DESIGN AND ANALYSIS OF POLARIZATION RECONFIGURABLE MICROSTRIP PATCH ANTENNAS

A Thesis submitted with partial fulfillment of Requirements for the degree of

Master of Technology

in

Communication and Networks

by

Ashish Kumar Sahu

Roll No: 213EC5249

Department of Electronics and Communication Engineering

National Institute of Technology Rourkela

Rourkela, Odisha, 769008

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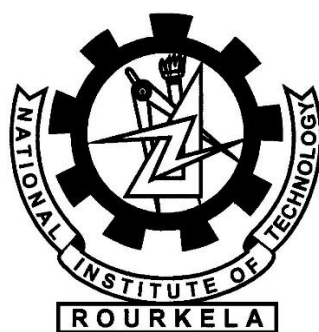Master of Technology

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Under the Guidance of

Dr. Santanu Kumar Behera

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DEPARTMENT OF ELECTRONICS AND COMMUNICATION

ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA

ROURKELA- 769008, ODISHA, INDIA

CERTIFICATE

This is to certify that the work in this thesis entitled "**DESIGN AND ANALYSIS OF POLARIZATION RECONFIGURABLE MICROSTRIP PATCH ANTENNAS**" by Mr. **ASHISH KUMAR SAHU** is a record of an original research work carried out by his during 2014-2015 under my supervision and guidance in partial fulfilment of the requirement for the award of the degree of Master of Technology in Electronics and Communication Engineering (Communication and Networks), National Institute of Technology, Rourkela. Neither this thesis nor any part of it, to the best of my knowledge, has been submitted for any degree or diploma elsewhere.

Place: NIT Rourkela

Date: 19th May 2015

Dr. Santanu Kumar Behera
Associate Professor

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA

ROURKELA- 769008, ODISHA, INDIA

Declaration

I certify that

a) The work comprised in the thesis is original and is done by myself under the supervision of my supervisor.

b) The work has not been submitted to any other institute for any degree or diploma.

c) I have followed the guidelines provided by the Institute in writing the thesis.

d) Whenever I have used materials (data, theoretical analysis, and text) from other sources, I have given due credit to them in the text of the thesis and giving their details in the references.

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Ashish Kumar Sahu

Roll No 213EC5249

Acknowledgements

Abstract

The objective of work is to design and develop Polarization Reconfigurable Microstrip patch antennas which radiate electromagnetic wave of various orthogonal patterns i.e. VLP, HLP, LHCP and RHCP. A progression of parametric study was done to get that how the features of the antenna depends on dimensions and material of geometry. Simulation of antenna has to be done by using CST microwave studio and HFSS. Antennas of various geometry have to be simulated and fabricated which radiates various orthogonal patterns of electromagnetic wave. The first antenna is to design and develop dual feed reconfigurable circularly polarized microstrip patch antenna feeding with microstrip line. Antenna consists of metallic square radiating patch with thin rectangular slot and dielectric substrate of permittivity 4.4. Radiating patch fed by microstrip line feeding. By using switch and two feedline antenna is capable to radiate RHCP and LHCP. The second antenna is to design and develop reconfigurable circularly polarized microstrip antenna with single feed line, feeding with Proximity coupled method. Antenna consists of metallic square ring radiating patch and two substrates of permittivity 1.06 and 4.4. Due to ring shape of radiating patch antenna is capable to radiate circularly polarized wave. Antenna is capable to radiate LHCP and RHCP with the help of proper switching action and reconfigurable feedline. The third design is to design and develop dual feed Quadri-Polarization States microstrip patch antenna feeding with microstrip line. Antenna consists of metallic square radiating patch and dielectric substrate of permittivity 2.65. Out of two feedline one is active and other should be isolated at a time. With the help of two feedline and 4 diodes antenna is capable to radiate VLP, HLP, LHCP, RHCP. On the patch two opposite corners are slotted and connect by using two PIN diodes. Due to slotted corner antenna is capable to radiate circularly polarized wave. The forth design is to design and develop polarization reconfigurable microstrip antenna with single feedline, feeding with microstrip line. Antenna consists of circular patch with U-slot at the center and two PIN diodes to make it as reconfigurable and dielectric substrate of permittivity 4.4. Antenna is capable to radiate electromagnetic wave of various pattern like LP, LHCP, RHCP. Various S-parameters, surface current distribution, axial ratio, and radiation patterns are shown for various antennas. Antennas are capable to radiate various orthogonal patterns which increase the diversity gain. Therefore, antenna have a features of multipath effects reduction i.e. reduction of fading and interference and antenna can be used as polarization diversity array.

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Chapter 1

Introduction

1.1 Overview

Wireless technology is very essential for human life. In most of the electronic device, wireless system are using. In wireless system, to radiate or receive EMW (electromagnetic wave) antenna is required. Antenna is very essential element for it. Antenna is a device which is used to couple the transmitter and receiver section in wireless communication. At transmitter section, antenna receives the electric power as input and converts it into the radio wave then radiate into free space. While in receiver section antenna receive radio wave from free space & convert back into the electric power.

There are such a large number of frameworks that uses antenna, for example, cellular phones, spacecraft, wireless phones, remote controlled television, radars, etc. Now a days wireless device demands the compact, small size, light weight, ease of installation. For that purpose we need antenna low profile. All this requirement can be fulfil by using microstrip patch antenna. Microstrip antenna is a low profile, light weight, narrow band antenna. It can easily manufacture by using printed circuit technology which consist of three layers. First layer is metallic layer in which radiating patch is fabricated by bonding particular shape. Second layer is dielectric substrate and third layer is metallic layer of ground plane. In some of microstrip antenna in place of dielectric substrate, dielectric spacers can be used which increase the bandwidth but coast also increases.

Microstrip antennas are mechanical rugged and low profile antenna and can easily manufactured on planar and nonplanar surfaces. Microstrip antenna size depends on operating wavelength generally $\lambda/2$. The size of antenna depends on operating frequency. As operating frequency increases size of antenna decreases. Therefore in microstrip antenna operating frequency should be greater than microwave frequency because if frequency is less size of antenna is very small which have no sense. The use of microstrip patch antenna is increasing day by day in industrial sector also because of its less expensive, ease of manufacture i.e. by using printed circuit technology. As increase research in the area of microstrip patch antenna it can be expect that in future all the conventional antennas can be replaced by microstrip patch antenna.

1.2 Objective

Here we design the microstrip antenna with polarization reconfigurable in which single antenna act as no of antennas by using the switch. Each antenna radiate different pattern so it increase the no of patterns and increase the diversity gain.

In many of application of polarization reconfigurable, microstrip antenna is used due to its low profile properties i.e. light weight, small size, ease of installation, conformability etc.

Antenna diversity, also known as special diversity or space diversity is wireless diversity scheme that uses number of antennas to improve the reliability and quality of wireless communication. Polarization reconfigurable antennas have the features of multipath effects reduction i.e. reduction of fading and interference due to increase in diversity gain.

The shape of the patch of microstrip antenna can be any of rectangular, circular, square, triangular, rings etc. Each of them has some theoretical design formula. The design of antenna is inventive where we study the invention of new antenna. By selecting the shape of antenna we can design reconfigurable antenna in term of polarization, frequency and pattern.

Aim of the work is to study the change of antenna performance with respect to various parameters of microstrip antenna. Simulation has to be done by using CST MW and HFSS software.

1.3 Outline

Chapter 1 consist of overview of microstrip antenna, reconfigurable technique and polarization diversity technique. This chapter also includes the objective of work and outline of thesis.

Chapter 2 consists of introduction of various parameters of microstrip antenna like gain. Directivity, radiation pattern, efficiency, bandwidth, field region which depend on antenna performance.

Chapter 3 consist of basics of microstrip antenna. It includes performance of microstrip antenna, radiation mechanism, advantage and disadvantage, major applications. Various feeding techniques are used with advantage and disadvantage of each technique. Most popular rectangular microstrip antenna discussed with various modelling techniques. Fringing

field and its effects on various parameters like length and width of patch and resonant frequency are discussed. Second most popular microstrip antenna i.e. circular patch antenna with various design equations are discussed in chapter.

Chapter 4 deals polarization of an antenna and radiating wave. It consist of various polarization techniques like VLP, HLP, LHCP, RHCP. This chapter deals conditions for various polarizations with polarization curve.

Chapter 5 explains the design and simulation of polarization reconfigurable antenna of various geometry. Various switching techniques are shown to switch various polarizations and to increase no pattern to increase diversity gain. Various simulation results and plots are explained to increase the performance of antenna. Antennas are simulated by using CST microwave studio and HFSS software.

Chapter 6 consist of conclusion and future work.

Chapter 2

Parameters of Antenna

There are various parameters used antenna and it changes with its application. Performance and quality of antenna is decided by number of parameters these are Gain, Bandwidth, Directivity, Efficiency, Aperture effect Radiation pattern etc. These parameters are explained in brief below

2.1 Directivity

Directivity of antenna is the ratio of maximum radiation intensity of test antenna to the average radiation intensity of test antenna [21], [24]. [26].

$$Directivity = \frac{\text{maximum radiation intensity of test antenna}}{\text{average radiation intensity of test antenna}}$$

With respect to isotropic radiator, directivity is defined as the ratio of maximum radiation intensity of test antenna to the radiation intensity of isotropic antenna i.e.

$$Directivity = \frac{\text{maximum radiation intensity of test antenna}}{\text{radiation intensity of isotropic antenna}}$$

If antenna is isotropic radiator then directivity is 1. If antenna is transmitting antenna then directivity in given angle represent the radiation intensity is maximum in that direction. Whereas, if it is receiving antenna then it shows the power efficiency in particular direction.

2.2 Gain

Gain of the antenna is the ratio of maximum radiation intensity from test antenna to the radiation intensity from isotropic antenna (lossless) with same power input [21], [24], [26].

$$Gain = \frac{\text{maximum radiation intensity of test antenna}}{\text{radiation intensity of isotropic (lossless)antenna with same power input}}$$

For transmitting antenna, it shows the how efficiently it transmit the electromagnetic wave into free space in given direction with electrical power as input. While in receiving antenna, it shows the how efficiently it receive electromagnetic wave and convert it into electrical power.

2.3 Antenna Efficiency

Antenna efficiency is the ratio of radiated power to total input power and it is denoted by η [21], [24], [26].

$$\eta = \frac{\text{Power Radiated}}{\text{Total Input Power}}$$

Relation between gain (G), directivity (D) and efficiency (η) is

$$G = \eta. D.$$

When direction is given then

$$\text{Directive Gain } (\theta, \pi) = \eta . D (\theta, \pi).$$

2.4 Radiation Patterns

Radiation Pattern is also called as Far-Field Pattern or Antenna Pattern. It is the three dimensional graphical representation of variation of field strength at particular distance from antenna. It is a function of direction. In radiating sphere the field strength is not same in all direction. In some direction it is very high and very less or zero in another direction. The energy at particular direction in particular distance is measured in term of "field strength". It can also be drawn in 2D plane. If azimuth angle is constant then radiation pattern is azimuth plane pattern, whereas if elevation angle is constant then it is elevation plane pattern. If radiation is expressed in term of electric field then pattern is called field strength pattern, whereas if radiation in particular direction is represented in term of power then resulting pattern is called power pattern [21], [26]. In term of radiation pattern, there are various type of antenna described below

(a) Isotropic antenna:

An antenna which radiate uniformly in all direction is called isotropic antenna. At particular distance from antenna field strength is same in all direction. It is an ideal and reference to compare actual antenna and not physically realizable [21], [26].

(b) Directional Antenna:

Directional antenna is the one which radiate with more strength in particular direction as compare to other directions. It is also known as Beam Antenna. Directional antenna is useful for point to point application at base station to transmit in particular direction in satellite communication. Horn, Yagi, Log-periodic panel antennas are examples of directional antenna [21], [26].
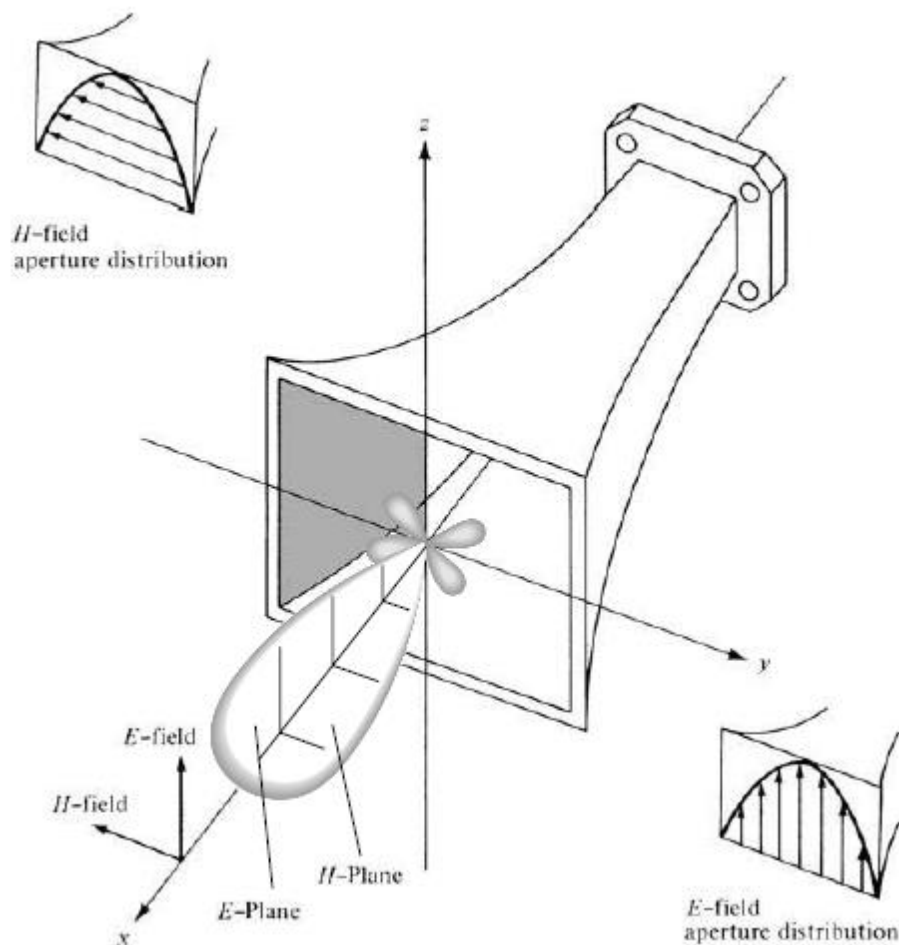
Figure 2.1 Radiation pattern of directional antenna (Horn antenna).

(c) Omnidirectional Antennas:

An antenna whose radiation pattern is equally distributed and uniform in one plane (generally horizontal plane) and non-uniform in other plane. In many applications like FM radio, wireless computer network, cell phones, walkie talkies, GPS, cordless phones requires uniform radiation pattern in one plane. Figure 2.2 shows the pattern in which azimuth plane [g(ϕ), θ= π/2] is non-directional and elevation plane [f(θ), ϕ=constant] is directional. Radiation pattern shape is like doughnut shape. Dipole antenna, whip antenna, discone antenna, slot antenna duck antenna are omnidirectional low gain antenna. Gain of an omnidirectional antenna can be increase by narrowing the beamwidth in vertical plane which increase the density of energy in horizontal plane. Therefore in omnidirectional antenna if beamwidth is less then gain is high and if beamwidth is high then gain is less. So if gain is low then efficiency in vertical plane is high [21], [26].
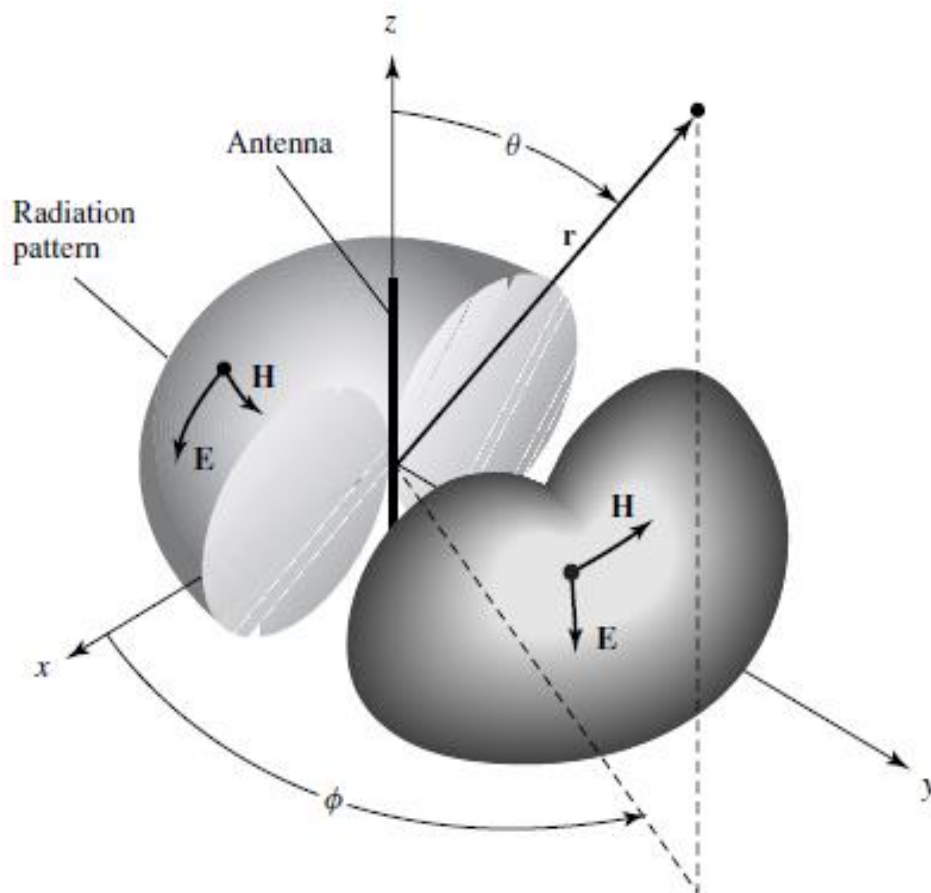
Figure 2.2 Omnidirectional antenna patterns.

2.5 Field Regions

The radiating sphere is divided into three regions:

(i) Reactive near- field region,

(ii) Radiating near-field (Fresnel) region,

(iii) Far-field (Fraunhofer region)

Reactive near- field region is radiation sphere surrounding the antenna wherein reactive field is more effective. The boundary is $R_1 < 0.62\sqrt{(D^3/\lambda)}$. Radiating near-field region also known as Fresnel region in radiation sphere is in between reactive near- field region and far-field region. In this region radiation fields are more effective and field strength depends upon radius of radiating sphere [21], [26]. In far-field region also known as Fraunhofer region radiation intensity is independent upon radius of radiating sphere. Its boundary is $R_2 > 2D^2/\lambda$.
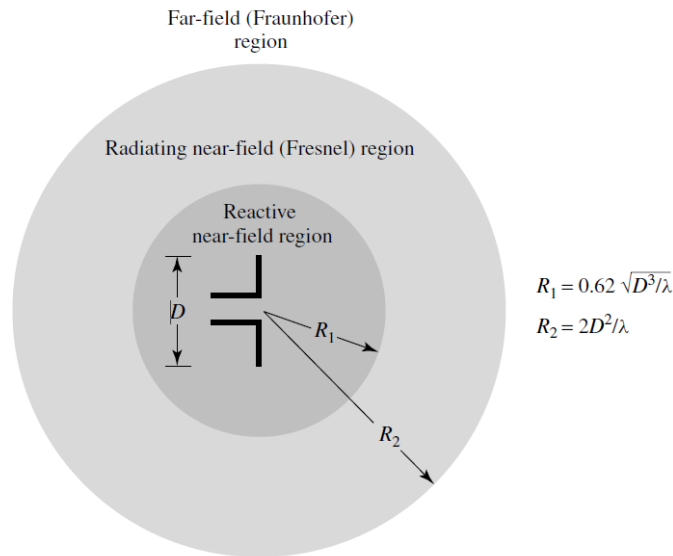
Figure: 2.3 Field regions of an antenna.

2.6 Antenna Bandwidth

The bandwidth of an antenna is range of frequency over which it fulfils the required characteristics. It can be representing on the basis of plot of gain, return loss, axial ratio,

VSWR or impedance. Impedance bandwidth is represent as the range of frequency over which line impedance of feeding line is perfectly matched [21]. Impedance bandwidth can be represented as

$$BW = \frac{S-1}{Q_T\sqrt{S}}$$

(2.1)

Where, Q_T = Q factor,

S = VSWR.

Fractional bandwidth of microstrip antenna can be represented as

$$BW = \frac{f_2-f_1}{f_c}$$

(2.2)

Where, f_2 = upper frequency,

f_1 = lower frequency,

f_c = centre frequency.

The range of VSWR is 1 to ∞. For matched line, ideally VSWR should be 1. In practical case VSWR should be 2.
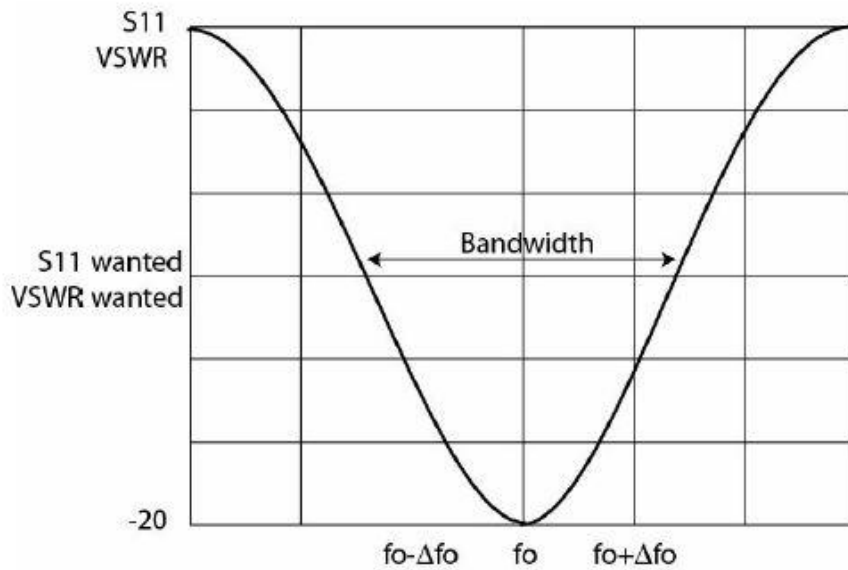
Figure 2.4 Antenna Bandwidth.

Chapter 3

<u>Microstrip Patch Antenna</u>

3.1 Introduction

At the beginning of 19th century we have used parallel line and coaxial line for transmission of electromagnetic wave in microwave devices. In the middle of 20th century printed circuit board invented allow us to printed circuitry design of transmission lines and it was very cheap and simple. In printed circuit technology, two wire line act as microstrip line. Most basic form of microstrip line consists of 3 layers. First layer is metallic radiating patch, second layer dielectric material and third layer is metallic ground plane. The thought in transit that microstrip structures can be utilized as radiator for EMW got in 1950s. In 1953 Deschamps presents first time the idea of microstrip patch antenna. A patent of Gutton and Baissinot was introduced in the year of 1955. After receiving the idea of microstrip antenna around 20 year practical microstrip radiator was fabricated. At the beginning commercial microstrip antenna was not available because of poor radiation, high losses, limited existing in laboratory.

In mobile and wireless communication, where small size light weight, ease of installation, aero dynamic properties are required, low profile antenna can be used [21]. Currently there are some other aircraft, satellite, spacecraft, and satellite application that require similar specification. We can use microstrip antenna to get all these requirements [21]. Microstrip antenna is low profile, comfortable in any surface, low cost, easily fabricated, robust when attached in rigid surface [14], [15], [21]. By selecting the proper patch shape, mode of operation, they are flexible in polarization, resonant frequency, and pattern. By using switch such as pin diode, Varacter diode we can designed reconfigurable antenna with respect to frequency, polarization, and pattern.

Basic microstrip antenna consist of two thin metallic layers (t $<< \lambda_0$) separated by dielectric substrate of thickness (h $<< \lambda_0$ usually $0.003\lambda_0 \leq$ h $\leq 0.05\lambda_0$) one as patch and other as ground [21]. Generally copper is used as metallic patch.
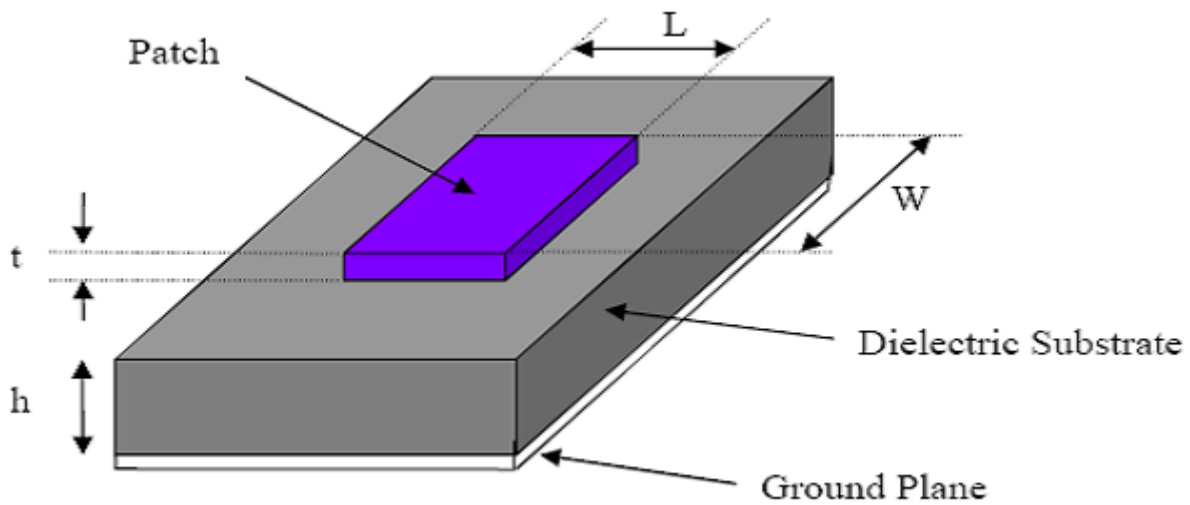
Figure 3.1 Microstrip Patch Antenna.

Microstrip antennas are also called as path antennas. The shape of patch can be any of square, circle, Dipole, rectangle, elliptical, Triangle, Disc sector, Circular ring, Ring sector, or any other shape. These are shown in figure 3.2. Most basic shapes square, circular, and rectangular and dipoles are used commonly because of its easy of fabrication and analysis, and their sharp results, specially co-polarization and cross-polarization. For substrate, no of dielectrics can be used which should be in the range of $2.2 \leq \varepsilon_r \geq 12$ [14], [15], [21]. Microstrip dipole antennas are very attractive due to large bandwidth and small size, which is suitable for antenna array. We can design linear or circular polarized antenna by using single antenna or arrays of antenna.

Main drawback of microstrip antenna is very narrow bandwidth. But in some narrowband is required like security system, in that case microstrip patch antenna is useful. Bandwidth can be increase by increasing the substrate thickness but it will also increase the surface wave and due to which losses in power and it affects the characteristics and performance of antenna [14], [23], [21]. Thick substrate with low dielectric constant increase the efficiency and bandwidth but increase the size of antenna. For microwave circuitry, thin substrate and high dielectric constant is desirable but it has small bandwidth and less efficiency.
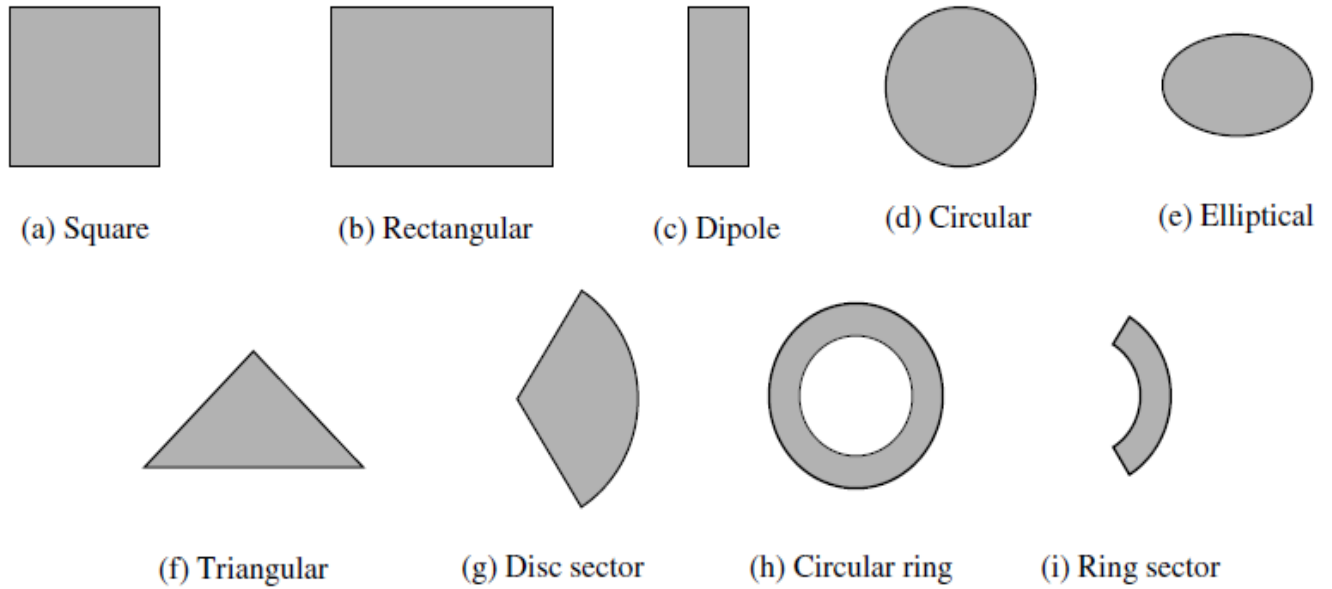
Figure 3.2 Shape of patch of microstrip patch antenna.

Features of antenna not only depends on size of antenna but also depends on input impedance of antenna and impedance offered by transmission line i.e. impedance matching of microstrip line and antenna. Generally impedance offered by microstrip patch antenna is complex and that of transmission line is real (generally 50Ω). Therefore impedance mismatch and voltage standing wave ratio will introduce and due to which impedance bandwidth will decrease. To solve this problem, we can use impedance matching network. There are various impedance matching circuitry are available in circuit theory.

Different methods are presented by researchers like parasitic patch; deserted ground plane, stacking and bandwidth improvement are interesting topics for research. By selecting the particular patch shape and mode of operation we can design a patch antenna for particular radiation pattern, resonant frequency and polarization. By using the switches like MEMS switch, PIN diode, Varacter diode we can design reconfigurable antenna.

3.2 Feeding Methods

There are large numbers of techniques used to feed microstrip patch antenna [14], [23], [21].

(a) Microstrip line feed,   (b) Coaxial probe feed,

(c) Aperture coupled feed,   (d) Proximity-coupled feed.

Each method has some advantages and disadvantages. According to requirement we can choose any one of suitable technique. The main work of feedline is to transfer electrical power from transmission line to radiating patch. There should be proper impedance matching between feed line and radiating patch. For impedance matching we need extra matching circuit. Therefore feedline should be design in such a way that matching circuit should be design with radiating patch. If we increase the thickness of dielectric substrate, it will increase bandwidth but also introduce surface wave as well as spurious feed radiation. Two parameters, spurious feed radiation as well as surface wave depend on the feedline structure. Spurious feed radiation introduce side lobe in radiation pattern as well as increase the cross polarisation and surface wave reduce the efficiency of antenna. Out of the above four feeding techniques, Microstrip line feed and Coaxial probe feed are contacting feeding technique because feedline directly connected to radiating patch. Whereas Proximity coupled and Aperture coupled feeding techniques are non-contacting feeding techniques because feedline mutually coupled to radiating patch. In contacting feeding techniques spurious feed radiation is more causes compare to non-contacting feeding techniques. So in both microstrip line feed as well as coaxial feed, introduction of side lobe and generate higher order mode cause increase cross-polarization are more compare to aperture coupled and proximity coupled feeding techniques.

3.2.1 Microstrip Line Feed
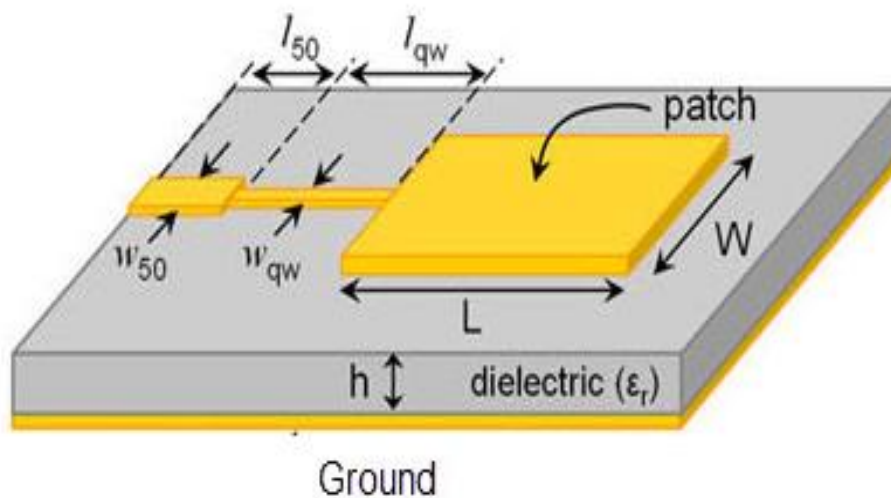
Figure 3.3 Microstrip line feed.

Microstrip line feed is a metal stripline of thickness equal to radiating patch. Its width is much less compare to radiating patch. In this method antenna consist of two metal layers of patch and ground plane on both side of dielectric substrate. This is most basic form of feeding technique and easy to fabricate. In this method impedance matching is also very easy by position control only. This technique is contacting technique, so feedline is directly connected to patch [20], [21], [22]. Therefore it introduce more surface wave and higher order mode causes cross-polarization. Its bandwidth is also very less about 2-5%.

3.2.2 Coaxial Probe Feed

It is a contacting feed technique. Coaxial probe consists of two coaxial conductors. Inner conductor is connected to metallic patch and outer conductor is connected to ground plane. It is simple in structure and matched line. It is very difficult to design if thickness of substrate is very high. Here spurious feed radiation is less compare to microstrip line feed. It also generate higher order mode and surface wave causes introduce cross-polarization and side lobe.
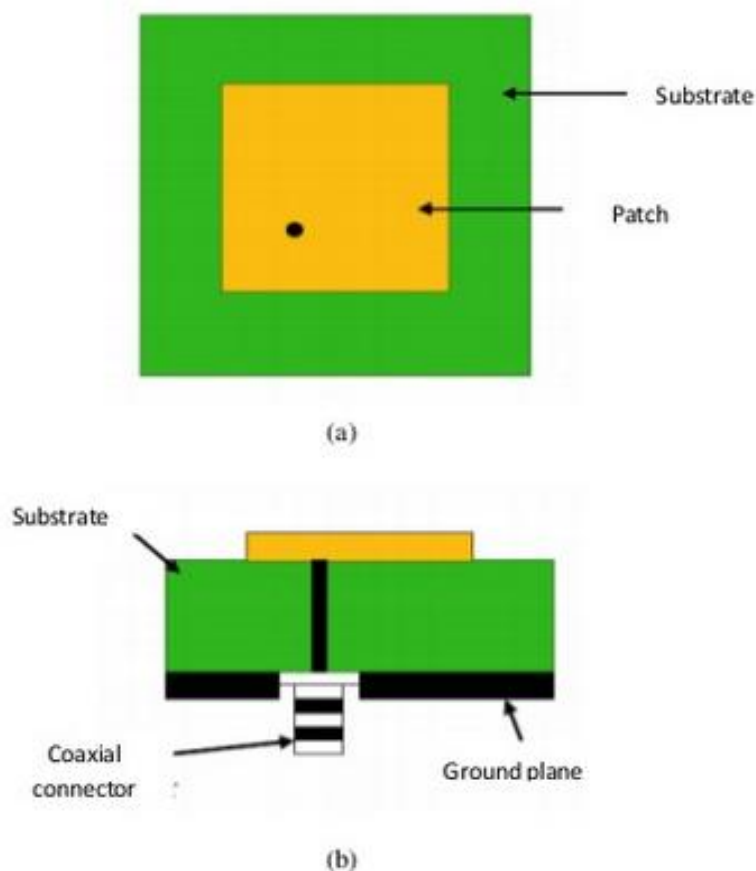
Figure 3.4 Coaxial probe feed, (a) Top view, (b) Side view.

Its bandwidth is also very less like microstrip feeding technique [21]. To overcome problems in contacting feeding techniques, non-contacting feeding techniques are introduced.

3.2.3 Aperture-coupled feed

In aperture coupled technique two different substrates are used, separated by metallic ground plane. Radiating patch is on the top side of upper substrate and feedline is placed below of bottom substrate. This technique is most difficult as compare to others. Bandwidth and field pattern depends on dimensions and dielectric constant of bottom substrate i.e. feedline substrate. Thickness of bottom dielectric substrate is less and permittivity is high as compare to upper substrate to increase the bandwidth good field pattern [21]. Thickness of upper dielectric should be less to reduce the fringing field. Field is mutually coupled to the patch from feed line through slot created in ground plane. Different types of shape of slot are used. Generally circular and rectangular slots are used. This is a non-contacting technique.
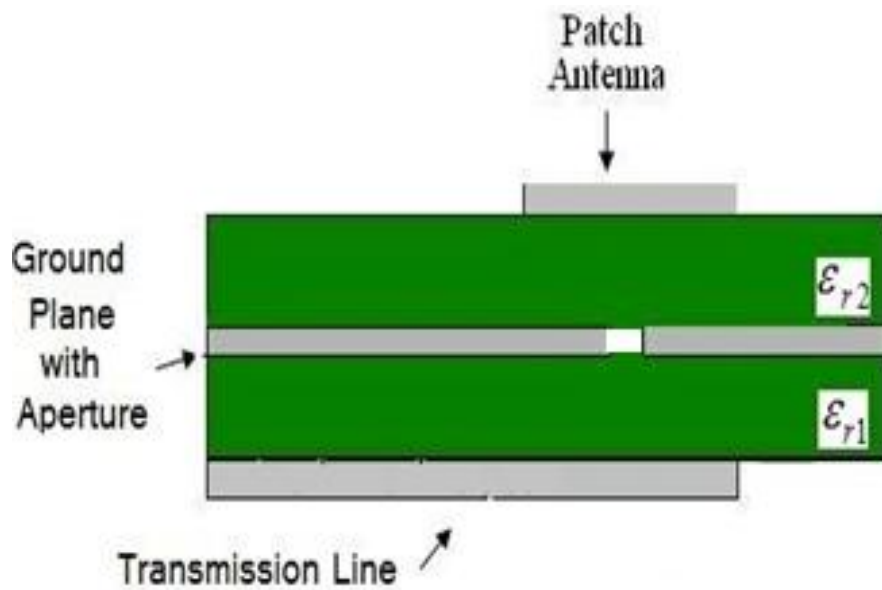
Figure 3.5 Aperture-coupled feed.

Field coupling can be maximum by proper dimension of slot and position of slot and feedline. Its bandwidth is very less and fabrication is easy. Because of ground plane, feedline is separated from radiating patch. Therefore spurious feed radiation is very less causes low cross-polarization and high polarization purity. In this design dimension of substrate, slot, feedline and permittivity of substrate optimize the design. In the case of circular polarization we are using cross and ring slots are used. From electrical theory of

distribution of voltage and current, at the corner E-field is max and at the centre H-field is max. If aperture slot is just below the centre of the patch then H-field is max and E-field is zero [21]. For better impedance matching, feedline length is stretched over slots. The extra portion of extended feedline acts as open circuit stub. Stub reduces the reactive component of aperture or slot.

3.2.4 Proximity-Coupled Feed

Proximity-coupled technique is a non-contacting technique. In this technique also two dielectric substrates are used. Two substrates are separated by microstrip feedline. Energy is mutually coupled to patch from feedline. High dielectric constant and thin substrate is used as bottom substrate as compare to upper substrate to increase the bandwidth and improve the field pattern [21]. To reduce the fringing field upper substrate should be thin. Since, feedline is separated from radiating patch so spurious feed radiation is less. Therefore generation of higher order modes are less and cross-polarization is less. Its fabrication is difficult because of proper management of position of feedline is difficult. Bandwidth of proximity coupled technique is high (approximate 13%) as compare to other techniques.
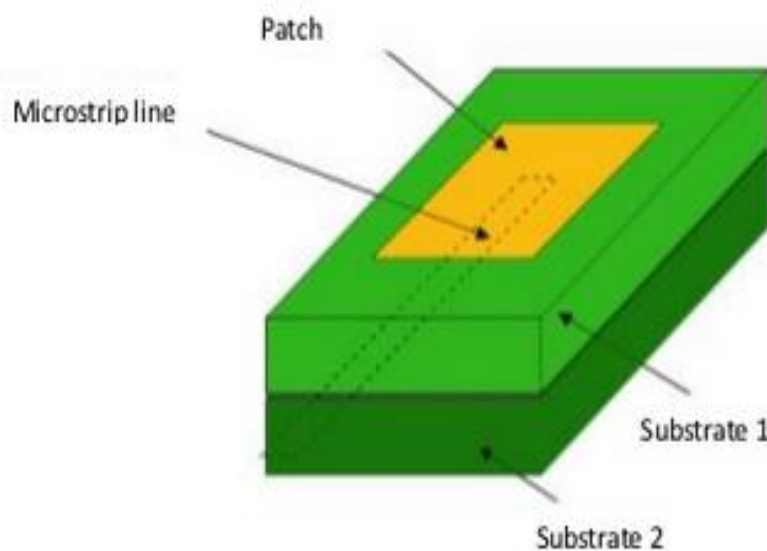
Figure 3.6 Proximity-coupled feed technique.

The equivalent circuit diagram of above four techniques is shown below.

(a) Microstrip line

(b) Probe

(c) Aperture-coupled

(d) Proximity-coupled
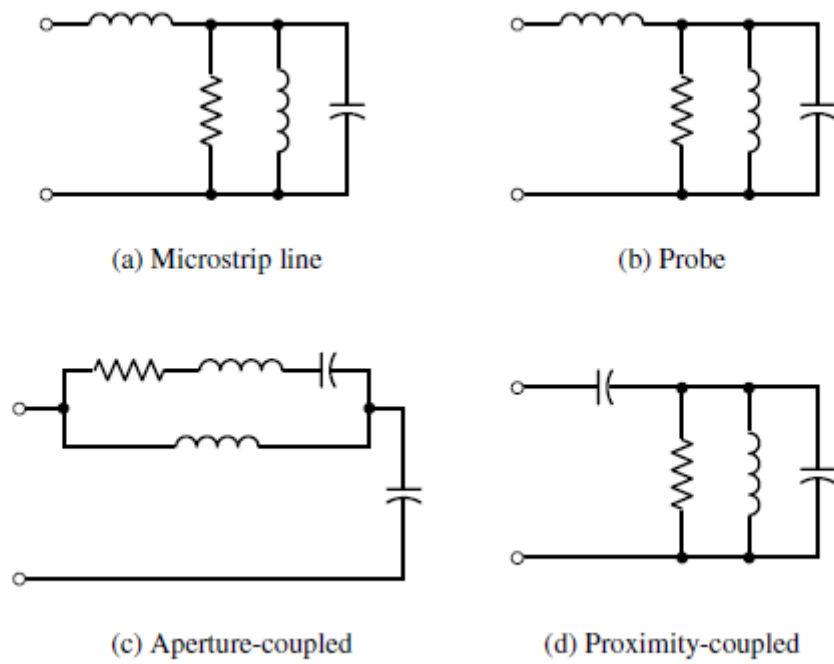
Figure 3.7 Equivalent circuit diagram of feeding techniques.

3.3 Rectangular Microstrip Patch Antenna

It is most basic microstrip antenna. Antenna characteristic depends on the length and width of patch. Radiating patch is separated from ground metallic plane by dielectric substrate with the distance of integer multiple of half wavelength [14], [21]. From the radiating edges fringing fields will come.
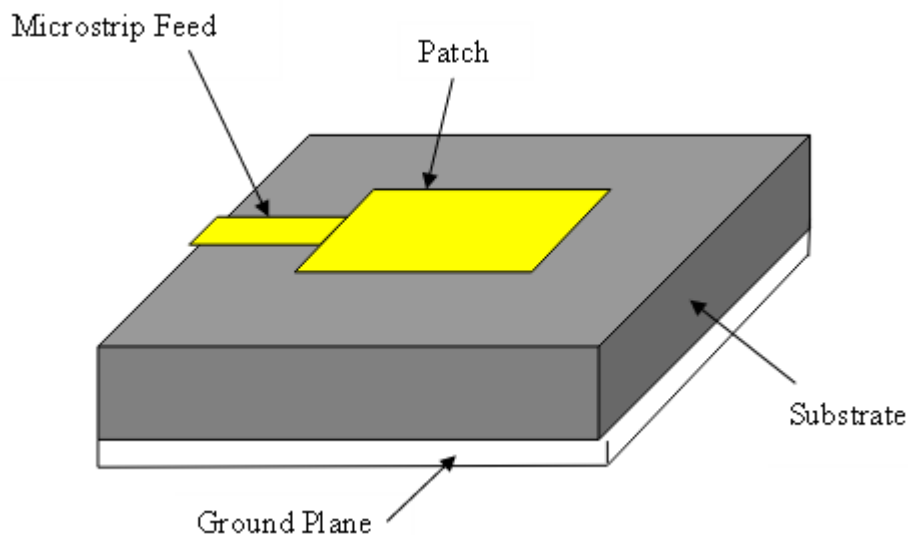
Figure 3.8 Rectangular patch microstrip antenna.

To analyse it, various methods are available. Out of these commonly used methods are

(1) Transmission- Line,

(2) Cavity,

(3) Full Wave.

Transmission line model is less accurate but easiest, whereas cavity model is more accurate but complex.

3.3.1 Transmission-Line Model

Microstrip patch antenna has two radiating slots, each radiating slot act as equivalent impedance separated by fixed length. The resistive part represents the radiation loss of radiating slot [21]. At resonance the input impedance is resistive because reactive part becomes zero.

3.3.1.1 Fringing Effects

Since the dimensions of patch i.e. length and width are finite, fringing field comes out at radiating slots as shown in figure 3.9. In figure fringing field arises along the length, same arises along the width also. Fringing field depends on dimension of patch i.e. length and width and height of substrate also. Fringing field also depends on dielectric constant of substrate [21]. If fringing field arises along the length then it depends upon length to height ratio (L/h). In microstrip patch antenna height of substrate is very less as compare to length of patch, therefore fringing field is very less.

(a) Microstrip line   (b) Electric field lines
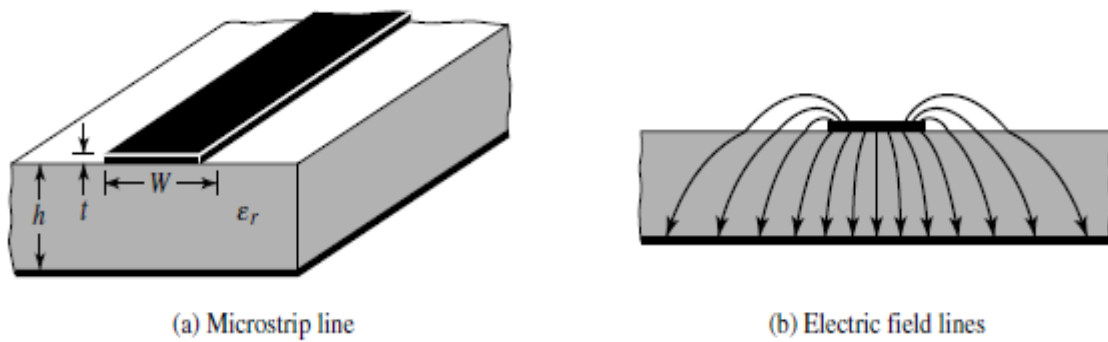
Figure 3.9 Microstrip line and its electric field line.

From above figure we can see, electric field passes through two dielectrics i.e. air followed by substrate. Some electric field lines are in air and most are in substrate. If W/h >> 1 and ε_r >> 1 then most lines are in substrate [15], [21]. Since, electric field lines travel in air and substrate both, so effective dielectric constant ε_{reff} is introduced. Due to fringing field electrical dimension of radiating patch is more compare to physical dimension.

If permittivity of dielectric material is more than almost all the lines are inside the dielectric substrate due to this fringing effects are less. Whereas for the less permittivity of substrate, electric field lines are loosely bonded into substrate and travel more into air. As we know that radiation from the microstrip patch antenna is only because of fringing field, therefore for better radiation pattern dielectric constant should be less. If dielectric constant is less then efficiency will increase and better antenna performance.
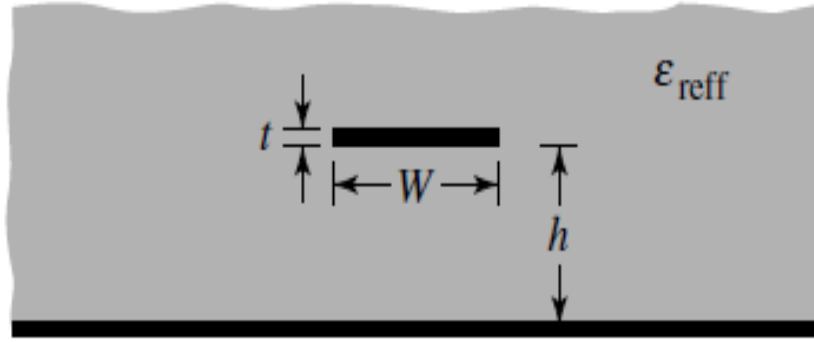
Figure 3.10 Effective dielectric constant.

In microstrip line due to air above the substrate, the range of effective dielectric constant is $1 < \varepsilon_{reff} < \varepsilon_r$ [21]. In various application permittivity of substrate is very high i.e. $\varepsilon_r \gg 1$. As permittivity of substrate (ε_r) increases, effective permittivity (ε_{reff}) will more closer to ε_r and most of field line reside into substrate. Effective permittivity (ε_{reff}) is also the function of operating frequency. As frequency of operation increases then Effective permittivity (ε_{reff}) is closer to permittivity of substrate (ε_r). Figure 3.11 shows the variation in Effective permittivity (ε_{reff}) of different with respect to operating frequency.

From figure at low frequency, effective permittivity (ε_{reff}) is constant, less than permittivity of dielectric substrate (ε_r) and independent of frequency. At middle frequency, effective permittivity (ε_{reff}) increases with increase in operating frequency and approaches towards permittivity of dielectric substrate (ε_r). At high frequency, effective permittivity (ε_{reff}) is constant, approximate equals to permittivity of dielectric substrate (ε_r) and independent of frequency [21].

For W/h>1

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \left[1 + 12\frac{h}{W}\right] \qquad (3.1)$$
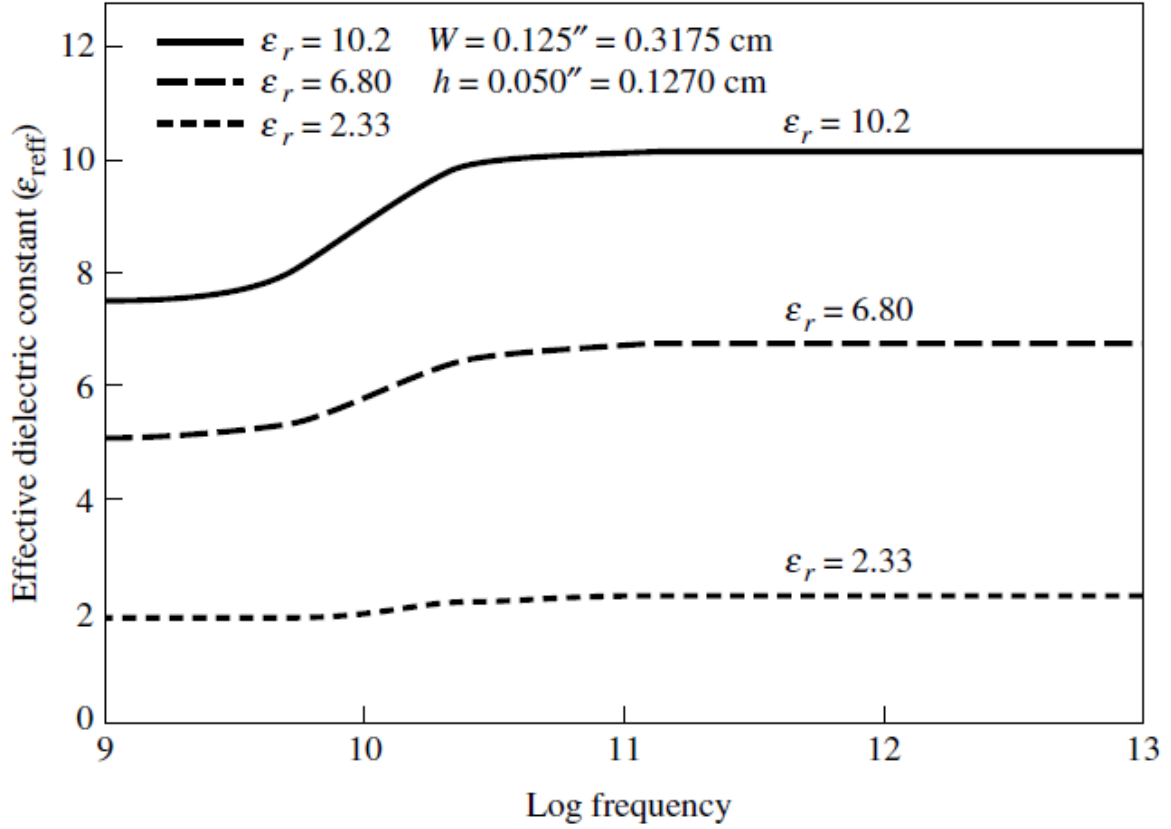
Figure 3.11 Effective permittivity (ε_{reff}) versus operating frequency (f).

3.3.1.2 Effective Length

Because of fringing effect at radiating slots, electrical length of patch is greater than of its physical length, as shown in figure. These extensions of length are because of generation of mode along the length. If radiating slots are along the width then fringing field will generate along the width and due to this extension of length is also consider. From figure we can see electrical length of patch increase by ΔL on both sides. ΔL depends on effective permittivity (ε_{reff}) and patch width and substrate height [14], [21].

$$\frac{\Delta\text{L}}{\text{h}} = 0.412\frac{\left(\varepsilon_{reff}+0.3\right)\left(\frac{W}{h}+0.264\right)}{\left(\varepsilon_{reff}-0.258\right)\left(\frac{W}{h}+0.8\right)} \tag{3.2}$$

Due to fringing effective length i.e. electrical length is

$$L_{eff} = L + 2\Delta L \tag{3.3}$$

Due to fringing effect, at dominant mode TM_{010} effective length is 0.48λ in place of 0.5λ i.e. physical length of patch.

(a) Top view

(b) Side view
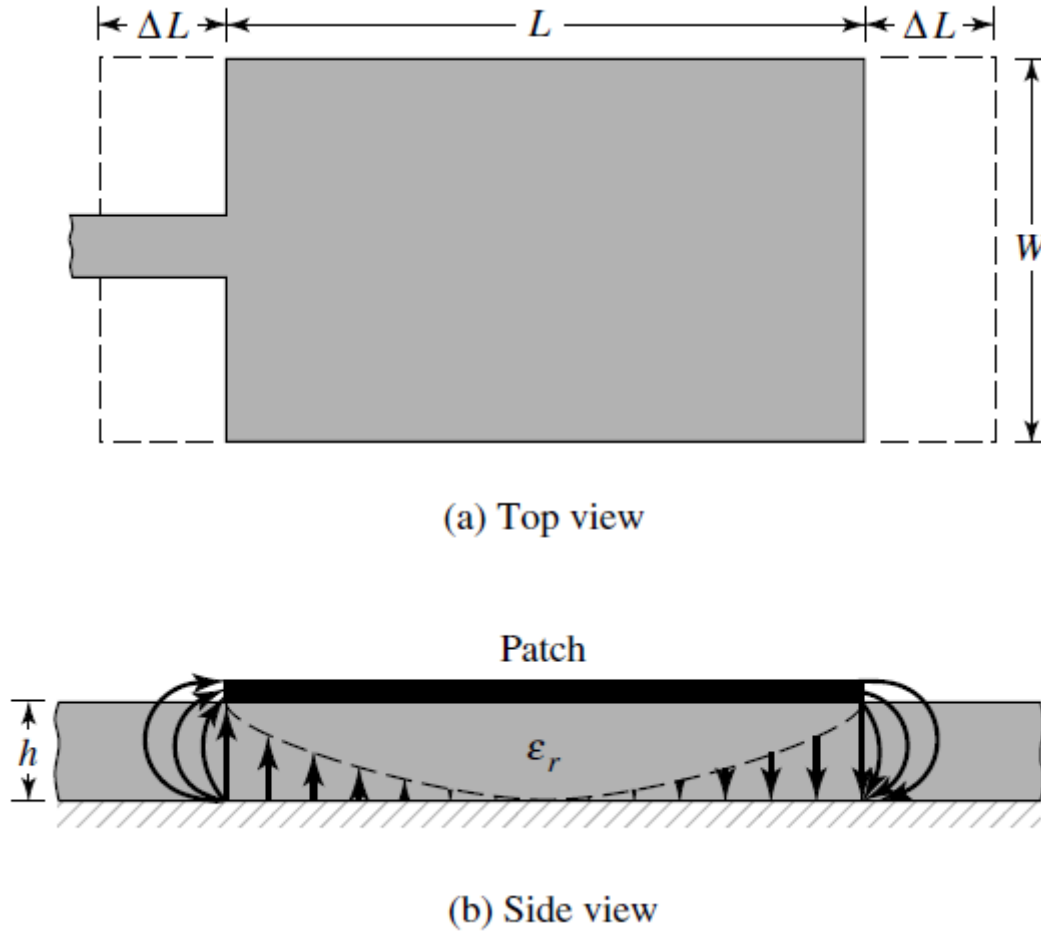
Figure 3.12 Effective length of patch due to fringing.

3.3.1.3 Resonant frequency

Resonance frequency for the dominant mode TM_{010} without considering fringing effect is

$$f_r = \frac{1}{2L\sqrt{\varepsilon_r}\sqrt{\mu_0 \varepsilon_0}}$$ (3.4)

$$= \frac{c_0}{2L\sqrt{\varepsilon_r}}$$

From above equation, we can see resonance frequency depends on length of patch and length depends on fringing fields. Therefore resonance frequency also depends on fringing field [21].

$$f_{rc} = \frac{1}{2L_{eff}\sqrt{\varepsilon_{reff}}\sqrt{\mu_0 \varepsilon_0}}$$

$$= \frac{1}{2(\mathrm{L} + 2\Delta\mathrm{L})\sqrt{\varepsilon_{reff}}\sqrt{\mu_0 \varepsilon_0}}$$

$$= q\,\frac{1}{2\mathrm{L}\sqrt{\varepsilon_r}\sqrt{\mu_0 \varepsilon_0}}$$

$$= q\,\frac{c_0}{2\mathrm{L}\sqrt{\varepsilon_r}} \qquad\qquad (3.5)$$

Where,

$$\mathrm{q} = \frac{f_{rc}}{f_r}$$

q= fringing factor also known as length reduction factor.

Fringing field increase with the height of the substrate, as a result distance between radiating edges increase and resonant frequency decrease [21], [23].

3.3.1.4 Effective Width

In dominant mode TM_{010}, there is no fringing field along the width so effective permittivity (ε_{reff}) is equal to permittivity of dielectric substrate (ε_r) [21].

$$\varepsilon_{reff} = \varepsilon_r$$

Therefore in formula for width we will consider ε_r in place of ε_{reff} and it is

$$W = \frac{1}{2f_r\sqrt{\mu_0 \varepsilon_0}} \sqrt{\frac{2}{\varepsilon_r + 1}}$$

$$= \frac{c_0}{2f_r} \sqrt{\frac{2}{\varepsilon_r + 1}} \qquad (3.6)$$

Where, c_0 is the velocity of light in free space.

Design:

Based on the above simplified formula we can easily design the rectangular microstrip patch antenna by using following steps [21]

(a) Specify: ε_r, h, and f_r

(b) Calculate   W and L

3.4 Circular Patch Microstrip Antenna

Circular patch is also commonly used like rectangular patch in microstrip antenna. As we have seen two parameters, length and width of rectangular patch antenna calculated to study the various parameters of antenna, similarly in circular to study the performance of antenna, we need to calculate only radius of patch [21]. The schematic diagram of circular patch microstrip antenna is shown below
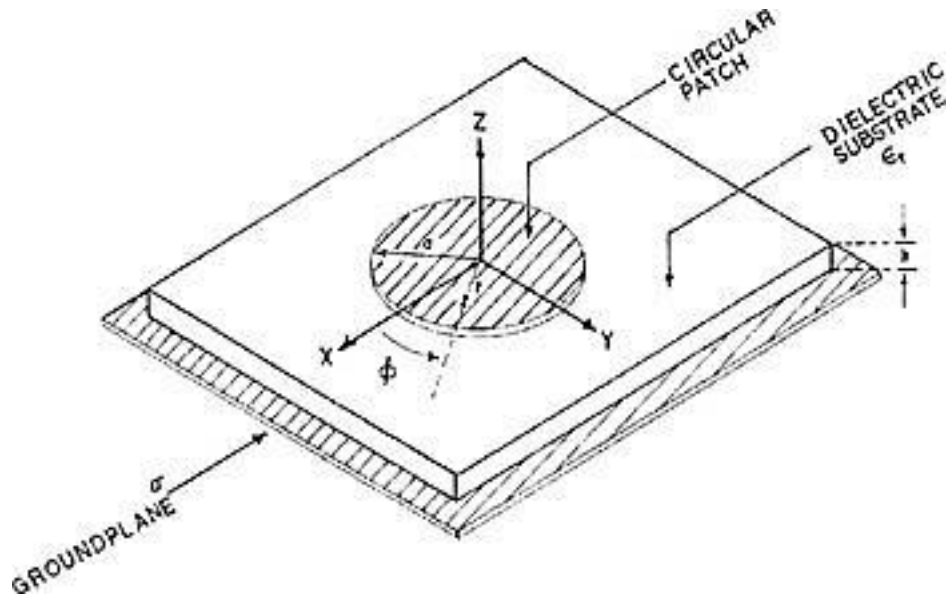

Figure 3.13 Circular Patch Microstrip Antenna.

From above figure we can see that antenna consist of three layers. First layer is metallic circular patch, second layer is dielectric substrate and third layer is metallic ground plane. Here, feeding mechanism is coaxial feeding. Metallic patch is fed at a point of distance 'r' from centre and angle 'ϕ' from x-axis. Analysis can be done by assuming cavity having two metallic walls (metallic patch and metallic ground plane) and edges are acting as magnetic walls. The E-field component of radiating wave is

$$E_z = E_0 J_n(kr)\cos(n\phi) \qquad (3.7)$$

Similarly, H-field component is

$$H_r = -\frac{j\omega\varepsilon n}{k^2 r} E_0 J_n(kr)\sin(n\phi) \qquad (3.8)$$

$$H_\phi = -\frac{j\omega\varepsilon}{k} E_0 j_n{}'(kr)\cos(n\phi) \qquad (3.9)$$

Where,

J_n is Bessel's function of order 'n',

$j_n{}'$ is derivative of Bessel's function of order 'n',

k is propagation constant.

For TM_{mn} mode, resonant frequency is

$$f_{mn} = \frac{X_{mn} c}{2\pi\varepsilon_{eff}\sqrt{\varepsilon_r}} \qquad (3.11)$$

Where,

X_{mn} is the zeroes of Bessel's function derivative of order 'n'

and c represents the light velocity in free space.

Radius of patch can be calculated by

$$a = \frac{X_{mn}c}{2\pi\sqrt{\varepsilon_r}} \left[1 + \frac{2h}{\pi a \varepsilon_r} \left(\ln\left\{\frac{\pi a}{2f_{mn}h}\right\} + 1.7726\right)\right]^{-1/2} \qquad (3.12)$$

Similarly, for a /h >> 1, effective radius of patch can be calculated as

$$a_{eff} = a \left[1 + \frac{2h}{\pi a \varepsilon_r} \left(\ln\left\{\frac{\pi a}{2h}\right\} + 1.7726\right)\right]^{-1/2} \qquad (3.13)$$

Table 3.1 Bessel's Function value

Zeroes of Bessel's function derivative of order 'n' for different modes [21] are

| TM_{mn}	1,1	2,1	0,2	3,1
X_{mn}	1.84118	3.05424	3.83171	4.20119

Chapter 4

Polarization of Antenna

4.1 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 change by changing the points in the radiating sphere i.e. polarization can be change by changing with direction from antenna [21]. Therefore in pattern, at different part polarization is also different.

Polarization is the study of relative orientation of two planar component of electric field component of radiated electromagnetic wave. Another way, we can define as the polarization is the orientation of magnitude of electric field with direction. Here the direction is the time varying direction. Therefore, we can say polarization is a function of time, direction and magnitude also. Figure 4.1 show 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. As the distance from antenna increases upto infinity, radius of radiation sphere also increases to infinity and strength of decreases. The propagated wave is always appears like a plane wave.

In any direction from antenna, at any point of radiation sphere polarization is the compose of two orthogonal polarizations which are co-polarization and cross-polarization. Co-polarization characterizes as the polarization the antenna wants to radiate, while cross-polarization is the polarization orthogonal to radiated polarization. It is an unwanted component.
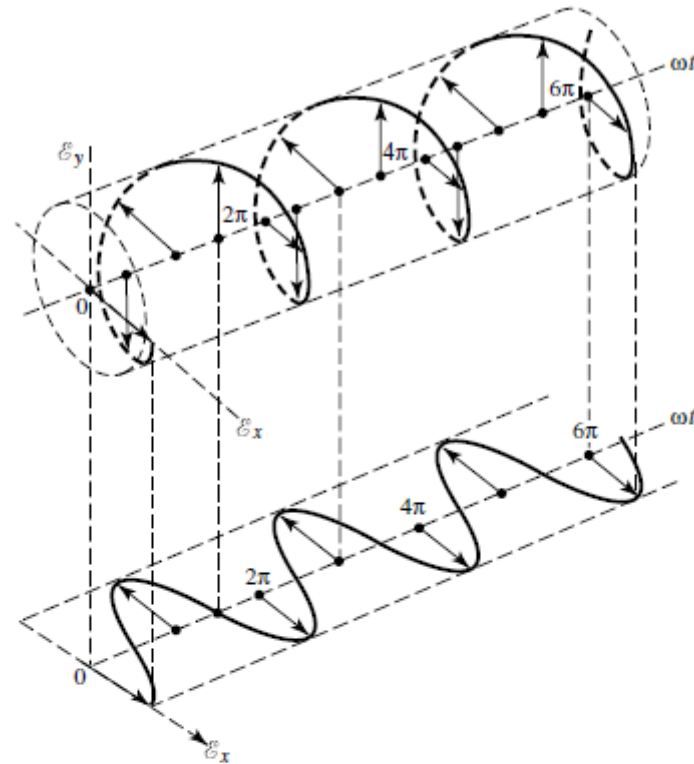
(a) Rotation of wave
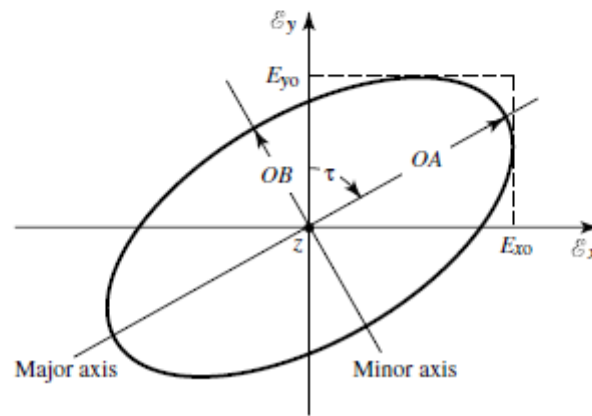
(b) Polarization ellipse

Figure 4.1 Rotation of a plane of EMW and its polarization.

4.2 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

$$E(z; t) = E_x(z; t)\ \hat{\boldsymbol{a}}_x + E_y(z; t)\ \hat{\boldsymbol{a}}_y \tag{4.1}$$

Where,

$$E_x(z; t) = \text{Re}\left[E_x\, e^{-j(wt+kz)}\right]$$

$$= \text{Re}\left[E_{x0}\, e^{-j(wt+kz+\phi_x)}\right] \tag{4.2}$$

And
$$E_y(z; t) = \text{Re}\left[E_y\, e^{-j(wt+kz)}\right]$$

$$= \text{Re}\left[E_{y0}\, e^{-j(wt+kz+\phi_y)}\right] \tag{4.3}$$

Where, E_{x0} and E_{y0} are maximum amplitude of x and y component of electric field component.

4.2.1 Linear Polarization

In linear polarized wave, two planar component of electric field component of equal or unequal amplitude are in phase [4], [5], [21].

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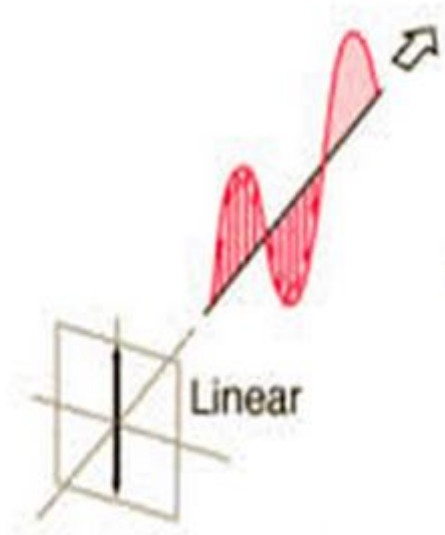

Figure 4.2 Linearly Polarized Curve.

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.

4.2.2 Circular Polarization

In any given point of radiation sphere, if the electric field component of radiated wave traces a circle with time then the wave is said to be circular polarized. In circular polarized wave, two planar component of electric field component of equal amplitude are in odd multiple of 90^0 phase difference [2], [6], [21].

$$E_{x0} = E_{y0}$$

And $\Delta\phi = \phi_y - \phi_x$

$$= \begin{cases} + \left(\frac{1}{2} + n\right)\pi, & n = 0, 1, \dots\dots \quad for\ CW \\ - \left(\frac{1}{2} + n\right)\pi, & n = 0, 1, \dots\dots \quad for\ CCW \end{cases} \tag{4.4}$$
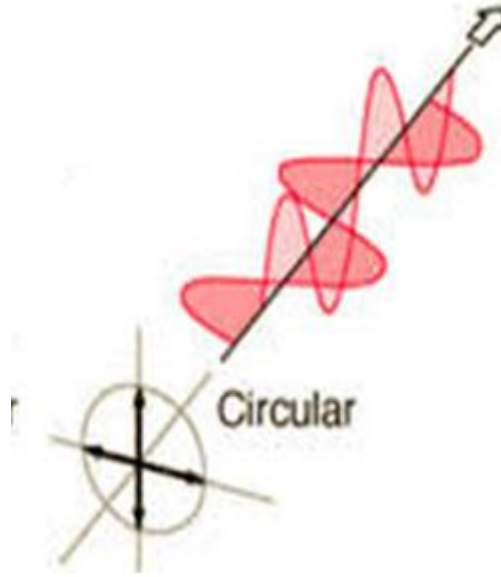
Figure 4.3 Circularly Polarized Curve.

4.2.3 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. In elliptical polarized wave, two planar component of electric field component have unequal amplitude and in odd multiple of 90^0 phase difference or when phase difference is not equal to integer multiple of 90^0 [2], [7], [21].

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

And
$$\Delta\phi = \phi_y - \phi_x$$

$$= \begin{cases} + \left(\frac{1}{2} + n\right)\pi, & n = 0, 1, \ldots\ldots & for\ CW \\ - \left(\frac{1}{2} + n\right)\pi, & n = 0, 1, \ldots\ldots & for\ CCW \end{cases} \tag{4.5}$$

Or

$$\Delta\phi = \phi_y - \phi_x \neq \pm \frac{n}{2}\pi = \begin{cases} > 0, & for\ CW \\ < 0, & for\ CCW \end{cases} \tag{4.6}$$

$$n = 0, 1,2,3, \ldots\ldots$$

31
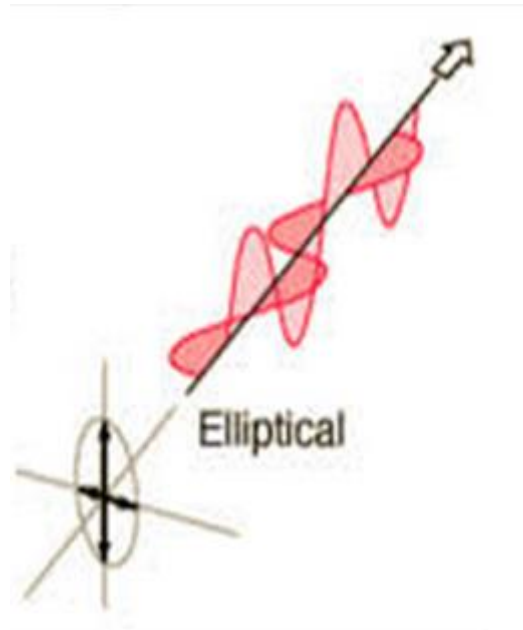
Figure 4.4 Elliptical Polarized Curve.

4.3 Left hand and Right hand Polarization

For the sense of rotation for the circular and elliptical polarized wave, if the left hand figures align along the advancing time with the thumb along the propagation direction the wave is said to be left circular or left elliptical polarized. Similarly, if the right hand figures align along the advancing time with the thumb along the propagation direction the wave is said to be right circular or right elliptical polarized [10], [21].
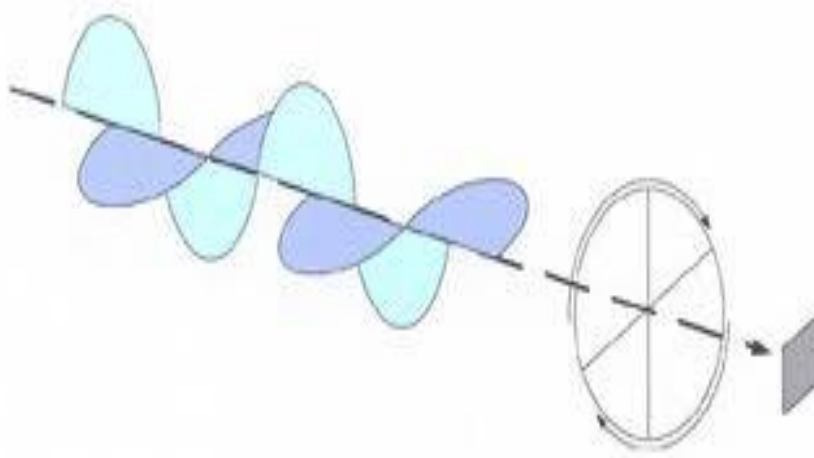
Figure 4.5 Left hand circular polarized wave.

4.4 Axial Ratio

Axial Ratio is a parameter which can be used to differentiate polarization of an antenna. It gives the relation between major axis and minor axis. Axial Ratio is defined as the ratio of major axis to the minor axis [8], [21].

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

In case of linear polarization minor axis = 0,

So $\qquad AR = \infty.$

In case of circular polarization major axis = minor axis,

So $\qquad AR = 1.$

In case of elliptical polarization major axis > minor axis,

So $\qquad 1 < AR < \infty.$

Chapter 5

Polarization Reconfigurable Antenna

5.1 Design1

Dual feed reconfigurable circularly polarized microstrip patch antenna

The design consists of metallic square radiating patch with rectangular thin slot and dual feed network. Because of thin slot antenna radiate circular polarized wave. Antenna feeds power by microstrip line feeding technique. Out of two feedline at a time one feedline is on by switching technique to make antenna as reconfigurable [1], [19], [12]. Antenna is fabricated on dielectric substrate of permittivity 4.4 (i.e. FR4 substrate).
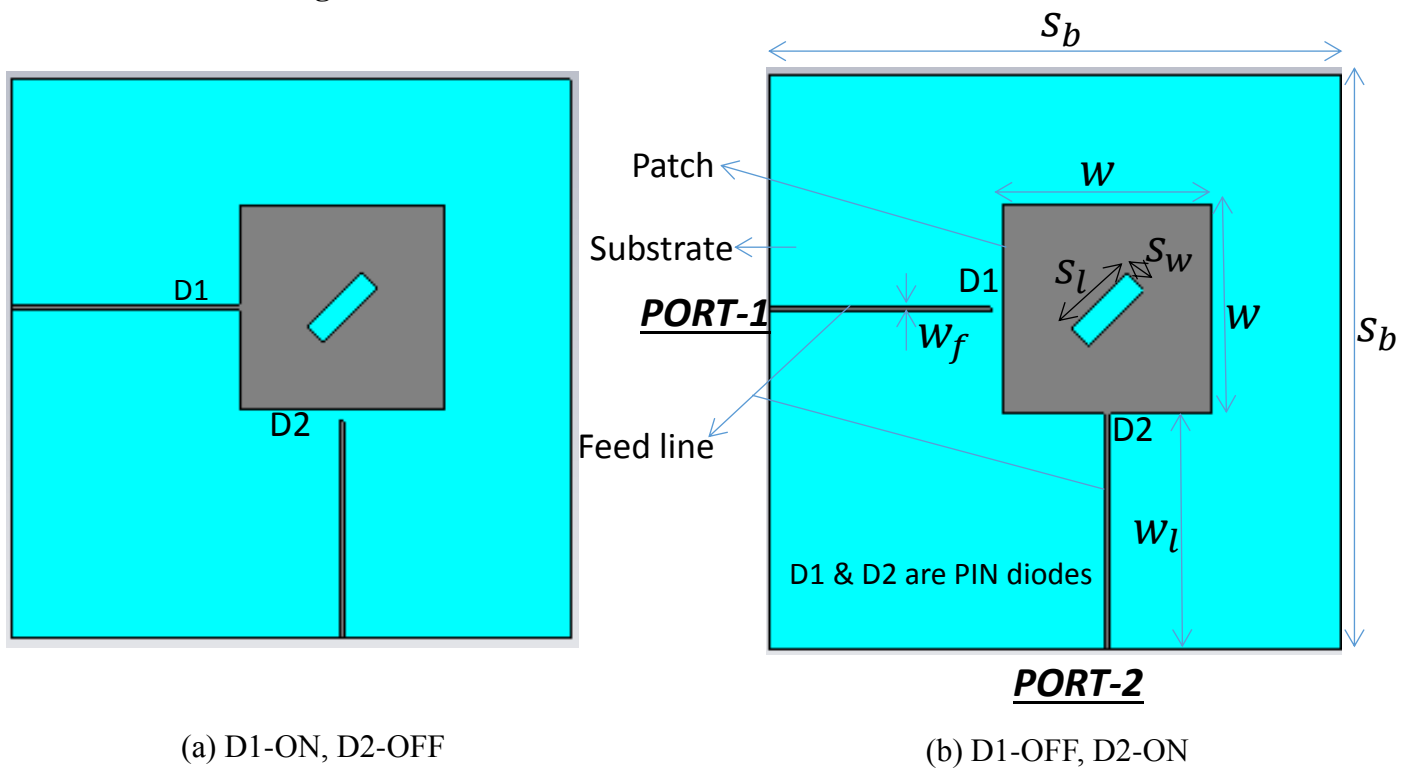
5.1.1 Antenna design

(a) D1-ON, D2-OFF   (b) D1-OFF, D2-ON

Figure 5.1 Geometry of antenna (a) LHCP, (b) RHCP
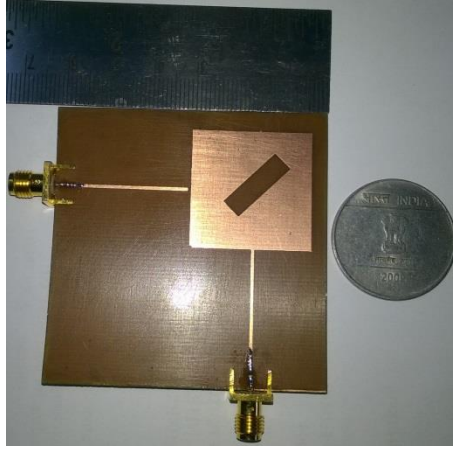
Figure 5.2 Geometry of fabricated antenna

Table 5.1 Dimensions of proposed antenna

h	s_b	s_l	s_w	t	w	w_f	w_l
1.58	60	10	3	0.05	26.81	0.704	30

(All dimensions are in mm)

Table 5.2 Configuration of two pin diodes

D1	D2	Polarization
ON	OFF	LHCP
OFF	ON	RHCP

Out of two pin diode one diode is on at a time at make antenna as reconfigurable antenna. When D1 is on and D2 is off then antenna radiate right hand circular polarized wave. Whereas if D1 is off and D2 is on then it radiate left hand circular polarized wave. Therefore by using diodes and two feedline, antenna can radiate electromagnetic wave with two orthogonal patterns and antenna antenna act as reconfigurable antenna [12]. As number of patterns increases, diversity gain increases. Therefore antenna have a features of multipath effects reduction i.e. reduction of fading and interference. Figure 5.2 shows the fabricated antenna.
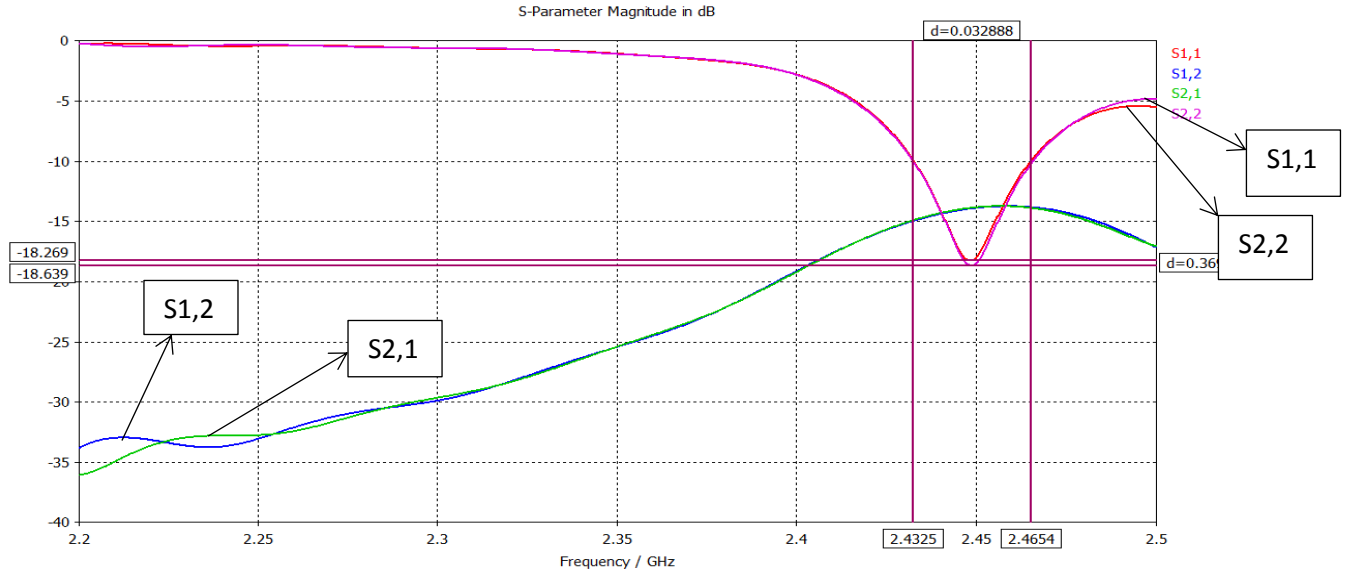
5.1.2 Simulation Results

Figure 5.3 Simulated S-Parameters for the proposed antenna in LHCP & RHCP.
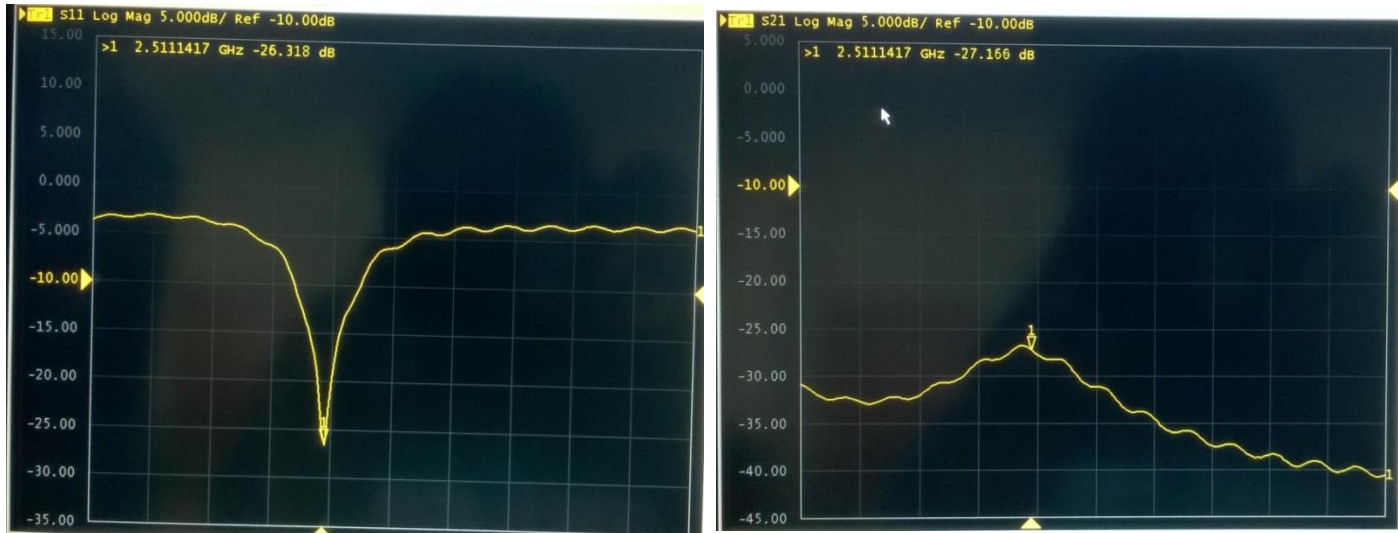

Figure 5.4 S-Parameters for the fabricated antenna in RHCP (a) S22, (b) S12.

For LHCP (D1 is ON and D2 is OFF) return loss S1,1 = -18.639 dB at f_r = 2.45 GHz and BW = 32.5 MHz and isolation of port 2 i.e. second feedline at resonant frequency is S2,1 = -14 dB. Similarly for RHCP (D1 is OFF and D2 is ON) return loss S2,2 = -18.269 dB at f_r = 2.45 GHz and BW = 32.5 MHz and isolation of port 1 i.e. first feedline at resonant frequency is S1,2 = -14 dB. Figure 5.4 show the S-Parameters of fabricated RHCP antenna. From figure S22 =-26.318 dB at 2.51GHz frequency and S12 = -27.166dB at 2.511GHz frequency.

Figure 5.6 shows the VSWR plot for LHCP and RHCP. At resonance frequency VSWR for both LHCP and RHCP is 1.03.

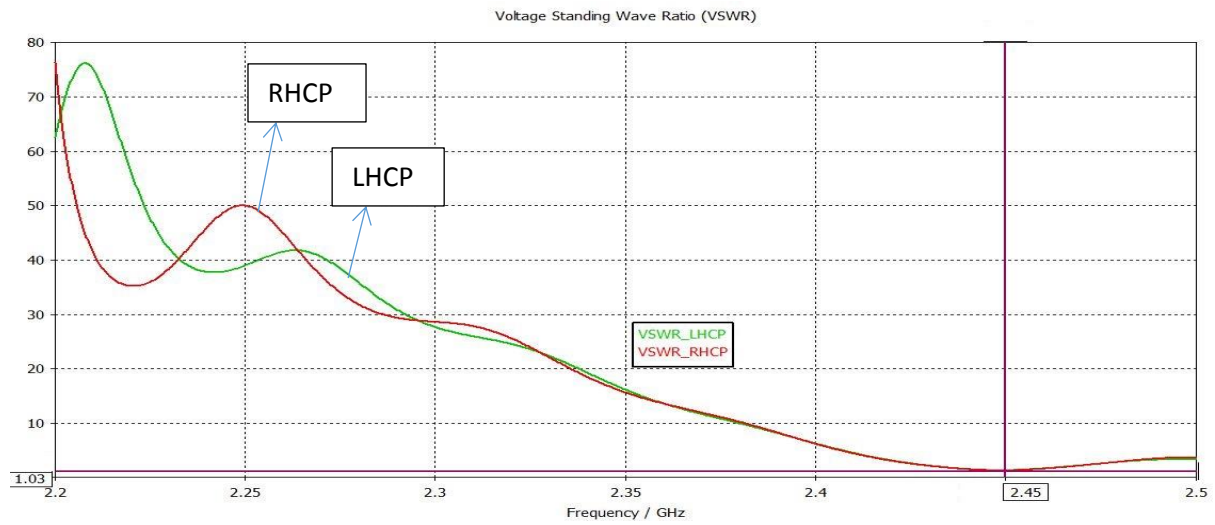
Figure 5.5 Simulated VSWR for the proposed antenna in LHCP & RHCP.

t= 0   t= T/4   t= T/2

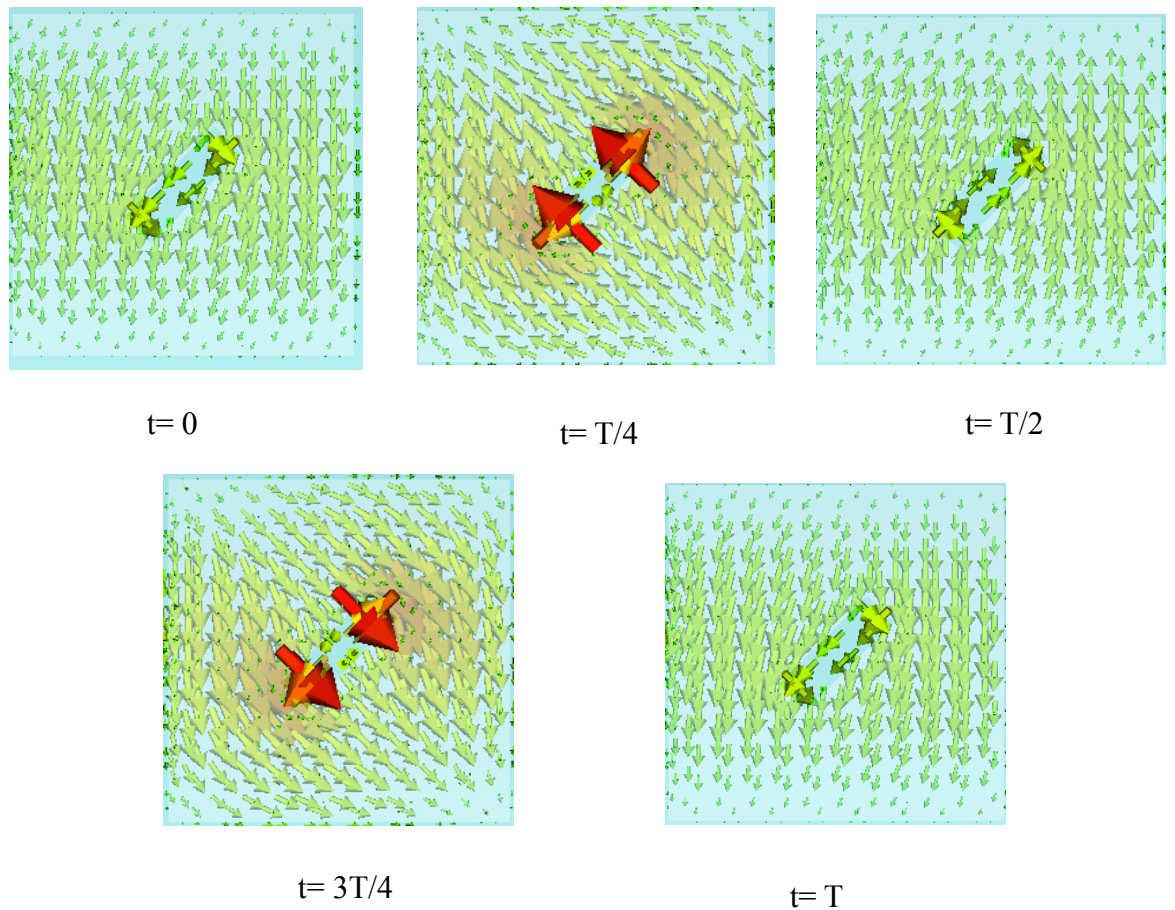t= 3T/4   t= T

Figure 5.6 Distribution of surface current for LHCP configuration.

Figure 5.7 shows the surface current distribution for LHCP. From figure we can see that current is rotating clockwise with advancing of time. Similarly, in case of RHCP current will rotate anticlockwise with advancing of time.

For circular polarized wave axial ratio should be 1. Figure 5.8 shows axial ratio plots for LHCP and RHCP. For LHCP axial ratio is 1.47 and for RHCP it is 0.75.
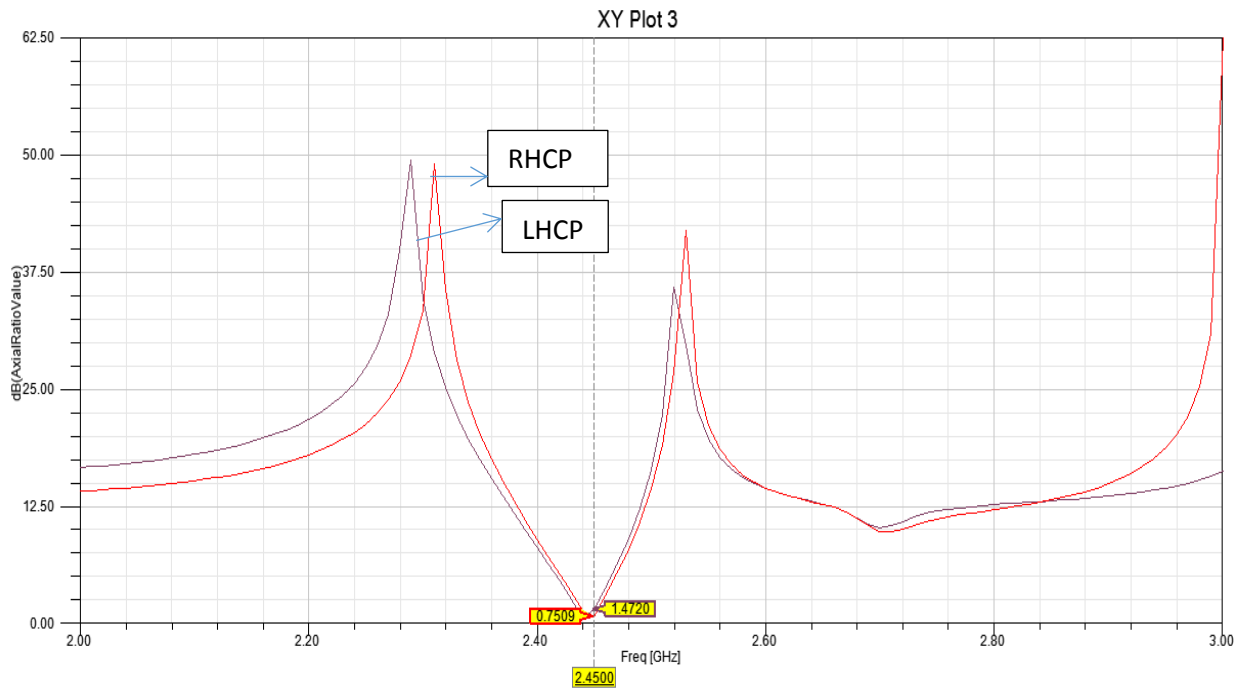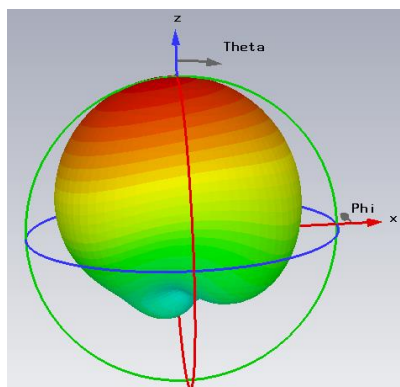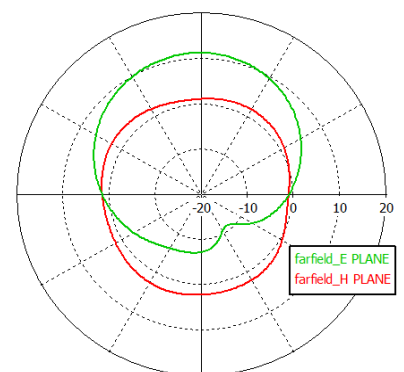

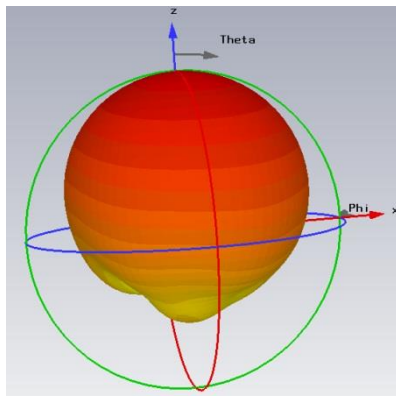Figure 5.7 Simulated Axial Ratio for the proposed antenna.

(a) 3-D Plot

Frequency = 2.45
Main lobe magnitude = 11.3 dB
Main lobe direction = 2.0 deg.
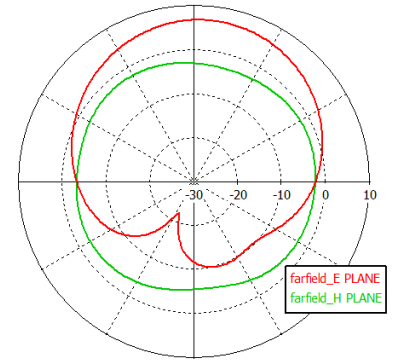Angular width (3 dB) = 91.8 deg

(b) Polar Plot

Figure 5.8 Simulated radiation pattern of the LHCP antenna at 2.45 GHz.

| (a) 3-D Plot | (b) Polar Plot |

Figure 5.9 Simulated radiation pattern of the RHCP antenna at 2.45 GHz.

Figure 5.9 show the radiation pattern for LHCP which consist of 3-D plot and polar plot at resonant frequency 2.45 GHz. Polar plot consist of E-plane and H-plane. From figure we can see that antenna is a directional antenna and its main lobe magnitude is 11.3 dB and its direction is 2^0. The angular width i.e. 3 dB bandwidth or half power beam width is 91.8^0. Similarly, figure 5.10 shows the same for RHCP configuration in which 'a' part is 3-D plot and 'b' part is polar plot. In this case at resonant frequency main lobe magnitude is 6.8 dB and its direction is 0^0. Side lobe magnitude is -18.5 dB. 3 dB bandwidth or angular width is 76^0.

Table 5.3 Gain, Directivity and Efficiency of Antenna

Polarization	Gain (dB)	Directivity(dB)	Efficiency (%)
LHCP	6.8	7.7	88.3
RHCP	6.5	7.6	85.5

Summary

By using dual feed and switching action antenna is capable to radiate RHCP and LHCP. S-parameters at its resonant frequency 2.45 GHz are S1,1 = -18.639 dB, S2,1 = -14 dB, S2,2 = -18.269 dB, S1,2 = -14 dB. Bandwidth for LHCP and RHCP are same i.e. 32.5 MHz. For LHCP axial ratio is 1.47 and for RHCP it is 0.75.

5.2 Design 2

Reconfigurable circularly polarized microstrip antenna feeding with single feed line

A square ring polarization reconfigurable microstrip antenna is proposed. Antenna can be radiating either LHCP wave or RHCP wave by switching action. Antenna operates at its dominant mode TM_{11} mode. Radiating patch is excited by feedline through proximity coupling technique. Antenna is suitable for Polarization diversity array [2], [17], [18].

5.2.1 Antenna design

$$\varepsilon_{r1} = 1.06, \ \varepsilon_{r2} = 4.4,$$
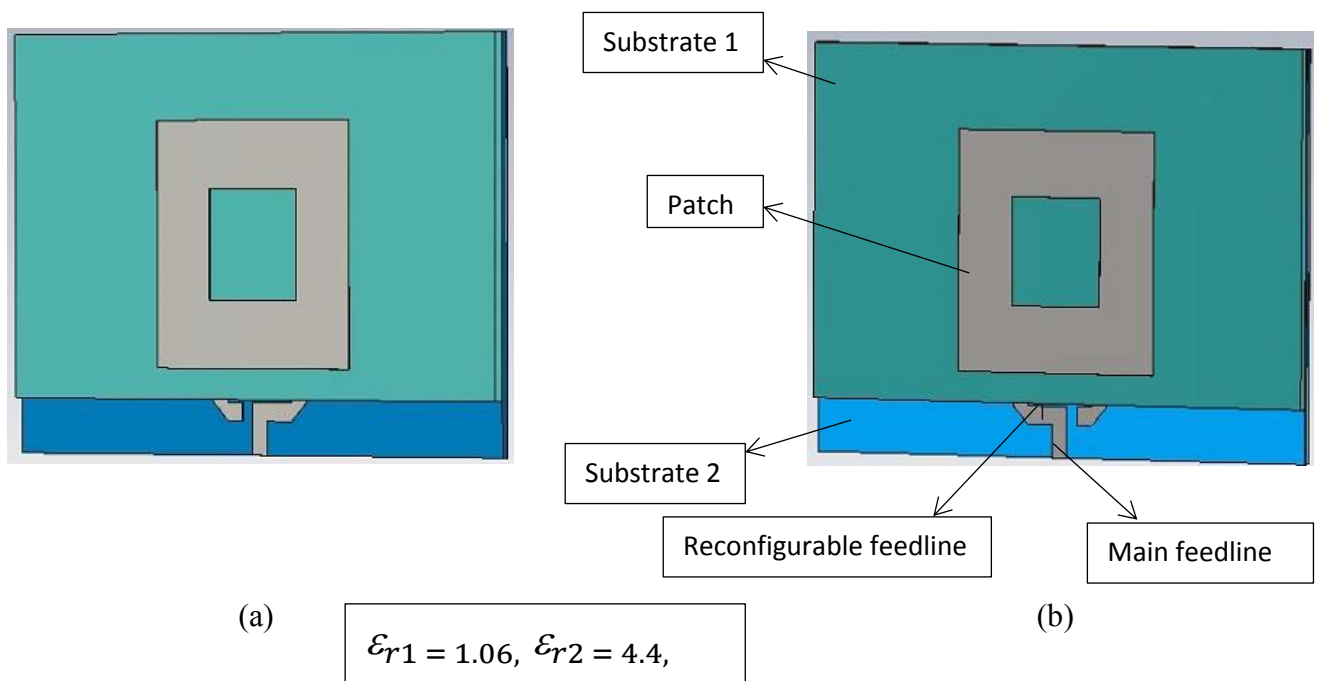
Figure 5.10 Geometry of proposed antenna (a) RHCP, (b) LHCP.

From figure 5.7 we can see feedline is sandwich between two substrates of permittivity 1.06 (upper) and 4.4 (lower). In proximity coupled feeding technique lower substrate has always higher permittivity than lower substrate. When main feedline connect to right end of reconfigurable feedline then current flow in radiating square ring patch is clockwise and radiating wave is RHCP wave. Similarly, when main feedline connect to left end of reconfigurable feedline then current flow in patch is anti-clockwise and radiating wave

is left hand circularly polarized wave. Therefore we can see here number of pattern increases and diversity gain increases. So we can use this antenna as polarization diversity array.

5.2.2 Antenna dimensions

Table 5.4 Dimensions of proposed antenna

R_1	R_2	h_2	L_s	L_v	w_f
10	20	1.6	21.5	4	3
L_h	r_f	L_0	w_0	h_1	
3	8.1	68	100	2	

$R_2{:}R_1 = 2{:}1$ (All dimensions are in mm)

Figure 5.11 Dimensions of proposed antenna.
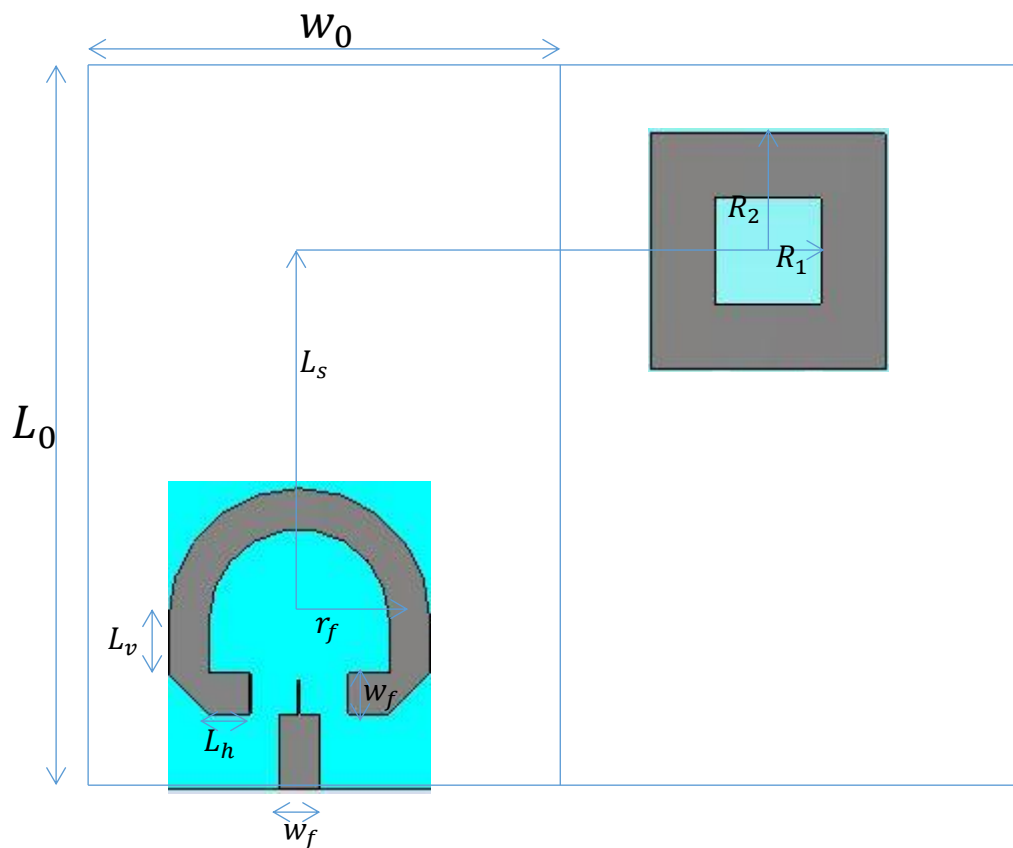
5.1.2 Simulation Results

Figure 5.9 shows the return loss plots for both LHCP and RHCP configurations. For LHCP, S1,1 = -20.295 dB at f_r = 2.45 GHz. Similarly, for RHCP S1,1 = -19.694 dB at f_r = 2.45 GHz. For both LHCP and RHCP bandwidth is same i.e. 79.13 MHz.
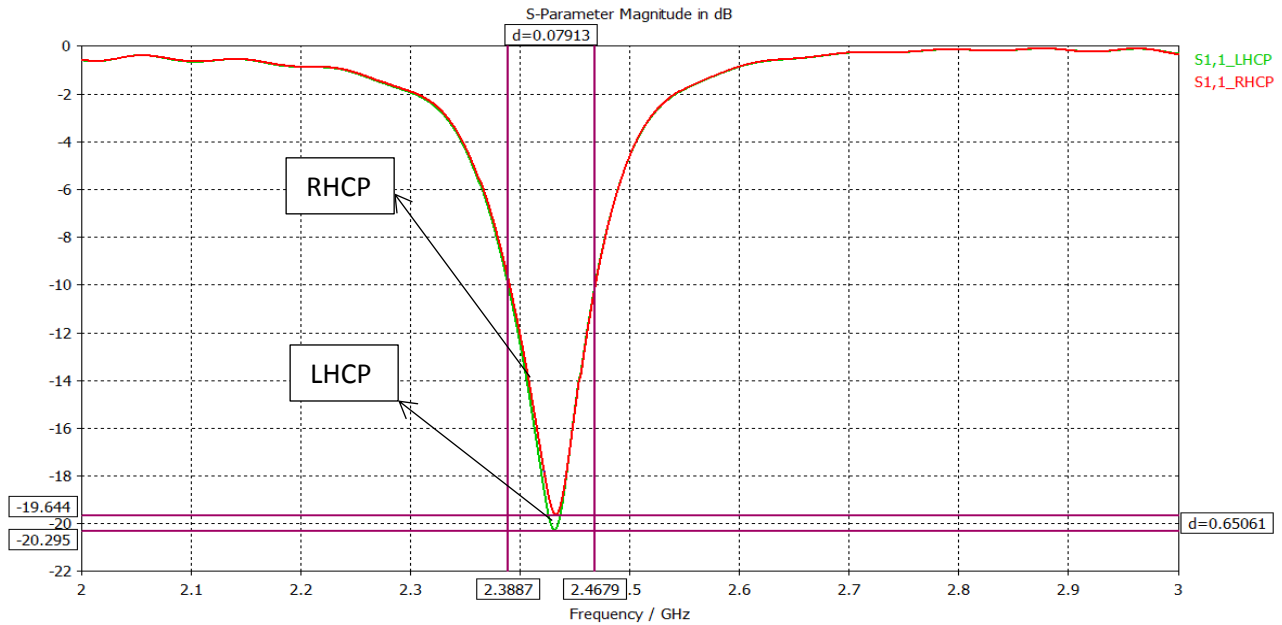
Figure 5.12 S-Parameters for the antenna in LHCP & RHCP.
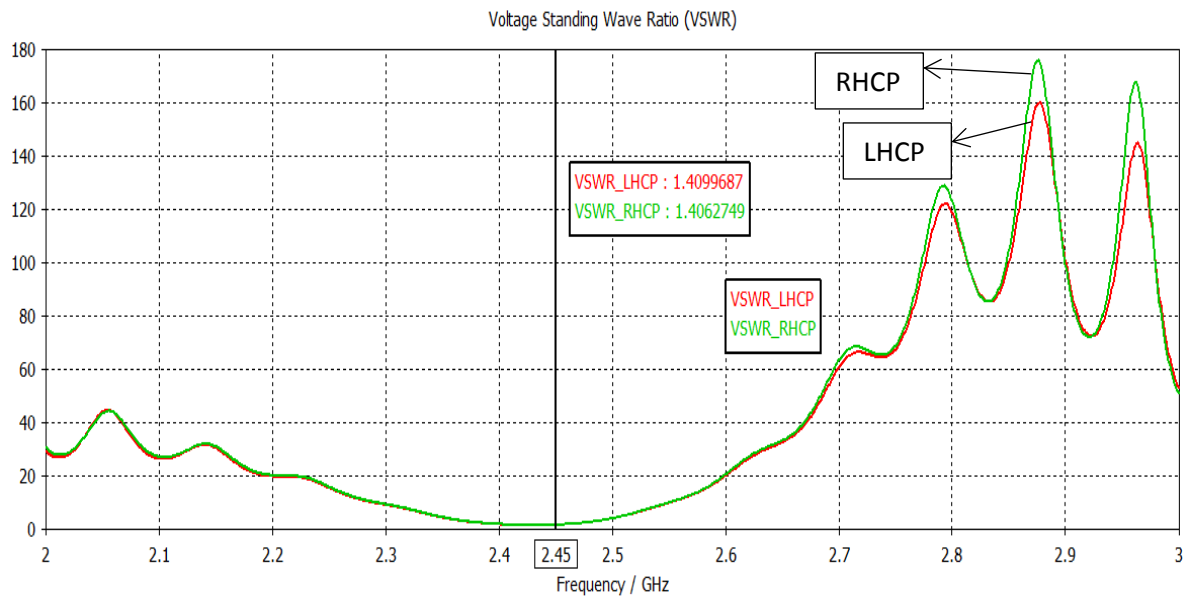
Figure 5.13 VSWR for the antenna in LHCP & RHCP.

Figure 5.10 shows the VSWR plots for RHCP and LHCP configuration. At resonant frequency f_r = 2.45 GHz, VSWR for LHCP is 1.409 and for RHCP is 1.406. For LHCP, AR= 1 dB at 2.5 GHz and for RHCP, AR= 3 dB at 2.5 GHz.
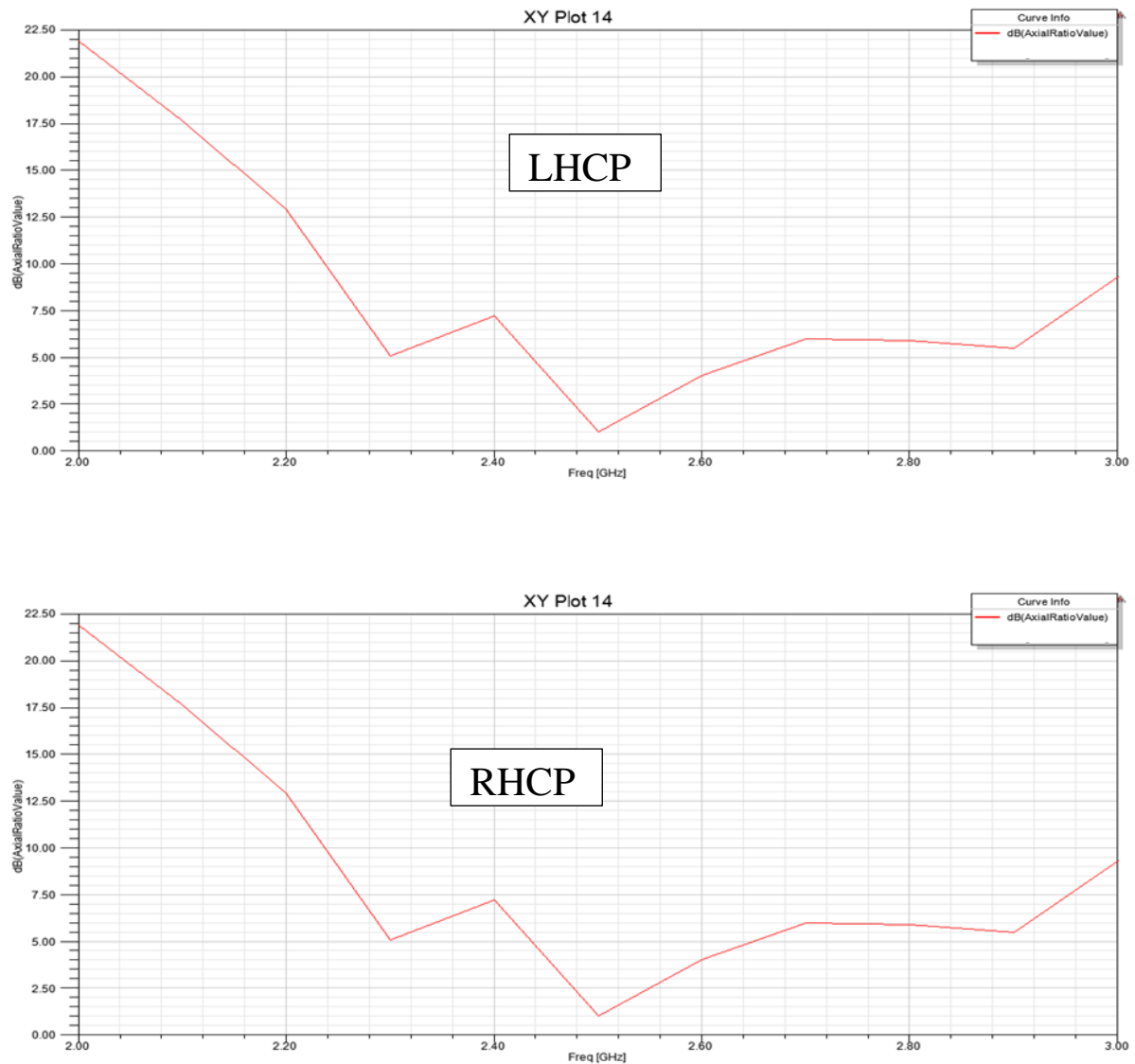
Figure 5.14 Axial Ratio plots for LHCP and RHCP.

Figure 5.12 shows the radiation pattern for LHCP configuration at resonant frequency. Polar plot consist of E-plane and H-plane. It is a directional antenna. At resonant frequency f_r = 2.45 GHz, main lobe magnitude is 8.4 dB and its direction is 0^0. Side lobe magnitude is -19.7 dB. Angular width or 3 dB bandwidth is -19.7 dB.
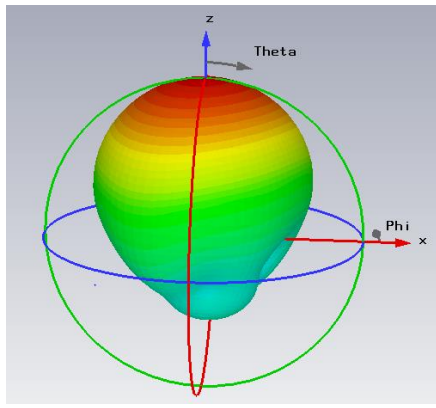
(a) 3-D Plot
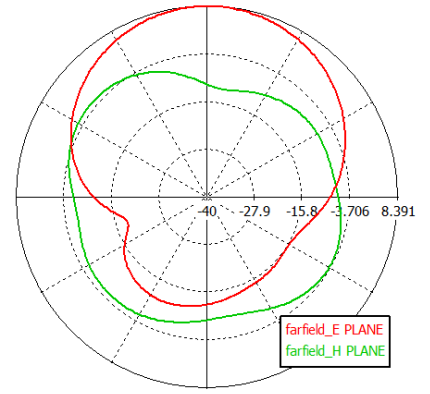
(b) Polar Plot

Figure 5.15 Radiation pattern of the LHCP antenna at 2.45 GHz.
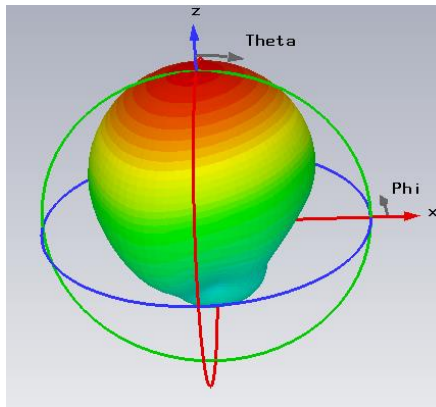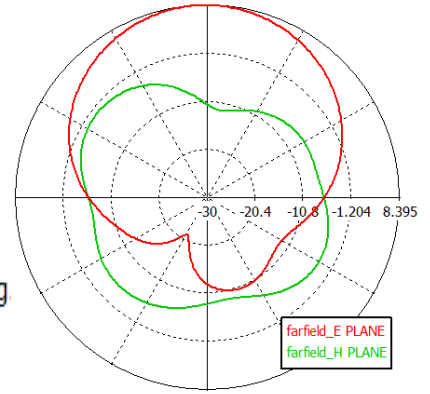
(a) 3-D Plot   (b) Polar Plot

Figure 5.16 Radiation pattern of the RHCP antenna at 2.45 GHz.

Figure 5.13 shows the radiation pattern for RHCP configuration at its resonant frequency f_r = 2.45 GHz. From polar plot we can observe that the direction of main lobe i.e. direction of maximum radiation is 2^0 and in this direction maximum magnitude is 8.4 dB. Angular width or half power beam width or 3 dB bandwidth is 78.7^0.

Summary

By using reconfigurable feed line and switching action antenna is capable to radiate RHCP and LHCP. For LHCP, S1,1 = -20.295 dB at f_r = 2.45 GHz. Similarly, for RHCP S1,1 = -19.694 dB at f_r = 2.45 GHz. For both LHCP and RHCP bandwidth is same i.e. 79.13 MHz. For LHCP, AR= 1 dB at 2.5 GHz and for RHCP, AR= 3 dB at 2.5 GHz.

5.3 Design 3

Dual feed Quadri-Polarization States microstrip patch antenna.

A square patch polarization reconfigurable microstrip antenna is capable to radiate four polarization states i.e. VLP, HLP, LHCP, RHCP by using switching action. Square patch fed by two microstrip line feed network. On the patch two opposite corners are slotted and diodes are used to connect the slots as shown in figure. The substrate use in antenna has permittivity ε_r of 2.65. Substrate is sandwich by radiating metallic patch and ground plane of same metal as used for patch. Thus antenna is able to radiate four different patterns. It increases the diversity gain. Antenna is suitable for polarization diversity array [4], [9], [16].

5.3.1 Antenna design
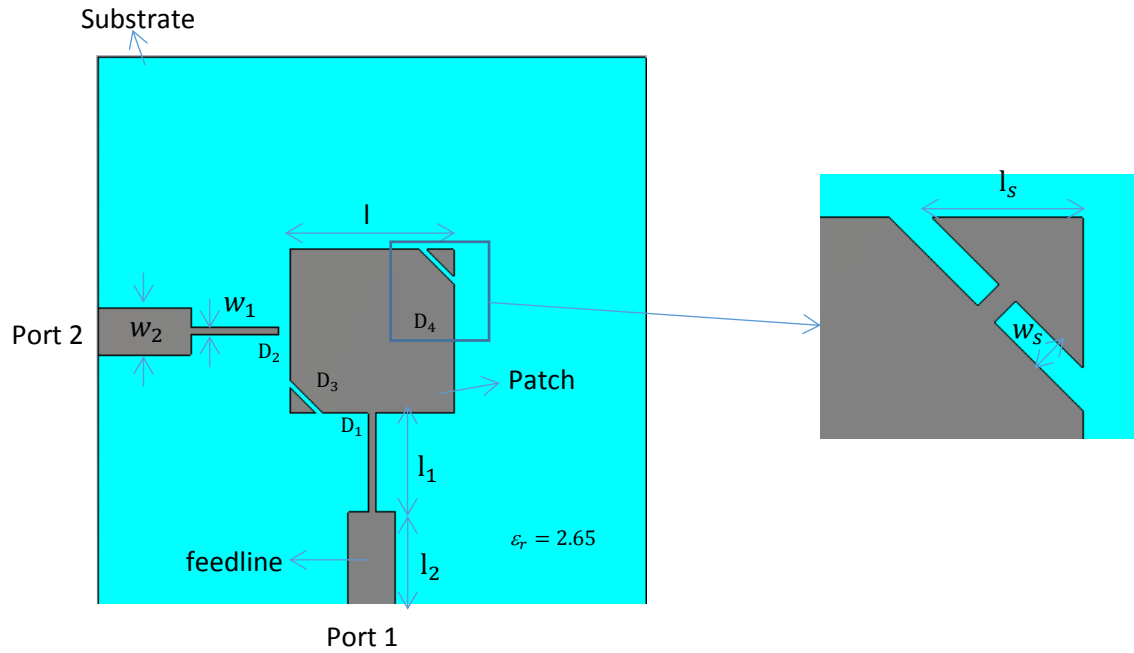
Figure 5.17 Geometry of proposed antenna.

Table 5.5 Dimensions of proposed antenna

w_1	w_2	l	l_1	l_2
0.5	3.3	12	7	6.5
l_s	w_s	h	t	
2	0.3	1.6	0.05	

(All dimensions are in mm)

Table 5.6 Configuration of four pin diodes

D$_1$	D$_2$	D$_3$	D$_4$	Polarization
on	off	on	on	LP1(Vertical)
off	on	on	on	LP2(Horizontal)
on	off	off	off	RHCP
off	on	off	off	LHCP

Table 5.5 shows the different configuration with switching action. When diodes D3 and D4 are on then antenna radiates linear polarized wave. In this case when D1 is on and D2 is off then radiated wave is vertical linear polarized wave and when D1 is off and D2 is on then wave is horizontal linear polarized wave. Similarly, When D3 and D4 are off then radiated wave is circular polarized wave. In this case when D1 is on and D2 is off then radiated wave is RHCP and if D1 is off and D2 is on then radiated wave is LHCP wave.

5.3.2 Simulation Results
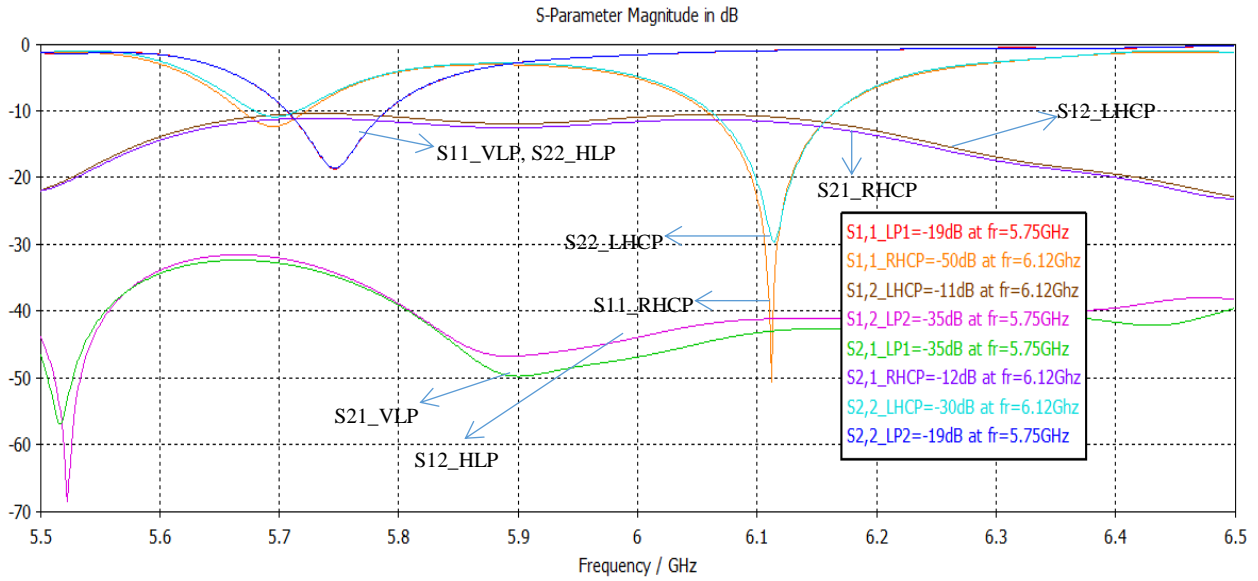
Figure 5.18 Simulated S parameters for the proposed antenna in LHCP & RHCP.

Figure 5.15 shows the various S parameters for various configurations. When D1 is on and D2 is off then radiating patch will feed from vertical feedline and horizontal feedline will be isolated and vice versa. For vertical linear polarization S1,1 = -19 dB at resonant frequency 5.75 GHz and isolation of horizontal feedline i.e. S2,1 = -35 dB. Similarly, for horizontal linear polarization S2,2 = -19 dB at resonant frequency 5.75 GHz and isolation of vertical feedline i.e. S1,2 = -35 dB, for LHCP S2,2 = -30 dB at resonant frequency 6.12 GHz and isolation of vertical feedline i.e. S1,2 = -11 dB, for RHCP S1,1 = -50 dB at resonant

frequency 6.12 GHz and isolation of horizontal feedline i.e. S2,1 = -12 dB. For linear polarization bandwidth is 0.07 GHz and for circular polarization bandwidth is 0.11 GHz.

t= 0

t= T/4

t= T/2

t= 3T/4

t= T
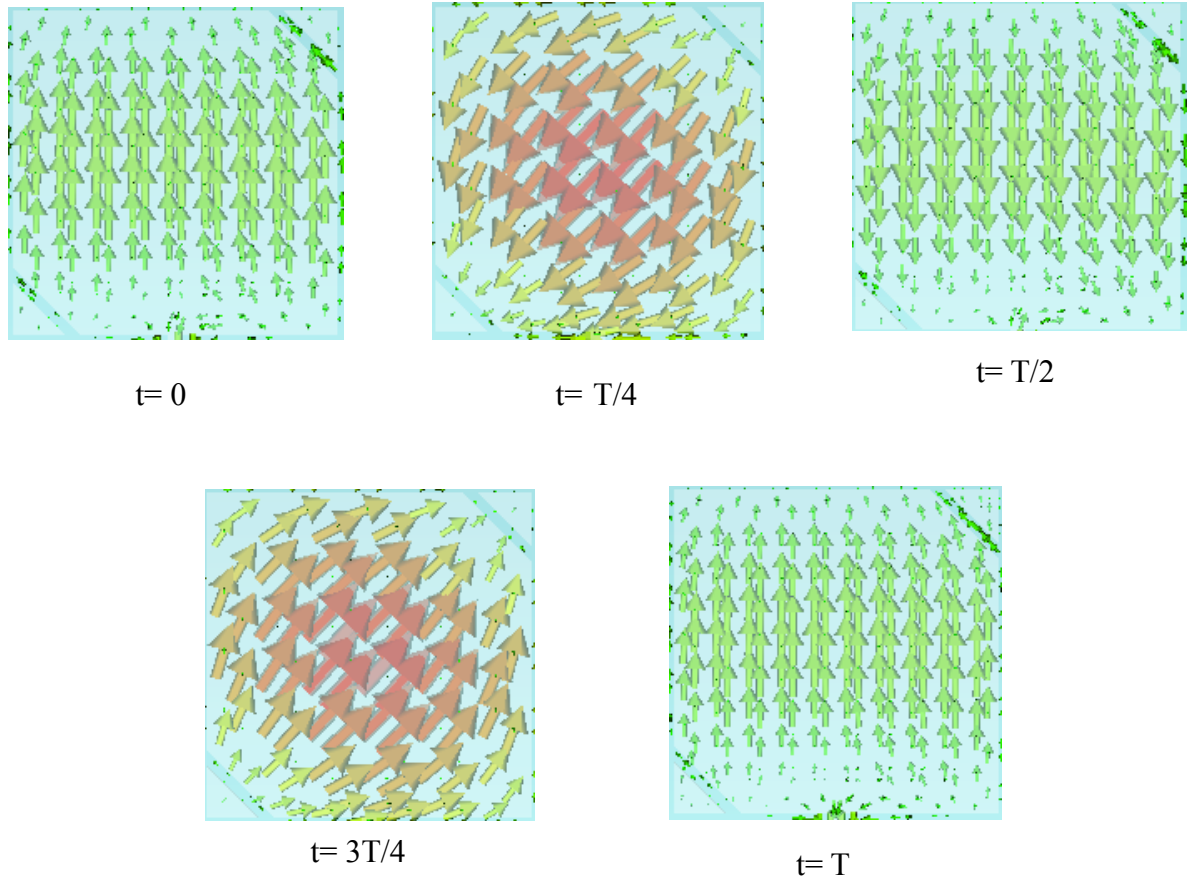
Figure 5.19 Electric surface current distributions on the RHCP patch antenna.

Figure 5.16 shows the surface current distributions for RHCP configuration. We can see with advancing of time current is rotating anti-clockwise direction. Similarly, for LHCP configuration rotation of current is clockwise direction. For vertical linear polarization, direction of current is vertical up and vertical down side for one complete time period. For horizontal linear polarization, direction of current is horizontal left and horizontal right side for one complete time period.

Ideally axial ratio should be one for circularly polarized wave and infinity for linearly polarized wave. Figure 5.17 shows the simulated axial ratio result for both LHCP and RHCP wave. For LHCP, AR= 0.2 dB at 6.04 GHz and for RHCP, AR= 1.2 dB at 6.08 GHz.
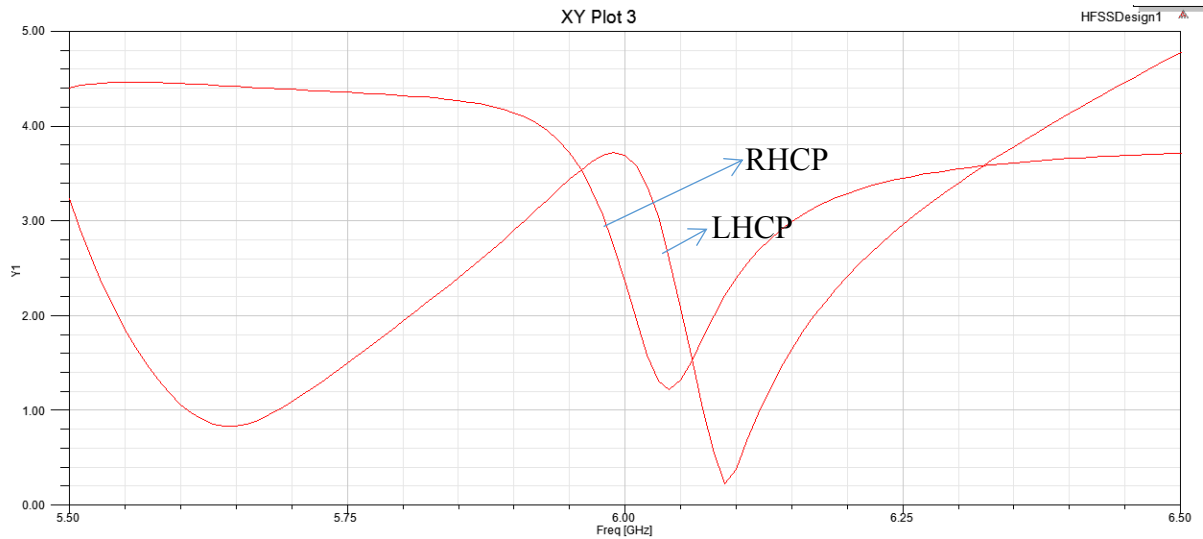
Figure 5.20 Simulated Axial Ratio for the proposed antenna.
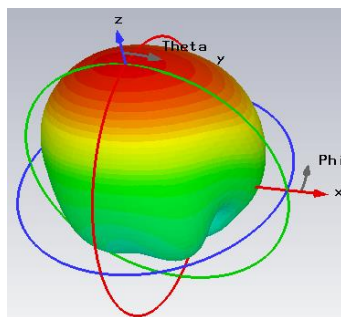
(a) VLP_3-D Plot
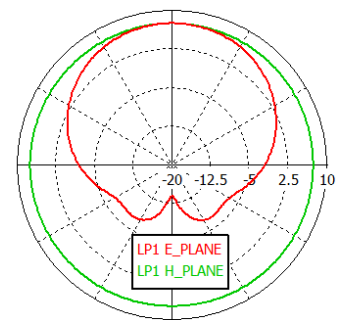
(b) HLP_Polar Plot

Figure 5.21 Simulated radiation pattern of the vertical LP antenna at 5.75 GHz.

(a) HLP_3-D Plot

(b) LP2_Polar Plot

Figure 5.22 Simulated radiation pattern of the horizontal LP antenna at 5.75 GHz.

Figure 5.18 shows the radiation pattern for vertical linear polarized antenna at resonant frequency 5.75 GHz. Polar plot consists of E-plane and H-plane plots. It is a directional antenna. Direction of main lobe is 0^0 and its magnitude is 7.4 dB. Side lobe magnitude is -14.9 dB. 3dB bandwidth or angular width of main lobe is 98.7^0. Similarly,

figure 5.19 shows the radiation pattern for horizontal polarization case. Magnitude of main lobe is 7.4 dB and its direction is 0^0. Side lobe magnitude is -15.1 dB. Angular width or 3 dB bandwidth of main lobe is 97.7^0.

Main lobe magnitude =   8.0 dBi
Main lobe direction =   0.0 deg.
Angular width (3 dB) =   72.9 deg.
Side lobe level =   -18.3 dB
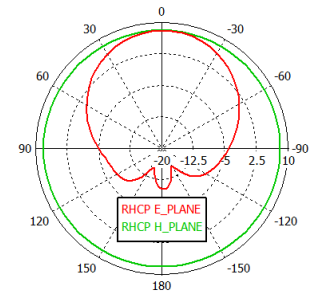
(a) RHCP_3-D   (b) RHCP_Polar Plot

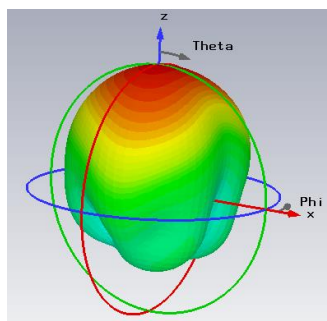Figure 5.23 Simulated radiation pattern of the RHCP antenna at 6.12 GHz.
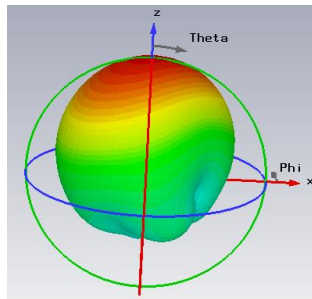
Main lobe magnitude =   8.0 dBi
Main lobe direction =   3.0 deg.
Angular width (3 dB) =   83.0 deg.
Side lobe level =   -17.8 dB
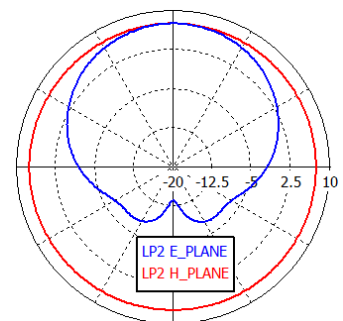
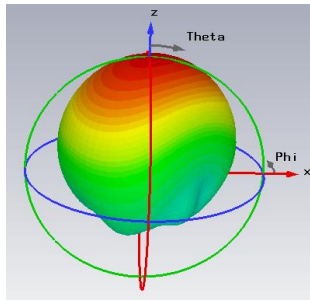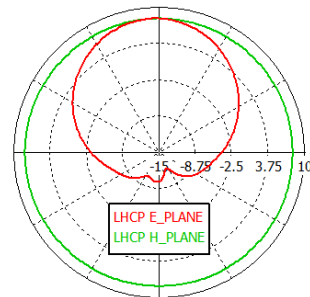(a) LHCP_3-D Plot   (b) LHCP_Polar Plot

Figure 5.24 Simulated radiation pattern of the LHCP antenna at 6.12 GHz.

Figure 5.20 shows the radiation pattern of RHCP antenna at resonant frequency 6.12 GHz. Amplitude of main lobe is 8 dB and its direction is 0^0. Side lobe magnitude is -18.3 dB. 3dB bandwidth or angular width of main lobe is 72.9^0. Figure 5.21 shows the radiation pattern for LHCP configuration. Main lobe magnitude is 8dB and its direction is 3^0. Magnitude of side lobe is -17.8dB. 3db bandwidth or angular width of main lobe is 83^0.

Table 5.7 Gain and Efficiency of Antenna

Polarization	Gain (dB)	Efficiency (%)
LP1(Vertical)	7.4	89.7
LP2(Horizontal)	7.4	89.7
RHCP	8	92.99
LHCP	8	90.99

Summary

By using dual feed and switching action antenna is capable to radiate VLP, HLP, RHCP and LHCP. For different configurations, S-parameters, axial ratio, VSWR, radiation pattern and surface current results are presented and analysed.

5.4 Design 4

Single feed U-slot polarization reconfigurable microstrip patch antenna

Antenna consists of metallic circular patch feeding with microstrip line. A U-shape slot is created at the center of patch and two PIN diodes are connected to make antenna as reconfigurable. A dielectric substrate of permittivity 4.4 i.e. FR4 substrate, is sandwich between radiating patch and metallic ground plane. Antenna can radiate linear polarization, right hand circular polarization and left hand circular polarization. Since no of patterns increases, diversity gain of antenna will increase. So this antenna can be used in MIMO system. Antenna is suitable for polarization diversity array [3], [6].

5.4.1 Antenna design

D1=OFF, D2=OFF

(a) LP

D1=ON, D2=OFF

(b) LHCP

$\varepsilon_r = 2.65$

D1=OFF, D2=ON

(C) RHCP
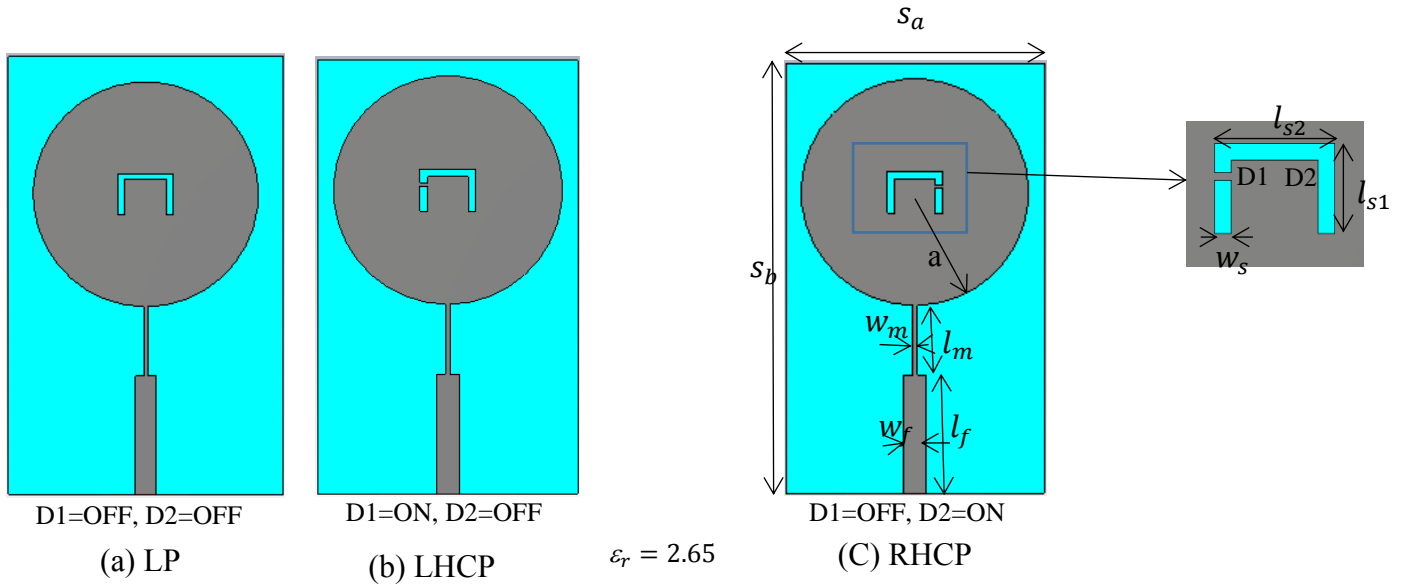
Figure 5.25 Geometry of proposed antenna.

Table 5.8 Dimensions of proposed antenna

w_m	l_m	a	s_b	s_a	l_f	w_f
0.63	10	16.35	62	18.6	17.11	3.28
l_{s1}	l_{s2}	l_{s3}	w_s	h	t	
6	8	1.55	1.1	1.6	0.05	

(All dimensions are in mm)

Table 5.9 Configuration of two PIN diodes

D1	D2	Polarization
OFF	OFF	LP
ON	OFF	RHCP
OFF	ON	LHCP

From figure 1.22 we can see the different switching action. When both the diodes are off then antenna can radiate linearly polarized wave. Similarly, when diode D1 is on and D2 is off then antenna can radiate right hand circular polarized wave and when D1 is off and D2 is on then it can radiate left hand circular polarized wave [10], [12]. Thus we can see by using switch and U-slot antenna can radiate number of different patterns and increase the diversity gain to reduce the multi path effects and interference.

5.4.2 Simulation Results
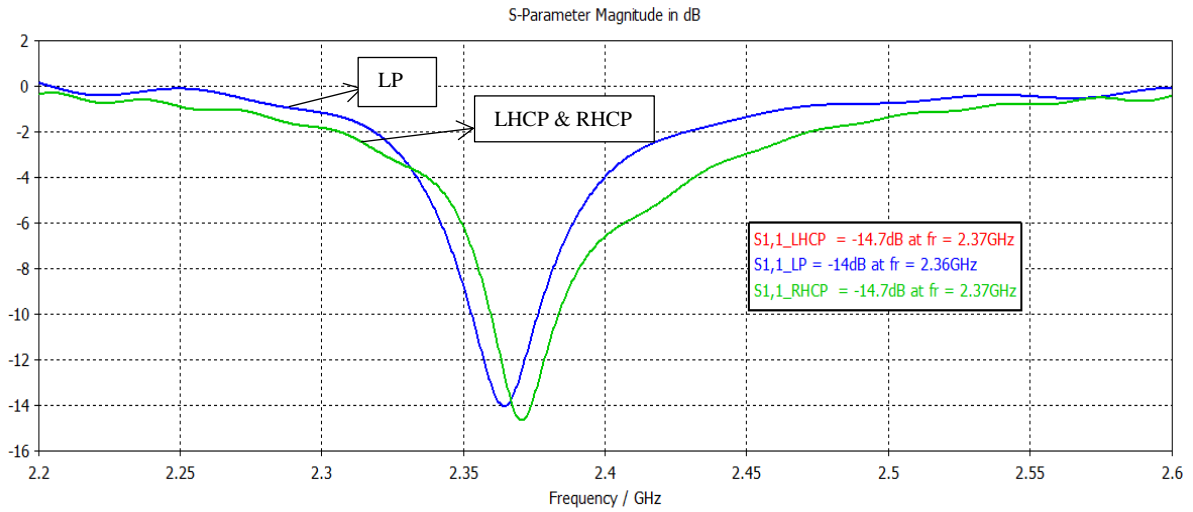
For LP, BW= 22.7MHz
For CP, BW= 24.2MHz

Figure 5.26 S-Parameters for the proposed antenna in LHCP & RHCP.

Figure 5.22 shows the return loss plots for different configuration of antenna i.e. linear polarization, left hand circular polarization, right hand circular polarization. In case of linear polarization S11 = 14 dB at resonant frequency f_r = 2.36 GHz and bandwidth is 22.7MHz. S11 for left hand circular polarization and right hand circular polarization are overlap to each other and it is -14.7 dB at resonant frequency f_r = 2.37 GHz and its bandwidth is 24.2MHz.

51

t= 0   t= T/4   t= T/2

t= 3T/4   t= T
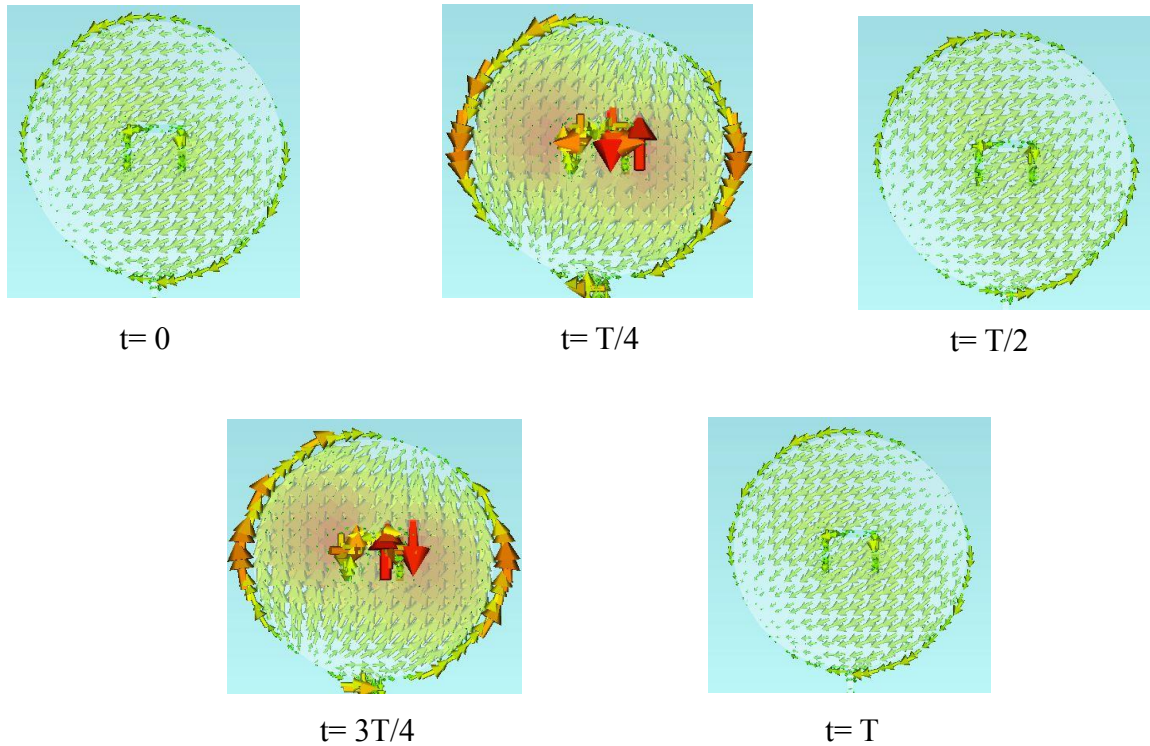
Figure 5. 27 Electric surface current distributions on the RHCP patch antenna.

Figure 5.24 shows the current distribution over the patch in case of right hand circular polarization. Here, we can see with advancing of time current is rotating anti-clockwise direction, therefore the radiated wave act as right hand circular polarized wave. Similarly, in case of left hand circularly polarized wave, current is rotating clockwise direction.

Frequency = 2.37
Main lobe magnitude =   4.1 dB
Main lobe direction =   0.0 deg.
Angular width (3 dB) =   80.7 deg.
Side lobe level =   -9.3 dB

Polar Plot   3-D Plot

Figure 5.28 Simulated radiation pattern of LHCP antenna at resonant frequency.

Figure 5.25 shows the radiation pattern in left hand circular polarization configuration. Polar plot consist of E-plane and H-plane. At resonant frequency main lobe magnitude is 4.1 dB and its direction is 0^0. Side lobe magnitude is -9.3 dB. Angular width or 3 dB bandwidth is 80.7^0.

Polar Plot

Frequency = 2.37
Main lobe magnitude =   4.1 dB
Main lobe direction =   0.0 deg.
Angular width (3 dB) = 80.7 deg.
Side lobe level = -9.3 dB

3-D Plot

Figure 5.29 Simulated radiation pattern of RHCP antenna at resonant frequency.

Figure 5.26 shows the radiation pattern in right hand circular polarization configuration. At resonant frequency main lobe magnitude is 4.1 dB and its direction is 0^0. Side lobe magnitude is -9.3 dB. Angular width or 3 dB bandwidth is 80.7^0.

Polar Plot

Frequency = 2.36
Main lobe magnitude =   5.4 dB
Main lobe direction =   0.0 deg.
Angular width (3 dB) = 72.9 deg.
Side lobe level = -11.8 dB

LP_E PLANE
LP_H PLANE

3-D Plot
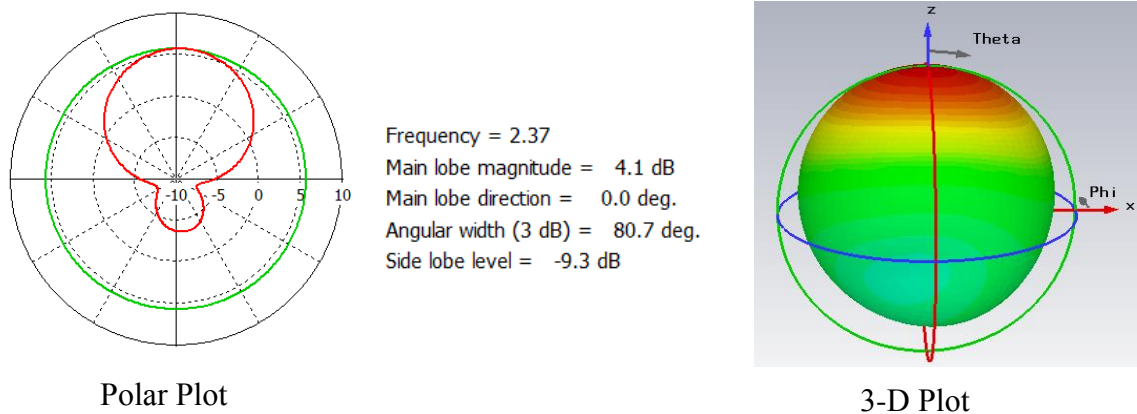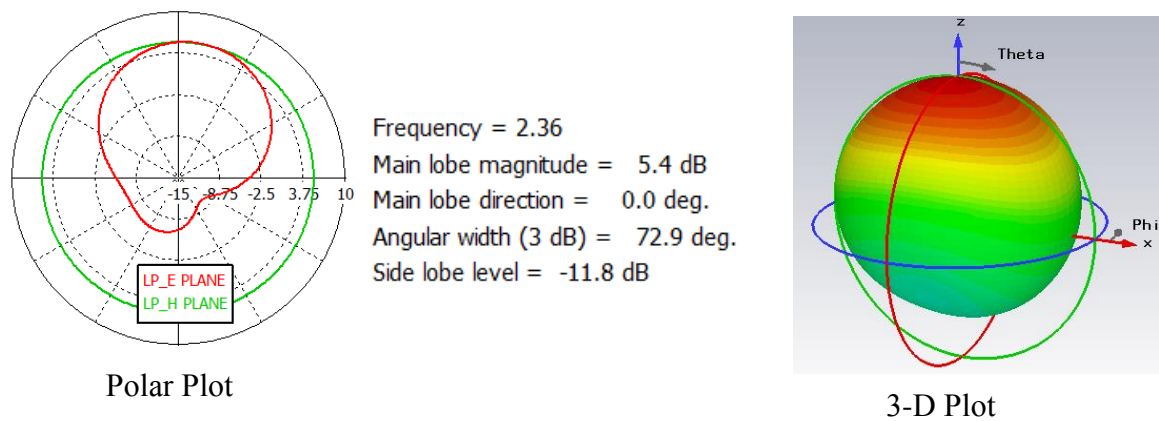
Figure 5.30 Simulated radiation pattern of LP antenna at resonant frequency.

Figure 5.27 shows the radiation pattern in linear polarization configuration. At resonant frequency main lobe magnitude is 5.4 dB and its direction is 0^0. Side lobe magnitude is -11.8 dB. Angular width or 3 dB bandwidth is 72.9^0.
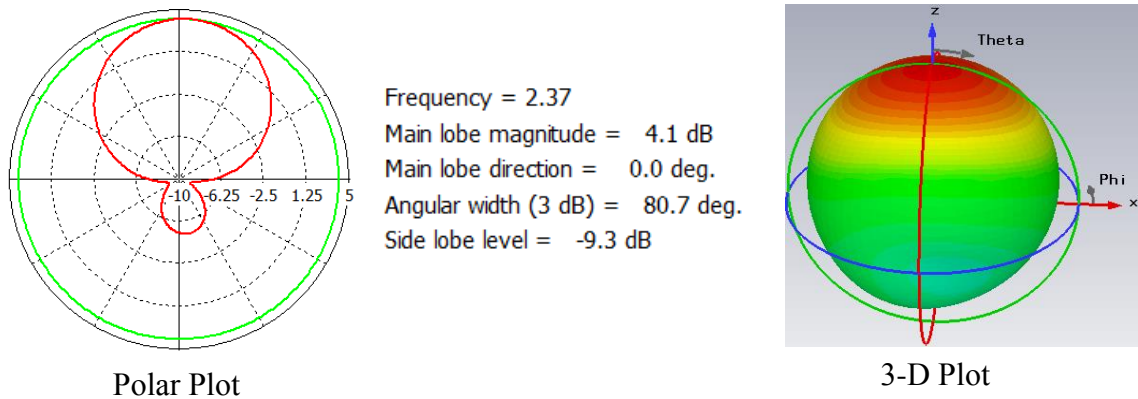
Table 5.10 Gain, Directivity and Efficiency of Antenna

Polarization	Gain (dB)	Directivity(dB)	Efficiency (%)
LP	5.4	5.9	91.52
LHCP	4.1	5.7	71.92
RHCP	4.1	5.7	71.92

Table 5.8 shows the gain, directivity and efficiency for different configuration of antenna. We can see that efficiency is high in case of linear polarization as compare to LHCP and RHCP. In linear polarization configuration gain is 5.4 dB, directivity is 5.9 dB and efficiency is 91.52%. Similarly, in right hand circular polarization and left hand circular polarization both have same radiation pattern i.e. gain is 4.1 dB, directivity is 5.7 dB and efficiency is 71.92%.

Summary

By using U- slot and switching action antenna is capable to radiate LP, RHCP and LHCP. For different configurations, S-parameters, axial ratio, VSWR, and radiation pattern results are presented and analysed.

Chapter 6

Conclusion and Future Work

In this thesis four different polarization reconfigurable antennas with different geometry are explained. First and second geometry are capable to radiate two orthogonal pattern i.e. right hand circular polarized and left hand circular polarized wave. Third design can radiate four different patterns i.e. vertical linear polarized, horizontal linear polarized, right hand circular polarized and left hand circular polarized wave. Forth design can radiate three different patterns i.e. linear polarization, left hand circular polarization and right hand circular polarization. Out of four, vertical linear polarization and horizontal linear polarization are orthogonal pattern and right hand circular polarization and left hand circular polarization are orthogonal pattern. So, by using polarization reconfigurable technique with suitable bias arrangement and feeding technique we can increase the number of patterns and increase the diversity gain of antenna. Therefore, we can conclude that Polarization reconfigurable antennas have the features of multipath effects reduction i.e. reduction of fading and interference due to increase in diversity gain. So, this design can be used as a polarization diversity array and suitable for MIMO system.

Since, all the four antennas have very less bandwidth, in future some optimization technique can be used to increase the bandwidth and enhance the antenna performance. In future fabrication work for reconfigurable to be done.

References

[1] Sennouni, M.A.; Zbitou, J.; Tribak, A.; Benaissa, A.; Latrach, M., "Circular polarized square patch antenna array for wireless power transmission," *Renewable and Sustainable Energy Conference (IRSEC), 2013 International* , vol., no., pp.504,508, 7-9 March 2013.

[2] Jingjing Huang; Kin-Fai Tong; Baker, C., "A new polarization reconfigurable microstrip antenna for diversity array," *Radar Conference, 2008. RADAR '08. IEEE* , vol., no., pp.1,4, 26-30 May 2008.

[3] Taeho Song; Youngki Lee; Deukhyeon Ga; Jaehoon Choi, "A polarization reconfigurable microstrip patch antenna using PIN diodes," *Microwave Conference Proceedings (APMC), 2012 Asia-Pacific* , vol., no., pp.616,618, 4-7 Dec. 2012.

[4] Xue-Xia Yang; Bo Gong; Fang Yang; Elsherbeni, A.Z., "A reconfigurable patch antenna with quadri-polarization states using dual feed ports," *Antennas and Propagation Society International Symposium (APSURSI), 2012 IEEE* , vol., no., pp.1,2, 8-14 July 2012.

[5] Parihar, M.S.; Basu, A.; Koul, S.K., "Polarization reconfigurable microstrip antenna," *Microwave Conference, 2009. APMC 2009. Asia Pacific* , vol., no., pp.1918,1921, 7-10Dec.2009.

[6] Sedghara, A.; Atlasbaf, Z., "A new reconfigurable single-feed microstrip antenna with polarization diversity," *Antennas and Propagation (EuCAP), 2013 7th European Conference on* , vol., no., pp.2403,2406, 8-12 April 2013.

[7] *Sedghara, A.; Atlasbaf, Z., "Reconfigurable single-feed antenna with switchable polarization," Electrical Engineering (ICEE), 2013 21st Iranian Conference on , vol., no., pp.1,4,14-16May 2013.*

[8] Nasimuddin; Esselle, K.P.; Verma, A.K., "Improving the axial-ratio bandwidth of circularly polarized stacked microstrip antennas and enhancing their gain with short horns," *Antennas and Propagation Society International Symposium 2006, IEEE* , vol., no., pp.1545,1548, 9-14 July 2006.

[9] Jeen-Sheen Row; Ming-Jyun Hou, "Design of Polarization Diversity Patch Antenna Based on a Compact Reconfigurable Feeding Network," *Antennas and Propagation, IEEE Transactions*

on , vol.62, no.10, pp.5349,5352, Oct. 2014.

[10]   Noordin, N.H.; Wei Zhou; El-Rayis, A.O.; Haridas, N.; Erdogan, A.T.; Arslan, T., "Single-feed polarization reconfigurable patch antenna," *Antennas and Propagation Society International Symposium (APSURSI), 2012 IEEE* , vol., no., pp.1,2, 8-14 July 2012.

[11]   Hettak, K.; Delisle, G.Y.; Morin, G.; Stubbs, M., "A Novel reconfigurable single-feed CPW coupled patch antenna topology with switchable polarization," *Antennas and Propagation Society International Symposium, 2007 IEEE* , vol., no., pp.5199,5202, 9-15 June 2007.

[12]   Nikolaou, S.; Boyon Kim; Vryonides, P., "Reconfiguring antenna characteristics using PIN diodes," *Antennas and Propagation, 2009. EuCAP 2009. 3rd European Conference on* , vol., no., pp.3748,3752, 23-27 March 2009.

[13]   Petosa, A.; Ittipiboon, A., "Dielectric Resonator Antennas: A Historical Review and the Current State of the Art," *Antennas and Propagation Magazine, IEEE* , vol.52, no.5, pp.91,116,Oct.2010.

[14]   Lo, Y.T., Solomon, D.,and Richards , W.F.,"Theory and Experiment on microstrip Antenna," *IEEE Transactions on antenna and propagation,* March1979, vol. AP-27, pp. 137-149.

[15]   Richards, W.F., LO, Y.T., and Harrison, D.D., "An improved theory for microstrip antennas and application" *IEEE Transactions on antenna and propagation* January 1981,vol. AP-29,pp. 38-46.

[16]   Hansheng Su; Shoaib, I.; Xiadong Chen; Kreouzis, T., "Optically tuned polarisation reconfigurable antenna," *Antennas and Propagation (APCAP), 2012 IEEE Asia-Pacific Conference on* , vol., no., pp.265,266, 27-29 Aug. 2012.

[17]   Khidre, A.; Kai-Fong Lee; Fan Yang; Elsherbeni, A.Z., "Circular Polarization Reconfigurable Wideband E-Shaped Patch Antenna for Wireless Applications," *Antennas and Propagation, IEEE Transactions on* , vol.61, no.2, pp.960,964, Feb. 2013.

[18]   I-Chian Wu; Shyh-Kang Jeng, "A single-feed switchable wide-band circular polarization E-shaped patch antenna," *Antennas and Propagation Society International Symposium (APSURSI), 2013 IEEE* , vol., no., pp.568,569, 7-13 July 2013.

[19]   Hyuck Jin Kim; Ki Suk Yoon; Sung Min Kim; Woon Geun Yang, "Design and Implementation of Dual-Band Circular Polarization Square Patch Antenna for the Reception of

GPS and S-DMB Signals," *Antennas and Propagation Society International Symposium 2006, IEEE* , vol., no., pp.2657,2660, 9-14 July 2006.

[20]   Randy Bancroft, "Microstrip and Printed Antenna Design" 2nd edition, IET Publication, July 2008.

[21]   Constantine A. Balanis "Antenna Theory Analysis and Design" 3rd edition, (WILEY Publication, 2005).

[22]   Antar, Y.M.M., "Microstrip antenna design handbook [Book Review]," *Antennas and Propagation Magazine, IEEE* , vol.45, no.2, pp.86,86, April 2003.

[23]   Ramesh Garg P.bhatiya, Inder Bahal, A. Ittipiboon "Microstrip Antenna Design Handbook" (Artech House Publishers, 2001).

[24]   K. D. Prasad "Antenna and Wave Propagation" 3rd edition, (Tech India Publications, 2007).

[25]   David M. Pozar "Microwave Engineering" 4th edition, (Wiley Publication, 2013).

[26]   Matthew N. O. Sadiku "Elements of Electromagnetics" 4th edition, (Published by Oxford University Press, 2007).