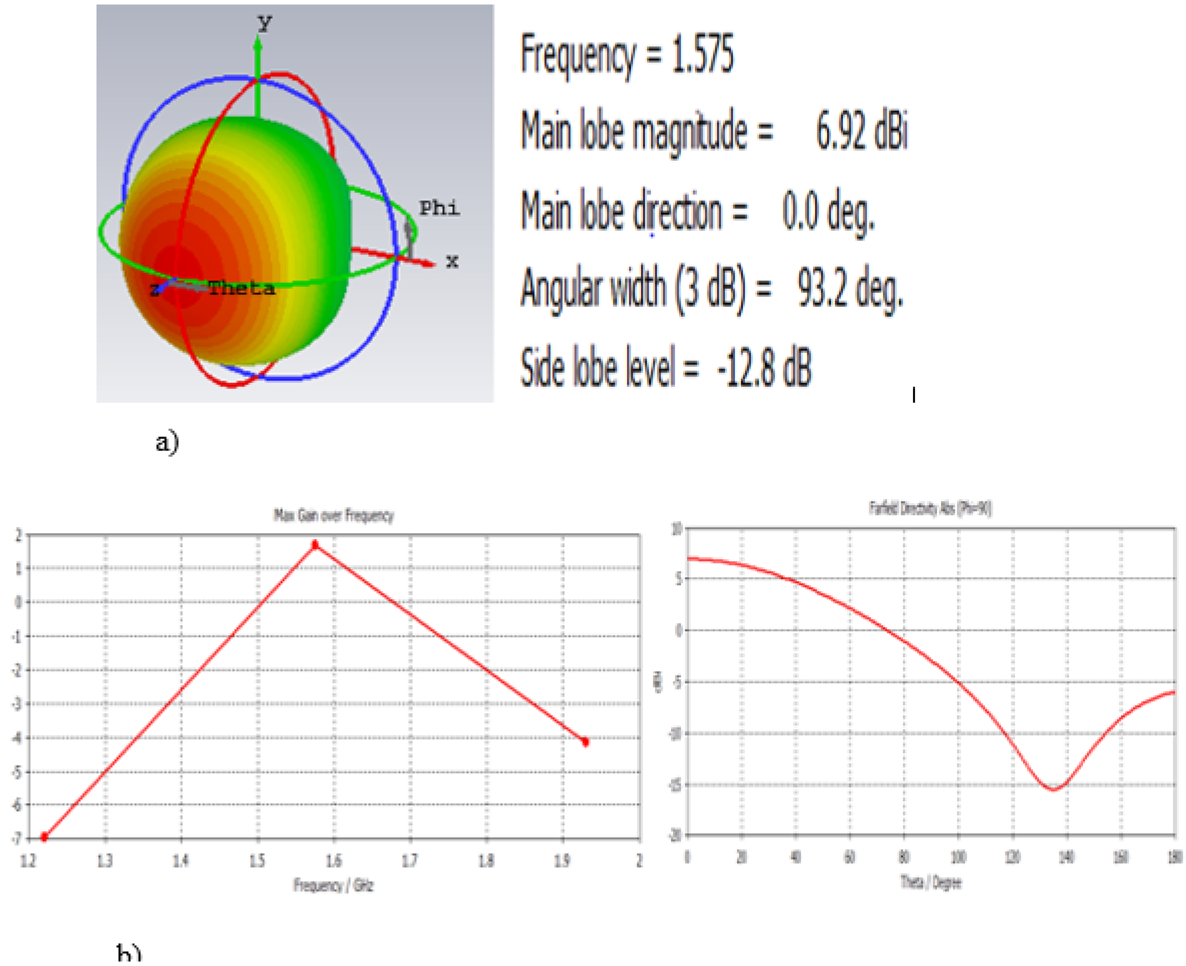
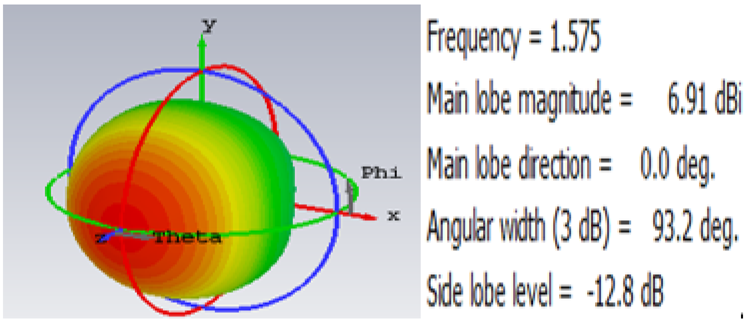
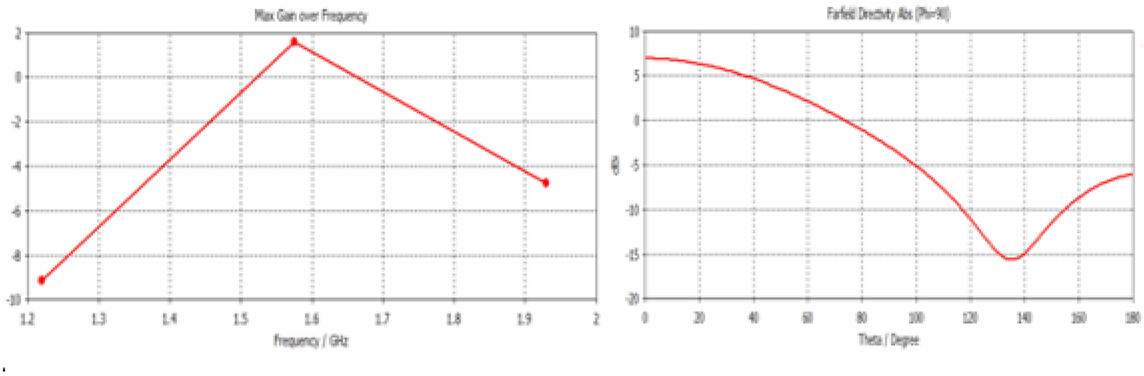


Figure 5.16: a) 3-D Radiation Pattern and b) Gain and directivity plot of LHCP at h = 2mm

The above Figure 5.16a shows the radiation pattern plot of LHC polarized micro strip antenna. From this one can observe an antenna is a directional antenna. In this case at resonant frequency the main lobe magnitude is 6.92 dBi and its direction is zero degree. Figure 5.16b plot shows the maximum gain and far field directivity of the antenna. The maximum gain at operating frequency (i.e. 1.575 GHz) is 1.69 dB and the main lobe direction directivity is 6.92 dBi.



a)



b)

Figure 5.17: a) 3-D Radiation Pattern and b) Gain and directivity plot of RHCP at h = 2mm

The above Figure 5.17a shows the radiation pattern plot of RHC polarized micro strip antenna. From this one can observe an antenna is a directional antenna. In this case at resonant frequency the main lobe magnitude is 6.91 dBi and its direction is zero degree. Figure 5.17b plot shows the maximum gain and far field directivity of the antenna. The maximum gain at operating frequency (i.e. 1.575 GHz) is 1.59 dB and the main lobe direction directivity is 6.91 dBi.

Table 5.3: Performance comparison and Results summary of different polarization at h = 2mm

Quantity	RHCP	LHCP	HP	VP
Return loss(dB)	−37.92	−33.601	−18.06	−31.2
Directivity(dBi)	6.91	6.92	6.92	6.42
Gain(dB)	1.59	1.69	0.958	1.74
Bandwidth efficiency(%)	4.36	4.28	4.19	4.75
Beam-width(degree)	93.2	93.2	95.8	93
VSWR	1.0257	1.04	1.056	1.286

5.4.3 Simulated Result and Discussion on substrate material RT/Duroid 6006

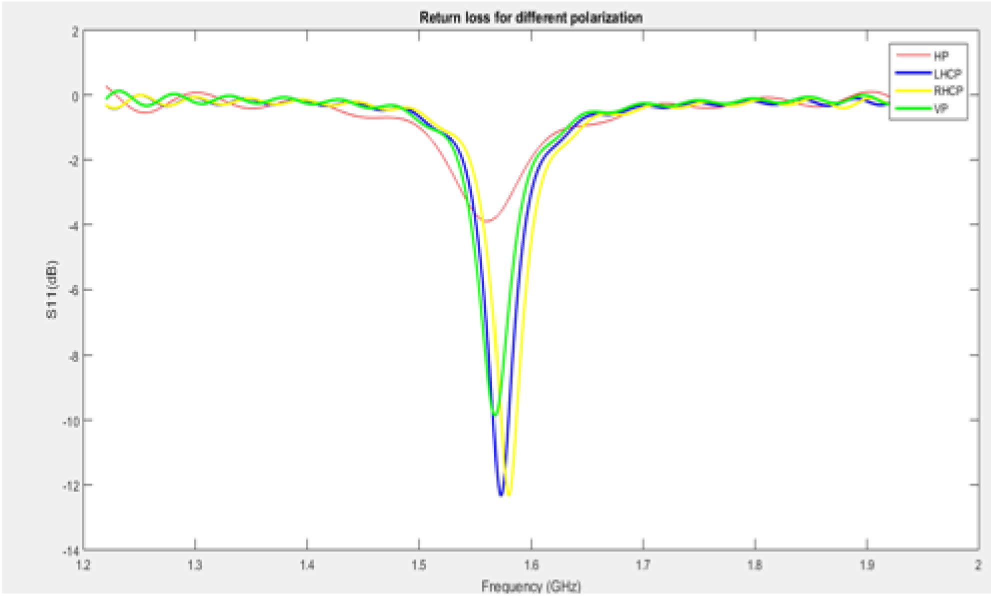


Figure 5.18: S11 (Return loss) parameter plot for different polarization at h = 1.6mm

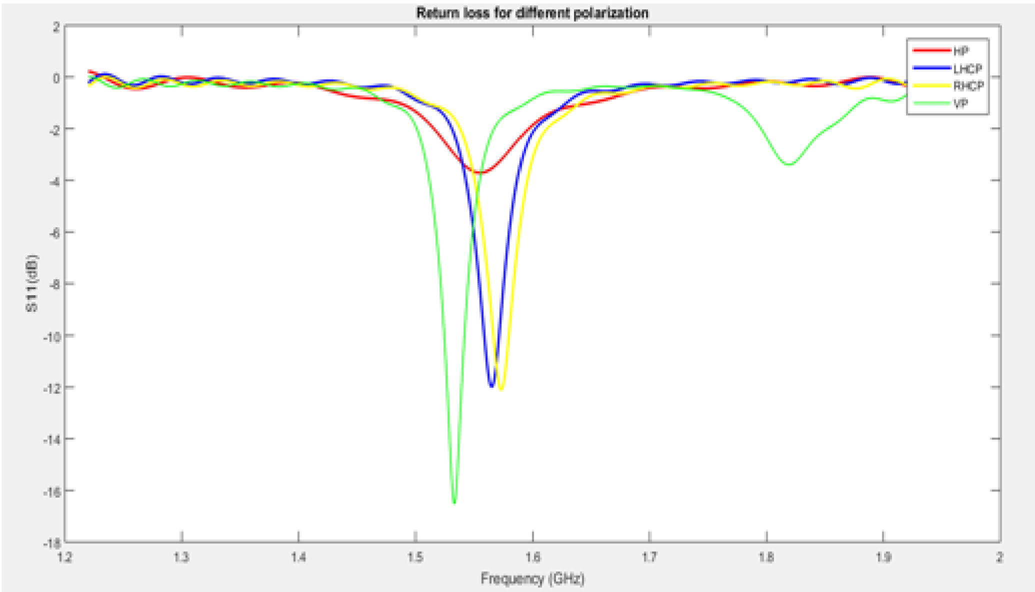


Figure 5.19: S11 (Return loss) parameter plot for different polarization at h = 1.8mm

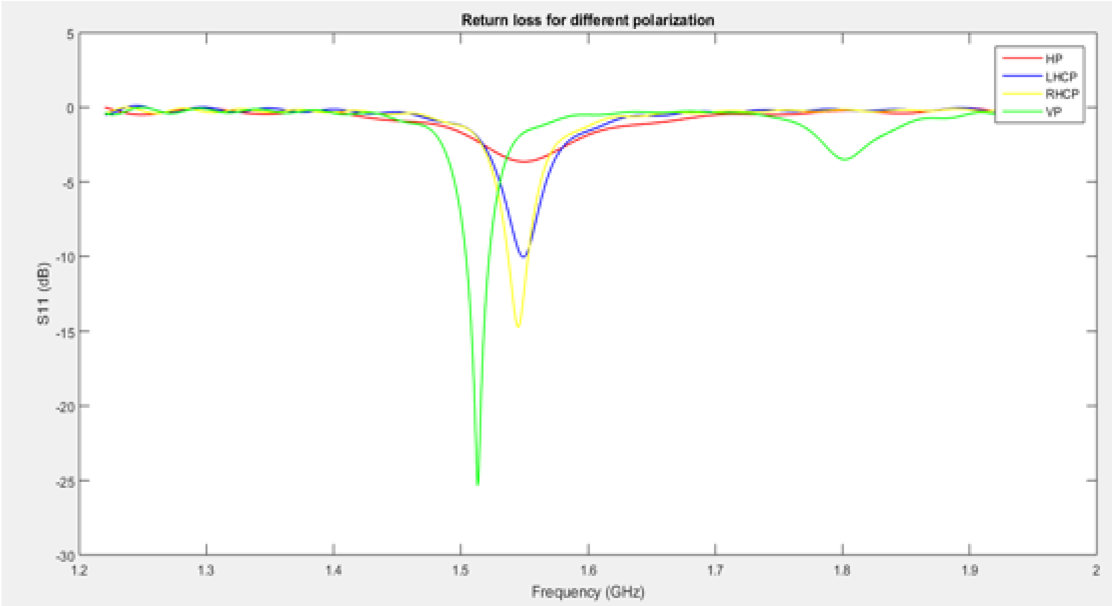
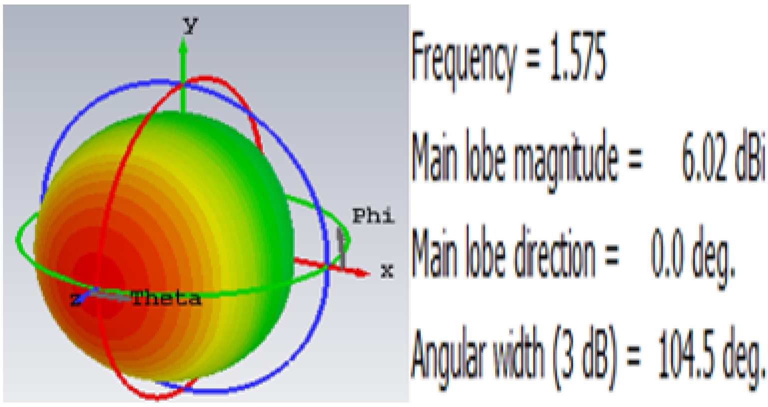
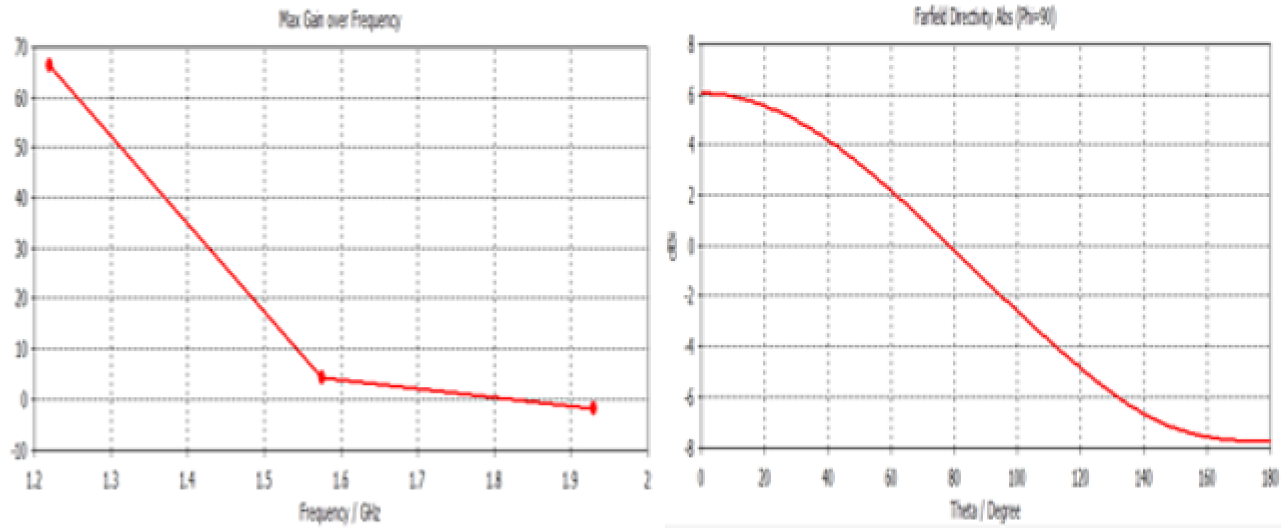


Figure 5.20: S11 (Return loss) parameter plot for different polarization at h = 2mm



a)



b)

Figure 5.21: a) 3-D Radiation Pattern and b) Gain and directivity plot for HP at h = 1.6mm

The above Figure 5.21a shows the radiation pattern plot of horizontal polarized micro strip antenna. In this case at resonant frequency the main lobe magnitude is 6.02dBi and its direction is zero degree. Figure 5.21b plot shows the maximum gain and far field directivity of an antenna, from this one can observe the gain value at operating frequency (i.e. 1.575 GHz) is 4.14 dB and the main lobe direction directivity is 6.02dBi.

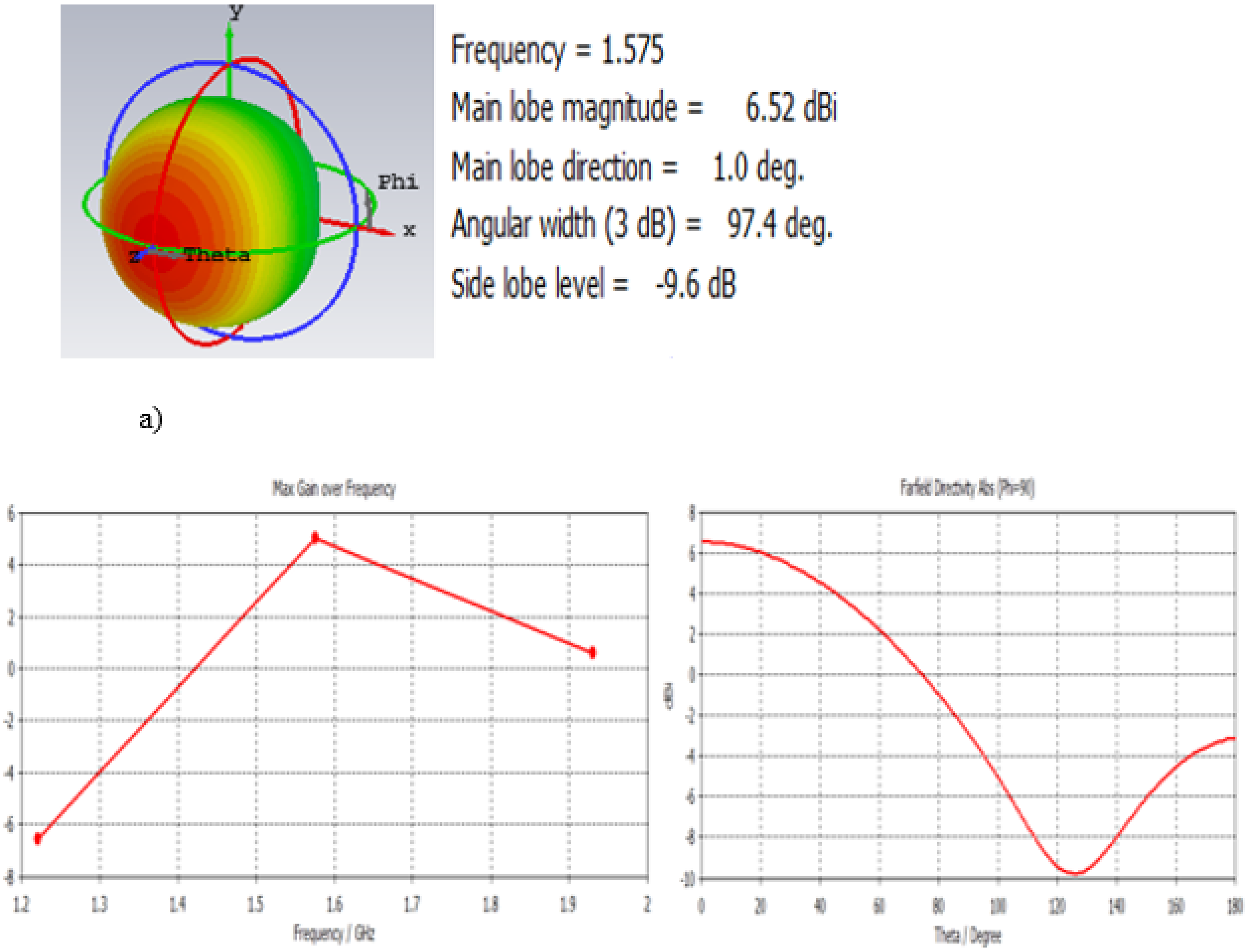
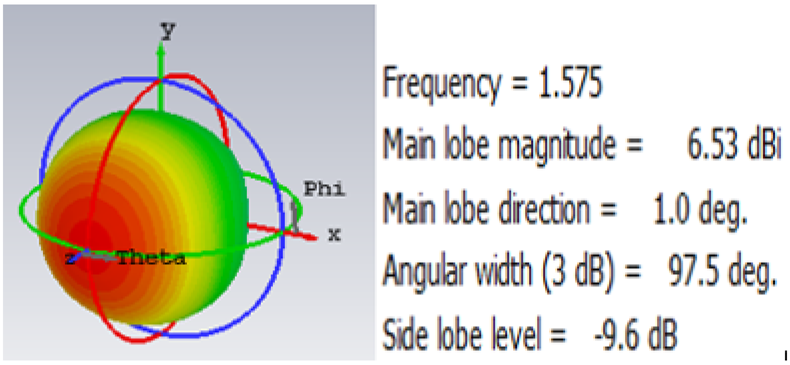
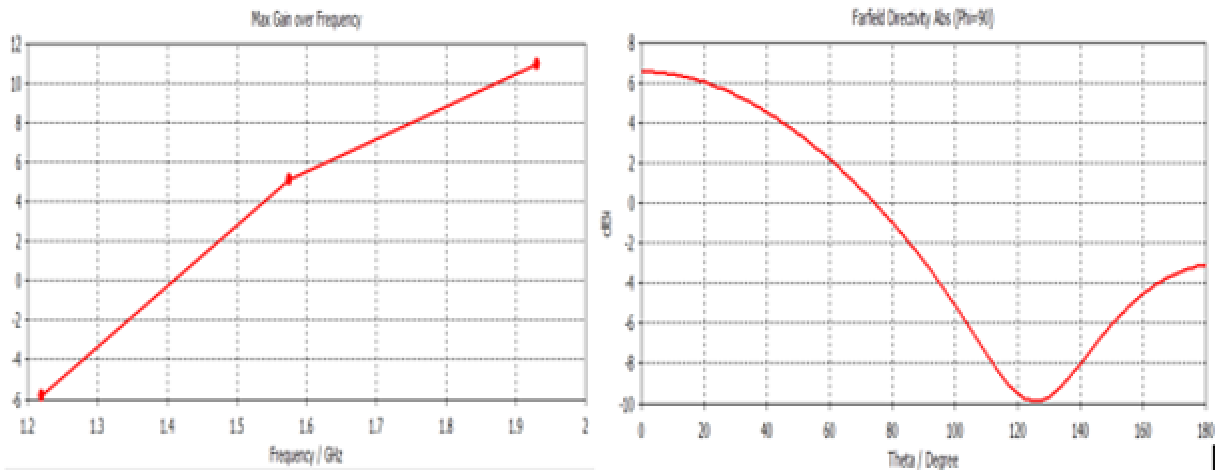


Figure 5.22: a) 3-D Radiation pattern and b) Gain and directivity plot for VP at h = 1.6mm

The above Figure 5.22a shows the radiation pattern plot of vertical polarized micro strip antenna. In this case at resonant frequency the main lobe magnitude is 6.52 dBi and its direction is one degree. Figure 5.22b plot shows the maximum gain and far field directivity of an antenna.The maximum gain at operating frequency (i.e. 1.575 GHz) is 5.02 dB and the main lobe direction directivity is 6.52 dBi



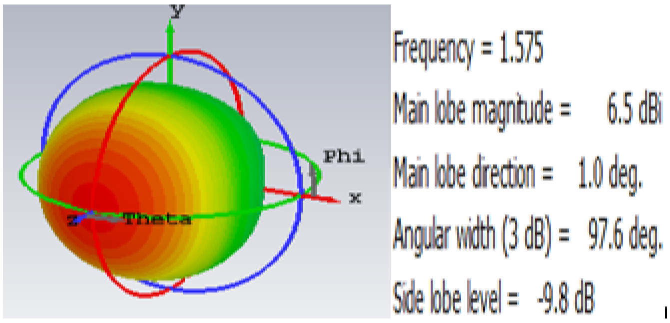
a)



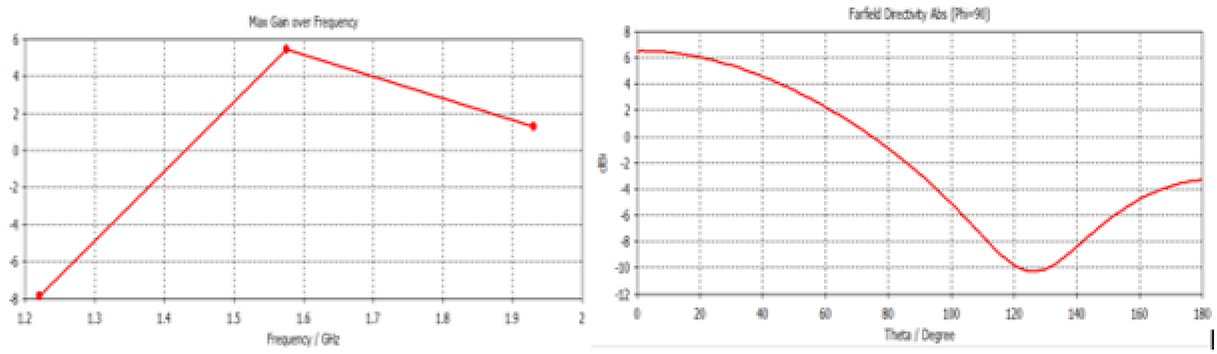
b)

Figure 5.23: a) 3-D Radiation pattern and b) Gain and directivity plot for LHCP at h = 1.6mm

The above Figure 5.23a shows the Radiation pattern plot of LHC polarized micro strip antenna. One can observe that an antenna is a directional antenna. In this case at resonant frequency the main lobe magnitude is 6.53 dBi and its direction is one degree. Figure 5.23b plot shows the maximum gain and far field directivity of an antenna. The maximum gain at operating frequency (i.e. 1.575 GHz) is 5.08 dB and the main lobe direction directivity is 6.53 dBi



a)



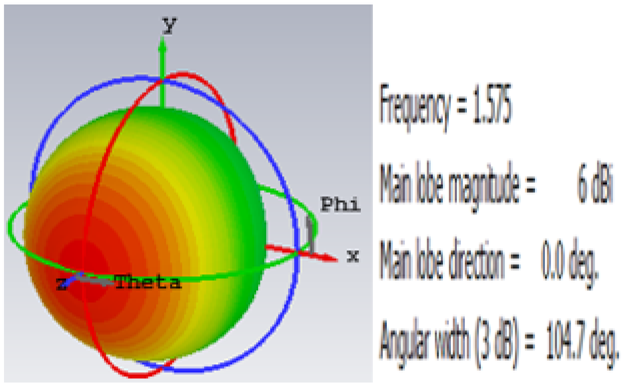
b)

Figure 5.24: a) 3-D Radiation pattern and b) Gain and directivity plot for RHCP at h = 1.6mm

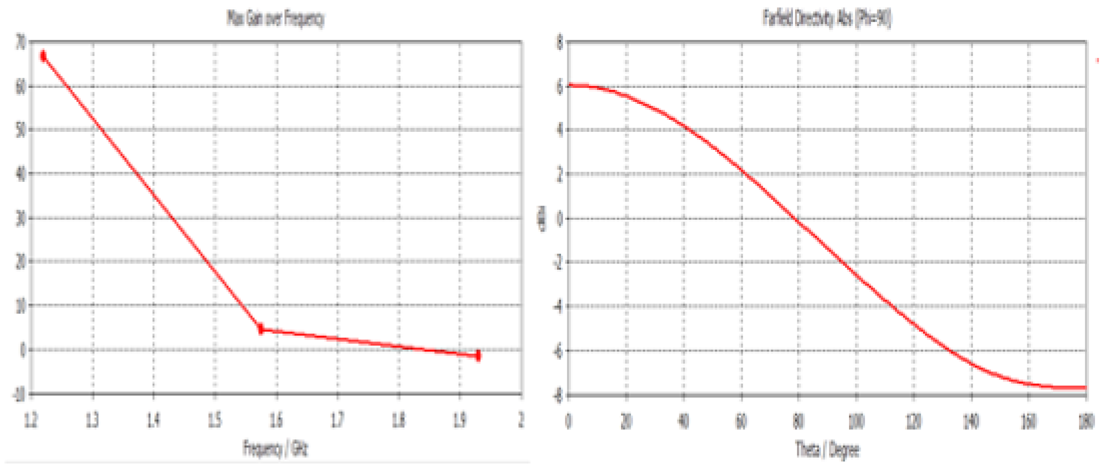
The above Figure 5.24a shows the radiation pattern plot of RHC polarized micro strip antenna. In this case at resonant frequency the main lobe magnitude is 6.5dBi and its direction is one degree. Figure 5.24b plot shows the maximum gain and far field directivity of an antenna, from this one can observe the gain value at operating frequency (i.e. 1.575 GHz) is 5.081 dB and the main lobe direction directivity is 6.5dBi

Table 5.4: Performance comparison and Results summary of different polarization at h =1.6mm

Quantity	RHCP	LHCP	HP	VP
Return loss(dB)	−12.0287	−12.0287	−3.89	−9.82
Directivity(dBi)	6.5	6.53	6.02	6.52
Gain(dB)	5.081	5.08	4.14	5.02
Bandwidth efficiency(%)	1.37	1.37	–	–
Beam-width(degree)	97.6	97.5	104.5	97.4
VSWR	1.668	1.66	4.53	1.95



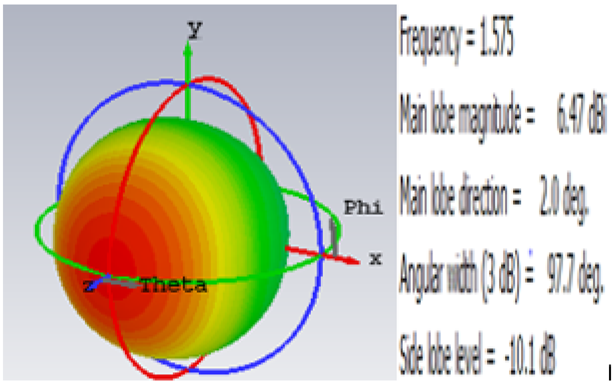
a)



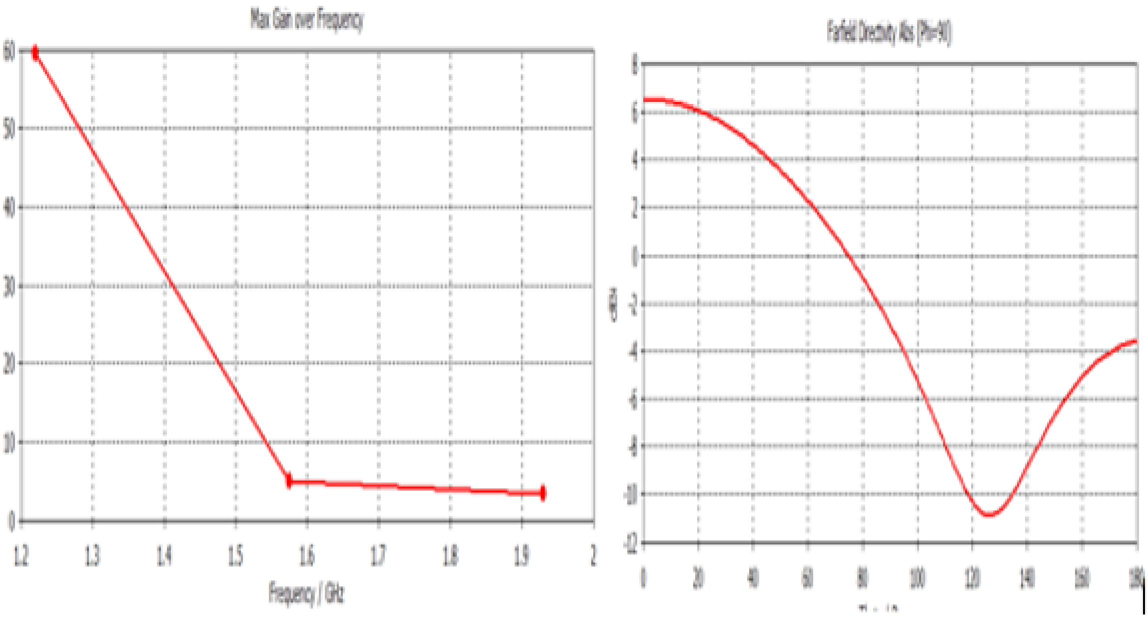
b)

Figure 5.25: a) 3-D Radiation pattern and b) Gain and directivity plot for HP at h = 1.8mm

The above Figure 5.25a shows the radiation pattern plot of horizontal polarized micro strip antenna. In this case at resonant frequency the main lobe magnitude is 6dBi and its direction is zero degree. Figure 5.25b plot shows the maximum gain and far field directivity of an antenna, from this one can observe the gain value at operating frequency (i.e. 1.575 GHz) is 4.43 dB and the main lobe direction directivity is 6dBi



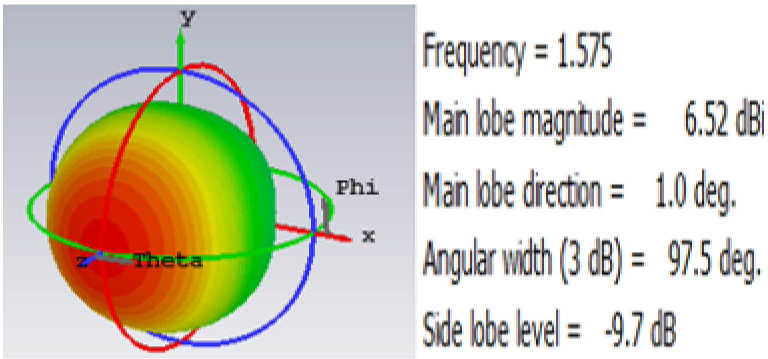
a)



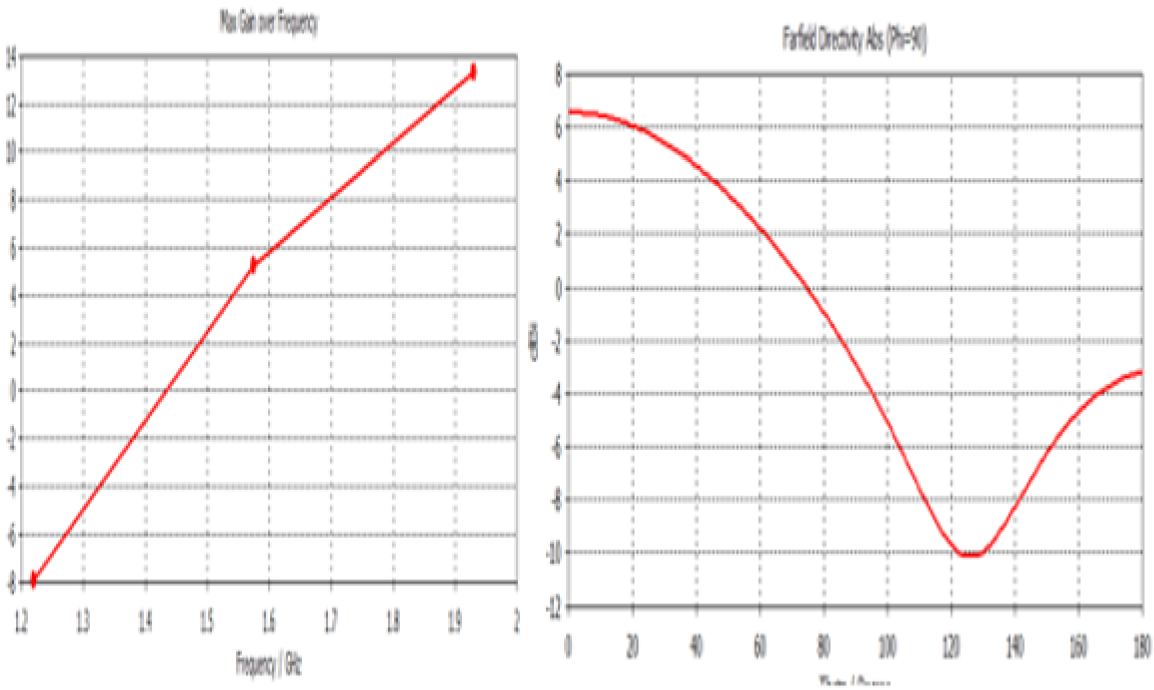
b)

Figure 5.26: a) 3-D Radiation Pattern and b) Gain and directivity of VP at h = 1.8mm

The above Figure 5.26a shows the radiation pattern plot of vertical polarized micro strip antenna. In this case at resonant frequency the main lobe magnitude is 6.47dBi and its direction is two degree. Figure 5.26b plot shows the maximum gain and far field directivity of an antenna, from this one can observe the gain value at operating frequency (i.e. 1.575 GHz) is 5.01 dB and the main lobe direction directivity is 6.4dBi



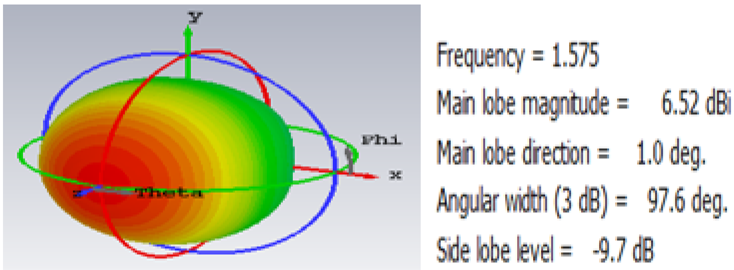
a)



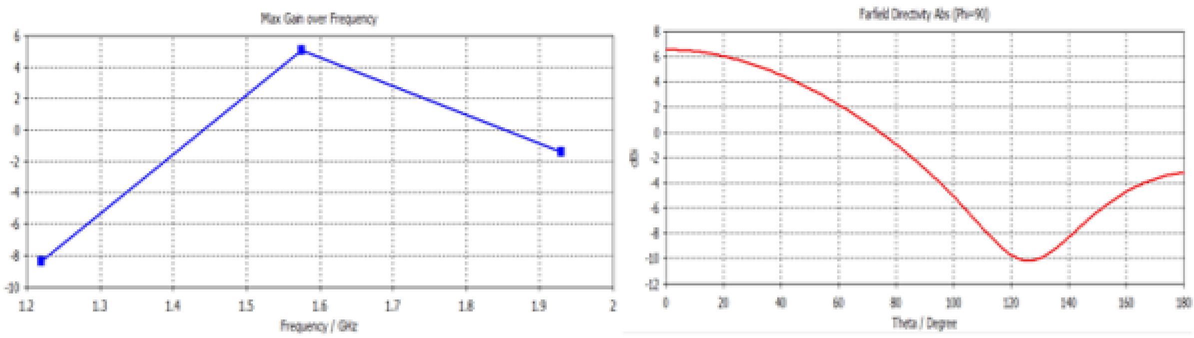
b)

Figure 5.27: a) 3-D Radiation Pattern and b) Gain and directivity of LHCP at h = 1.8mm

The above Figure 5.27a shows the radiation pattern plot of LHC polarized micro strip antenna. In this case at resonant frequency the main lobe magnitude is 6.52dBi and its direction is one degree. Figure 5.27b plot shows the maximum gain and far field directivity of an antenna, from this one can observe the gain value at operating frequency (i.e. 1.575 GHz) is 5.23 dB and the main lobe direction directivity is 6.52dBi



a)



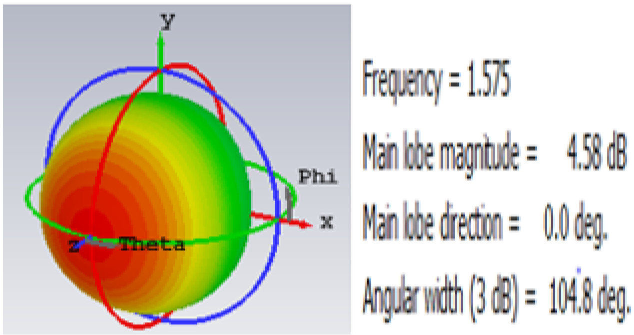
b)

Figure 5.28: a) 3-D Radiation Pattern and b) Gain and directivity of RHCP at h = 1.8mm

The above Figure 5.28a shows the radiation pattern plot of RHC polarized micro strip antenna. In this case at resonant frequency the main lobe magnitude is 6.52dBi and its direction is one degree. Figure 5.28b plot shows the maximum gain and far field directivity of an antenna, from this one can observe the gain value at operating frequency (i.e. 1.575 GHz) is 5.2dB and the main lobe direction directivity is 6.52dBi

Table 5.5: Performance comparison and Results summary of different polarization at h =1.8mm

Quantity	RHCP	LHCP	HP	VP
Return loss(dB)	−11.92	−12	−3.48	−16.41
Directivity(dBi)	6.52	6.53	6	6.47
Gain(dB)	5.2	5.23	4.43	5.01
Bandwidth efficiency(%)	1.29	1.37	–	1.77
Beam-width(degree)	96.7	97.5	104.7	97.7
VSWR	1.672	1.67	4.75	1.12



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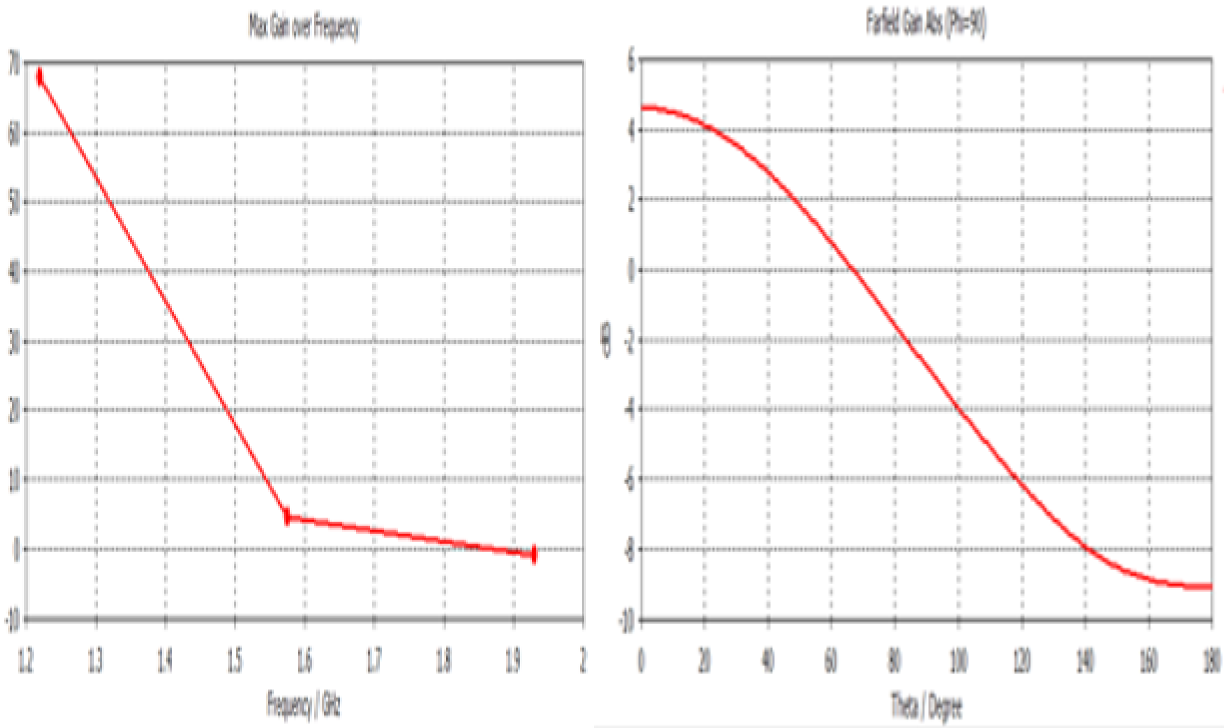
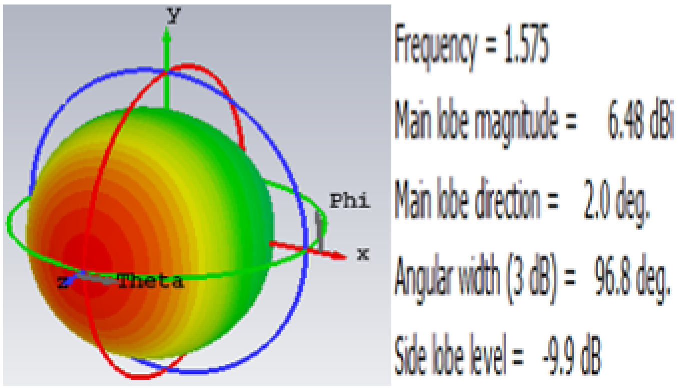


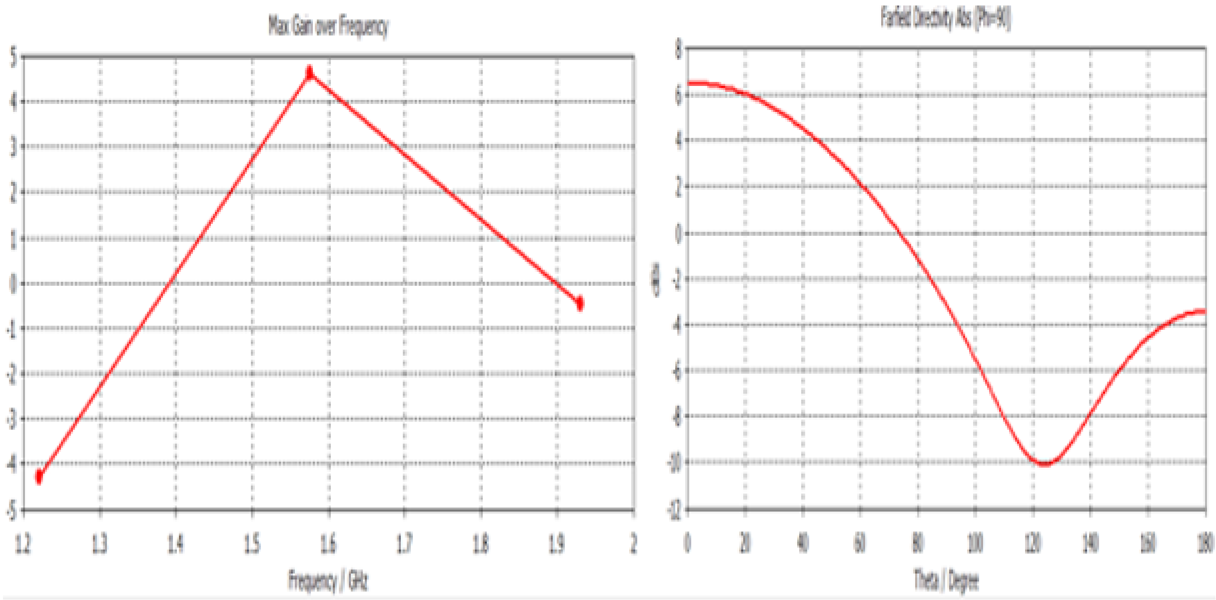
b)

Figure 5.29: a) 3-D Radiation Pattern and b) Gain and directivity of HP at h = 2mm

The above Figure 5.29a shows the radiation pattern plot of horizontal polarized micro strip antenna. In this case at resonant frequency the main lobe magnitude is 4.58dBi and its direction is zero degree. Figure 5.29b plot shows the maximum gain and far field directivity of an antenna, from this one can observe the gain value at operating frequency (i.e. 1.575 GHz) is 5.99dB and the main lobe direction directivity is 4.58dBi



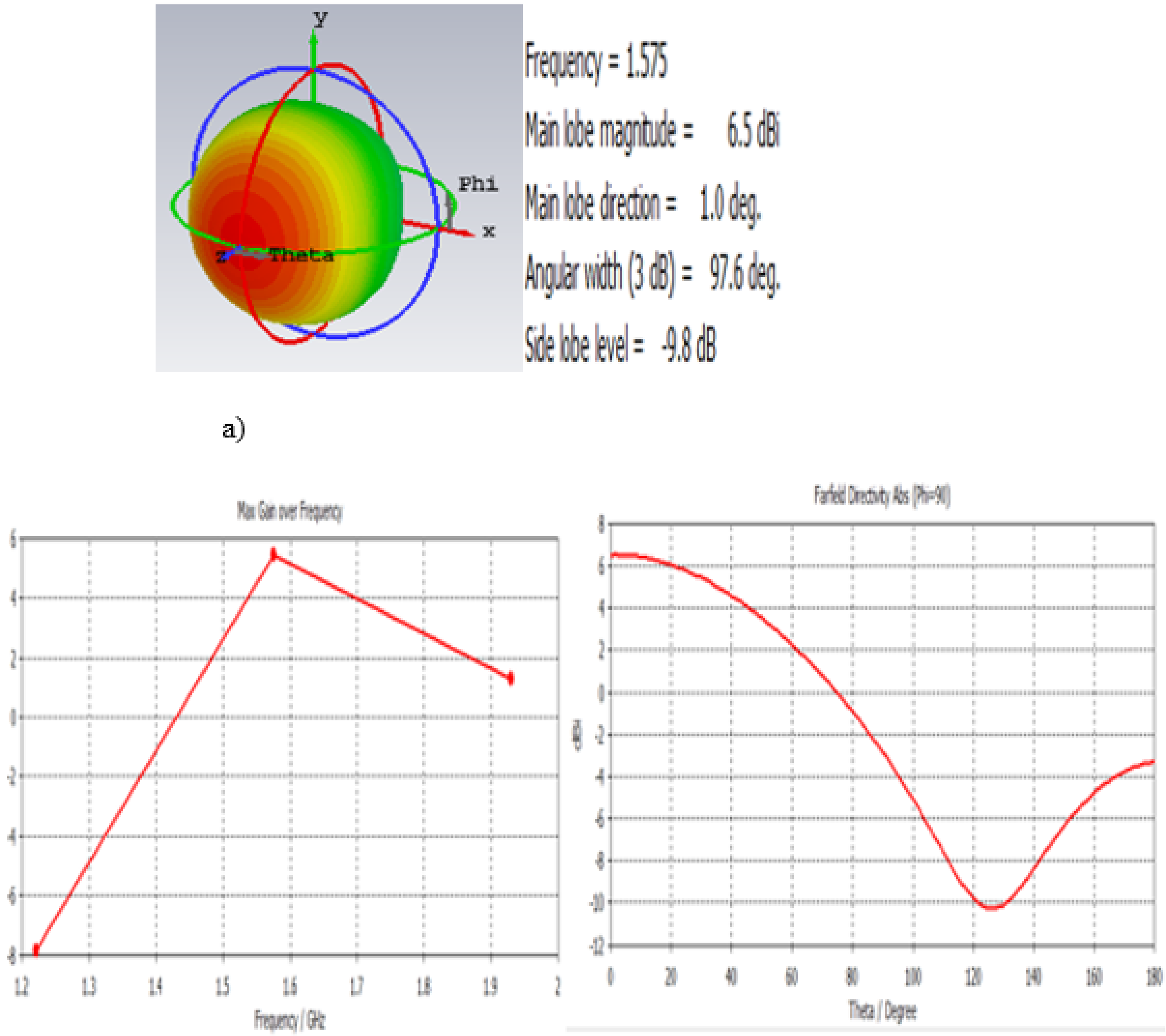
a)



b)

Figure 5.30: a) 3-D Radiation Pattern and b) Gain and directivity of VP at h = 2mm

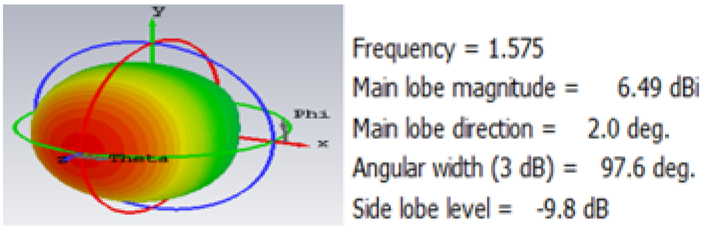
The above Figure 5.30a shows the radiation pattern plot of vertically polarized micro strip antenna. In this case at resonant frequency the main lobe magnitude is 6.48dBi and its direction is two degree. Figure 5.30b plot shows the maximum gain and far field directivity of an antenna, from this one can observe the gain value at operating frequency (i.e. 1.575 GHz) is 4.6dB and the main lobe direction directivity is 6.48dBi



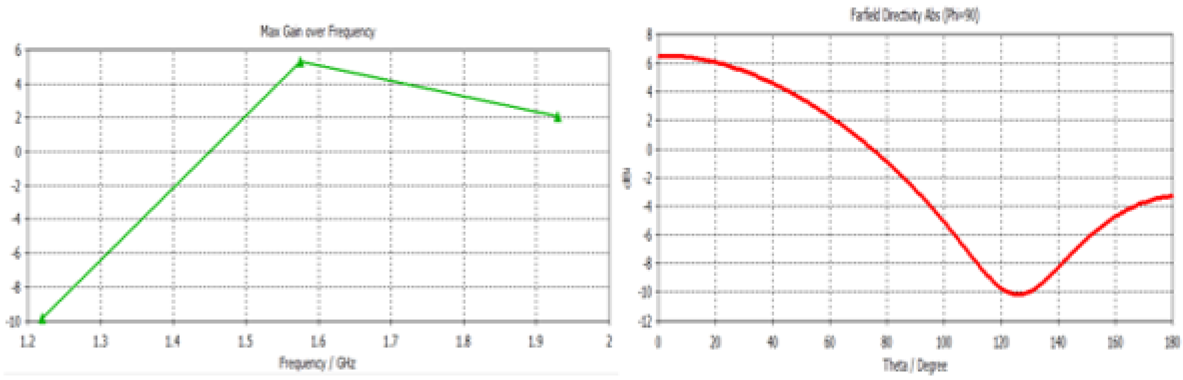
b)

Figure 5.31: a) 3-D Radiation Pattern and b) Gain and directivity of LHCP at h = 2mm

The above Figure 5.31a shows the radiation pattern plot of LHP polarized micro strip antenna. In this case at resonant frequency the main lobe magnitude is 6.5dBi and its direction is one degree. Figure 5.31b plot shows the maximum gain and far field directivity of an antenna, from this one can observe the gain value at operating frequency (i.e. 1.575 GHz) is 5.44dB and the main lobe direction directivity is 6.5dBi



a)



b)

Figure 5.32: a) 3-D Radiation Pattern and b) Gain and directivity of RHCP at h = 2mm

The above Figure 5.32a shows the radiation pattern plot of RHC polarized micro strip antenna. In this case at resonant frequency the main lobe magnitude is 6.49dBi and its direction is two degree. Figure 5.32b plot shows the maximum gain and far field directivity of an antenna, from this one can observe the gain value at operating frequency (i.e. 1.575 GHz) is 5.27dB and the main lobe direction directivity is 6.49dBi

Table 5.6: Performance comparison and Results summary of different polarization at h =2mm

Quantity	RHCP	LHCP	HP	VP
Return loss(dB)	−14.692	−10.02	−3.64	−21.41
Directivity(dBi)	6.49	6.49	5.99	6.47
Gain(dB)	5.27	5.44	4.6	4.58
Bandwidth efficiency(%)	1.61	–	–	1.86
Beam-width(degree)	97.6	97.6	104.8	96.8
VSWR	1.445	1.92	4.84	1.286

Chapter 6

CONCLUSION AND RECOMMENDATION FOR FUTURE WORK

6.1 Conclusion

Linearly and circularly polarized micro strip antenna has been designed and simulated for L-Band. Background information with regard to micro strip patch antenna has been presented , followed by a literature review on micro strip antenna and how it can be implemented to benefits the desired application. A single micro strip patch antenna has been successfully designed according to its design specifications, simulated and analyzed. The performance of the designed antenna was analyzed in terms of bandwidth, return loss, VSWR and radiation pattern. In this section, we will highlight some of the unique properties of the design. A clear improvement of the gain,directivity and patterns of micro strip antenna on high dielectric constant substrate (i.e. FR-4 and RT/duroin 6006) has been showed. The design was optimized to meet the best possible result by varying substrate material and the thickness of substrate material. (The use of rectangular patch geometry provided good directivity and simplicity in design process by using micro strip feed line techniques.) Based on the simulation obtained, Polarized micro strip antenna successfully simulated and designed at 1.575GHz frequency using computer simulation technology (CST) version 16. The computer simulation shows the right hand circular polarization has high gain (as high as 5.22dB), directivity 6.49dBi and the S_{11} parameter for antenna has a magnitude of much less than -10 dB at the operating frequency of 1.575GHz, which indicate that the polarization of the antenna does not expense much loss while transmitting signal. As for the voltage standing wave ratio(VSWR), it is not ideal, however, a value of under 2 which is considered acceptable was obtained and the level of mismatch is seen not to be high.

6.2 Recommendation for Future Work

In this thesis work different types of techniques for circular polarization have not been tested. Hence, Truncated corner is used for circular polarization but other techniques such as dual feed may give better results. The proper position to terminate the feed line also affects the performance of the antenna. As understand different type of feed technique affects the performance of the antenna. Thus need to be further investigation ,micro strip feed line is considered in this thesis and the results showed the performance of the antenna is good. Further research my focus on study of dielectric covers effect on the performance of antennas. In future through other different type of feed techniques can be used to evaluate the overall performance of the antenna without missing the optimized parameters in the action. Moreover, different shapes of micro strip patches such as square, circular and hexagonal shape can be used for further study.

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Appendix A :Mat lab codes for rectangular micro strip antenna

%Program to calculate the parameters to design a rectangular patch antenna

%the user have to feed the values of frequency, dielectric constant, and

%height of the dielectric.

%program will calculate automatically the width and length of the patch

%and the width and length of the transition and transmission feed line.

%and the width and the length of the ground plane

f = input('input frequency f in GHz ');

Er = input ('input dielectric constant of the substrate ');

h = input('input height of substrate h in mm: ');

h=h/1000;

f=f*1e9; % turn frequency to Hz

c = 3e8; % speed of light

% calculating Width and Length of the Patch

W = (c / (2 * f)) * ((2 / (Er + 1))exp0.5);

$Er_{eff} = (Er+1)/2 + ((Er-1)/2) * (1/(sqrt(1+(12*(h/W)))));$

$L_{eff} = c/(2*f*sqrt(Er_{e}ff));$

$a1 = (Er_{eff} + 0.3) * ((W/h) + 0.264); a2 = (Er_{eff} - 0.258) * ((W/h) + 0.8); delta_L = (0.412 * (a1/a2)) * h; L = L_{eff} - 2_L;$

$str = ['widthofthepatch =', num2str(W * 1000), 'mm'str = ['lengthofthepatch =', num2str(L * 1000), 'mm$

%Calculating the input impedance of the patch

$Zo = 90 * Er \exp 2 * (L/W) \exp 2/(Er-1);$

%Calculating the strip transition line

$Zt = sqrt(50 * Zo);$

$a3 = exp(Zt * sqrt(Er)/60);$

$p = -4 * h * a3;$

$q = 32 * h \exp 2;$

Appendix B :CST Micro wave Studio

Welcome to CST DESIGN STUDIO, the powerful and easy-to-use schematic design tool built for fast synthesis and optimization of complex systems. The tight integration with our electromagnetic field simulators allows considering systems at different levels of detail and takes into account various effects. CST DESIGN STUDIO is part of the CST STUDIO SUITE. Please refer to the CST STUDIO SUITE Getting Started manual first. The following explanations assume that you already installed the software and familiarized yourself with the basic concepts of the user interface. Within CST STUDIO SUITE, CST DESIGN STUDIO appears in two different flavors:

•As a stand-alone tool. It runs independently, without any connections to a specific field simulator project.

•As an associated view to a CST MICROWAVE STUDIO, CST CABLE STUDIO , CST PCB STUDIO, CST EM STUDIO or CST PARTICLE STUDIO project. It represents the schematic view that shows the circuit level description of the current field simulator project.

All steps necessary to set up a simulation in CST DESIGN STUDIO are identical for both flavors described above.

What is CST DESIGN STUDIO ?

CST DESIGN STUDIO is a schematic design tool for system level simulation. Several component libraries are available based on analytical and semi-analytical models. Library models can be expanded by means of field simulators of CST STUDIO SUITE. Measured data are taken into account as TOUCHSTONE or SPICE blocks and the support of the IBIS standard allows an easy I/O device description. A vendor library of linear and non-linear components helps to easily setup a design. CST DESIGN STUDIO (CST DS) is tightly integrated to various electromagnetic (EM) and multi-physics field simulation tools of CST STUDIO SUITE. A hierarchical task concept and a powerful 3D layout generator make CST DS a unique product for system assembly and modeling (SAM). SAM technology is able to extract a complex 3D system by connecting its individual components on a schematic level.

Main applications for CST DESIGN STUDIO

CST DS users will take advantage of its versatility and the seamless work flow between a circuit simulator and electromagnetic (or multi-physics) field simulators. Main applications are the following:

•Antenna module design with system performance optimization including matching/driver networks

•Microwave/RF device and system design, applicable for filters, diplexers, phase shifters, high performance RF amplifiers etc.

•Signal Integrity (SI) simulation of packages, 3D connectors and cables, system channels including high speed and control PBCs

•EMC/EMI analysis of complex systems, considering radiation phenomena from and into connected cable harnesses

•Multi-physics simulations like resonator optimizations to compensate the resonance frequency shift due to temperature depending deformation of the resonator geometry, induced by EM material losses. Figure 6.1 shows overview of user interface's structure,if one are use CST MWS he/she see a main window similar to the one shown below immediately after one have started the program.

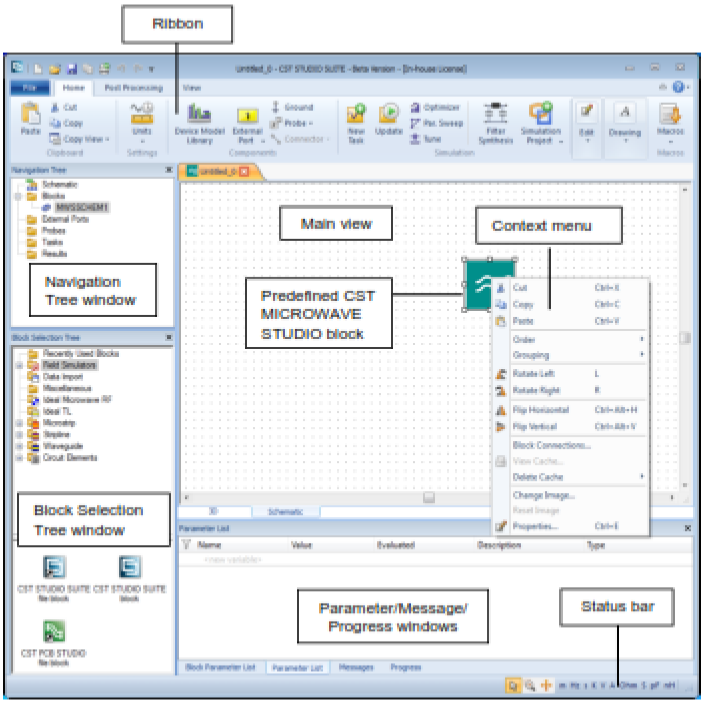

Figure 6.1: Work flow of CST design suite