DESIGN OF DUAL BAND CIRCULARY POLARIZED MICROSTRIP ANTENNA

Dissertation Submitted in partial fulfillment of the requirement for the degree of

MASTER OF TECHNOLOGY
IN
ELECTRONICS AND COMMUNICATION ENGINEERING

By

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May – 2014

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CERTIFICATE

This is to certify that the work titled **"DESIGN OF DUAL BAND CIRCULARLY POLARIZED MICROSTRIP ANTENNA"** submitted by "SAURAV MEHTA" in partial fulfillment for the award of degree of Master of Technology in Electronics and Communication Engineering, Jaypee University of Information Technology, Waknaghat has been carried out under my supervision. This work has not been submitted partially or wholly to any other University or Institute for the award of this or any other degree or diploma.

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This may seem long but the task of my thesis work both theoretically and practically may not have been completed without the help, guidance and mental support of the following persons.

I would like to thank my supervisor Associate Professor, Department of Electronics & Communication Engineering, Jaypee University of Information technology, Waknaghat, **Dr. Pradeep Kumar** sir for his constant help and guidance and provided me the idea and related material for the project proposal. He indeed guided me to do the task for my thesis in such a way that it seems to be research work. His continuous monitoring to support me and my research work encouraged me a lot for doing my thesis in very smooth manner.

At last, I would also like to take this opportunity to thank my parents for their continuous support and encouragement.

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Date: ...27.05.14...

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ABSTRACT

Microstrip antennas are one of the most widely used antennas today. They are used in cellular phones, spacecraft, missiles, radars and satellite systems. For most applications, circularly polarized wave is preferred over linearly polarized wave, as with circular polarization, antenna orientations are not important and it is immune to multipath distortion. With little modifications in the patch element, circular polarized waves can be generated. Also multiband antennas are always useful as they increase the system capacity. Hence, dual band circularly polarized microstrip antennas are much preferred these days.

The objective of this thesis is to design dual band circularly polarized antenna. Two designs are presented for which dual resonance and circular polarization is achieved successfully. Dual resonant frequencies are generated by inserting slots and circular polarization is achieved by feeding adjacent edges in one design and truncating square patch in another. Feeding technique used for both designs is microstrip line feeding. Antenna designs are simulated using FDTD based CST Microwave studio software. Corresponding reflection coefficient and axial ratio obtained on simulation are discussed.

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CHAPTER 1

INTRODUCTION

1.1 Wireless Communication

In communication industry, wireless communication has seen the most rapid growth. Most common example we can see around us is the usage of cellular phones. In addition, we find uses in wireless local area networks, wireless sensor networks, radar and satellite systems. Many new applications, including automated highways and factories, smart homes and appliances, and remote telemedicine, are emerging trends in communication systems. The explosive growth of wireless systems coupled with the usage of portable computers indicate a bright future for wireless networks, both as stand-alone systems and as part of the larger networking infrastructure[1][2].

1.2 Basic Wireless Communication System

In its most basic form, wireless communication system essentially consists of transmitter, free space as channel and receiver. Fig. 1.1 below shows simple example of transmitting a voice signal.

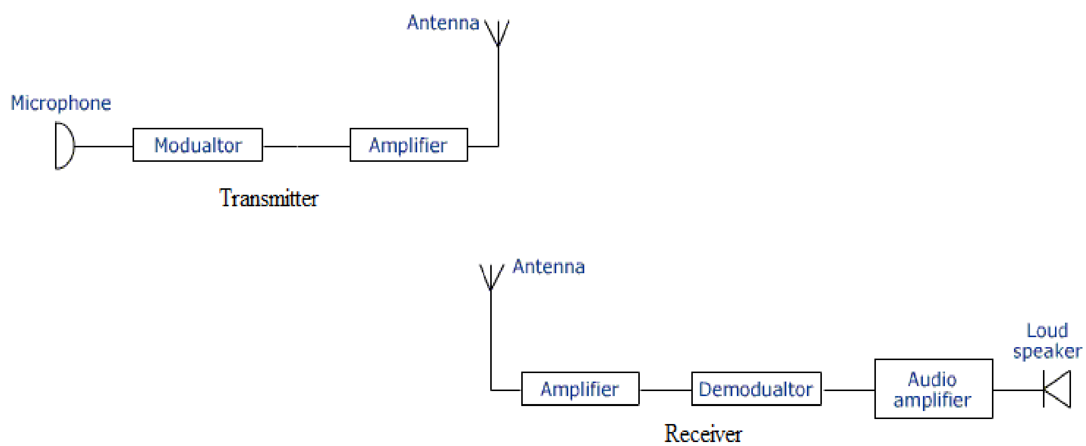


Fig. 1.1 A Basic Wireless Communication System.

1.3 Antenna as Vital Part of Wireless Communication System

Antennas are metallic structures which radiate and receive electromagnetic energy. An antenna acts as a transitional structure between the guiding device and the free space. It converts electrical signal into electromagnetic radiation at transmitter end and these information carrying waves then travel through free space. Upon reaching receiver these waves are converted back to electrical signals by receiver. The official IEEE definition of an antenna follows the concept: “That part of a transmitting or receiving system that is designed to radiate or receive electromagnetic waves”[3] .

Hence, we can say antennas are one of the most vital parts of wireless communication system, as without them communication between transmitter and receiver cannot be established.

1.4 Radiation

Antennas radiate due to time varying current flowing through them. Basically, radiation occurs because of charge acceleration or deceleration. A conducting wire radiates mainly because of time-varying current or an acceleration (or deceleration) of charge. When there is no motion of charges in a wire, no current flows and there is no radiation. If charges are moving with uniform velocity along a straight wire, even then radiation will not occur. But, charges moving with uniform velocity along a bent or curved wire will produce radiation. For charge oscillating with time, radiation occurs even along a straight wire [4].

The radiation from an antenna can be explained with the help of Fig. 1.2 which shows a voltage source connected to a two conductor transmission line. When a sinusoidal voltage is applied across the transmission line, a sinusoidal electric field is created which result in the creation of electric lines of force, which are tangential to the electric field. The magnitude of the electric field is indicated by the bunching of the electric lines of force. The free electrons on the conductors are forcibly displaced by the electric lines of force and the movement of these charges causes the flow of current which in turn leads to the creation of a magnetic field [4].

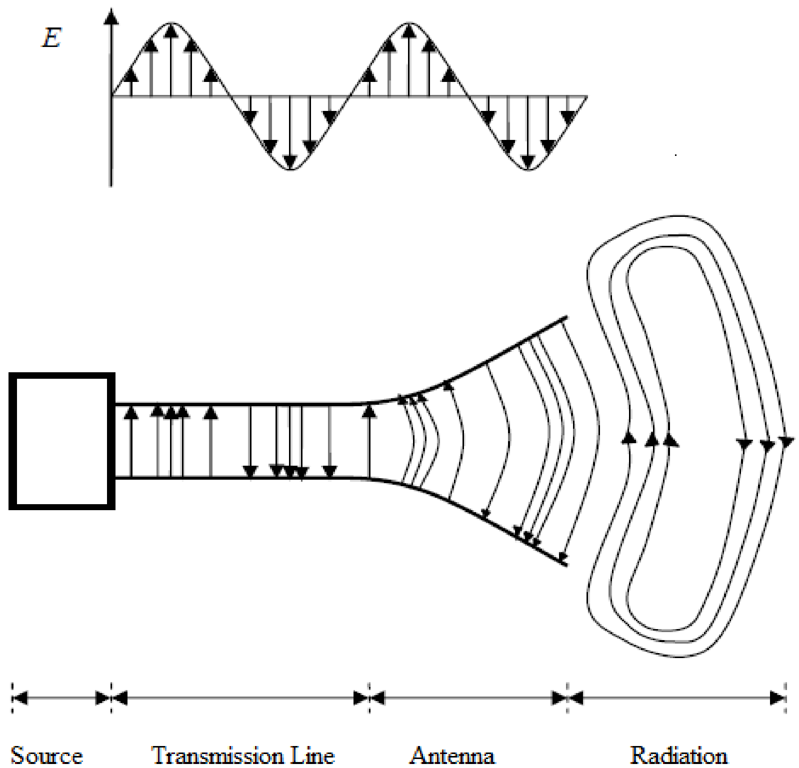


Fig. 1.2 Radiation from an Antenna

Due to the time varying electric and magnetic fields, electromagnetic waves are created and these travel between the conducting lines. As these waves advance towards open space, open ends of the electric lines connect to form free space waves. Since the applied sinusoidal source continuously creates the electrical disturbance, electromagnetic waves are generated continuously and these travel from the transmission line through the antenna into the free space. The electromagnetic waves are sustained inside the transmission line and the antenna due to the charges on conductors, but on entering the free space, they form closed loops and radiations are formed [4].

1.5 Antenna Types

There are different antennas, depending upon different applications. Few of the commonly used antennas are discussed next.

- **Wire antenna:** Wire antennas are most commonly found antennas. They can be seen on automobiles, ships, buildings etc. Various forms of wire antennas are straight wire antenna, loop antenna etc. [4].

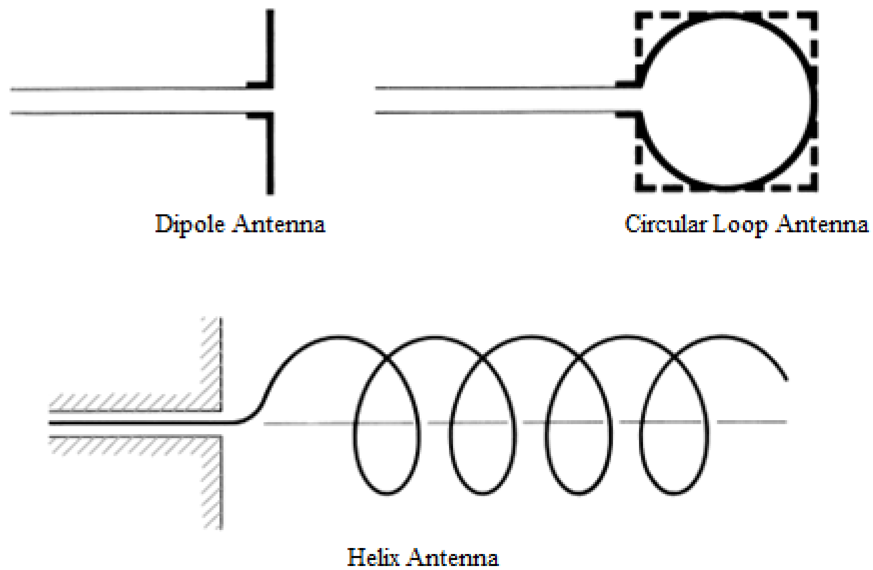


Fig 1.3 Various types of wire antenna configurations.

- **Aperture antenna:** Aperture antennas are being used these days more commonly

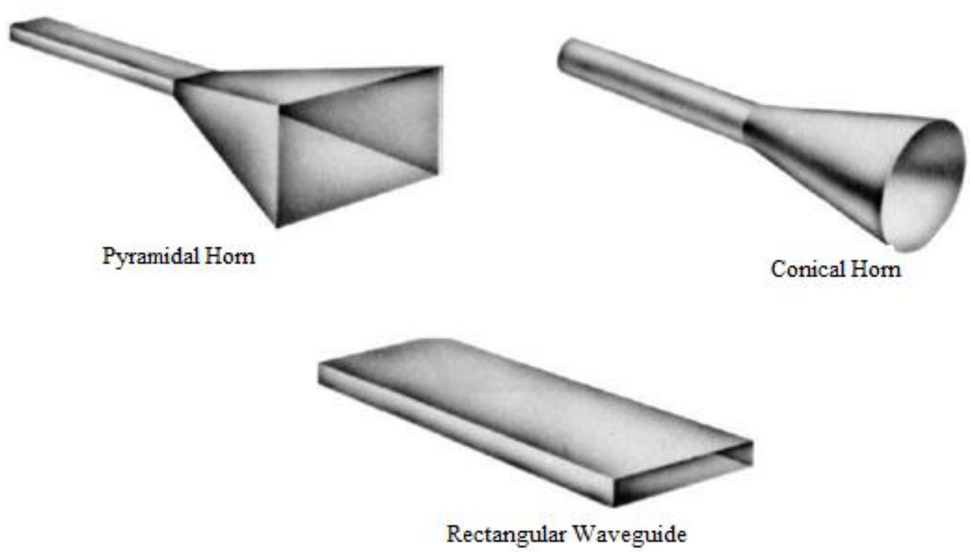


Fig. 1.4 Various aperture antenna configurations.

because of rising demand of sophisticated and high frequency antennas. These antennas find usage in aircrafts and spacecraft carriers as they can be easily mounted on their bodies. Horn antennas are the commonly found aperture antennas [4].

- **Microstrip antenna:** Initially these antennas became popular because of space related applications. They consist of metallic patch which lies on substrate which is in turn grounded. Metallic patch can be of various shapes such as rectangular, circular, triangular, elliptical etc. Of these shapes, rectangular and circular are most commonly used ones. These antennas find usage in mobile phones, space crafts, satellites and missiles [4].

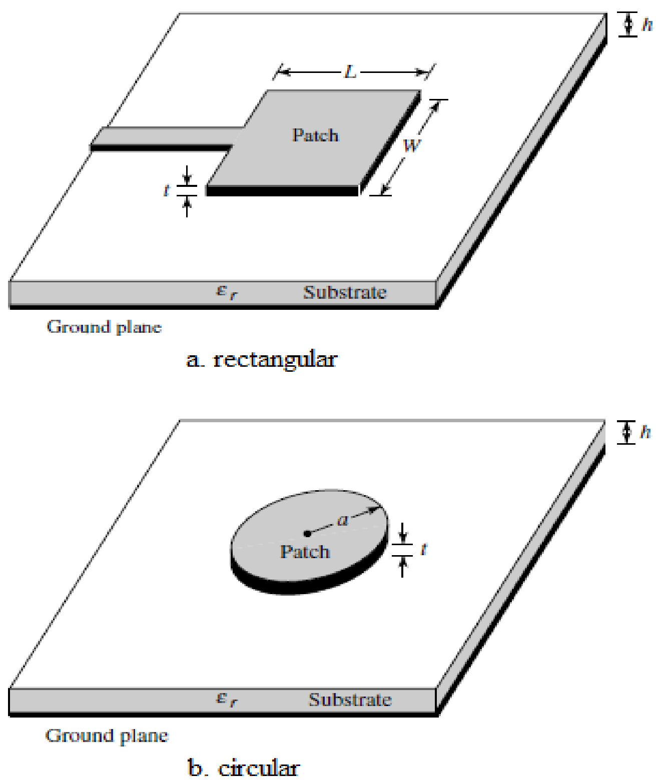


Fig. 1.5 Rectangular and circular microstrip antennas.

- **Reflector antenna:** Need to communicate signals over greater distances led to development of these antennas. Commonly seen form of reflector antenna is parabolic antenna. These antennas can have hundreds of meters of diameter and generally have very high gain [4].

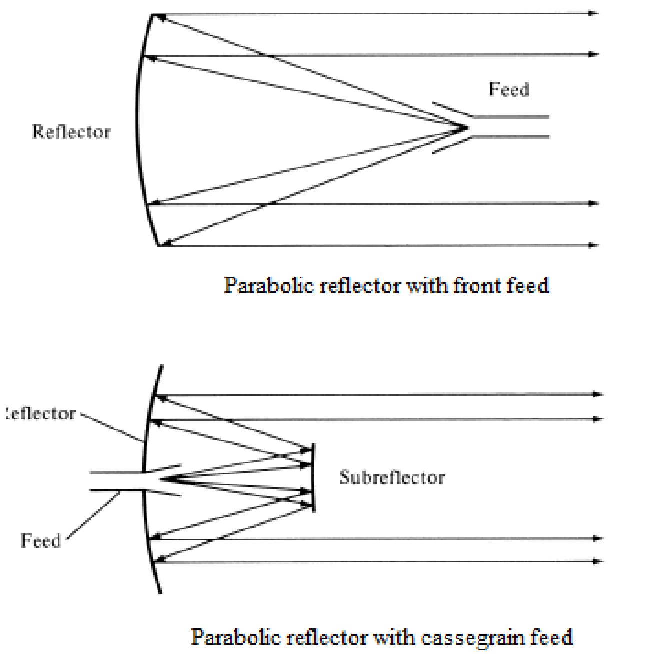


Fig. 1.6. Reflector antenna configurations.

- **Lens antenna:** These antennas are most commonly used for high frequency applications. They can be used to convert divergent rays into plane waves. These antennas are classified in accordance with material used for their construction or by their geometry [4].

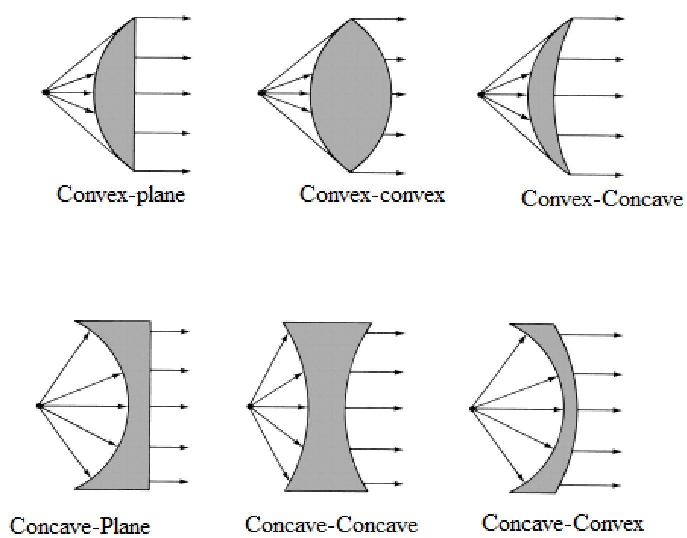


Fig. 1.7 Various lens antenna configurations.

1.6 Antenna Parameters

For defining performance of antenna various parameters are defined. Few important parameters are discussed next.

- **Radiation pattern:** Radiation pattern is generally defined as representation of the antenna radiation intensity as function of space coordinates. Basically it's a far field observation of radiation properties of antenna against spatial coordinates which are specified by elevation angle and azimuthal angle. Fig.1.8 shows the radiation pattern of directional antenna, which directs most of power along one direction [4,5].

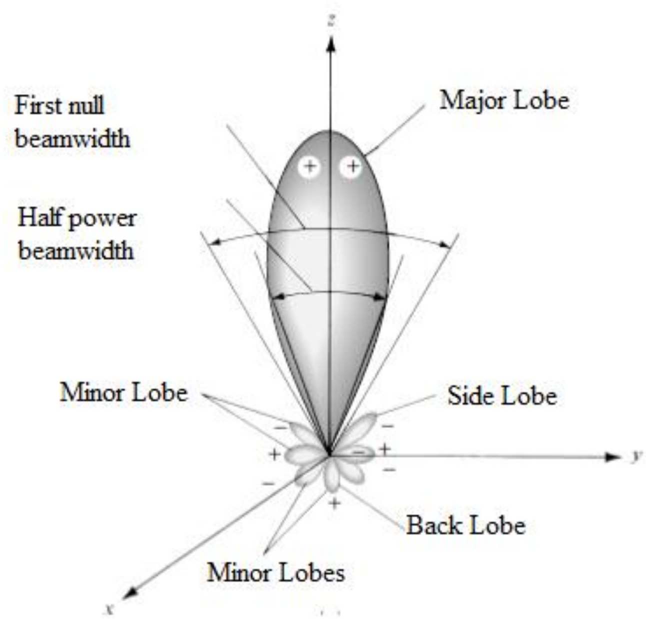


Fig. 1.8. Radiation pattern of a directional antenna.

Various terms shown in the figure are:

HPBW: The half power beamwidth (HPBW) can be defined as the angle subtended by the points of the main lobe where power level reaches half of the maximum value.

Main Lobe: The lobe containing the direction of maximum radiation is called main lobe.

Minor Lobe: All the lobes, other than the main lobe are defined as minor lobes. Minor lobes represent the radiation in direction other than desired.

Back Lobe: The minor lobe diametrically opposite to the main lobe is called back lobe.

Side Lobes: The minor lobes adjacent to the main lobe and separated by various nulls are side lobes. Mostly side lobes are the largest among the minor lobes.

- **Directivity:** The directivity of an antenna is defined as the ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged over all directions. Or we can say, directivity of a non-isotropic source equals to the ratio of its radiation intensity in a given direction, over radiation intensity of an isotropic source [4,5].

$$\mathrm{D} = \frac{U}{U_i} = 4\pi\frac{U}{P}$$

where D is the directivity of the antenna

U is the radiation intensity of the antenna

U_i is the radiation intensity of an isotropic source

P is the total power radiated

Since directivity is the ratio of two radiation intensities, it is a dimensionless quantity. Hence, it is generally expressed in dBi. One can estimate directivity of an antenna from the radiation pattern of the antenna as antenna having narrow main lobe would have better directivity, then the one which has a broad main lobe.

- **Gain:** Antenna gain and directivity are closely related parameters. We know that the directivity is how much energy is radiated in a particular direction than energy radiated in other directions. And gain is defined as ratio of radiation intensity in a given direction of non-isotropic source, to input power supplied to an isotropic source. So we can say that, if the antenna is 100% efficient, then the directivity would be equal to the antenna gain. Since all antennas will radiate more in some direction that in others, therefore the gain is the amount of power that can be achieved in one direction at the expense of the power lost in the others [6]. The gain is always related to the main lobe and is specified in the direction of maximum radiation unless indicated.

$$G(\theta,\varphi) = e_{cd}D(\theta,\varphi) \quad (dBi)$$

- **Efficiency:** The antenna efficiency is a parameter which takes into account the amount of losses at the terminals of the antenna and within the structure of the antenna. Main losses in antenna are reflection losses and conduction and dielectric losses. While reflection losses arise because of mismatch between the transmitter and the antenna, the conduction and dielectric losses on the other hand arise because of ohmic losses [4], [5].

  Hence the total antenna efficiency can be written as:

  $$e_t = e_r e_c e_d$$

  Where e_t = total antenna efficiency

  $e_r = (1-\Gamma)$ = reflection (mismatch) efficiency

  e_c= conduction efficiency

  e_d= dielectric efficiency

- **Reflection coefficient:** It is defined as ratio of power reflected back from antenna to total power supplied to the antenna. This parameter gives account of mismatch between transmitter and antenna. Higher value indicates higher amount of mismatch. It is denoted by Greek letter Γ.

  Mathematically,

  $$\Gamma = \frac{V_r}{V_i}$$

  Where, V_r is amplitude of reflected wave

  and V_i is amplitude of incident wave

- **Polarization:** It is property of electromagnetic wave, which describes orientation of electric field in space. Polarization of antenna refers to the polarization of wave radiated by antenna. Polarization can be linear, circular or elliptical, which means electric field varies linearly, circularly or elliptically, respectively [4]. Linear and circular polarization schemes are shown in Fig. 1.9.

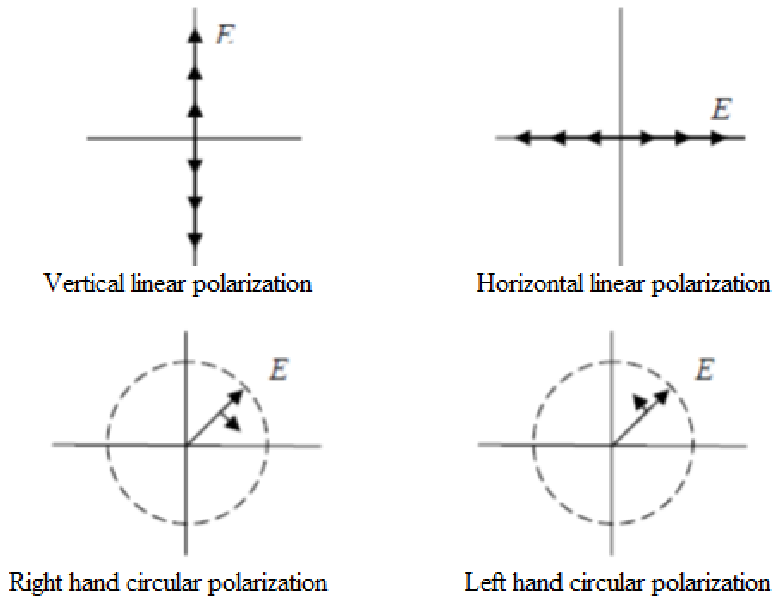


Fig. 1.9. Various polarization schemes.

- **Bandwidth:** The bandwidth of antenna can be defined as that range of frequencies on either side of the center frequency where antenna characteristics are almost similar to that obtained at the center frequency [4]. For broadband antenna, bandwidth is be defined as the ratio of the upper to lower frequencies, whereas for narrowband antenna, bandwidth can be defined as the percentage of the frequency difference over the center frequency.

1.7 Background

Microstrip antenna became popular in 1970s because of their use in spacecrafts and satellites. Ever since, these antennas have remained hot topic for researchers and hence, this antenna is constantly evolving. Initially antennas were made to use for single frequency and were linearly polarized. With time multi band antennas and circularly polarized antennas were introduced. Recent trends are towards developing multiband antennas which are circularly polarized. Multi band antennas increase the system capacity as same antenna can be used for multiple resonant frequencies. Circular polarization in antennas is preferred as circularly polarized antenna can be matched in wide range of orientations because the radiated waves oscillate in a circle that is perpendicular to the direction of propagation.

In the past few years, a lot of research work has been published on circularly polarized dual band antennas. Researchers have successfully designed and fabricated such antennas.

1.8 Motivation

Designing a circularly polarized dual band microstrip antenna is challenging; it requires combination of design steps. Initially it involves designing an antenna to operate at a given frequency. Then dual resonant paths are created for dual frequencies by inserting slots and circular polarization is achieved by feeding the antenna at adjacent edges so that orthogonal modes of equal magnitude but having 90° physical phase shift are generated. The shape and the dimensions of the perturbation have to be optimized to ensure that the antenna achieves an axial ratio that is below 3 dB at the desired design frequency.

1.9 Thesis Organization

Remaining part of thesis is organized as following:

Chapter 2: In this chapter microstrip antenna, its advantages and disadvantages, feeding techniques and methods of its analysis are discussed.

Chapter 3: This chapter explains various techniques of generating circular polarization and dual resonant frequencies.

Chapter 4 and chapter 5: In these chapters, designs of dual band circularly polarized antennas are discussed.

Chapter 6: This chapter concludes the thesis.

CHAPTER 2

MICROSTRIP ANTENNA

2.1 Introduction

In its most basic form, a Microstrip patch antenna consists of a very thin radiating patch on dielectric substrate which rests on a ground plane as shown in Figure 2.1. The patch is generally made of metallic material and can be of take any possible shape. The patch is then fed energy through one of the various feeding methods. The patch and the feed lines are usually photo etched on the dielectric substrate.

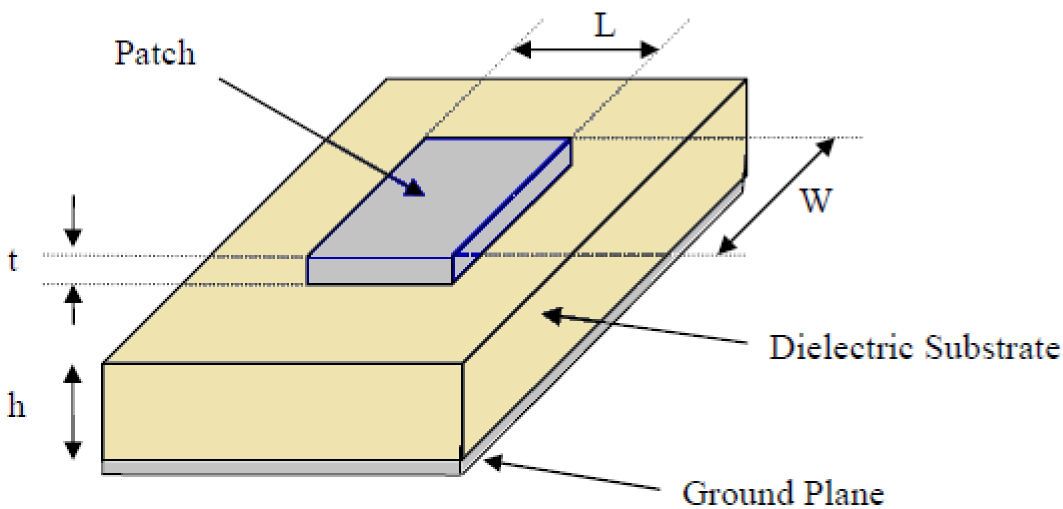


Fig.2.1. A Microstrip Antenna.

Usually, substrates used for patch antennas have dielectric constant lying in the range $2.2 < \varepsilon_r < 12$. Their height is generally in the range $0.003\lambda < h < 0.05\lambda$. Usually thicker substrates with lower dielectric constant are preferred as it leads to better bandwidth and better efficiency but at the cost of increased antenna size. For rectangular patch length L, is usually in the range $\lambda/3 < L< \lambda/2$ and thickness of patch t is taken such that $t << \lambda$ [4].

The radiating patch may be of square, rectangular, thin strip (dipole), circular, elliptical, triangular, or any other shape. Of these rectangular and circular are most commonly used shapes because of their ease in fabrication and good radiation characteristics. Also low cross polarization is observed for these patch shapes.

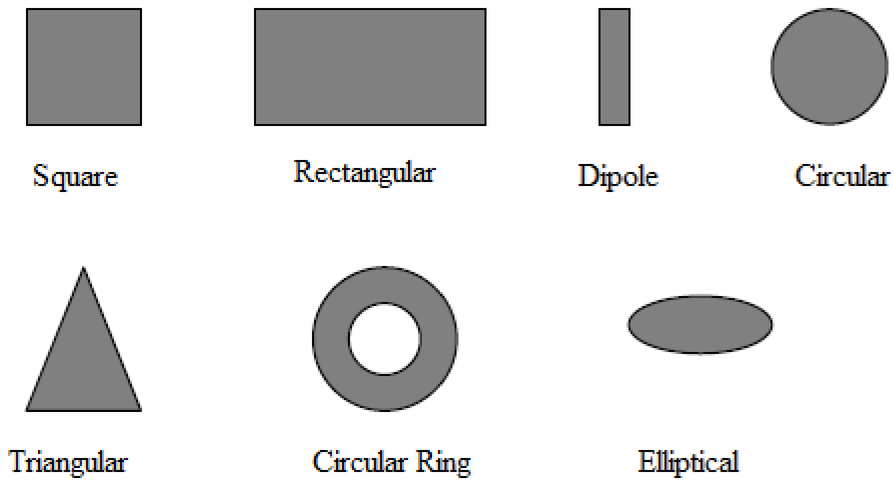


Fig. 2.2. Various shapes of patch element.

Radiation pattern of microstrip patch antennas is mostly broadside radiation, that is, maximum of radiation is perpendicular to the patch. End fire radiators can also be designed by properly choosing modes beneath the patch. Reason because of which these antennas radiate is the fringing fields, which arise between the patch edge and the ground plane. These fields add up in phase and lead to radiation [4].

2.2 Advantages and Disadvantages

Microstrip patch antennas are one of the most widely used antennas today. They are increasing in popularity by their use in wireless applications due to their low-profile structure. Therefore they are extremely compatible for embedded antennas which are used in handheld wireless devices such as cellular phones, pagers etc. The telemetry and communication antennas on missiles need to be thin and conformal and hence Microstrip patch antennas are best match for them. Also they are widely used in satellite communications. Some of their principal advantages as given in [4] and [7] are discussed below:

- Light weight and low volume.
- Low profile planar configuration which can be easily made conformal to host surface.
- Low fabrication cost, hence can be manufactured in large quantities.
- Supports both, linear as well as circular polarization.
- Can be easily integrated with microwave integrated circuits (MICs).
- Capable of dual and triple frequency operations.
- Mechanically robust when mounted on rigid surfaces.

Despite these numerous advantages, microstrip patch antennas suffer from a number of disadvantages as well. Some of their major disadvantages are given below:

- Narrow bandwidth
- Low efficiency
- Low Gain
- Extraneous radiation from feeds and junctions
- Poor end fire radiator except tapered slot antennas
- Low power handling capacity.
- Surface wave excitation

These antennas have a very high antenna quality factor (Q). This factor represents the losses associated with the antenna and a large Q implies lower efficiency and narrower bandwidth. By increasing the thickness of the dielectric substrate, Q can be reduced. But as the thickness increases, a larger fraction of the total power delivered goes into a surface wave. This surface wave contribution is an unwanted power loss since it is ultimately scattered at the dielectric edges which in turn decreases efficiency. This problem can be minimized by use of photonic band gap structures. Other problems such as lower gain and lower power handling capacity can be overcome by using an array configuration for the elements.

2.3 Feeding Techniques

Energy can be fed to microstrip patch antennas by a variety of methods. These methods can be broadly classified into two categories- contacting and non-contacting. In the contacting method, the RF power is fed directly to the radiating patch using a connecting element such as a microstrip line. In the non-contacting scheme, electromagnetic field coupling is done to transfer power between the microstrip line and the radiating patch. The four most popular feed techniques used are the microstrip line, coaxial probe, aperture coupling and proximity coupling. First two techniques fall under contacting method and last two techniques are non-contacting schemes. These are further explained next.

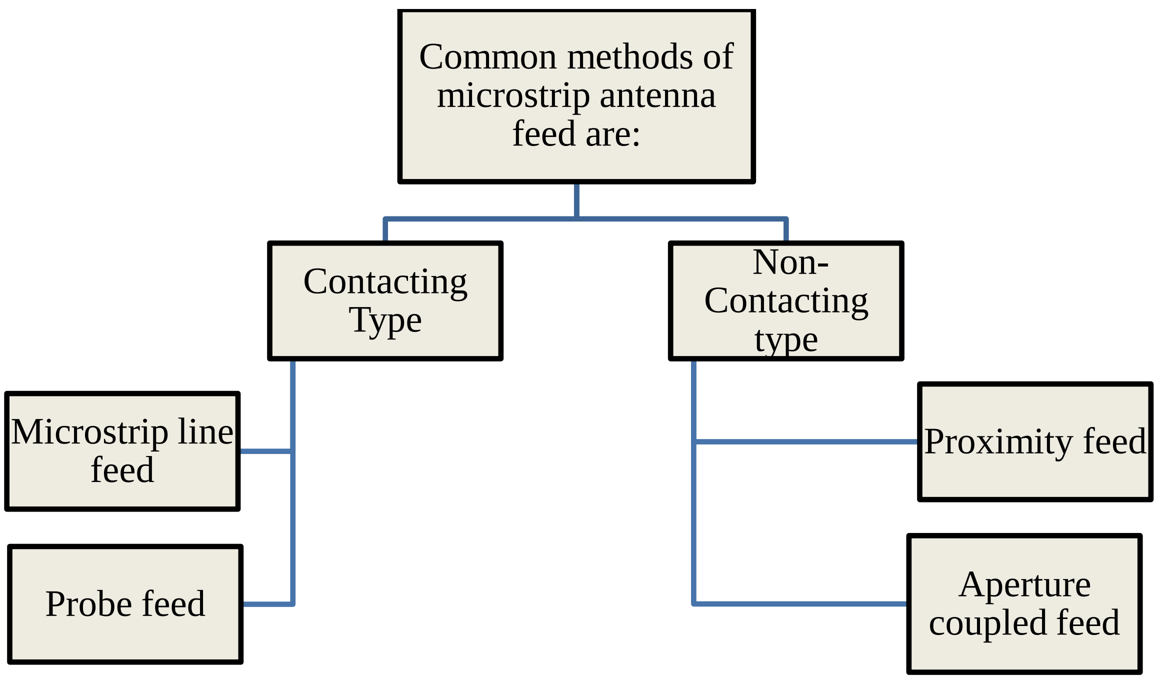


Fig.2.3. Different types of feeding methods.

- **Microstrip Line Feed**

  In this feeding technique, a conducting strip usually of the same material as patch, is connected directly to one of the edge of the patch as shown in Figure 2.4. The width of strip is smaller as compared to the patch. An advantage of this kind of feeding arrangement is that the feed can be etched on the same substrate where patch is etched so as to provide a planar structure. The inset is cut in the patch purposefully, so that impedance of feed line matches to the impedance of patch without requiring any additional matching element. The impedance match is achieved by properly controlling the inset position. Another advantage of this technique is its simplicity in modeling and it provides ease of fabrication as well as impedance matching.. However, this feeding method has few disadvantages, such as undesired cross polarized radiation is generated and provides narrow bandwidth [4], [7].

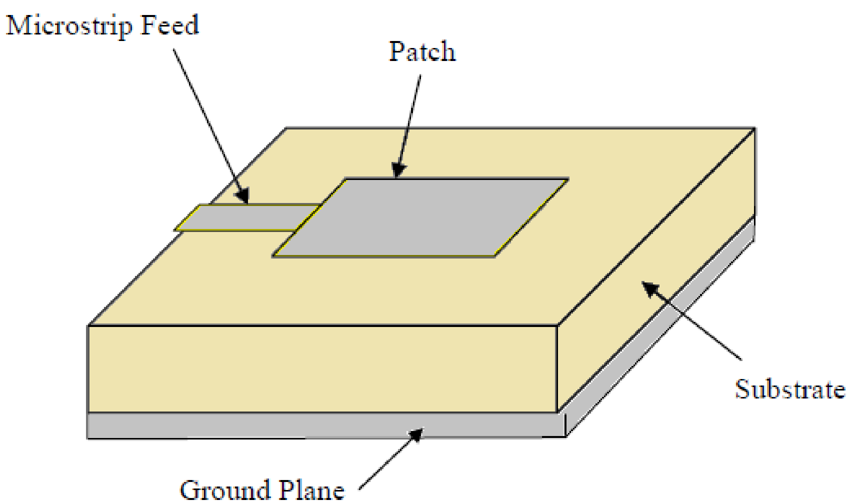


Fig. 2.4. A microstrip line feeding scheme.

- **Coaxial Feed**

One of the most common techniques used for feeding Microstrip patch antennas is coaxial feeding technique. In this technique the inner conductor of the coaxial connector extends through the dielectric substrate and is connected to the patch, while the outer conductor of cable is connected to the ground plane. The main advantage of this type of feeding scheme is that the impedance match can be easily provided. This is done by placing the feed at any desired location inside the patch.

Few other advantages of this feed method include its ease in fabrication and low spurious radiation. However, it provides narrow bandwidth and is difficult to model since a hole has to be drilled in the substrate and the connector extends out of the ground plane, thus not making it completely planar. For thicker substrates, the probe length increases which makes the input impedance more inductive. This in turn leads to impedance matching problems [4].

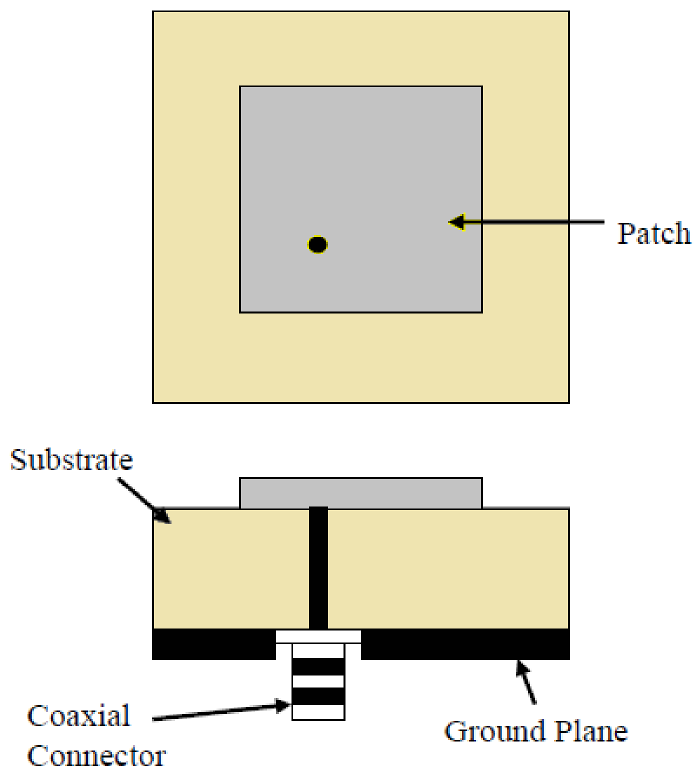


Fig. 2.5. Coaxial feeding method.

- **Aperture Coupled Feed**

  For thicker substrates, as discussed above, the microstrip line feed and the coaxial feed suffer from various disadvantages. Thus non-contacting feed techniques were introduced to solve these problems. One of the types of non-contacting feeding methods is aperture coupled feeding technique. In this type of feeding technique, the patch and the microstrip feed line are parted by the ground plane as shown in Figure 2.6. Coupling between the radiating patch and the microstrip feed line is made through a slot or an aperture in the ground plane and hence the name aperture coupled feed [4], [7].

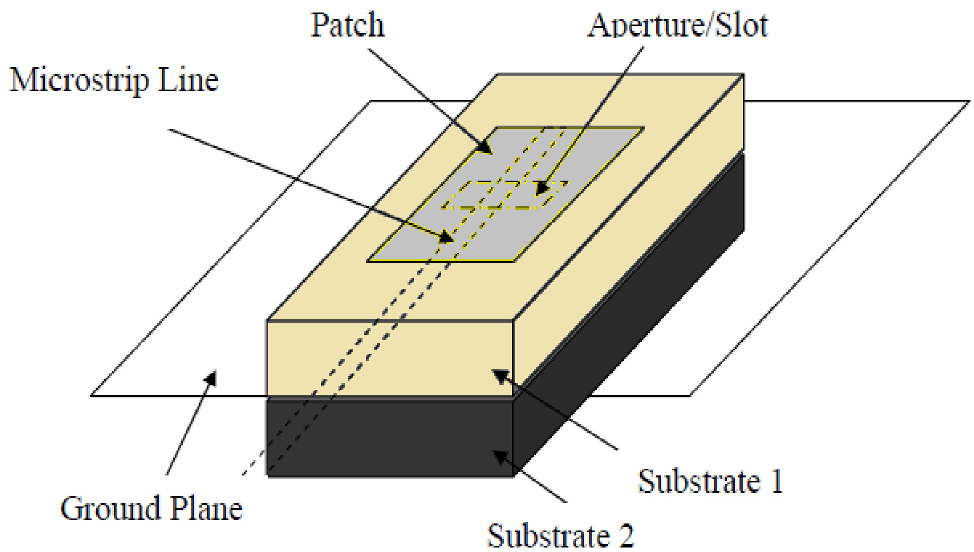


Fig. 2.6. Aperture coupling scheme.

The coupling slot is usually located under the patch, which provides symmetry of the configuration that leads to lower cross polarization. The amount of coupling from the feed line to the patch depends upon the shape, size and location of the aperture. Also spurious radiation is minimized since the ground plane separates the radiating patch and the feed line. Usually, a material of high dielectric constant is used for the bottom substrate and a thicker, low dielectric constant material is used for the top substrate. The major disadvantage of this feed technique is difficulty in fabrication due to multiple layers, which in turn increases the antenna size. Also this feeding scheme provides narrower bandwidth [4].

- **Proximity Coupled Feed**

  In this type of feeding technique, two dielectric substrates are used such that the feed line is sandwiched between the two substrates and the radiating patch is on top of the upper substrate. The major advantage of this feed technique is that it provides very high bandwidth (as high as 13%) by eliminating spurious feed radiations. To optimize the individual performances, this scheme provides choices between two different dielectric media, one for the patch and one for the feed line. Impedance matching is achieved by controlling the length of the feed line and the width-to-line ratio of the patch. However, this feeding scheme is difficult to fabricate as the two dielectric layers need proper alignment. This counts in as major disadvantage of this feeding type [4].

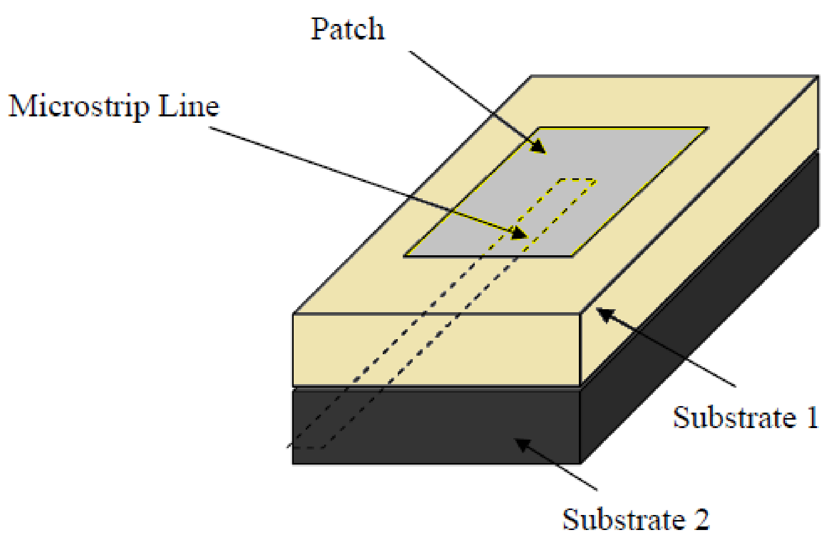


Fig. 2.7. A proximity coupled feeding method.

2.4 Methods of Analysis

Few popular models for the analysis of Microstrip patch antennas are the transmission line model, cavity model, and full wave model. Of these models, transmission line model is the simplest one and gives good physical insight but its results are least accurate. The cavity model is more accurate but is complex in nature. The full wave models are extremely accurate, versatile and can be used for analysis of single elements, arrays, stacked elements and arbitrary shaped elements. These give less insight as compared to the previous two models mentioned above and are far more complex.

2.4.1 Transmission Line Model

In this model, the microstrip antenna is considered of array of two slots where each slot is of width *W* and height *h*, and is separated by a transmission line of length L. When patch is energized electric field is generated between the patch and ground. But microstrip is a nonhomogeneous line of two dielectrics, typically the substrate and air. From Figure 2.8, it can be seen that most of the electric field lines reside in the substrate and some lines travel through air [4].

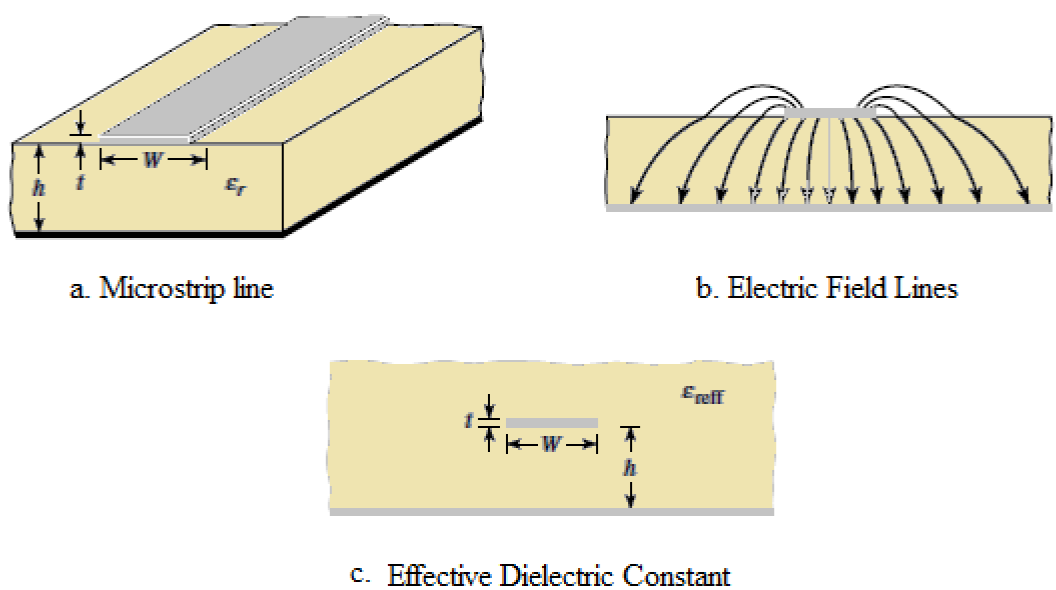


Fig. 2.8. Fringing fields in microstrip antenna.

These fields which travel through air into substrate are called fringing fields. In order to account for the fringing, an effective dielectric constant ε_{reff} must be obtained. The value of ε_{reff} is slightly less than ε_r because the fringing fields around the periphery of the patch are not confined in the dielectric substrate but are also spread in the air.

The expression for ε_{reff} is given as:

$$\varepsilon_{\mathrm{reff}} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}[1 + 12\frac{h}{W}]^{-\frac{1}{2}}$$

Where ε_{reff} = Effective dielectric constant of the substrate

ε_r = Actual dielectric constant of the substrate

W= Width of the patch element

h= Height of the substrate

The fringing fields along the width can be modeled as radiating slots and electrically the patch of the microstrip antenna looks greater than its physical dimensions. The dimensions of the patch along its length have now been extended on each end by a distance ΔL, which is given empirically as:

$$\Delta \mathrm{L} = 0.412\mathrm{h}\frac{(\varepsilon_{reff} + 0.3)(\frac{W}{h} + 0.264)}{(\varepsilon_{reff} - 0.258)(\frac{W}{h} + 0.8)}$$

The effective length of patch now becomes:

$$L_{eff} = L + 2\Delta \mathrm{L}$$

And for a given resonant frequency f_o effective length is given by:

$$L_{eff} = \frac{c}{2f_o\sqrt{\varepsilon_{reff}}}$$

Consider Fig. 2.9, which shows a rectangular microstrip patch antenna of length *L*, width *W* placed on a substrate of height *h*. The spatial co-ordinates are selected such that the length is along the *x* direction, width is along the *y* direction and the height is along the *z* direction.

When operating in the fundamental TM_{10} mode, the length of the patch is slightly less than $\lambda/2$ where λ is the wavelength in the dielectric medium and is equal to $\lambda_o/\sqrt{\varepsilon_{reff}}$ where λ_o is the free space wavelength. The TM_{10} mode means that the field varies half cycle of wavelength along the length and doesn't vary along the width of the patch. In the Fig. 2.10, the microstrip patch antenna is represented by two slots, separated by a transmission line of length L and open circuited at both the ends. The voltage is maximum along the slots and current is minimum due to the open ends, which gives high value of input impedance.

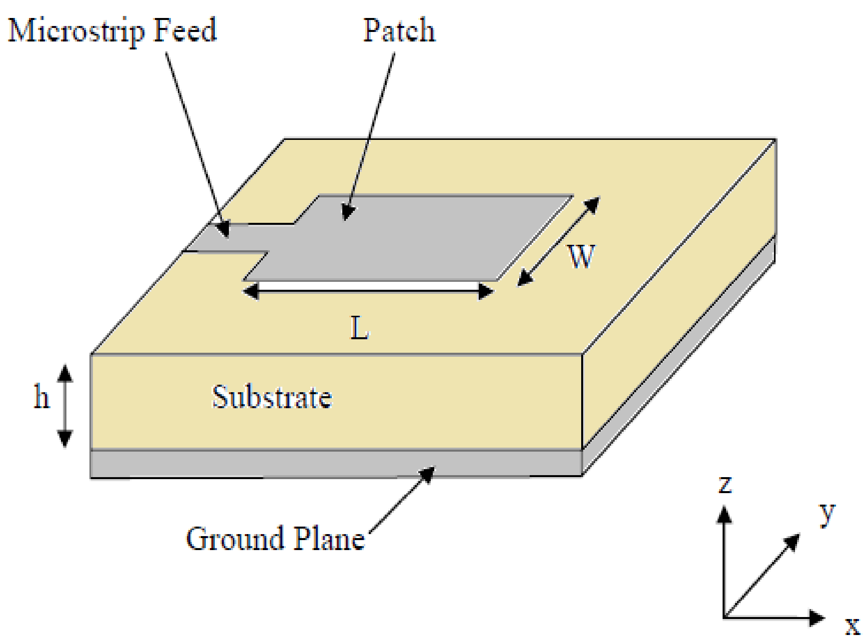


Fig. 2.9. A microstrip antenna.

The fields at the edges consist of normal and tangential components with respect to the ground plane. From Fig. 2.10 it can be seen that the normal components of the electric field at the two edges along the width are in opposite directions and are out of phase and hence they cancel out each other. However, tangential components are in phase, which means that the resulting fields combine to give maximum radiated field normal to the surface of the structure. Hence, microstrip antenna can be modeled as array of two radiating slots, which are λ / 2 apart and excited in phase and radiating in the half space above the ground plane [4].

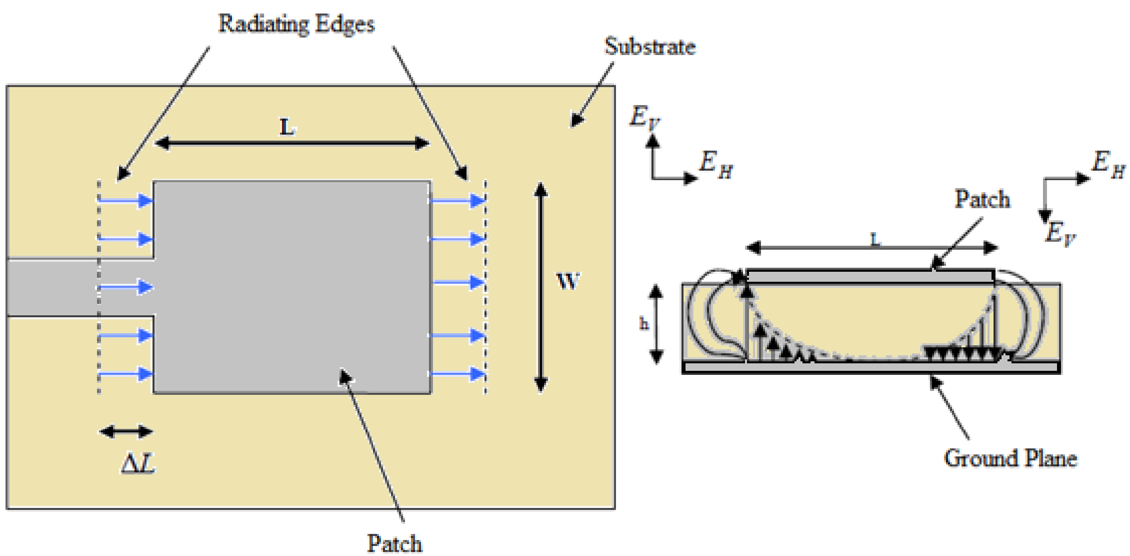


Fig. 2.10. Electric field lines from radiating edges.

2.4.2 Cavity Model

Though the transmission line model is easy to use, it yields less accurate results. Also, it ignores field variations along the radiating edges. To overcome these disadvantages cavity model is used. In this model, the interior region of the dielectric substrate, below the patch is modeled as a cavity bounded by electric walls on the top and bottom. This assumption is made because for thin substrates (h << λ), the fields in the interior region do not vary much in the z direction, i.e. normal to the patch. Also, the electric field is z directed only, and the magnetic field has only the transverse components H_x and H_y in the region bounded by the patch metallization and the ground plane [7].

Consider Fig. 2.11 shown next. When the microstrip patch is fed energy, a charge distribution is resulted on the upper and lower surfaces of the patch and at the bottom of the ground plane. Two mechanisms control this charge distribution, an attractive mechanism and a repulsive mechanism. The attraction occurs between the opposite charges on the bottom side of the patch and the ground plane, which helps in keeping the charge concentrated at the bottom of the patch [8].

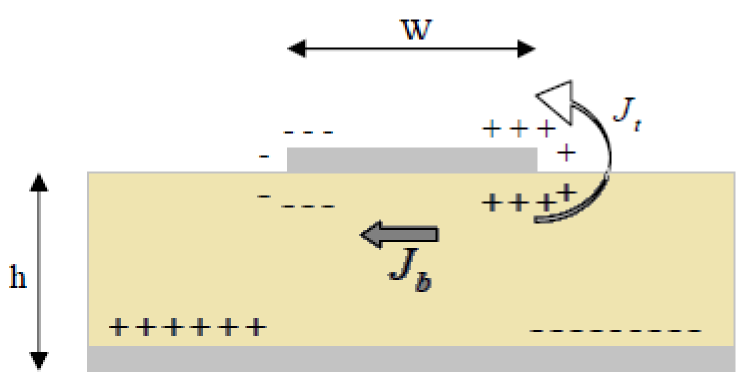


Fig. 2.11. Charge distribution in microstrip antenna.

The repulsion occurs between the same charges on the bottom surface of the patch, which results in pushing of some charges from the bottom, to the top of the patch. Currents flow at the top and bottom surface of the patch because of this charge movement. This 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. This results in keeping most of the charge and the current below the patch surface. A lot less current flow on the top surface of the patch and as the height to width ratio is decreased further; the current on the top surface of the patch becomes almost equal to zero, which would not allow the generation of any tangential magnetic field components. Hence, the four sidewalls could be modeled as perfectly magnetic conducting surfaces. As a result, magnetic fields and the electric field distribution beneath the patch would not be disturbed. However, in practice, there is always a finite width to height ratio which means that tangential magnetic fields would not be completely zero. But being very small, the side surfaces could be approximated to be perfectly magnetic conducting [4].

If the walls of the cavity and the material within are considered lossless, its input impedance would be purely reactive and the cavity would not radiate. Hence, in order to generate radiation and a lossy cavity must be modeled. For this one must introduce a radiation resistance R_r and a loss resistance R_L. A lossy cavity would now represent an antenna and the loss is taken into account by the effective loss tangent δ_{eff} which is given as:

$$\delta_{eff} = {}^{1}/_{Q_t}$$

Here, Q_t is the total antenna quality factor and has been expressed in the form:

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

And Q_c is quality factor for conductor

Q_d is quality factor for dielectric

Q_r is quality factor for radiation.

CHAPTER 3

DUAL BAND CIRCULARLY POLARIZED ANTENNA

In microstrip antennas, circular polarization is highly preferred these days. This is because of numerous advantages of circularly polarized wave over linearly polarized one. At the same times, using multiple band antennas always provide an additional edge as it increases system capacity. In this section various techniques to develop circular polarization and multiple band antennas and their advantages are discussed.

3.1 Circular Polarization

Circular polarization is very important in the antenna design industry, as it has some inherent advantages. Few of its advantages are that, it eliminates the importance of orientation of antenna in the plane perpendicular to the propagation direction, it provides immunity from polarization mismatch caused by Faraday's rotation, it provides much more flexibility to the angle between transmitting & receiving antennas, and it enhances weather penetration and mobility [9], [10] and [11]. Because of these advantages circularly polarized antenna are used in many commercial and militarily applications.

To generate circular polarization in microstrip antenna, two orthogonal modes equal in magnitude and 90 degree out of phase are needed to be created. Microstrip antenna on its own doesn't generate circular polarization; some modifications are needed to be done to the patch of antenna to generate the circular polarization [12], [13]. These antennas can be broadly classified in accordance to the number of feeding points required to produce circularly polarized wave. Generally single feed and dual feeds are used for circular polarization, generation which is discussed briefly in following subsections.

3.1.1 Single Feed Circularly Polarized Microstrip Antenna

Single feed microstrip antennas are simple, easy to fabricate, lower in cost and compact in structure. It eliminates the use of complex hybrid polarizer, whose designing can become very complex. Single fed circularly polarized microstrip antennas are considered to be one of the simplest antennas that can produce circular polarization. To achieve circular polarization using only single feed, two orthogonal modes should be excited with equal amplitude and phase differed by 90 degrees. For this few modifications in the patch design are required. Perturbation segments split the field into two orthogonal modes which are of equal magnitude and 90° phase shifted [14], [15]. Therefore the circular polarization requirements are met. Several techniques used to achieve circular polarization in single fed microstrip antenna are; fractal boundary method[16], [17] and [18], square patch with shaped slots[19], [20], embedding cross slot in metallic patch or the ground plane, stack antennas, annular ring with strip line inside the inner ring [21] and truncated edges patches[22]-[25].

3.1.1.1 Square patch with shaped slots

Cutting a slot in a microstrip patch antenna perturbs the field which leads to circularly polarized wave generation. The shape and the dimensions of slot can be used to optimize the bandwidth.

A slot cut in the shape of letter C in a square patch microstrip antenna is shown in Fig. 3.1. Good circular polarization is achieved by mounting the substrate on a foam layer. Antenna is fed using aperture coupling feeding method. Those dimensions of the slot are used for which optimum value of axial ratio and impedance bandwidth is achieved [26].

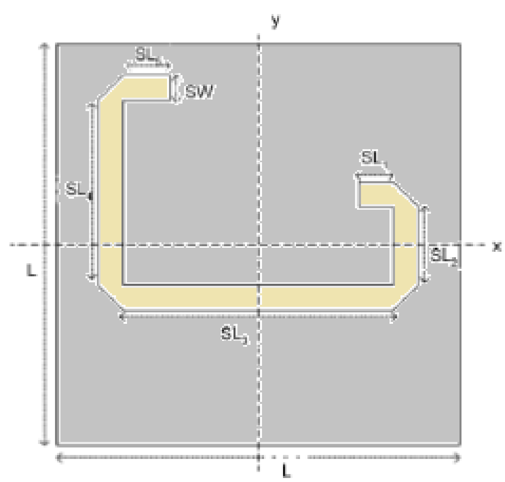


Fig. 3.1. C shaped slot.

F-shaped slotted microstrip antenna is shown in Fig. 3.2. Again circular polarization is achieved when fields are perturbed by the slot. Good values of axial ratio are obtained corresponding to this design confirming circular polarization [27].

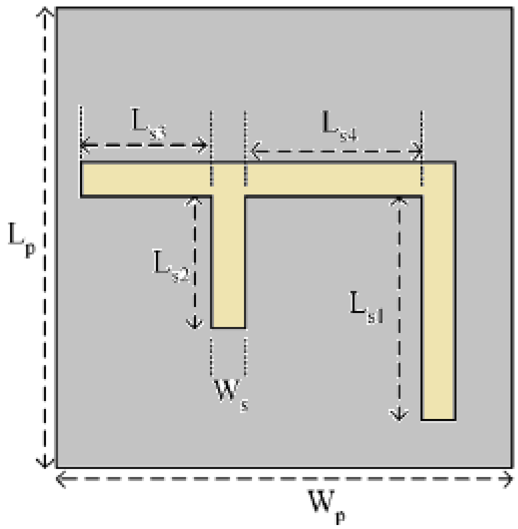


Fig. 3.2. F shaped slot.

Circular polarization can also be achieved by inserting two connected rectangular slots [28] along the diagonal of a square patch microstrip antenna as shown in Fig. 3.3.

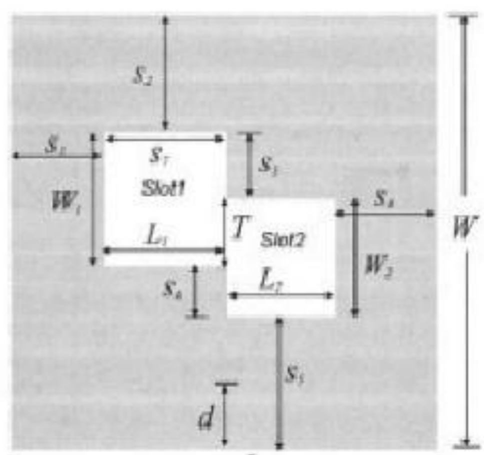


Fig. 3.3. Connected rectangular slots.

3.1.1.2 Cross slot

Inserting a cross slot in a circular patch antenna as shown in Fig. 3.4 generates circularly polarized wave. Cross slot dimensions and the ratio between the two arms of slot can be adjusted to optimize axial ratio and impedance bandwidth. Increasing the slot length decreases the resonant frequency and hence decreases the antenna size [29].

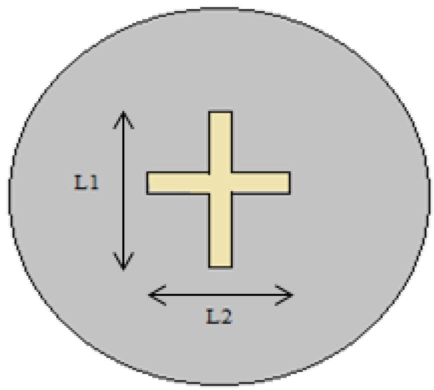


Fig. 3.4. Crossed slot circular patch.

3.1.1.3 Stacking antennas

Stacking patches can also be used to generate circular polarization. When the antennas are designed at the same frequency, good value of axial ratio is achieved and increase in polarization bandwidth is seen. And when the antennas are designed at different frequencies, dual band circularly polarized antenna at both frequencies is achieved. Stacking a square patch over a nearly square ring for circular polarization is shown in Fig. 3.5 [30].

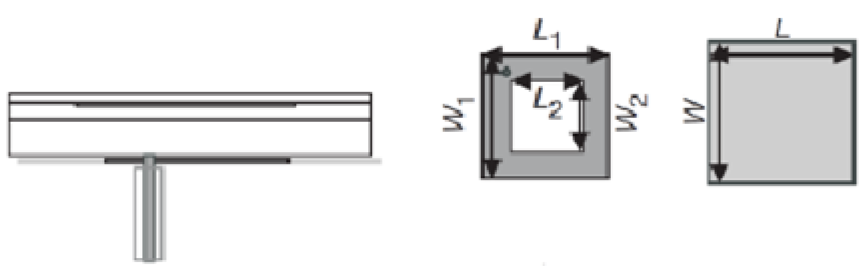


Fig. 3.5 Square ring and square patch stacking.

3.1.1.4 Truncated edges patches

Truncated corners square microstrip patch antenna is one of the most basic techniques to generate circular polarization in patch antennas. In this method opposite corners of the square patch are cut which results in generation of diagonal modes. These modes can be made of equal magnitude and 90 degree phase shifted by adjusting the size of the cut thereby generating circular polarization.

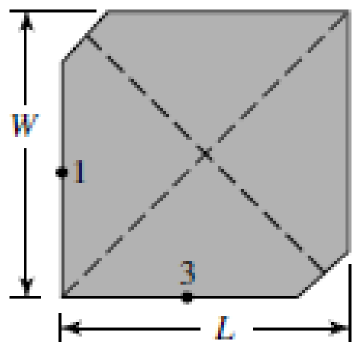


Fig. 3.6. Truncated corner square patch.

Truncated edges elliptical antenna, in which opposite edges of the elliptical antenna parallel to the major axis are truncated is shown in Fig. 3.7. This antenna gives good values of axial ratio and circular polarization achieved by it is better than the conventional elliptical antenna [31].

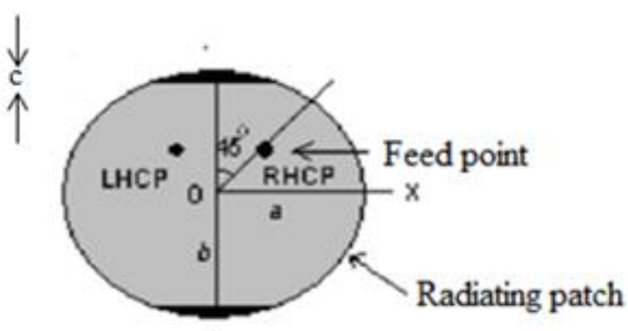


Fig. 3.7. Truncated elliptical patch.

Truncated peripheral edge circular antenna with embedded cross slot and fed with coaxial cable is shown in Fig. 3.8. This antenna produces circular polarization in antenna with compact structure [32].

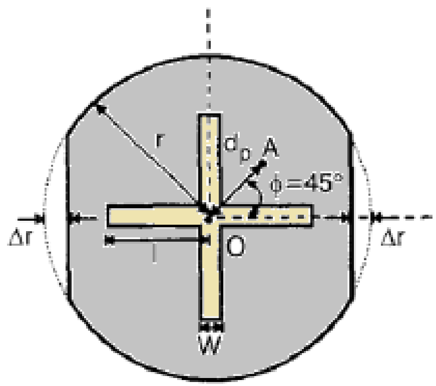


Fig. 3.8. Truncated peripheral edge circular antenna.

3.1.2 Dual Feed Circularly Polarized Microstrip Antenna

Circular polarization is achieved when two basic phenomenon are achieved. One is generating two orthogonal modes of equal magnitude and another is phase shifting them by 90 degrees.

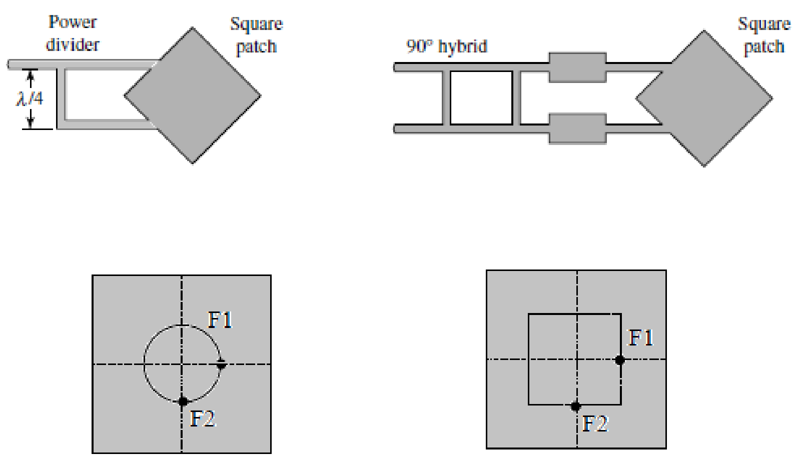


Fig. 3.9. Various dual feed circular polarization generating schemes.

Using dual feeds these two phenomenon can be easily achieved. The two feed points are chosen perpendicular to each other as shown in Fig. 3.9. Dual feed can be accomplished using quadrature hybrid, ring hybrid, Wilkinson power divider, T-junction power splitter or two coaxial feeds with physical phase shift 90° [33], [34].

3.2 Multiple Band Antennas

Multiple band antennas are in popular culture these days. Dual band and triple band antennas commonly used multiband antennas. Major advantage of using multiple band antennas is that same antenna can be used for different frequencies and as such, it restricts the need for another antenna. Hence, in a way it increases the system capacity. Dual resonant frequencies can be generated by using either single resonator or double resonators.

3.2.1 Single Resonator Dual Band Antenna

A single patch element can be used to generate double resonant frequencies. This is accomplished by inserting slots in the patch. Slots can be inserted in patch in the manner shown in Fig 3.10. Cutting a slot from patch perturbs the natural frequency of the patch and creates multiple resonant paths. As a result of this, a new resonance value is achieved for frequency. This new frequency can be either greater or lesser than natural frequency generated by the patch [35], [36].

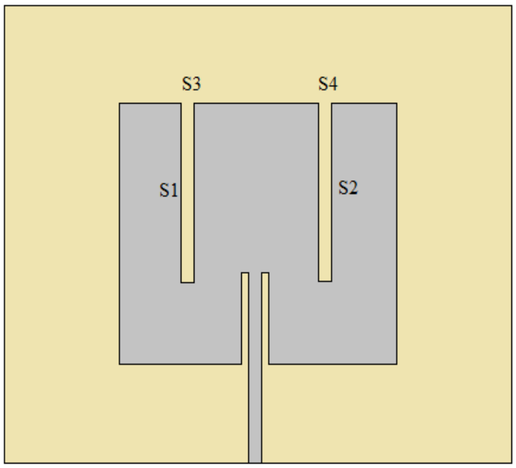


Fig. 3.10. Slots for dual band generation.

3.2.2 Multiple Resonator Dual Band Antennas

Multiple patches are used to generate dual resonant frequencies. Values of the resonant frequencies depend upon length of the patch elements. Few techniques of dual band generation are discussed next.

3.2.2.1 Coupled Microstrip Dipoles

In this technique of dual frequency generation, a pair of narrow patch elements called microstrip dipoles are placed in close proximity with separation of d as shown in Fig 3.11. These patches are then fed with coupled microstrip line. As usual, upper and lower frequencies are function of lengths of the patches.

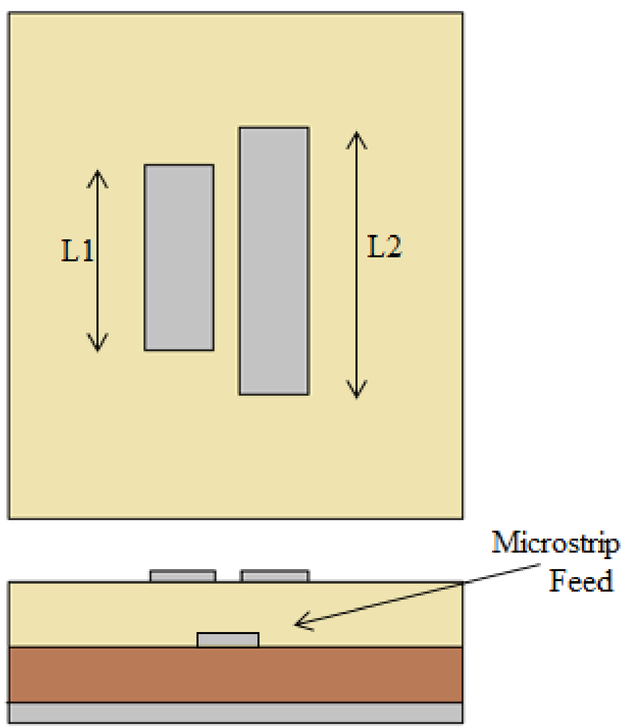


Fig. 3.11. Coupled microstrip dipoles for dual resonance generation.

3.2.2.2 Stacked Rectangular Microstrip Antenna

Dual resonant frequencies can be generated by stacking patches as shown in Fig. 3.12. The lower patch is usually larger than the upper patch and acts as ground plane for upper patch. Since upper patch is smaller, it is high frequency element for the antenna and lower patch provides lower frequency [37], [38].

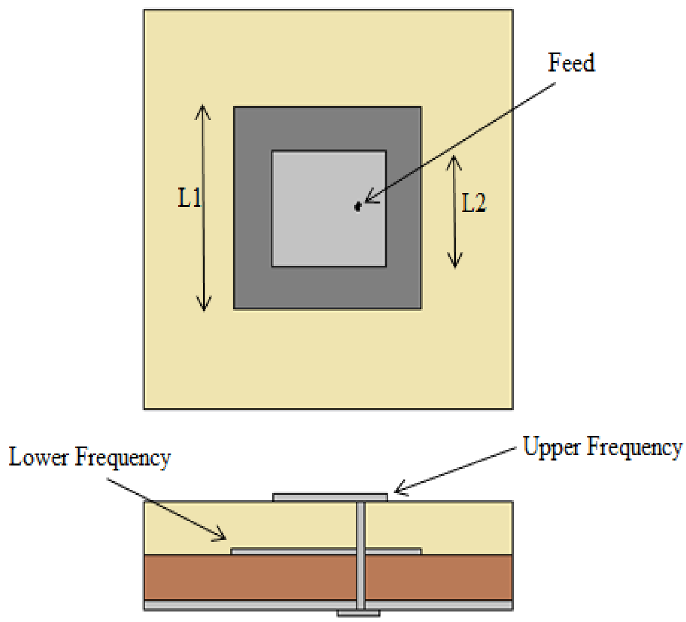


Fig. 3.12. Stacked patches for dual resonance generation.

CHAPTER 4

ANTENNA DESIGN I AND RESULTS

In this chapter design of antenna and results obtained on simulation are discussed. Designed antenna is simulated using CST Microwave studio software which is based upon FDTD technique.

4.1 Design Specifications

A circularly polarized antenna is designed which operates at dual frequencies. Designing such an antenna involves various steps which can be listed below:

- First step requires choosing substrate material. Substrate material used for design is Arlon AD having dielectric constant of 2.5. A substrate with a low dielectric constant has been selected since it enhances the bandwidth of the antenna.
- Then in accordance with frequency, length of patch is taken. For the design, square shaped patch is taken whose side length is considered according to 2.9 GHz frequency.
- For good impedance bandwidth volume of antenna should be more. Volume in turn depends upon height of dielectric substrate. So, height of substrate is important factor in antenna design. At the same time care should be taken that antenna doesn't become too bulky and large. So, for the design, height h is taken equal to 2.58 mm.
- Feeding technique which can be easily implemented and yields good results must be considered. For the design microstrip line feeding technique is considered.
- For circular polarization, adjacent edges of the patch are fed through power divider. In this method, two orthogonal modes are generated which are 90 degree phase shifted by delay introduced in one of the feed branch.
- Dual resonant frequencies are generated by inserting a U shaped slot in the patch. As a result of this slot, natural frequency of the slot is perturbed and new resonant frequency is generated.

4.2 Antenna Geometry and Various Dimensions

Geometry of the designed antenna is shown in Fig. 4.1. Square shaped patch is taken from which U shaped slot is cut for dual frequencies. This patch is placed over grounded substrate of dielectric constant 2.5 and ground plane dimensions are taken as 60×60 mm^2. Adjacent edges are fed through microstrip line which produces circular polarization.

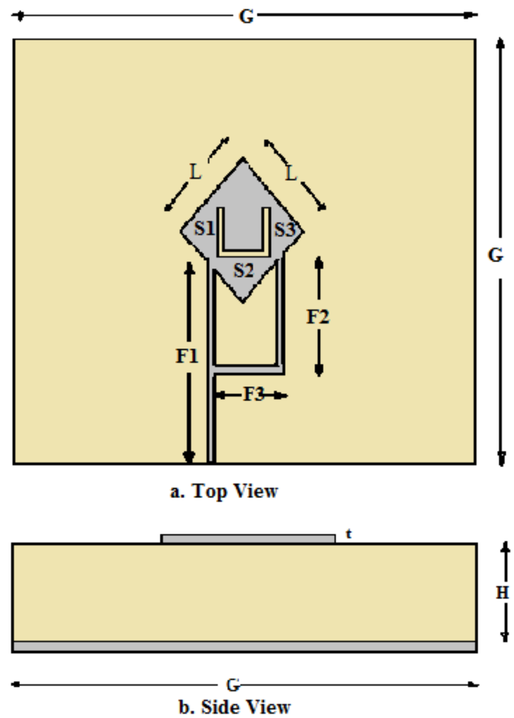


Fig. 4.1. Geometry of the designed antenna.

Lengths of various segments of the antenna are given in Table 4.1 below.

Table 4.1. Different segment lengths.

PARAMETER	VALUE(mm)
G	60
L	28.28
F1	50
F2	25
F3	28
T	0.01
H	2.58
S1	16
S2	14
S3	16

4.3 Simulation Results

The designed antenna is optimized using CST Microwave studio software and corresponding reflection coefficient, axial ratio and radiation pattern are observed.

The reflection coefficient of the antenna is shown in Fig. 4.2. Two resonant frequencies are obtained at 2.907 GHz and 2.22 GHz and for each of the resonant frequencies return loss less than -18 dB is obtained.

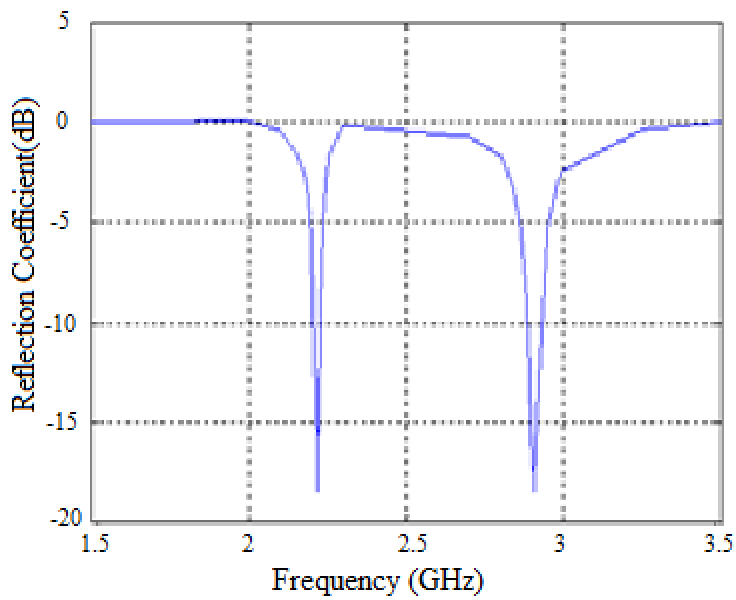


Fig. 4.2. Reflection coefficient of the designed antenna.

Fig. 4.3 shows axial ratio versus frequency curve. Axial ratio less than practical limit of 3dB at resonant frequency 2.22 GHz is obtained which shows antenna is circularly polarized for this resonant frequency. Polarization bandwidth of approximately 50 MHz is obtained corresponding to this frequency.

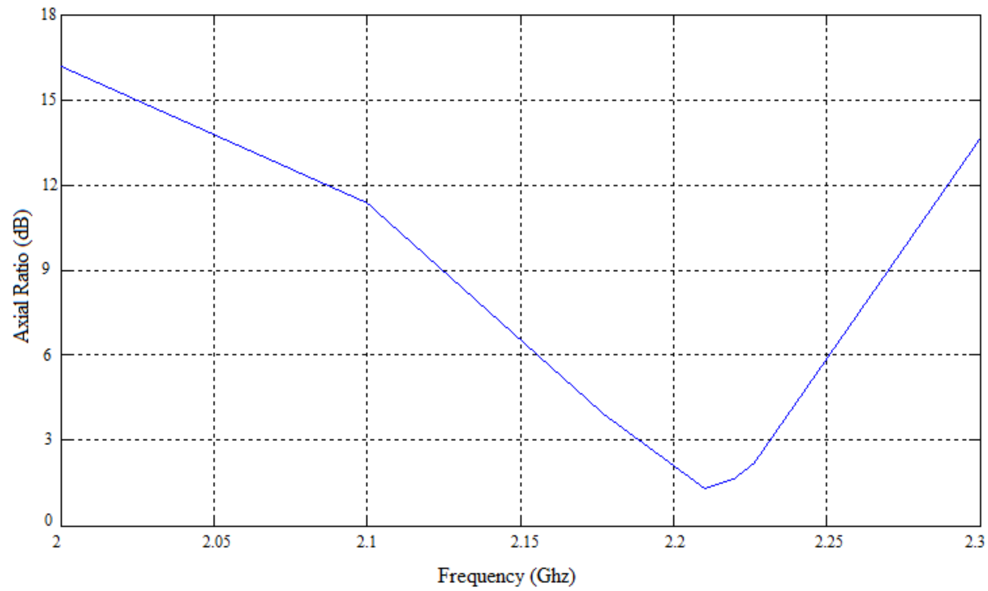


Fig. 4.3. Axial ratio curve for 2.2 GHz resonant frequency.

Fig. 4.4 below gives the axial ratio at another resonant frequency of 2.907 GHz.Again axial ratio is less than 3dB for resonant frequency and hence circular polarization is attained.

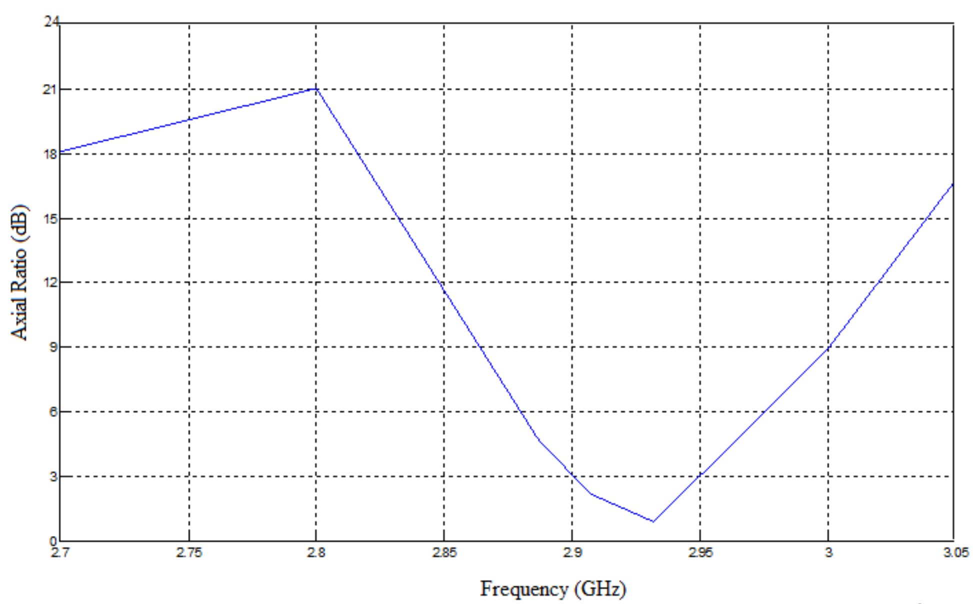
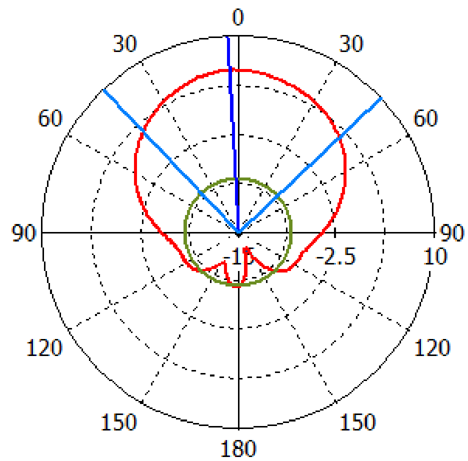
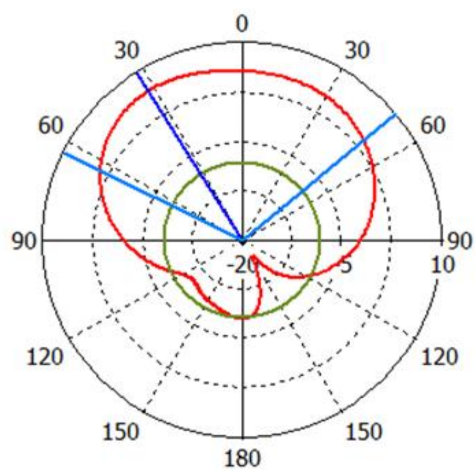


Fig. 4.4. Axial ratio curve for 2.9 GHz resonant frequency.

Radiation pattern at 2.907 GHz of the proposed antenna is shown in Fig. 4.5. Maximum directivity value of 6.7 dBi obtained.



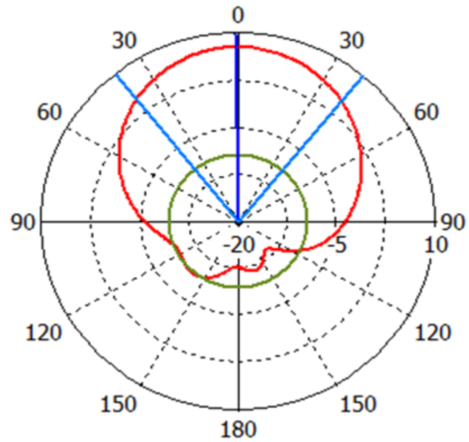
(a)



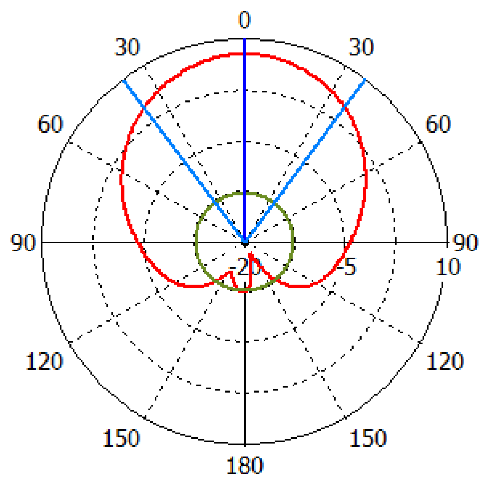
(b)

Fig.4.5. Radiation pattern at 2.907 GHz resonant frequency. (a) H-Plane. (b) E-Plane.

Radiation pattern at 2.22 GHz of the proposed antenna is shown in Fig. 4.6. Maximum dirctivity of 7.8 dBi is obtained.



(a)



(b)

Fig. 4.6. Radiation pattern at 2.22 resonant frequency. (a) H-Plane. (b) E-Plane.

CHAPTER 5

ANTENNA DESIGN II AND RESULTS

Another dual band circularly polarized antenna is designed and is simulated through CST Microwave studio software. The corresponding reflection coefficient, axial ratio and radiation pattern are obtained and discussed. Design steps used are similar to those used in previous design. However in this design circular polarization and dual resonance are achieved through different techniques.

5.1 Design Considerations

For this antenna design, different methodologies are adopted. Circular polarization is achieved by truncating opposite corners of the patch while dual resonance is achieved by inserting slots in the patch.

As discussed in chapter 3, circular polarization can be achieved by truncating the opposite corners of the patch. By cutting opposite corners, two diagonal modes are generated, which are made of equal magnitude and 90 degree phase shifted by optimizing the size of the cut.

Dual resonant frequencies are generated by cutting the rectangular slots of equal length from geometrically opposite directions of the patch. In this process patch acquires W letter shape and slots introduce multiple resonant paths which produces the required dual frequencies.

5.2 Antenna Geometry

A square patch is designed from which slots are cut and opposite corners truncated in order to produce circularly polarized dual resonant frequencies. Arlon AD 250 is used as substrate material which has dielectric constant of 2.5. Patch is fed through microstrip line and feed is matched by optimizing the position of inset. Geometry of designed antenna is as shown in Fig. 5.1. Dual resonant frequencies are realized by cutting the rectangular slots from the patch and circular polarization is achieved by cutting opposite corners of the patch. Dimensions of the various segments of the designed antenna are given in Table 5.1.

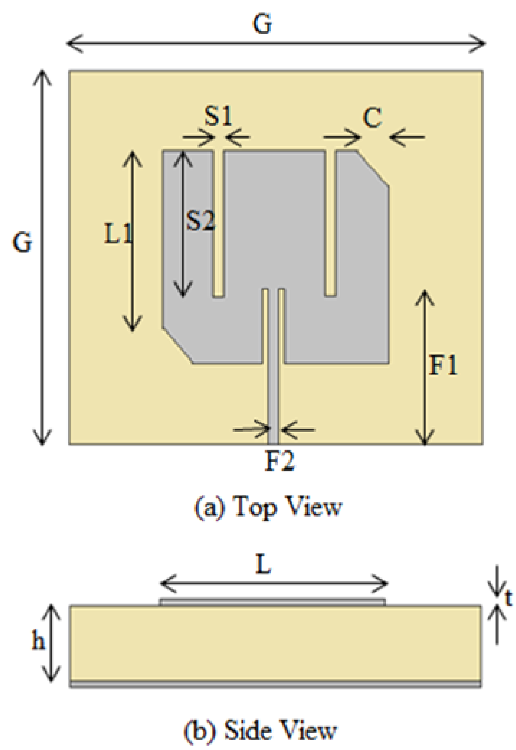


Fig. 5.1 Geometry of the designed antenna.

Table 5.1 below gives the lengths of various segments of antenna.

Table 5.1. Dimensions of the designed antenna.

PARAMETER	VALUE(mm)
G	76
L	43
L1	38
S1	2
S2	29.5
F1	32
F2	2
C	5
T	.01
H	1.58

5.3 Simulation Results

Fig. 5.2 shows the simulated reflection coefficient curve of the proposed antenna. Resonating frequencies are obtained at 2.148 GHz and 4.136 GHz at which reflection coefficient values are -20 dB and -17.12 dB, respectively. Narrow impedance bandwidths of 30 MHz and 55 MHz are obtained at 2.148 GHz and 4.136 GHz frequencies, respectively

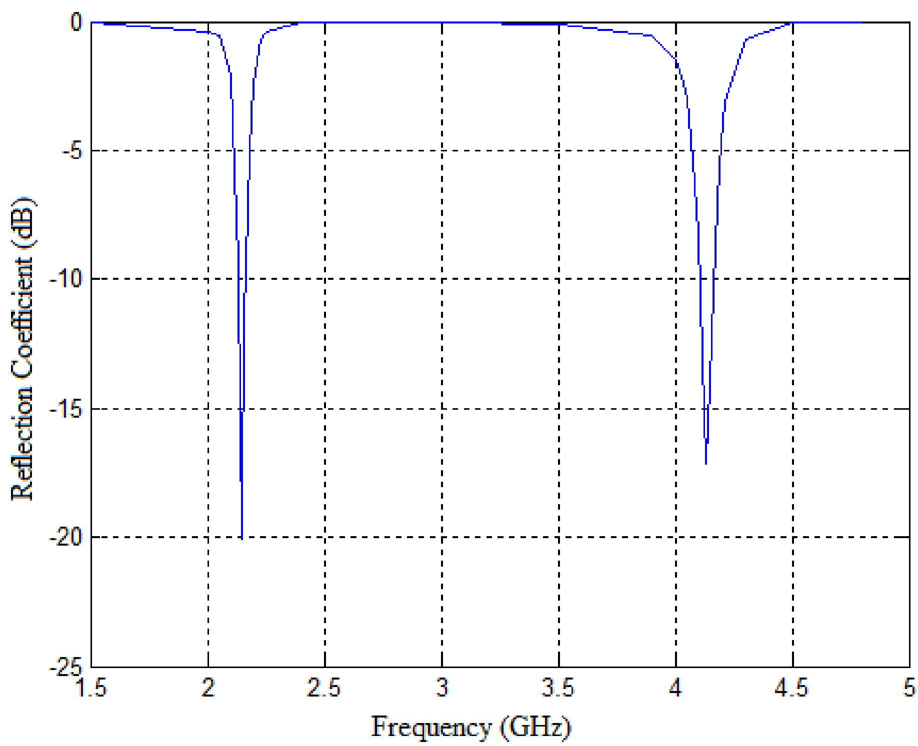
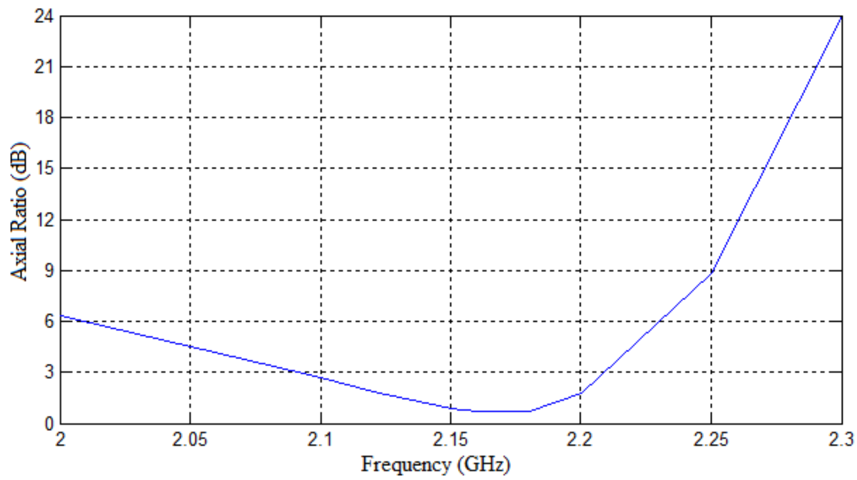
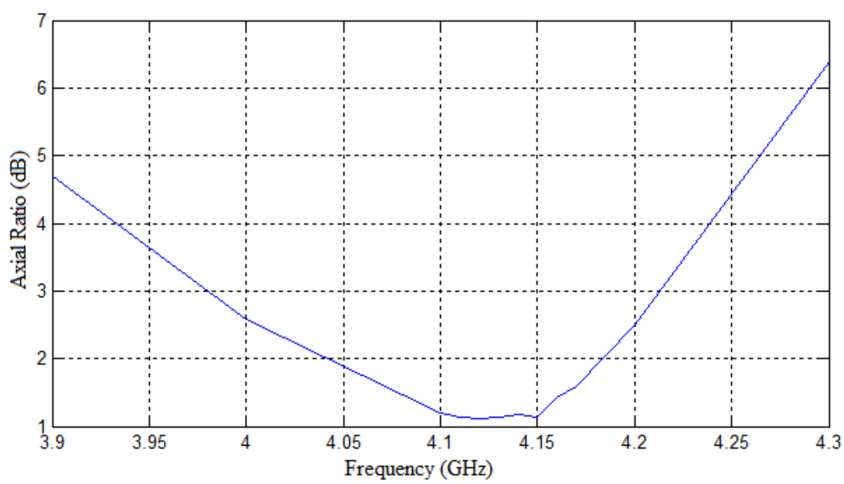


Fig. 5.2. Reflection Coefficient of antenna.

Axial ratio at both operating frequencies is shown in Fig. 5.3. At both frequencies, axial ratio is well below 3 dB, which shows antenna is circularly polarized at these frequencies. Good values of polarization bandwidth are attained at both the frequencies.



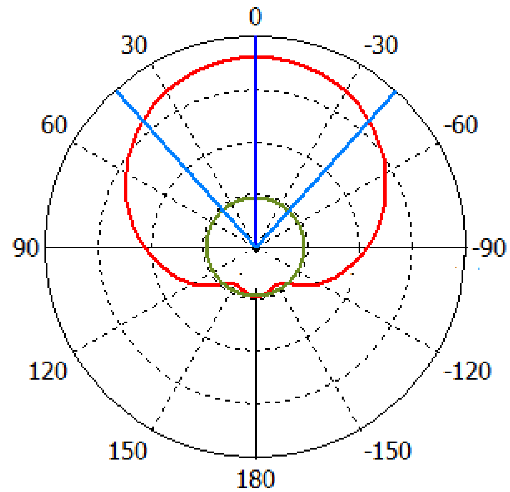
(a)



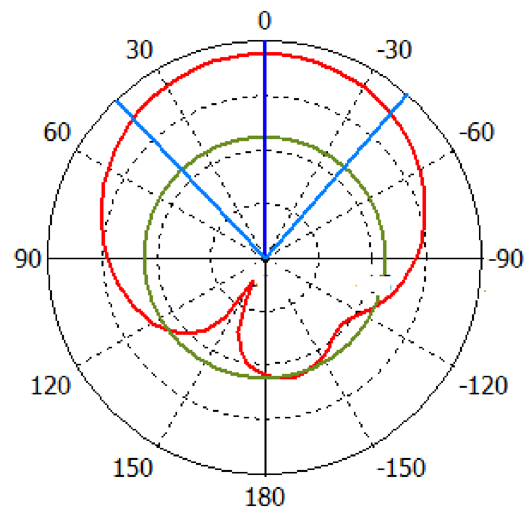
(b)

Fig.5.3. Axial ratio curves for antenna. (a) For 2.148 GHz frequency. (b) For 4.136 GHz frequency.

In Fig. 5.4, radiation pattern for 2.148 GHz frequency is shown. Broadside radiation pattern is obtained and directivity of 7.196 dBi is achieved.



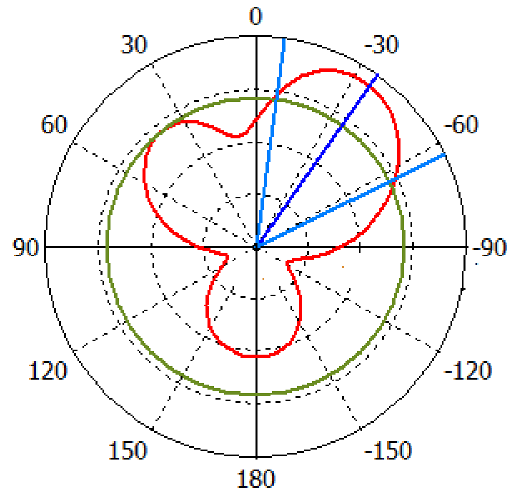
(a)



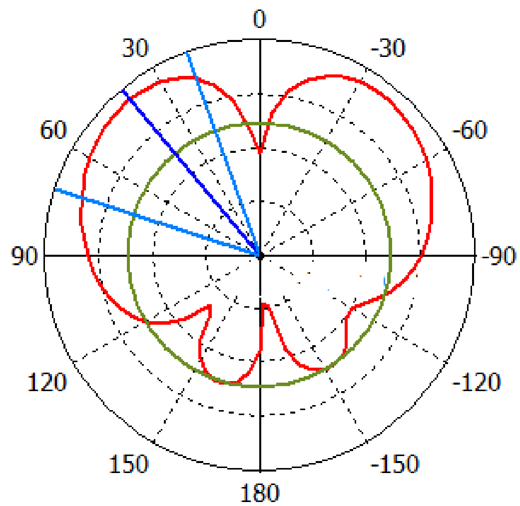
(b)

Fig. 5.4. Radiation pattern for 2.148 GHz frequency. (a) H-Plane. (b) E-Plane.

Radiation pattern for 4.136 GHz frequency is shown in Fig. 5.5. At this frequency, value of directivity achieved is 7.79 dBi.



(a)



(b)

Fig. 5.5. Radiation pattern for 4.136 GHz frequency. (a) H-Plane. (b)E-Plane.

CHAPTER 6

CONCLUSION

Both antenna designs are of a circularly polarized, dual band antenna. Different techniques have been used for generation of circular polarization and dual resonance in both designs. In first design dual resonant frequencies are generated by inserting a U letter shaped slot in the patch and circular polarization is achieved by feeding the edges of patch by power divider. Patch is simulated using FDTD based CST microwave studio software. Simulation results show return loss of less than -18 dB at resonant frequencies 2.22 GHz and 2.907 GHz respectively. At these frequencies patch is circularly polarized as axial ratio less than 3 dB is attained. Because of simple design patch can be used in array formation. The designed antenna can be used in radar systems for 2.9 GHz resonant frequency and in medium capacity point to point communication for 2.22 GHz resonant frequency.

In second design antenna, circular polarization is achieved through cutting the opposite corners of the patch while dual resonance is achieved by inserting slots. The design is simulated using CST studio software again. Design is kept simple by feeding patch through microstrip line. Resonance is attained at frequencies 2.148 GHz and 4.136 GHz and at both the frequencies antenna is circularly polarized. This frequency range and compact and simple design of antenna makes it useful for satellite spacecraft applications.

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Degree/Exam	**Institution**	**University/Board**	**Year of Passing**	**Percentage**
M.Tech (ECE)	Jaypee University Of Information Technology, Solan	Jaypee University Of Information Technology	2014	64 (till 3rd sem)
B.Tech (ECE)	IEET Baddi, Solan	Himachal Pradesh University	2010	64.33
Senior Secondary	D.A.V. College, Chandigarh	C.B.S.E.	2005	64
Matriculation	D.A.V. School, Chopal	H.P.B.S.E.	2003	80.7

AREAS OF INTEREST

- Microstrip Antennas
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ACADEMIC PROJECTS

<u>M.Tech Project</u>
Project Title **:** Microstrip Antenna.

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TRAININGS AND SEMINARS

- Four weeks training course in BSNL Chota Shimla, Shimla (H.P.).

- Six weeks training course in SCADA at H.P.S.E.B. Power House, Shimla (H.P.).
- Seminar and workshop on ''Cognitive Radio'' in Jaypee University of Information Technology.

STRENGTHS AND ACHIEVEMENTS

- Secured 1st position in matriculation examination in school.
- Qualified GATE twice in EC in Years-2011 and -2012 with 89.5 and 95.13 percentile respectively.
- Coordinator of hospitality committee in college fest.
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