TRIPLE BAND H-SHAPED SLOTTED CIRCULAR PATCH ANTENNA

A Project report submitted in partial fulfilment of the requirements forthe award of the degree of

BACHELOR OF TECHNOLOGY IN

ELECTRONICS AND COMMUNICATION ENGINEERING

Submitted By

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DEPARTMENTOFELECTRONICSANDCOMMUNICATIONENGINEERING

ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY AND SCIENCES
(UGC AUTONOMOUS)
(*Permanently Affiliated to AU, Approved by AICTE and Accredited by NBA & NAAC with 'A' Grade*)
Sangivalasa, Bheemili mandal, visakhapatnam dist.(A.P) 2020-2021

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CERTIFICATE

This is to certify that the project report entitled **"TRIPLE BAND H-SHAPE SLOTTED CIRCULAR PATCH ANTENNA"** submitted by **T. RAMYA (317126512053), M. SUPREETHI (317126512037), B.A. VENKATESWARA RAO (317126512009), K. SAI VIKAS (317126512028), C. BABASAIKUMAR (317126512013)** in partial fulfillment ofthe requirements for the award of the degree of **Bachelor of Engineering** in **Electronics & Communication Engineering** of Andhra University, Visakhapatnam is a record of Bonafide work carried out under my guidance and supervision.

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ABSTRACT

Wireless technology is one of the main areas of research in the world of communication systems today and a study of communication systems is incomplete without an understanding of the operation and fabrication of antennas. This was the main reason for selecting our project focusing on this field.

Microstrip patch antenna is having a wide range of applications due to their advantages like light weight, low cost, easy to fabricate and many more. Thus, these MSA have more advantages and better prospects when compared to that of conventional antennas. This project is to design a triple band (2.4GHz, 4.5GHz, 6.5GHz) circular patch antenna with H-shape slot. In order to increase the performance of microstrip patch antenna, there are several techniques. One of the simple technique is introducing a slot onto the patch. In proposed antenna design, the performance of antenna depends upon the slot dimension and feed position of patch. The design and analysis of proposed antenna is done by the HFSS software. And the following results were obtained - Return loss, VSWR, Gain.

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CHAPTER 1

Antenna Fundamentals

In this chapter, the elementary concept of an antenna is provided, and its working is explained. Next, some critical performance parameters of antennas are discussed. Finally, some communal types of antennas are introduced.

1.1 Introduction:

An antenna is a metallic structure that captures and/or transmits radio electromagnetic waves. Antennas come in all shapes and sizes from little ones that can be found on your roof to watch TV to really big ones that capture signals from satellites millions of miles away. Antennas act as matching systems between sources of electromagnetic energy and space.

Evolution of Antenna:

An Abridged History of Electromagnetism:

Over 2600 years ago (and likely well before that) the ancient Greeks discovered that a piece of amber rubbed on a piece of fur would attract lightweight objects like feathers. Around the same time, the ancients discovered lodestone, which are pieces of magnetised rock.

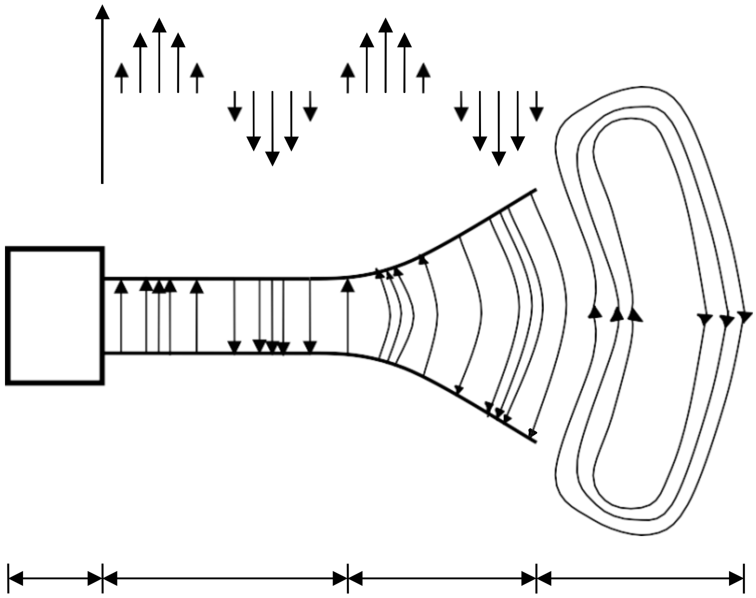
It took a few hundred years more to determine that there are two different properties of attraction and repulsion (magnetic and electric) likes repel and opposites attract. Another 2000 years passed before scientists first discovered that these two entirely different novelties of nature were inextricably linked. In the early nineteenth-century, Hans Christen Oersted_placed a wire perpendicular to a compass needle and saw nothing. But when he rotated the wire parallel to the compass needle and passed a current through the wire, it deflected in one direction. When he passed the current through the wire in the opposite direction, the compass needle deflected in the opposite direction.

Shortly after, Nikola Tesla wirelessly lit lamps in his workshop, demonstrated the first remote-control toy boat and established the alternating-current system we use to transfer electricity throughout the world today. Less than a full century after Orstead's experiment, Guglielmo Marconi_devised a way to send the first wireless telegraph signals across the Atlantic.

1.1.2 How Does an Antenna Work:

In order to know how an antenna radiates, let us first consider how radiation occurs. In physics, radiation is the emission or transmission of energy in the form of waves or particles_ through space or through a material medium. A conducting wire radiates principally because of time-varying current or an acceleration (or deceleration) of charge. If there is no motion of charges in a wire, then no radiation takes place, since no flow of current occurs in the wire. Radiation will not occur even if charges are moving with uniform velocity in a straight wire. However, charges moving with uniform velocity along a curved or bent wire will produce radiation. The radiation from an antenna can be explained with the help of Figure 1.1 which shows a voltage source connected to a two conductor transmission line. When a sinusoidal voltage is applied across the transmission line, an electric field is created which is sinusoidal in nature and these results 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.



Source Transmission Line Antenna Free space wave

Figure 1.1 - Radiation from an antenna

1.1 Antenna Parameters

An antenna is an electrical conductor or system of conductors

- Transmitter - Radiates electromagnetic energy into space
- Receiver - Collects electromagnetic energy from space

The IEEE definition of an antenna as given by Stutzman and Thiele is, “That part of a transmitting or receiving system that is designed to radiate or receive electromagnetic waves”. The major parameters associated with an antenna are defined in the following sections.

1.1.1 Antenna Gain

Gain is a measure of the ability of the antenna to direct the input power into radiation in a particular direction and is measured at the peak radiation intensity.

Consider the power density radiated by an isotropic antenna with input power P_0 at a distance R which is given by $S = P_0/4\pi R^2$. An isotropic antenna radiates equally in all directions, and its radiated power density S is found by dividing the radiated power by the area of the sphere $4\pi R2$. An isotropic radiator is considered to be 100% efficient. The gain of an actual antenna increases the power density in the direction of the peak radiation:

$$S = \frac{P_0 G}{4\pi R^2} = \frac{|\mathbf{E}|^2}{\eta} \quad \text{or} \quad |\mathbf{E}| = \frac{1}{R}\sqrt{\frac{P_0 G \eta}{4\pi}} = \sqrt{S\eta}$$

Gain is achieved by directing the radiation away from other parts of the radiation sphere.

In general, gain is defined as the gain-biased pattern of the antenna.

$$S(\theta,\phi) = \frac{P_0 G(\theta,\phi)}{4\pi R^2} \qquad \text{power density}$$

$$U(\theta,\phi) = \frac{P_0 G(\theta,\phi)}{4\pi} \qquad \text{radiation intensity}$$

1.1.2 Antenna Efficiency

The surface integral of the radiation intensity over the radiation sphere divided by the input power $P0$ is a measure of the relative power radiated by the antenna, or the antenna efficiency.

$$\frac{P_r}{P_0} = \int_0^{2\pi}\int_0^{\pi} \frac{G(\theta,\phi)}{4\pi}\sin\theta\, d\theta\, d\phi = \eta_e \qquad \text{efficiency}$$

where Pr is the radiated power. Material losses in the antenna or reflected power due to poor impedance match reduce the radiated power.

1.1.3 Effective Area

Antennas capture power from passing waves and deliver some of it to the terminals. Given the power density of the incident wave and the effective area of the antenna, the power delivered to the terminals is the product.

$$P_d = SA_{\text{eff}}$$

For an aperture antenna such as a horn, parabolic reflector, or flat-plate array, effective area is physical area multiplied by aperture efficiency. In general, losses due to material, distribution, and mismatch reduce the ratio of the effective area to the physical area. Typical estimated aperture efficiency for a parabolic reflector is 55%. Even antennas with infinitesimal physical areas, such as dipoles, have effective areas because they remove power from passing waves.

1.1.4 Directivity

Directivity is a measure of the concentration of radiation in the direction of the maximum.

$$\text{directivity} = \frac{\text{maximum radiation intensity}}{\text{average radiation intensity}} = \frac{U_{\max}}{U_0}$$

Directivity and gain differ only by the efficiency, but directivity is easily estimated from patterns. Gain—directivity times efficiency must be measured. The average radiation intensity can be found from a surface integral over the radiation sphere of the radiation intensity divided by 4π, the area of the sphere in steradians:

$$\text{average radiation intensity} = \frac{1}{4\pi}\int_0^{2\pi}\int_0^{\pi} U(\theta,\phi)\sin\theta\, d\theta\, d\phi = U_0$$

This is the radiated power divided by the area of a unit sphere. The radiation intensity *U(θ,φ)* separates into a sum of co- and cross-polarization components:

$$U_0 = \frac{1}{4\pi} \int_0^{2\pi} \int_0^{\pi} [U_C(\theta, \phi) + U_\times(\theta, \phi)] \sin\theta \, d\theta \, d\phi$$

Both co- and cross-polarization directivities can be defined:

$$\text{directivity}_C = \frac{U_{C,\max}}{U_0} \qquad \text{directivity}_\times = \frac{U_{\times,\max}}{U_0}$$

Directivity can also be defined for an arbitrary direction *D(θ,φ)* as radiation intensity divided by the average radiation intensity, but when the coordinate angles are not specified, we calculate directivity at *U*max.

1.1.5 Antenna Polarization

For the electromagnetic wave the polarization is effectively the plane in which the electric wave vibrates. This is important when looking at antennas because they are sensitive to polarisation, and generally only receive or transmit a signal with a particular polarization.

For most antennas it is very easy to determine the polarization. It is simply in the same plane as the elements of the antenna. So a vertical antenna (i.e. one with vertical elements) will receive vertically polarised signals best and similarly a horizontal antenna will receive horizontally polarised signals.

Different types of electromagnetic wave polarisation propagate in slightly different ways under some circumstances. This means that for some forms of broadcasting, radio communications or for some wireless systems, different forms of polarisation may be used.

In general the advantages and disadvantages of the various forms of polarisation are relatively subtle, but form some forms of broadcasting, wireless links of for radio communications or mobile communications systems these small differences can make a large difference.

There are several categories of polarisation, and within each type there are several sub categories. Along with this the relevant antennas have corresponding polarisations.

Linear polarisation: Linear polarisation is the most common form of antenna polarisation. It is characterised by the fact that all of the radiation is in one plane - hence the term linear:

- **Horizontal polarisation:** This form of antenna polarisation has horizontal elements. It picks up and radiates horizontally polarised signals, i.e. electromagnetic waves with the electric field in the horizontal plane.
- **Vertical polarisation:** This form of antenna is typified by the vertical elements within the antenna. It could be a single vertical element. One of the reasons for using vertical polarisation is that antennas comprising of a single vertical element can radiate equally around it in the horizontal plane. Typically vertically polarised antennas have what is termed a low angle of radiation enabling a large proportion of their power to be radiated at an angle close to the earth's surface. Vertically polarised antennas are also very convenient for use with automobiles.

Circular polarisation: This has a number of benefits for areas such as satellite applications where it helps overcome the effects of propagation anomalies, ground reflections and the effects of the spin that occur on many satellites. Circular polarisation is a little more difficult to visualise than linear polarisation. However it can be imagined by visualising a signal propagating from an RF antenna that is rotating. The tip of the electric field vector will then be seen to trace out a helix or corkscrew as it travels away from the antenna.

- **Right hand circular polarisation:** In this form of polarisation the vector rotates in a right handed fashion.
- **Left hand circular polarisation :** In this form of polarisation the vector rotates in a left handed fashion, i.e. opposite to right handed.

Based on polarization, there are two types of antenna; Linearly polarized antennas: Linear polarization is relative to the surface of the earth. Circularly polarized antennas: A circularly polarized wave basically spins as it travels.

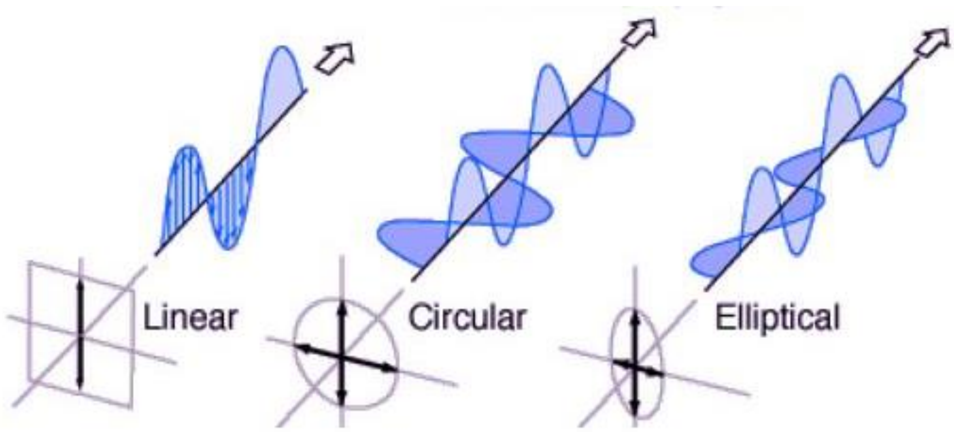


Figure 1.2 - Direction of propagation of polarized antennas

1.1.6 Input Impedance

The input impedance of an antenna is defined as “the impedance presented by an antenna at its terminals or the ratio of the voltage to the current at the pair of terminals or the ratio of the appropriate components of the electric to magnetic fields at a point”. Hence the impedance of the antenna can be written as given below.

$$Z_{in} = R_{in} + jX_{in}$$

where Zin is the antenna impedance at the terminals

Rin is the antenna resistance at the terminals

Xin is the antenna reactance at the terminals

The imaginary part, Xin of the input impedance represents the power stored in the near field of the antenna. The resistive part, Rin of the input impedance consists of two components, the radiation resistance Rr and the loss resistance Rl. The power associated with the radiation resistance is the power actually radiated by the antenna, while the power dissipated in the loss resistance is lost as heat in the antenna itself due to dielectric or conducting losses.

1.1.7 Antenna Factor

The engineering community uses an antenna connected to a receiver such as a spectrum analyzer, a network analyzer, or an RF voltmeter to measure field strength E. Most of the time these devices have a load resistor ZL that matches the antenna impedance. The incident field strength Ei equals antenna factor AF times the received voltage Vrec. We relate this to the antenna effective height:

$$\mathrm{AF} = \frac{E_i}{V_{\mathrm{rec}}} = \frac{2}{h}$$

AF has units meter−1 but is often given as dB(m−1). Sometimes, antenna factor is referred to the open-circuit voltage and it would be one-half the value given by equation 1.11. We assume that the antenna is aligned with the electric field; in other words, the antenna polarization is the electric field component measured:

$$\mathrm{AF} = \sqrt{\frac{\eta}{Z_L A_{\mathrm{eff}}}} = \frac{1}{\lambda}\sqrt{\frac{4\pi}{Z_L G}}$$

This measurement may be corrupted by a poor impedance match to the receiver and any cable loss between the antenna and receiver that reduces the voltage and reduces the calculated field strength.

1.1.8 Return Loss

It is a parameter which indicates the amount of power that is “lost” to the load and does not return as a reflection. Hence the RL is a parameter to indicate how well the matching between the transmitter and antenna has taken place. Simply put it is the S11 of an antenna. A graph of s11 of an antenna vs frequency is called its return loss curve. For optimum working such a graph must show a dip at the operating frequency and have a minimum dB value at this frequency. This parameter was found to be of crucial importance to our project as we sought to adjust the antenna dimensions for a fixed operating frequencyy (say 1.9 GHz). A simple RL curve is shown in figure 1.3

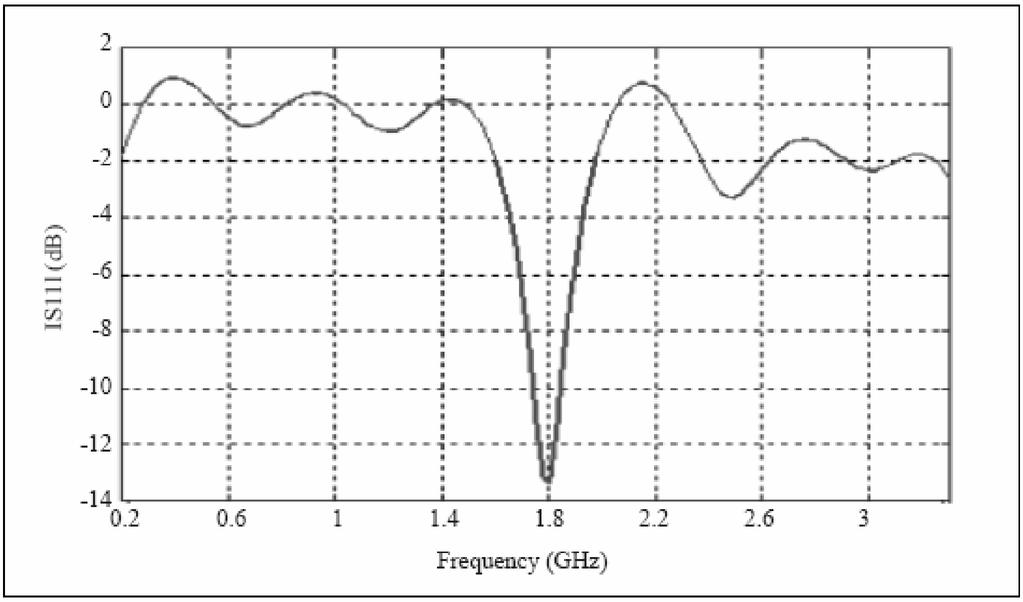


Figure 1.3 - RL curve of an antenna

1.1.9 VSWR:

VSWR stands for Voltage Standing Wave Ratio. It is a measure that numerically describes how well the antenna is impedance matched with the radio or transmission line it is connected to.

$$VSWR = \frac{1+|\Gamma|}{1-|\Gamma|}$$

1.1.9 Radiation Pattern

An antenna radiation pattern or antenna pattern is defined as a mathematical function or a graphical representation of the radiation properties of the antenna as a function of space coordinates.

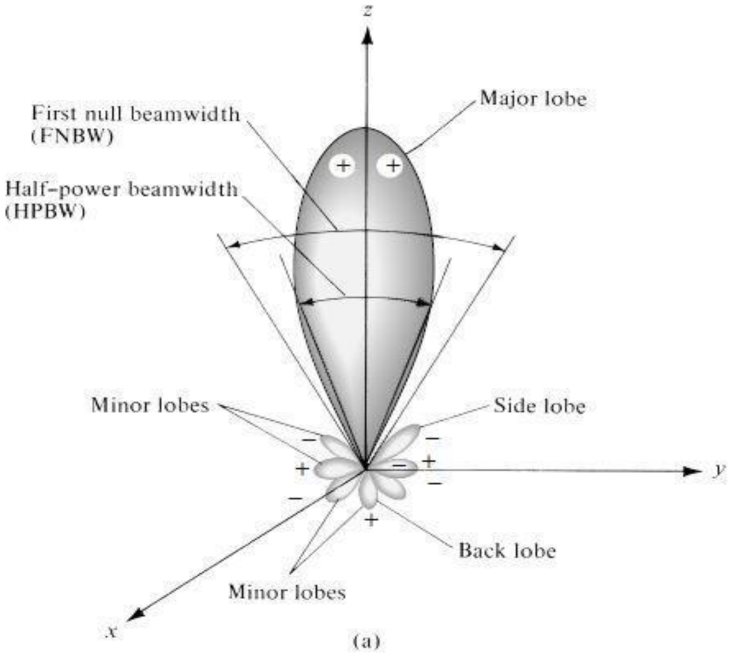


Figure 1.4 - Radiation Pattern Lobes

A radiation lobe is a portion of the radiation pattern bounded by regions of relatively weak radiation intensity.

- Main lobe
- Minor lobes
- Side lobes
- Back lobes

Minor lobes usually represent radiation in undesired directions, and they should be minimized. Side lobes are normally the largest of the minor lobes.

The level of minor lobes is usually expressed as a ratio of the power density, often termed the side lobe ratio or side lobe level.

In most radar systems, low side lobe ratios are very important to minimize false target indications through the side lobes (e.g., -30 dB).

Components in the Amplitude Pattern:

There would be, in general, three electric-field components (E_r , E_θ, E_φ) at each observation point on the surface of a sphere of constant radius.

In the far field, the radial E_r component for all antennas is zero or vanishingly small.

Some antennas, depending on their geometry and also observation distance, may have only one, two, or all three components.

Isotropic, Directional, and Omnidirectional Patterns are the types of radiation patterns.

- **Isotropic Radiator**: A hypothetical lossless antenna having equal radiation in all directions.
- **Omnidirectional Radiator:** An antenna having an essentially nondirectional pattern in a given plane (e.g., in azimuth) and a directional pattern in any orthogonal plane.
- **Directional Radiator:** An antenna having the property of radiating or receiving more effectively in some directions than in others. Usually the maximum directivity is significantly greater than that of a half-wave dipole.

Figure 1.5 - ScienTech Antenna Trainer Kit

The transmitter of the kit was rotated through 360 degrees in 20 degree intervals and the received power was measured (in µV - converted to dB) by a receiver to plot the radiation patterns of a few antennas. A simple MATLAB code written by us to obtain the 2D Polar Plots is given in Appendix A. The main disadvantage of this trainer kit is that it works only at 750MHz. However, it helped us to visualize the radiation patterns of some antennas shown in the following pages.

Because this parameter was so important to our software simulations we needed to understand it completely. For this purpose we obtained the 2D polar plots of radiation patterns for a few antennas in our lab using a ScienTech antenna trainer kit shown in figure 1.5.

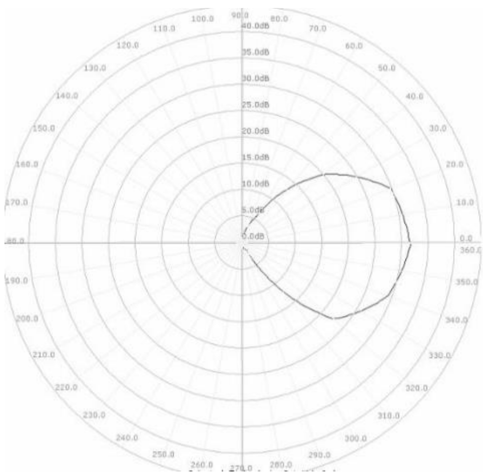


Figure 1.6 - 2D Polar Plot for a Yagi Antenna

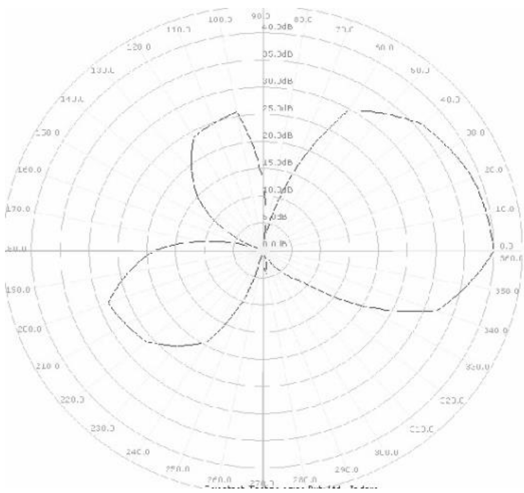


Figure 1.7 - 2D Polar Plot for a Helical Antenna

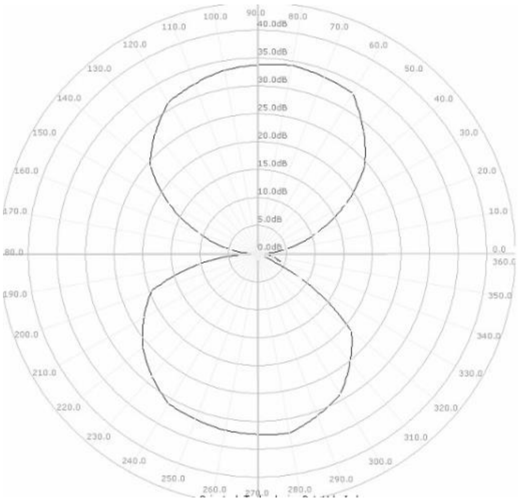


Figure 1.8 - 2D Polar Plot for a Rhombus Patch Antenna

A general 3D radiation pattern is shown in figure 1.9

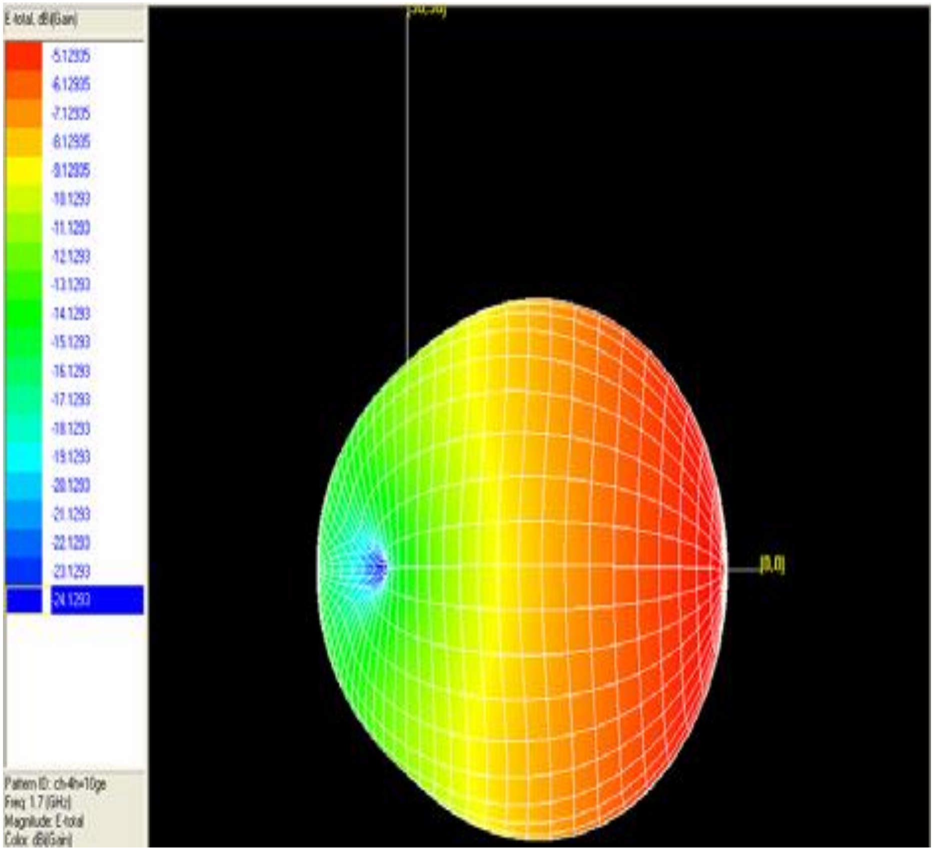


Figure 1.9 - 3D Radiation Pattern for a rectangular patch

1.2.10 Beamwidth

Beamwidth of an antenna is easily determined from its 2D radiation pattern and is also a very important parameter. Beamwidth is the angular separation of the half-power points of the radiated pattern. The way in which beamwidth is determined is shown in figure 1.10.

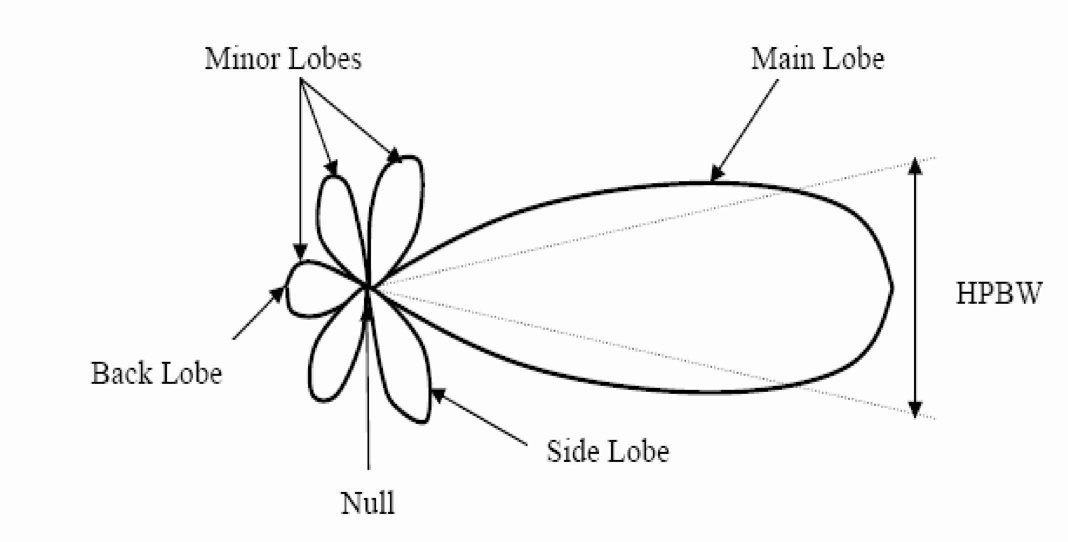


Figure 1.10 - Determination of HPBW from radiation pattern

1.2.11 Bandwidth

The bandwidth of an antenna is defined by as “the range of usable frequencies within which the performance of the antenna, with respect to some characteristic, conforms to a specified standard.” The bandwidth can be the range of frequencies on either side of the center frequency where the antenna characteristics like input impedance, radiation pattern, beamwidth, polarization, side lobe level or gain, are close to those values which have been obtained at the center frequency. The bandwidth of a broadband antenna can be defined as the ratio of the upper to lower frequencies of acceptable operation.

1.2 Types of Antennas

Antennas can be classified in several ways. One way is the frequency band of operation. Others include physical structure and electrical/electromagnetic design. Most simple, non-directional antennas are basic dipoles or monopoles. More complex, directional antennas consist of arrays of elements, such as dipoles, or use one active and several passive elements, as in the Yagi antenna. New antenna technologies are being developed that allow an antenna to rapidly change its pattern in response to changes in direction of arrival of the received signal. These antennas and the supporting technology are called adaptive or "smart" antennas and may be used for the higher frequency bands in the future. A few commonly used antennas are described in the following sections.

1.2.1 Log-Periodic Antennas

A log-periodic antenna is also named a log-periodic array. It is a multi-element, directional narrow beam antenna that works on a wide range of frequencies. This antenna is made of a series of dipoles placed along the antenna axis at different space intervals of time followed by a logarithmic function of frequency. A log-periodic antenna is used in a wide range of applications where variable bandwidth is required along with antenna gain and directivity.

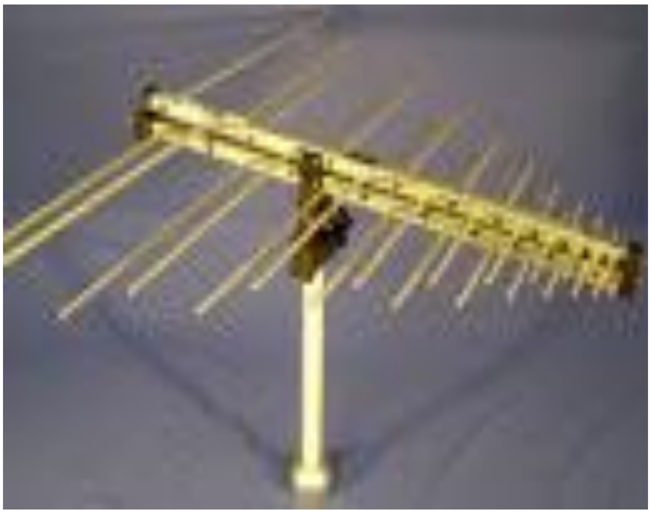


Figure 1.11 - Log Periodic Antenna

1.2.2 Wire Antennas

Wire antennas are also known as linear or curved antennas. These antennas are very simple, cheap, and are used in a wide range of applications. These antennas are further subdivided into four as explained below.

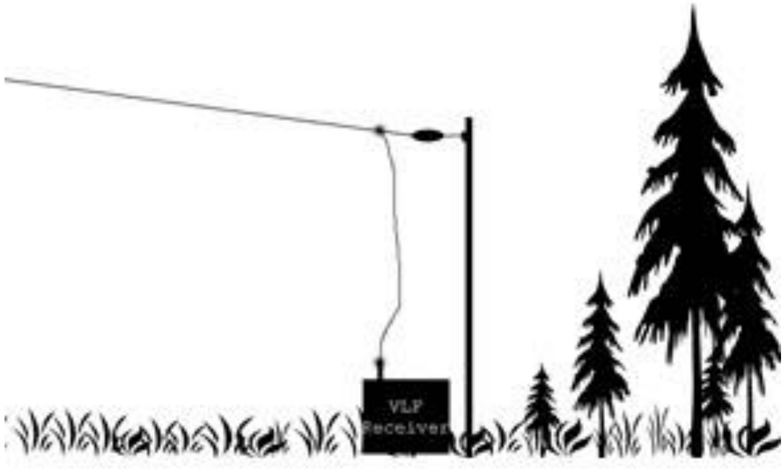


Figure 1.12 - Wire Antenna

1.3.3 Dipole Antenna

A dipole antenna is one of the most straightforward antenna alignments. This dipole antenna consists of two thin metal rods with a sinusoidal voltage difference between them. The length of the rods is chosen in such a way that they have a quarter length of the wavelength at operational frequencies. These antennas are used in designing their own antennas or other antennas. They are very simple to construct and use.

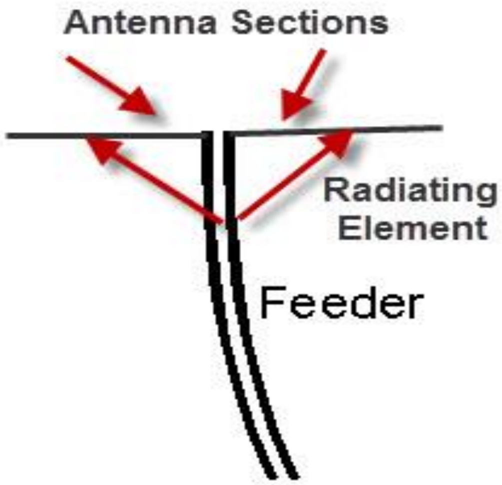


Figure 1.13 - Dipole Antenna

The dipole antenna consists of two metallic rods through which current and frequency flow. This current and voltage flow makes an electromagnetic wave and the radio signals get radiated. The antenna consists of a radiating element that splits the rods and makes current flow through the center by using a feeder at the transmitter out that takes from the receiver. The different types of dipole antennas used as RF antennas include half wave, multiple, folded, non-resonant, and so on.

Short-Dipole Antenna

It is the simplest of all types of antennas. This antenna is an open-circuited wire in which short denotes “relative to a wavelength” so this antenna gives priority to the size of the wire relative to the wavelength of the frequency of operation.

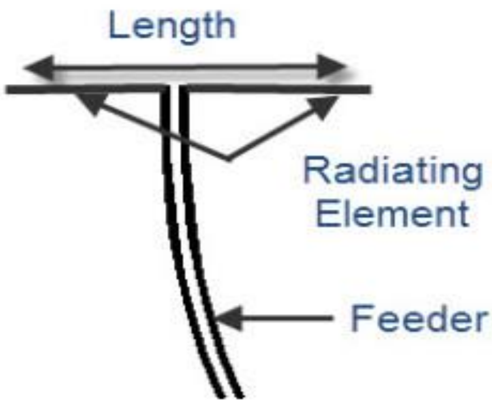


Figure 1.14 – Short Dipole Antenna

It does take any consideration about the absolute size of the dipole antenna. The short dipole antenna is made up of two co-linear conductors that are placed end to end, with a small gap between conductors by a feeder. A Dipole is considered short if the length of the radiating element is less than a tenth of the wavelength.

$$L<\lambda/10$$

The short dipole antenna is made of two co-linear conductors that are placed end to end, with a small gap between conductors by a feeder.

The short dipole antenna is infrequently satisfactory from an efficiency viewpoint because most of the power entering this antenna is dissipated as heat and resistive losses also become gradually high.

1.3.4 Monopole Antenna

Monopole antennas, as shown in Figure, constitute a group of derivatives of dipole antennas. Here, only half of the dipole antenna is needed for operation. A metal ground plane (ideally of infinite size) is used, with respect to which the excitation voltage is applied to the half structure. The half structure for a regular dipole antenna is called a monopole antenna, in reference to the presence of only one physical side. A similar half structure for a folded dipole antenna is called a folded monopole antenna. The presence of the ground plane allows the monopole antenna to operate as electrically equivalent to a dipole antenna. The ground plane equivalently replaces the lower half by an imaging principle, similar to creating an optical image through a mirror. Notice in Figure 1.14 that for the currents in the monopole and dipole structures to be the same, one needs the source voltage of the equivalent dipole antenna to be twice that of the monopole antenna. As a result, the input impedance of the monopole structure is half that of the corresponding dipole structure:

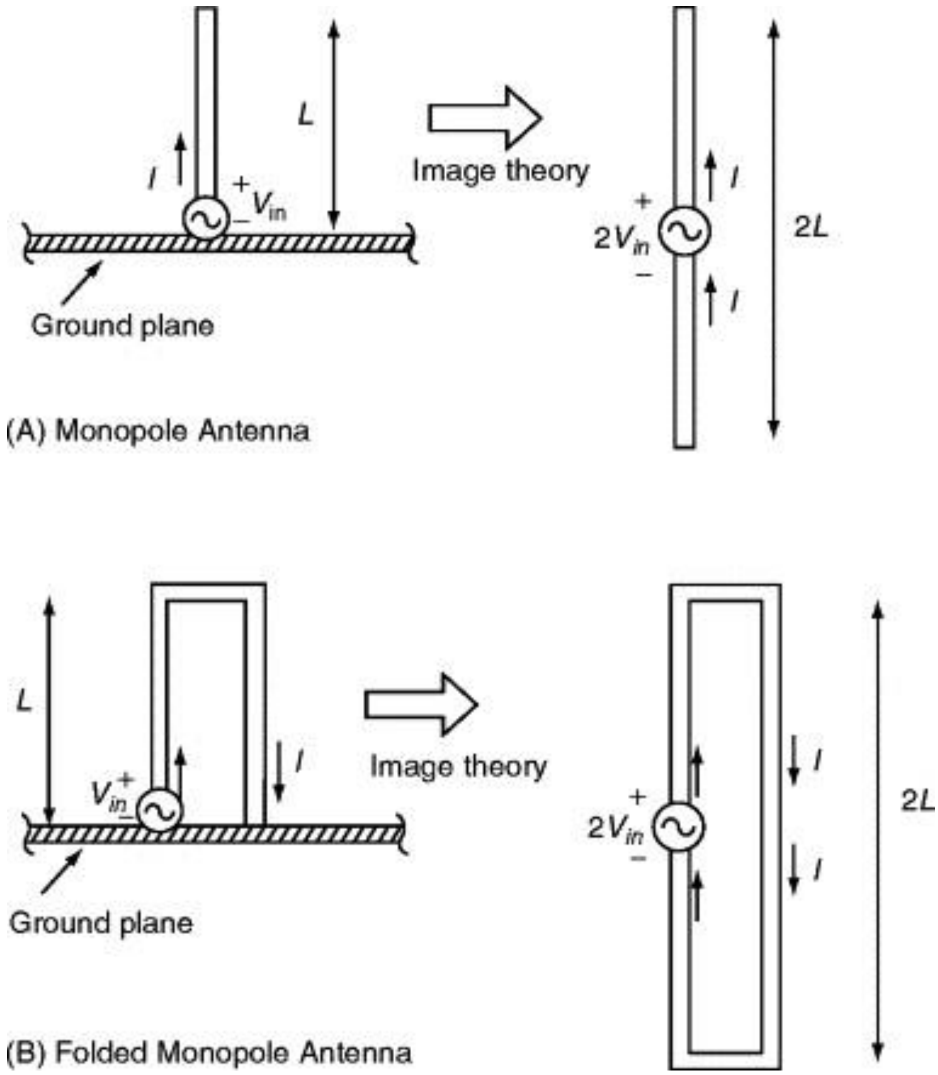


Figure 1.15 - Monopole Antenna

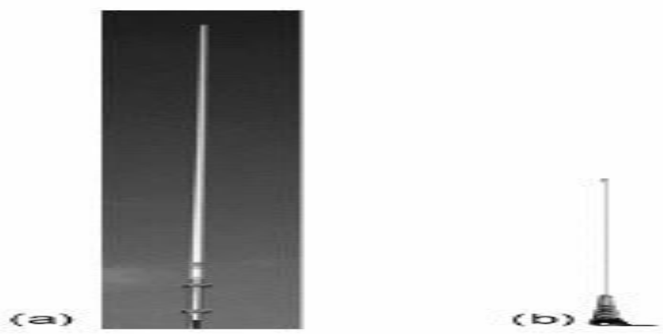


Figure 1.16 - Typical monopole antennas for (a) base-station applications and (b) mobile applications

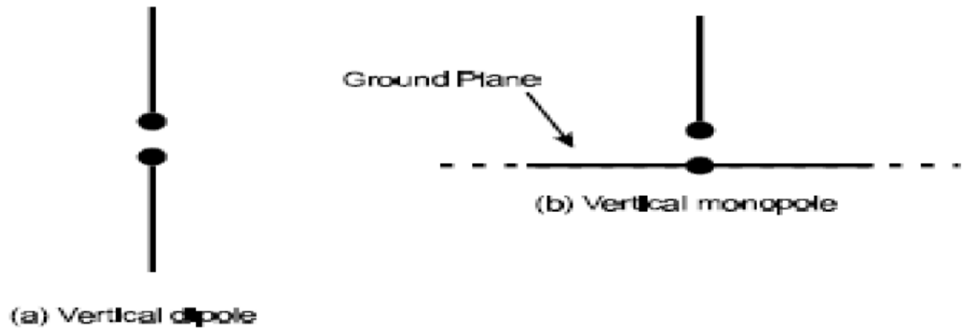


Figure 1.17 - (a) vertical dipole and (b) vertical monopole

1.3.5 Loop Antenna

An RF current carrying coil is given a single turn into a loop, can be used as an antenna called as loop antenna. The currents through this loop antenna will be in phase. The magnetic field will be perpendicular to the whole loop carrying the current.

Frequency Range

The frequency range of operation of loop antenna is around 300MHz to 3GHz. This antenna works in UHF range.

A loop antenna is a coil carrying radio frequency current. It may be in any shape such as circular, rectangular, triangular, square or hexagonal according to the designer's convenience.

Loop antennas are of two types.

- Large loop antennas
- Small loop antennas

Large loop antennas:

Large loop antennas are also called as resonant antennas. They have high radiation efficiency. These antennas have length nearly equal to the intended wavelength.

$$L=\lambda L=\lambda$$

Where,

- **L** is the length of the antenna
- **λ** is the wavelength

The main parameter of this antenna is its perimeter length, which is about a wavelength and should be an enclosed loop. It is not a good idea to meander the loop so as to reduce the size, as that increases capacitive effects and results in low efficiency.

Small loop antennas:

Small loop antennas are also called as magnetic loop antennas. These are less resonant.

These are mostly used as receivers.

These antennas are of the size of one-tenth of the wavelength.

$$L = \lambda/10$$

Where,

- **L** is the length of the antenna
- **λ** is the wavelength

The features of small loop antennas are −

- A small loop antenna has low radiation resistance. If multi-turn ferrite core constructions are used, then high radiation resistance can be achieved.
- It has low radiation efficiency due to high losses.
- Its construction is simple with small size and weight.

Due to its high reactance, its impedance is difficult to match with the transmitter. If loop antenna have to act as transmitting antenna, then this impedance mis-match would definitely be a problem. Hence, these loop antennas are better operated as receiver antennas.

Travelling Wave Antennas

These antennas are classified into different types which are discussed below.

1.3.6 Helical Antennas

Figure 1.18 – Helical Antenna

Helical antenna is an example of wire antenna and itself forms the shape of a helix. This is a broadband VHF and UHF antenna.

Frequency Range

- The frequency range of operation of helical antenna is around 30MHz to 3GHz. This antenna works in VHF and UHF ranges.
- Helical antenna or helix antenna is the antenna in which the conducting wire is wound in helical shape and connected to the ground plate with a feeder line. It is the simplest antenna, which provides circularly polarized waves. It is used in extra-terrestrial communications in which satellite relays etc., are involved.
- It consists of a helix of thick copper wire or tubing wound in the shape of a screw thread used as an antenna in conjunction with a flat metal plate called a ground plate. One end of the helix is connected to the center conductor of the cable and the outer conductor is connected to the ground plate.

- The radiation of helical antenna depends on the diameter of helix, the turn spacing and the pitch angle.
- Pitch angle is the angle between a line tangent to the helix wire and plane normal to the helix axis.

$$\alpha=\tan^{-1}(S\pi D)$$

where,

- D is the diameter of helix.
- S is the turn spacing (centre to centre).
- α is the pitch angle.

Advantages:

The following are the advantages of Helical antenna

- Simple design
- Highest directivity
- Wider bandwidth
- Can achieve circular polarization
- Can be used at HF & VHF bands also

Disadvantages:

The following are the disadvantages of Helical antenna

- Antenna is larger and requires more space
- Efficiency decreases with number of turns

Applications:

The following are the applications of Helical antenna

- A single helical antenna or its array is used to transmit and receive VHF signals
- Frequently used for satellite and space probe communications
- Used for telemetry links with ballistic missiles and satellites at Earth stations
- Used to establish communications between the moon and the Earth • Applications in radio astronomy

1.3.7 Yagi-Uda Antenna

Another antenna that makes use of passive elements is the Yagi-Uda antenna. This type of antenna is inexpensive and effective. It can be constructed with one or more reflector elements and one or more director elements. Yagi antennas can be made by using an antenna with one reflector, a driven folded-dipole active element, and directors, mounted for horizontal polarization in the forward direction.

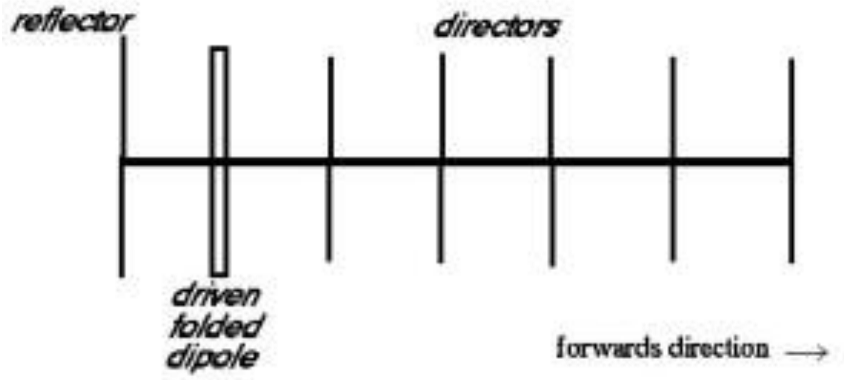


Figure 1.19 - The Yagi antenna - multiple elements

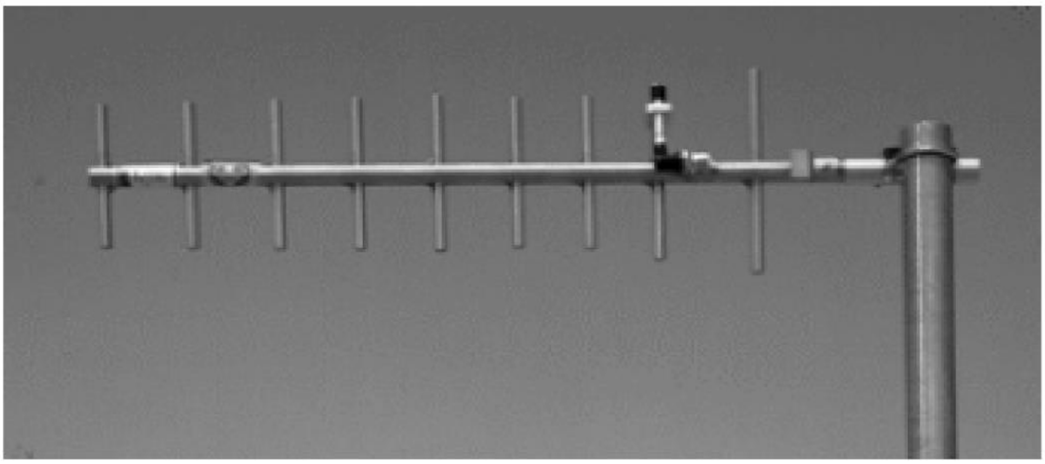


Figure 1.20 - A typical Yagi Uda antenna

Figure 1.21 is the typical radiation pattern obtained for a three element (one reflector, one active element, and one director) Yagi antenna. Generally, the more elements a

Yagi has, the higher the gain, and the narrower the beamwidth. This antenna can be mounted to support either horizontal or vertical polarization and is often used for point-to-point applications, as between a base station and repeater-station sites.

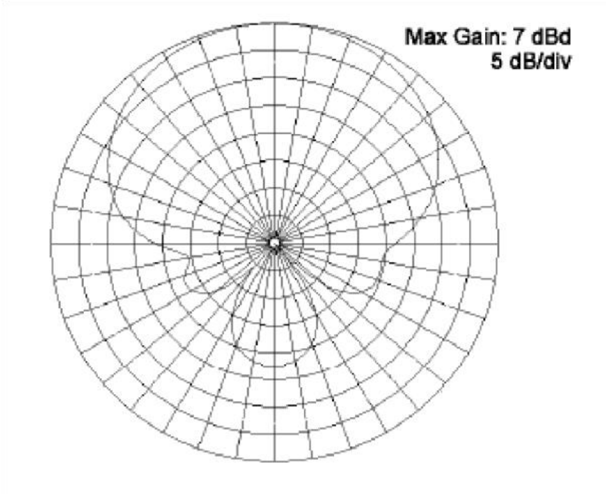


Figure 1.21 - A Yagi antenna horizontal plane pattern

1.3.8 Horn Antenna:

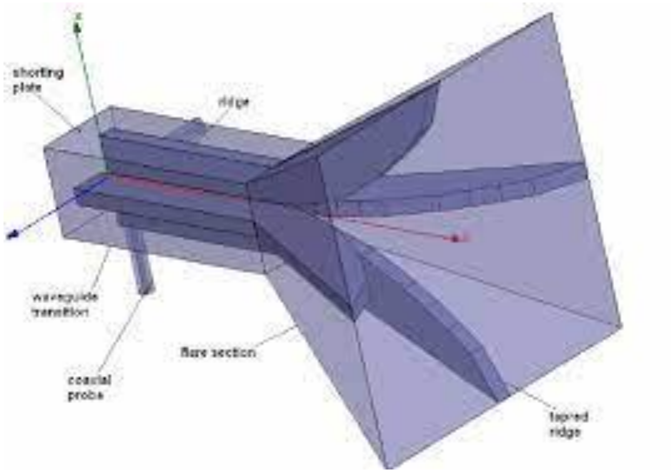


Figure 1.22 – Horn Antenna

To improve the radiation efficiency and directivity of the beam, the wave guide should be provided with an extended aperture to make the abrupt discontinuity of the wave into a gradual transformation. So that all the energy in the forward direction gets radiated. This can be termed as Flaring. Now, this can be done using a horn antenna.

Frequency Range:

The operational frequency range of a horn antenna is around 300MHz to 30GHz. This antenna works in UHF and SHF frequency ranges.

Sectoral horn:

This type of horn antenna, flares out in only one direction. Flaring in the direction of Electric vector produces the sectorial E-plane horn. Similarly, flaring in the direction of Magnetic vector, produces the sectorial H-plane horn.

Pyramidal horn:

This type of horn antenna has flaring on both sides. If flaring is done on both the E & H walls of a rectangular waveguide, then pyramidal horn antenna is produced. This antenna has the shape of a truncated pyramid.

Conical horn:

When the walls of a circular wave guide are flared, it is known as a conical horn. This is a logical termination of a circular wave guide.

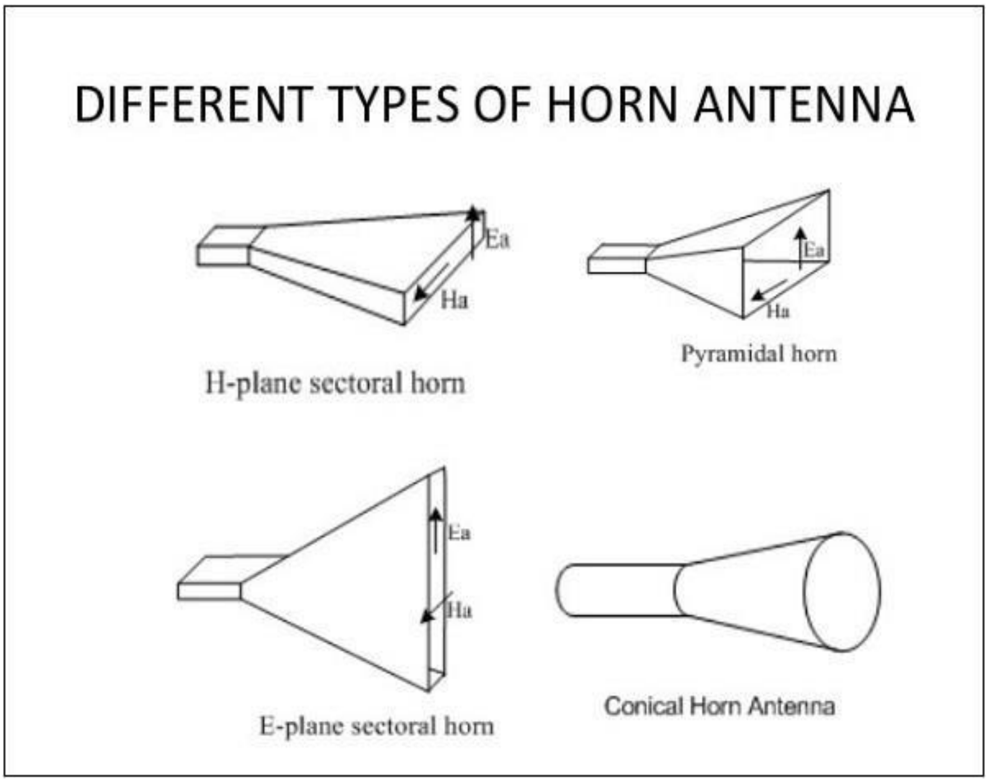


Figure 1.23 - Different types of Horn Antenna

The above figures show the types of horn configurations, which were discussed earlier.

Radiation Pattern:

The radiation pattern of a horn antenna is a Spherical Wave front. The following figure shows the radiation pattern of horn antenna. The wave radiates from the aperture, minimizing the diffraction of waves. The flaring keeps the beam focussed. The radiated beam has high directivity.

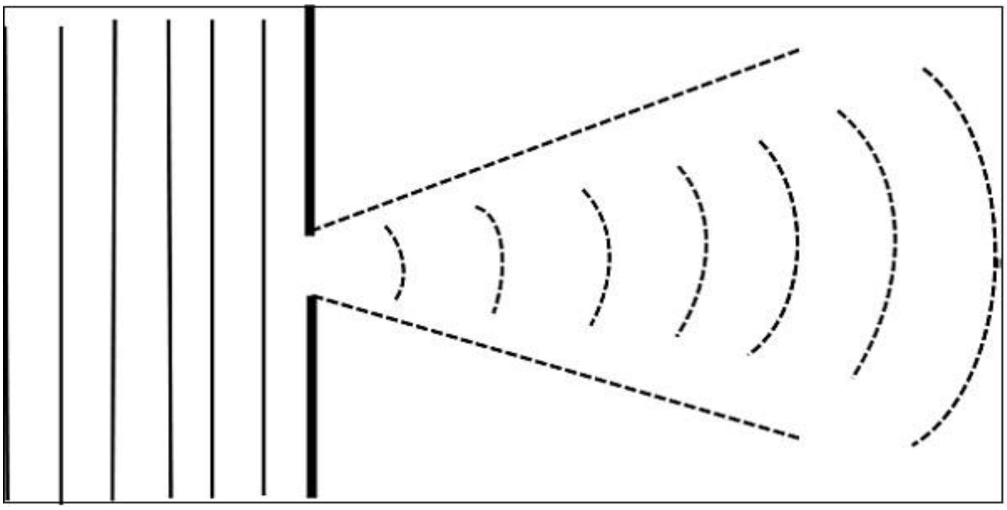


Figure 1.24 - Radiation pattern of horn antenna

Advantages:

The following are the advantages of Horn antenna −

- Small minor lobes are formed
- Impedance matching is good
- Greater directivity
- Narrower beam width
- Standing waves are avoided

Disadvantages:

The following are the disadvantages of Horn antenna −

- Designing of flare angle, decides the directivity
- Flare angle and length of the flare should not be very small

Applications:

The following are the applications of Horn antenna −

- Used for astronomical studies
- Used in microwave applications

1.3.9 Microwave Antennas

The antennas operating at microwave frequencies are known as microwave antennas. These antennas are used in a wide range of applications.

Rectangular Microstrip Antennas

For spacecraft or aircraft applications – based on the specifications such as size, weight, cost, performance, ease of installation, etc. – low profile antennas are preferred. These antennas are known as rectangular microstrip antennas or patch antennas; they only require space for the feed line which is normally placed behind the ground plane. The major disadvantage of using these antennas is their inefficient and very narrow bandwidth, which is typically a fraction of a percent or, at the most, a few percent.

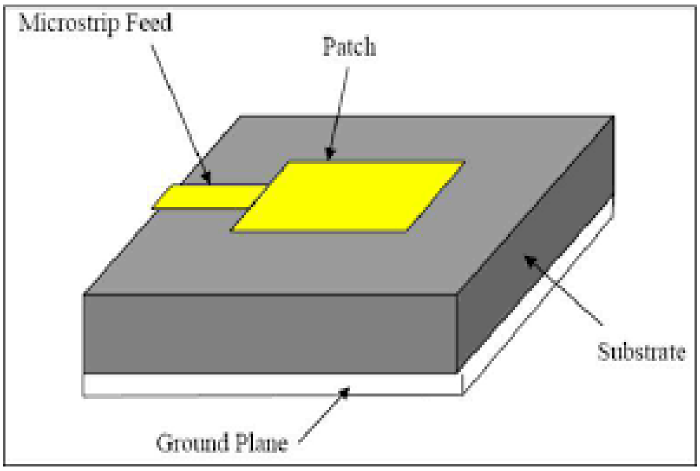


Figure 1.25 – Rectangular microstrip patch antenna

Reflector Antennas

These antennas are classified into two types which are discussed below.

Corner Reflector Antenna

The antenna that comprises one or more dipole elements placed in front of a corner reflector, is known as a corner-reflector antenna. The directivity of an antenna can be increased by using reflectors. In the case of a wire antenna, a conducting sheet is used behind the antenna for directing the radiation in the forward direction.

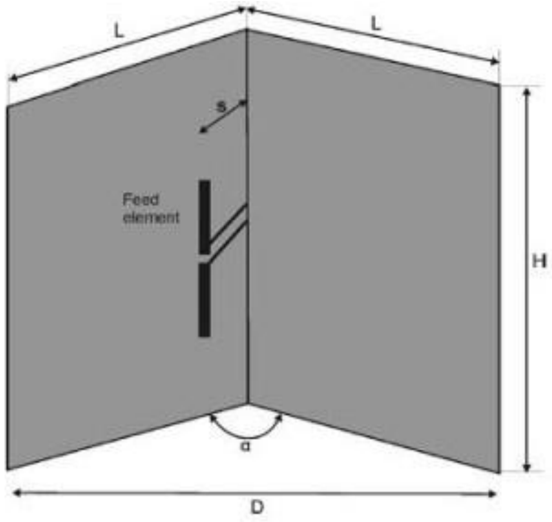


Figure 1.26 - Corner-reflector antennas

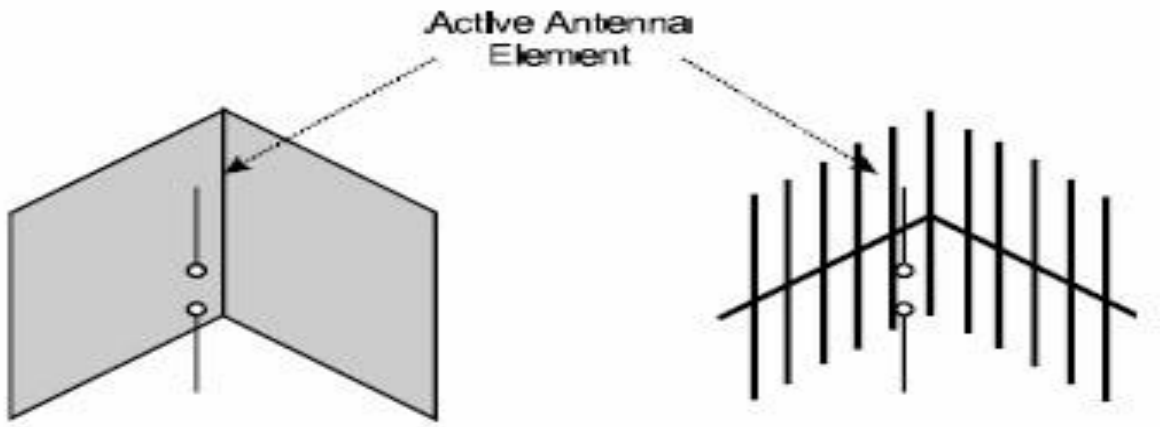


Figure 1.27 - Solid reflector and Wire reflector antennas

This antenna has moderately high gain, but its most important pattern feature is that the forward (main beam) gain is much higher than the gain in the opposite direction. This is called the front-to-back ratio and is evident from its radiation pattern shown in figure 1.27.

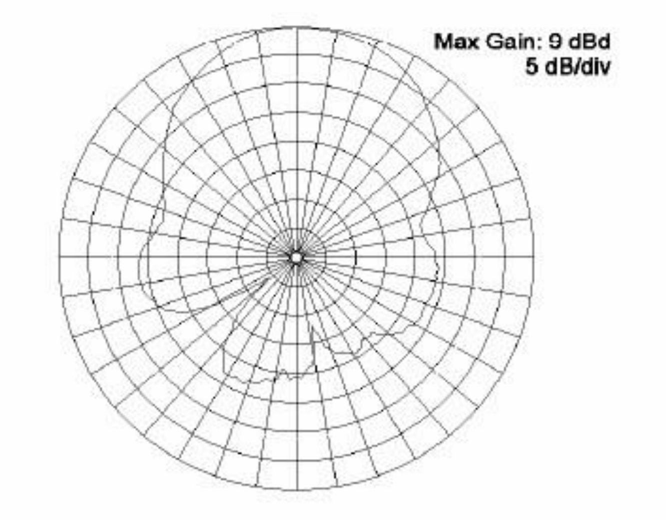


Figure 1.28 - A corner-reflector antenna horizontal-plane pattern

Parabolic-Reflector Antenna

The radiating surface of a parabolic antenna has very large dimensions compared to its wavelength. The geometrical optics, which depend upon rays and wavefronts, are used to know about certain features of these antennas. Certain important properties of these antennas can be studied by using ray optics, and of other antennas by using electromagnetic field theory.

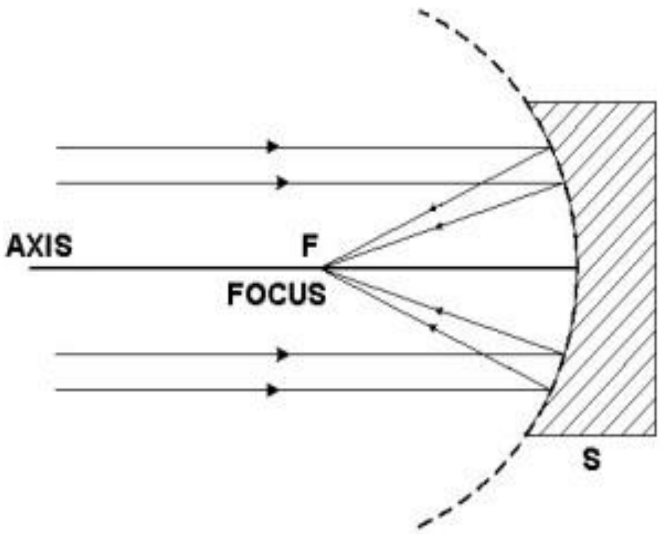


Figure 1.29 - Parabolic Reflector Antenna

One of the useful properties of this antenna is the conversion of a diverging spherical wavefront into a parallel wavefront that produces a narrow beam of the antenna. The various types of feeds that use this parabolic reflector include horn feeds, Cartesian feeds, and dipole feeds.

CHAPTER 2

2 Microstrip Patch Antennas

The software simulations of our project focused on designing and testing of patch antennas using software called HFSS (described later on in this chapter). Before the software results are presented the theory behind patch antennas is elucidated.

2.1 Introduction

Microstrip antennas are planar resonant cavities that leak from their edges and radiate. Printed circuit techniques can be used to etch the antennas on soft substrates to produce low-cost and repeatable antennas in a low profile. The antennas fabricated on compliant substrates withstand tremendous shock and vibration environments. Manufacturers for mobile communication base stations often fabricate these antennas directly in sheet metal and mount them on dielectric posts or foam in a variety of ways to eliminate the cost of substrates and etching. This also eliminates the problem of radiation from surface waves excited in a thick dielectric substrate used to increase bandwidth. In its most basic form, a Microstrip patch antenna consists of a radiating patch on one side of a dielectric substrate which has a ground plane on the other side as shown in Figure 2.1. The patch is generally made of conducting material such as copper or gold and can take any possible shape. The radiating patch and the feed lines are usually photo etched on the dielectric substrate. Arrays of antennas can be photoetched on the substrate, along with their feeding networks. Microstrip circuits make a wide variety of antennas possible through the use of the simple photoetching techniques[1].

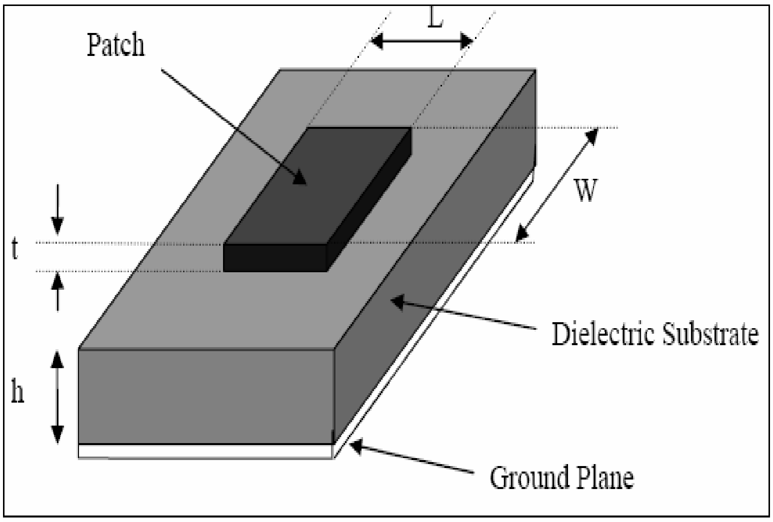


Figure 2.1 - A Typical Microstrip Patch Antenna

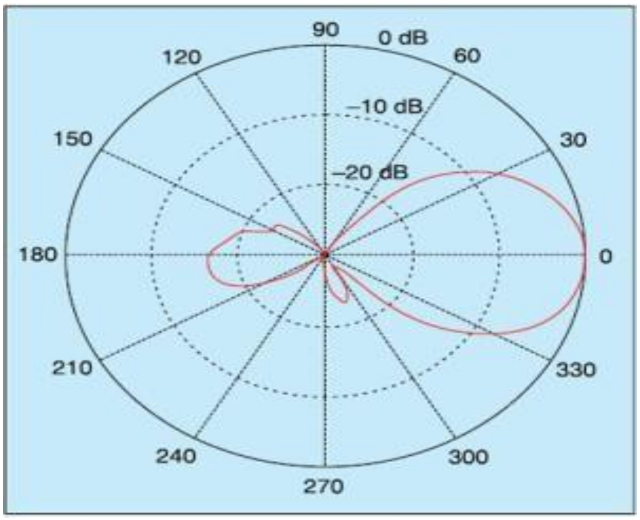


Figure 2.2 - Typical radiation pattern of microstrip patch antenna

In order to simplify analysis and performance prediction, the patch is generally square, rectangular, circular, triangular, elliptical or some other common shape. For a rectangular patch, the length L of the patch is usually $0.3333\lambda o < L < 0.5\lambda o$, where λo is the free-space wavelength. The patch is selected to be very thin such that $t << \lambda o$ (where t is the patch thickness). The height h of the dielectric substrate is usually 0.003

$\lambda o \leq h \leq 0.05\ \lambda o$. The dielectric constant of the substrate (εr) is typically in the range $2.2 \leq \varepsilon r \leq 12$.

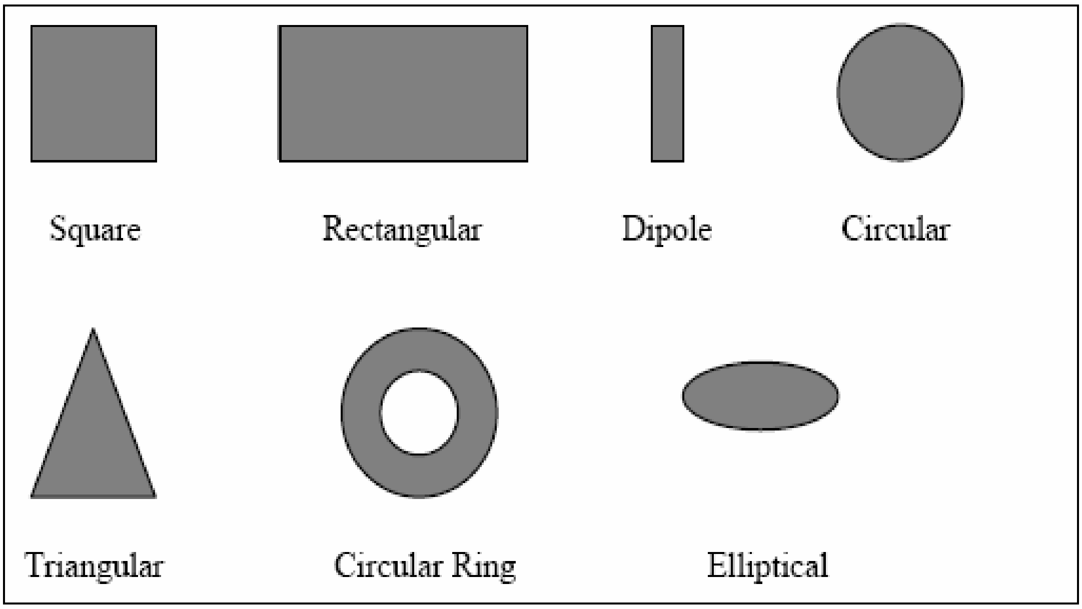


Figure 2.3 - Typical patch shapes

A patch radiates from fringing fields around its edges. The situation is shown in figure 2.4. Impedance match occurs when a patch resonates as a resonant cavity. When matched, the antenna achieves peak efficiency. A normal transmission line radiates little power because the fringing fields are matched by nearby counteracting fields. Power radiates from open circuits and from discontinuities such as corners, but the amount depends on the radiation conductance load to the line relative to the patches. Without proper matching, little power radiates. The edges of a patch appear as slots whose excitations depend on the internal fields of the cavity. A general analysis of an arbitrarily shaped patch considers the patch to be a resonant cavity with metal (electric) walls of the patch and the ground plane and magnetic or impedance walls around the edges.

For good antenna performance, a thick dielectric substrate having a low dielectric constant is desirable since this provides better efficiency, larger bandwidth and better radiation. However, such a configuration leads to a larger antenna size. In order to design a compact Microstrip patch antenna, higher dielectric constants must be used which are less efficient and result in narrower bandwidth. Hence a compromise must be reached between antenna dimensions and antenna performance.

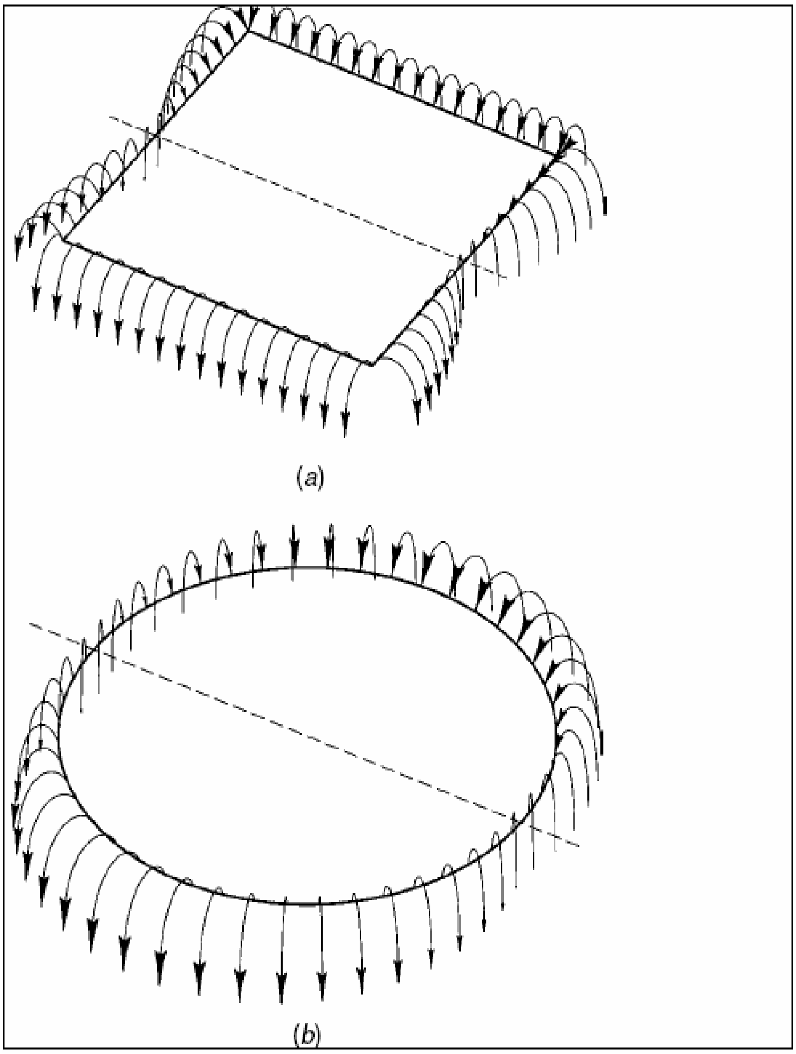


Figure 2.4 - Fringing Fields in Patch Antennas

➢ Rectangular Patch:

A rectangular micros trip patch antenna is a form of antenna which consists of a rectangular patch. This patch is of any planar or non-planar geometry on one side of dielectric substrate and a ground plane on the other side. The rectangular patch can be easily analysed using transmission line model and cavity model. Transmission line model yields less accurate results and lacks versatility. In cavity model the interior region of dielectric substrate is modeled as cavity bounded by electric walls on top and bottom.

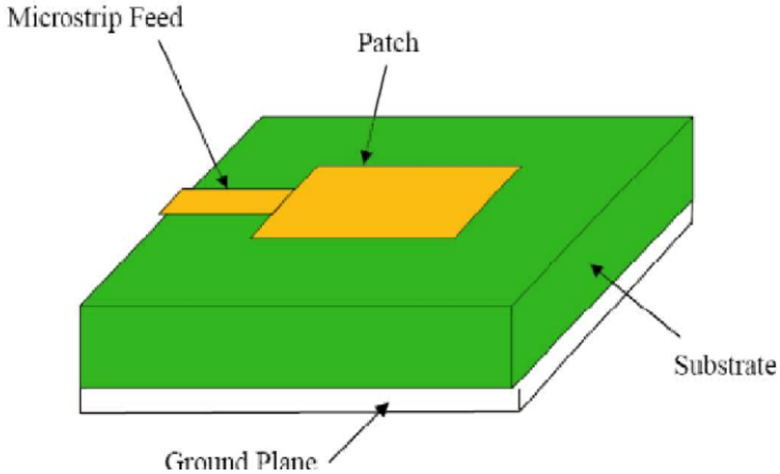


Figure 2.5 - Rectangular microstrip patch antenna

➢ Circular Patch:

The modes supported by the circular patch antenna can be found by treating the patch, ground plane, and material the between the two as a circular cavity. Substrate height is small (height << wavelength) are TM^z where TM is taken perpendicular to the patch.

In circular patch there is only one degree of freedom to control (radius of the patch). Doing this does not change the order of the modes; however it does change the absolute value of the resonant frequency of each.

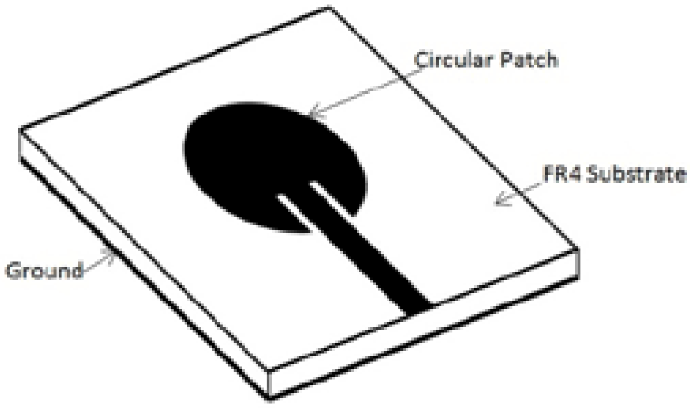


Figure 2.6 Circular Patch antenna

$$R_p = \frac{F}{\sqrt{1 + \frac{2h}{\pi \varepsilon F\left[\ln\left(\frac{F\pi}{2h}\right) + 1.7726\right]}}}$$

$$F = \frac{8.791 \times 10^9}{f\sqrt{\varepsilon}}$$

where Rp = Radius of the patch

h = Height of the substrate

f = Resonant frequency in Hz

2.2 Applications of Microstrip Patch Antennas

Microstrip patch antennas are increasing in popularity for use in wireless applications due to their low-profile structure. Therefore they are extremely compatible for embedded antennas in handheld wireless devices such as cellular phones, pagers etc. The telemetry and communication antennas on missiles need to be thin and conformal and are often microstrip patch antennas. Another area where they have been used successfully is in satellite communication[2].

2.2.1 Communication based applications:

Microstrip patch antenna finds several applications in wireless communication.

For example, satellite communication requires circularly polarised radiation patterns, which can be realised using either square or circular patch microstrip antenna. In global positioning satellite (GPS) systems, circularly polarized microstrip antenna are used. They are very compact in size and quite expensive due to their positioning.

Microstrip antenna are also used in the fields of RFID (radio frequency identification), mobile communication and healthcare. Basically, an RFID system consists of a tag and a reader. Generally, it uses frequencies between 30 Hz and 5.8 GHz.

In Tele-medicine application, Microstrip antenna operate at 2.45 GHz. Wearable microstrip antenna are suitable for wireless body area network. An antenna having gain of 6.7 dB and front-to-back ratio of 11.7 dB, and resonating at 2.45 GHz is suitable for telemedicine applications.

The IEEE 802.16 standard is known as WiMax (worldwide interoperability for microwave access). It can reach up to 48km (30-mile) radius with data rate of 70 Mbps. Microstrip antenna can resonate at more than one frequency. Therefore these can be used in WiMax based communication equipment.

Some communication-based applications of microstrip patch antenna are radio altimeters, command and control systems, remote sensing and environmental instrumentation, feed elements in complex antenna, satellite navigation receivers, mobile radio, integrated antenna, biomedical radiators and intruder alarms, Doppler and other radars, and satellite communication and direct broadcast services.

2.2.2 Mobile communication:

Mobile communication requires small, low-cost, low-profile antenna. In some mobile handsets, semiconductor-based diodes or detectors are used as antenna. They are much like pn diode photo-detectors but work at microwave frequency. Many times omnidirectional antenna is used in mobile phones. There are different kinds of antenna like planar inverted-F antenna, folded inverted conformal antenna and mono pole. Also retractable whip antenna is commonly used in handsets.

The phone is subdivided into roughly 60 components, each consisting of hundreds or even thousands of individual facets.

2.2.3 Medical application:

In the treatment of malignant tumours, microwave energy is said to be the most effective way of inducing hyperthermia. The radiator to be used for this purpose should be lightweight, easy to handle and rugged. Only a patch radiator fulfils these requirements. The initial designs of microstrip radiators for inducing hyperthermia were based on printed dipoles and annular rings that were designed on S-band (2-4 GHz). Later on the design was based on a circular microstrip disk at L-band (1-2 GHz). Two coupled microstrip lines with a flexible separation are used to measure temperature inside the human body.

2.2.4 Textile antenna:

There are some applications at present where antenna are used to continuously monitor biometric data of the human body. In order to do this, they need to be so close to the human body all the time that they can continuously monitor the biometric data and send the information to the outside world. If the antenna is hard, it cannot be kept always attached with the human body. An antenna made of textile material will not harm the human body and can be worn for extended periods. Wearable antenna will find use in healthcare, recreation, fire-fighting, etc.

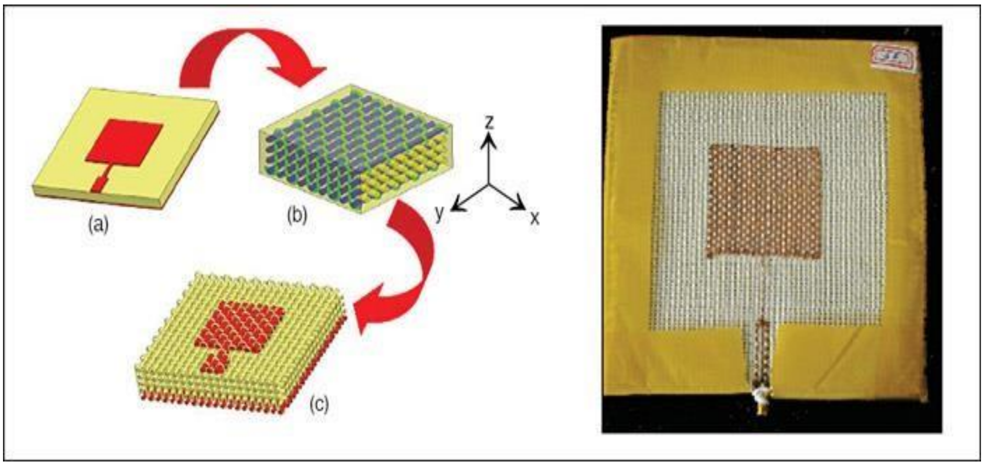


Figure 2.7 - Geometry of textile antenna

Textile materials are increasingly being used for development of flexible wearable systems due to the recent miniaturization of wireless devices. For flexible antenna, textile materials form interesting substrates, because fabric antenna can be easily integrated into clothes. In this special type of patch antenna, the radiating patch and the ground plane are made up of conductive textile material. The substrate too is a textile material with specific dielectric constant. As everything is made up of textile material, it is called textile antenna.

2.3 Advantages and Disadvantages of Patch Antennas

Some of their principal advantages of microstrip patch antennas are given 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.

Microstrip patch antennas suffer from a number of disadvantages as compared to conventional antennas. 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

Microstrip patch antennas have a very high antenna quality factor (Q). Q represents the losses associated with the antenna and a large Q leads to narrow bandwidth and low efficiency. Q can be reduced by increasing the thickness of the dielectric substrate. But as the thickness increases, an increasing fraction of the total power delivered by the source goes into a surface wave. This surface wave contribution can be counted as an unwanted power loss since it is ultimately scattered at the dielectric bends and causes degradation of the antenna characteristics. However, surface waves can be minimized by use of photonic bandgap structure. Other problems such as low gain and low power handling capacity can be overcome by using an array configuration for the elements.

3.4 Feed Techniques

Microstrip patch antennas can be fed by a variety of methods. These methods can be 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 (both contacting schemes), aperture coupling and proximity coupling (both non-contacting schemes)[6].

3.4.1 Microstrip Line Feed

In this type of feed technique, a conducting strip is connected directly to the edge of the microstrip patch as shown in Figure 2.6. The conducting strip is smaller in width as compared to the patch and this kind of feed arrangement has the advantage that the feed can be etched on the same substrate to provide a planar structure.

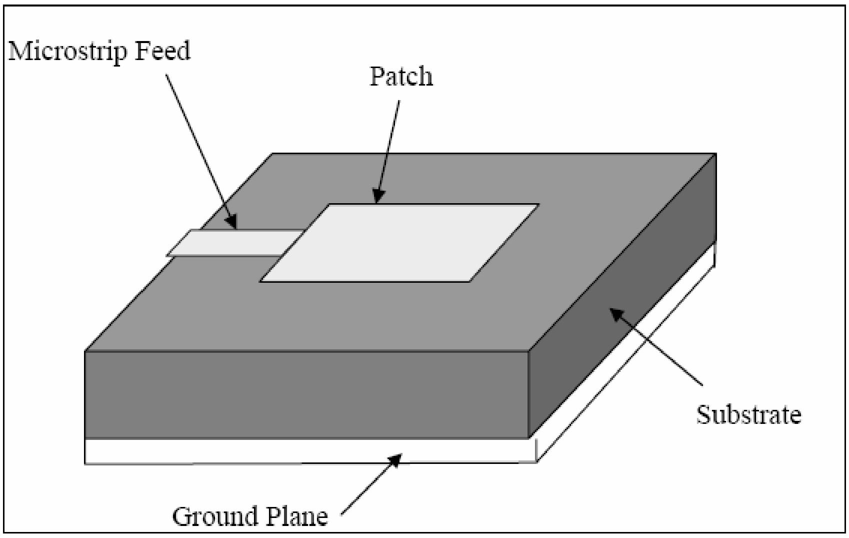


Figure 2.8 - Microstrip Line Feed

The purpose of the inset cut in the patch is to match the impedance of the feed line to the patch without the need for any additional matching element. This is achieved by properly controlling the inset position. Hence this is an easy feeding scheme, since it provides ease of fabrication and simplicity in modeling as well as impedance matching. However as the thickness of the dielectric substrate being used, increases, surface waves and spurious feed radiation also increases, which hampers the bandwidth of the antenna. The feed radiation also leads to undesired cross polarized radiation.

2.4.2 Coaxial Feed

The Coaxial feed or probe feed is a very common technique used for feeding Microstrip patch antennas. As seen from Figure 2.7, the inner conductor of the coaxial connector extends through the dielectric and is soldered to the radiating patch, while the outer conductor is connected to the ground plane. The main advantage of this type of feeding scheme is that the feed can be placed at any desired location inside the patch in order to match with its input impedance. This feed method is easy to fabricate and has low spurious radiation. However, its major disadvantage is that it provides narrow bandwidth and is difficult to model since a hole has to be drilled in the substrate and the connector protrudes outside the ground plane, thus not making it completely planar for thick substrates ($h > 0.02\lambda_o$). Also, for thicker substrates, the increased probe length makes the input impedance more inductive, leading to matching problems. It is seen above that for a thick dielectric substrate, which provides broad bandwidth, the microstrip line feed and the coaxial feed suffer from numerous disadvantages. The non-contacting feed techniques discussed below, solve these problems.

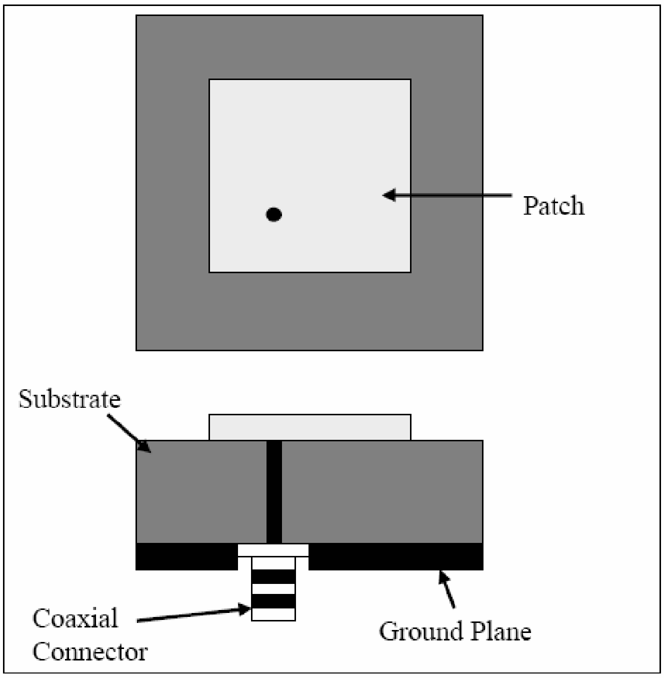


Figure 2.9 - Coaxial Feed

2.4.3 Aperture Coupled Feed

In this type of feed technique, the radiating patch and the microstrip feed line are separated by the ground plane as shown in Figure 2.10. Coupling between the patch and the feed line is made through a slot or an aperture in the ground plane. The coupling aperture is usually centered under the patch, leading to lower cross polarization due to symmetry of the configuration. The amount of coupling from the feed line to the patch is determined by the shape, size and location of the aperture. Since the ground plane separates the patch and the feed line, spurious radiation is minimized. Generally, a high dielectric material is used for the bottom substrate and a thick, low dielectric constant material is used for the top substrate to optimize radiation from the patch. The major disadvantage of this feed technique is that it is difficult to fabricate due to multiple layers, which also increases the antenna thickness. This feeding scheme also provides narrow bandwidth.

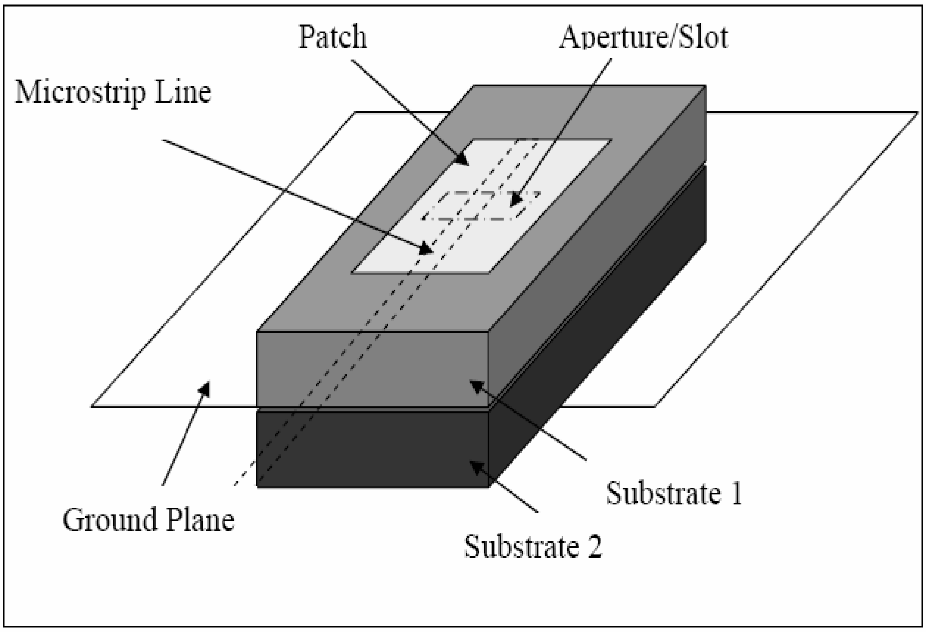


Figure 2.10 - Aperture Feed

2.4.4 Proximity Coupled Feed

This type of feed technique is also called as the electromagnetic coupling scheme. As shown in Figure 2.11, two dielectric substrates are used such that the feed line is between the two substrates and the radiating patch is on top of the upper substrate. The main advantage of this feed technique is that it eliminates spurious feed radiation and provides very high bandwidth (as high as 13%), due to overall increase in the thickness of the microstrip patch antenna. This scheme also provides choices between two different dielectric media, one for the patch and one for the feed line to optimize the individual performances. Matching can be achieved by controlling the length of the feed line and the width-to-line ratio of the patch. The major disadvantage of this feed scheme is that it is difficult to fabricate because of the two dielectric layers which need proper alignment. Also, there is an increase in the overall thickness of the antenna.

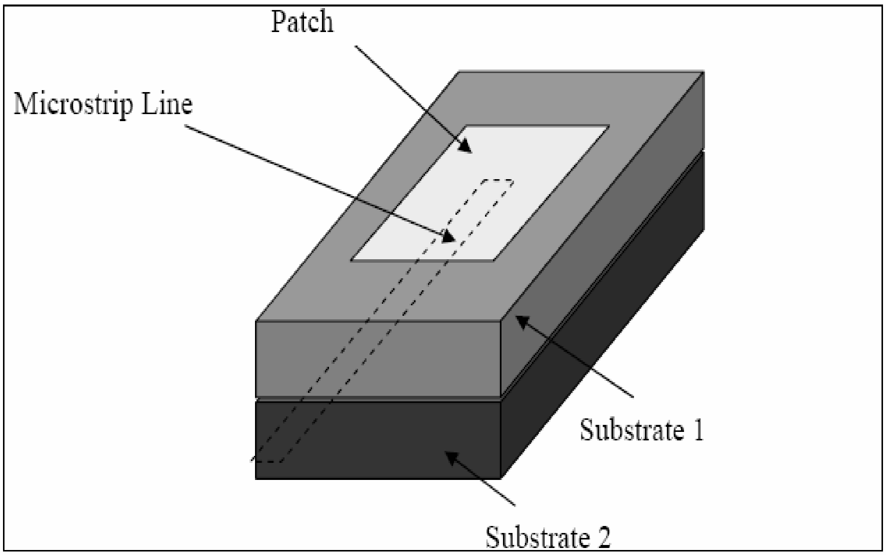


Figure 2.11 - Proximity Coupled Feed

Table 1.2 summarizes the characteristics of the different feed techniques.

Characteristics	Microstrip Line Feed	Coaxial Feed	Aperture coupled Feed	Proximity coupled Feed
Spurious feed radiation	More	More	Less	Minimum
Reliability	Better	Poor due to soldering	Good	Good
Ease of fabrication	Easy	Soldering and drilling needed	Alignment required	Alignment required
Impedance Matching	Easy	Easy	Easy	Easy
Bandwidth (achieved with impedance matching)	2-5%	2-5%	2-5%	13%

Table 1.1 - Comparison of different Feed Methods[7]

It is to be noted that in our project simulations we have used microstrip feed and co-axial feed techniques.

2.5 Methods of Analysis

The most popular models for the analysis of Microstrip patch antennas are the transmission line model, cavity model, and full wave model (which include primarily integral equations/Moment Method). The transmission line model is the simplest of all and it gives good physical insight but it is less accurate. The cavity model is more accurate and gives good physical insight but is complex in nature. The full wave models are extremely accurate, versatile and can treat single elements, finite and infinite arrays, stacked elements, arbitrary shaped elements and coupling[9].

It must be noted that our project is centered on the transmission line model and uses all of the empirical equations this model is based on for simulations. The cavity model is not at the centre of our project and is hence explained very briefly. The method of moments is explained in detail as it is used by several field solvers (such as HFSS) for simulations.

2.5.1 Transmission Line Model

This model represents the microstrip antenna by two slots of width W and height h, separated by a transmission line of length L. The microstrip is essentially a non homogeneous line of two dielectrics, typically the substrate and air. Figure 2.10 illustrates this.

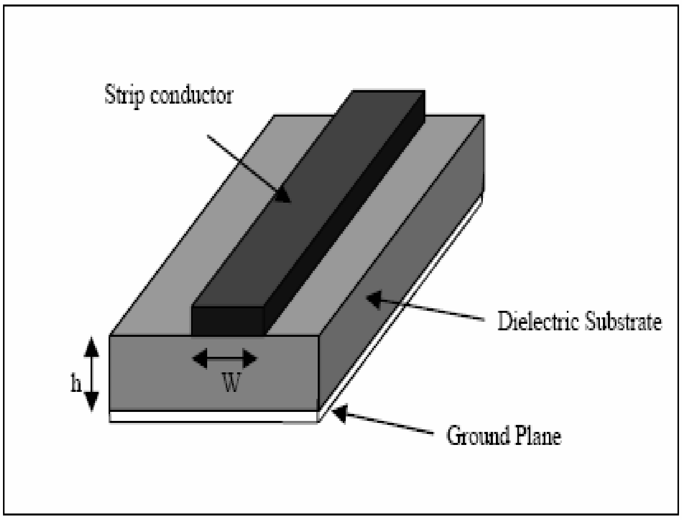


Figure 2.12 - Microstrip Line

As seen from Figure 2.13, most of the electric field lines reside in the substrate and parts of some lines in air. As a result, this transmission line cannot support pure transverse electric- magnetic (TEM) mode of transmission, since the phase velocities would be different in the air and the substrate. Instead, the dominant mode of propagation would be the quasi-TEM mode. Hence, an effective dielectric constant (ε_{reff}) must be obtained in order to account for the fringing and the wave propagation in the line.

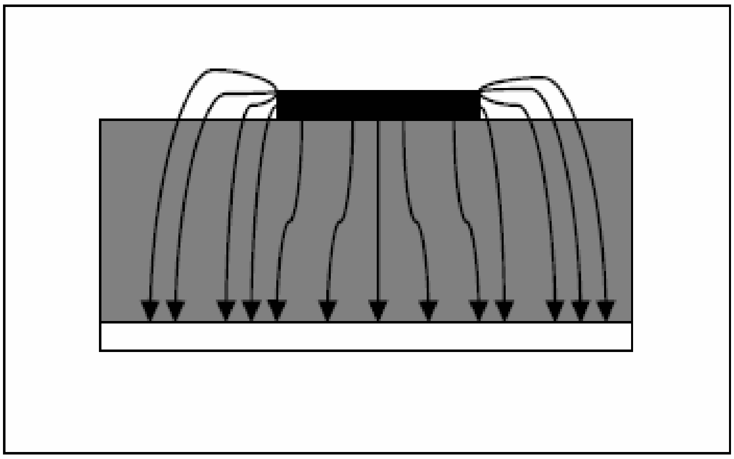


Figure 2.13 - Electric Field Lines

The value of εreff is slightly less then εr because the fringing fields around the periphery of the patch are not confined in the dielectric substrate but are also spread in the air as shown in Figure 2.11. The expression for εreff is given as:

εreff= (εreff + 1)/2 + (εreff - 1)/2[1+12h/W]-1/2

Where εreff = Effective dielectric constant

εr = Dielectric constant of substrate

h = Height of dielectric substrate

W = Width of the patch

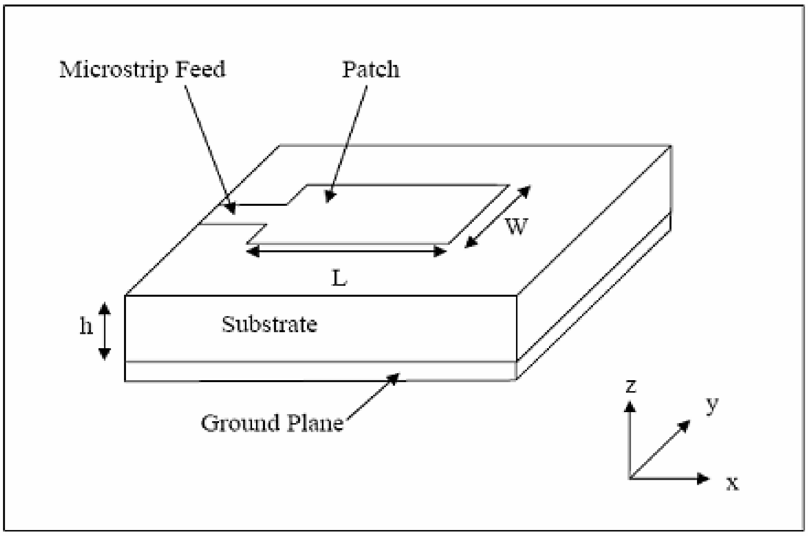


Figure 2.14 - Microstrip Patch Antenna

Figure 2.14 shows a rectangular microstrip patch antenna of length L, width W resting on a substrate of height h. The co-ordinate axis is selected such that the length is along the x direction, width is along the y direction and the height is along the z direction. In order to operate in the fundamental TM mode, the length of the patch must be slightly less than λ / 2 where λ is the wavelength in the dielectric medium and is equal to $\lambda o/\sqrt{(\varepsilon reff)}$ where λo is the free space wavelength. The TM mode implies that the field varies one λ / 2 cycle along the length, and there is no variation along the width of the patch. In figure 2.12, the microstrip patch antenna is represented by two slots, separated by a transmission line of length L and open circuited at both the ends. Along the width of the patch, the voltage is maximum and current is minimum due to the open ends. The fields at the edges can be resolved into normal and tangential components with respect to the ground plane[8].

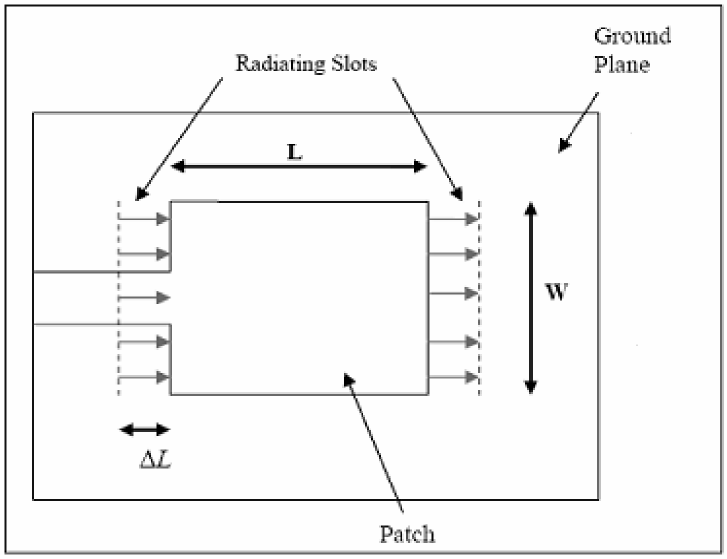


Figure 2.15 - Top View of Antenna

It is seen from figure 2.16 that the normal components of the electric field at the two edges along the width are in opposite directions and thus out of phase since the patch is $\lambda/2$ long and hence they cancel each other in the broadside direction. The tangential components (seen in figure 2.13), which are in phase, means that the resulting fields combine to give maximum radiated field normal to the surface of the structure. Hence the edges along the width can be represented as two radiating slots, which are λ / 2 apart and excited in phase and radiating in the half space above the ground plane.

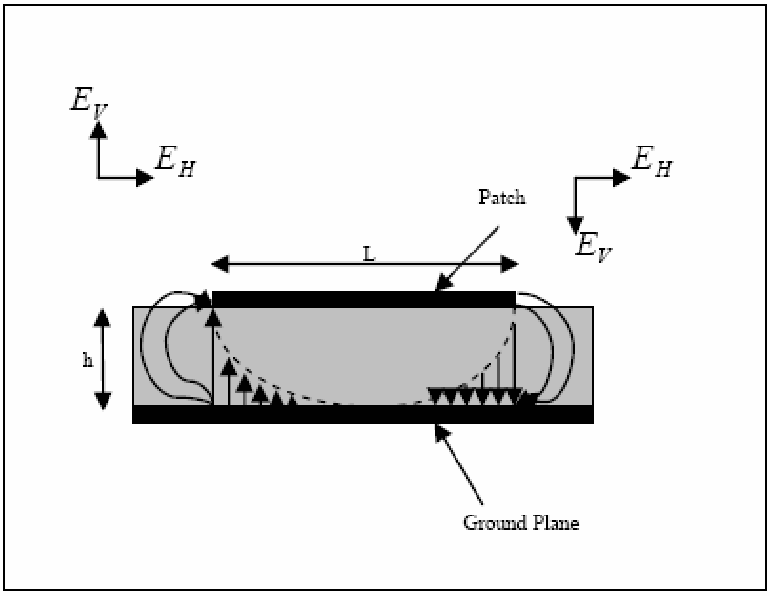


Figure 2.16 - Side View of Antenna

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 by as:

$$\Delta L=0.412h(\varepsilon reff+0.3)(W/h+0.264)/((\varepsilon reff-0.258)(W/h+0.8))$$

The effective length of the patch L_{eff} now becomes:

$$Leff=L+\Delta L$$

For a given resonance frequency f_o, the effective length is given by as:

$$Leff=c/(2fo\sqrt{}(\varepsilon reff)$$

For a rectangular Microstrip patch antenna, the resonance frequency for any TM mode is given as:

$$f_o = c/(2\sqrt{(\varepsilon_{reff})}[(m/L)^2+(n/W)^2]^{1/2}$$

Where m and n are modes along L and W respectively. For efficient radiation, the width W is given as:

$$W = c/(2f_o\sqrt{((\varepsilon_r+1)/2)})$$

2.5.2 Cavity Model

Although the transmission line model discussed in the previous section is easy to use, it has some inherent disadvantages. Specifically, it is useful for patches of rectangular design and it ignores field variations along the radiating edges. These disadvantages can be overcome by using the cavity model. In this model, the interior region of the dielectric substrate is modeled as a cavity bounded by electric walls on the top and bottom. The basis for this assumption is the following observations for thin substrates ($h \ll \lambda$).

- Since the substrate is thin, the fields in the interior region do not vary much in the *z* direction, i.e. normal to the patch.
- The electric field is *z* directed only, and the magnetic field has only the transverse components Hx and Hy in the region bounded by the patch metallization and the ground plane. This observation provides for the electric walls at the top and the bottom.

2.5.3 Full Wave Solutions-Method of Moments

One of the methods, that provide the full wave analysis for the microstrip patch antenna, is the Method of Moments. In this method, the surface currents are used to model the microstrip patch and the volume polarization currents are used to model the fields in the dielectric slab. It as been shown by Newman and Tulyathan how an integral equation is obtained for these unknown currents and using the Method of Moments, these electric field integral equations are converted into matrix equations which can then be solved by various techniques of algebra to provide the result. A brief overview of the method of moments is given below.

The basic form of the equation to be solved by the method of moments is:

$$F(g)=h$$

where F is a known linear operator, g is an unknown function, and h is the source or excitation function. The aim here is to find g, when F and h are known. The unknown function g can be expanded as a linear combination of N terms to give:

$$g = \sum_{n=1}^{N} a_n g_n = a_1 g_1 + a_2 g_2 + \ldots\ldots + a_N g_N$$

where an is an unknown constant and gn is a known function usually called a basis or expansion function. Substituting equation 2 in 1 and using the linearity property of the operator F, we can write:

$$\sum_{n=1}^{N} a_n F(g_n) = h$$

The basis functions gn must be selected in such a way, that each F(gn) in the above equation can be calculated. The unknown constants an cannot be determined directly because there are N unknowns, but only one equation. One method of finding these constants is the method of weighted residuals. In this method, a set of trial solutions is established with one or more variable parameters. The residuals are a measure of the difference between the trial solution and the true solution. The variable parameters are selected in a way which guarantees a best fit of the trial functions based on the minimization of the residuals. From the antenna theory point of view, we can write the Electric field integral equation as

$E = f_e(J)$

where E is the known incident electric field.

J is the unknown induced current.

f_e is the linear operator.

The first step in the moment method solution process would be to expand J as a finite sum of basis function given as:

$$J = \sum_{i=1}^{M} J_i b_i$$

where b_i is the ith basis function and J_i is an unknown coefficient. The second step involves the defining of a set of M linearly independent weighting functions, w_j. Taking the inner product on both sides and substituting equation 2.5 in equation 2.4 we get:

$$\langle w_j, E \rangle = \sum_{i=1}^{M} \langle w_j, f_e(J_i, b_i) \rangle$$

Where j=1,2….M

In matrix form we get [Zij][J]=[Ej]

Where Zij=<wjfe(bi)>

Ej=<wj,H>

J is the current vector containing the unknown quantities.

The vector E contains the known incident field quantities and the terms of the Z matrix are functions of geometry. The unknown coefficients of the induced current are the terms of the J vector. Using any of the algebraic schemes mentioned earlier, these equations can be solved to give the current and then the other parameters such as the scattered electric and magnetic fields can be calculated directly from the induced currents. HFSS is a powerful simulation software that uses the method of moments. It is an efficient field solver and this is why we used it for carrying out all our patch antenna simulations. The following section describes HFSS uses and merits.

CHAPTER 3

Software Aspects - Design and Simulation of Micrsostrip Patch Antennas

3.1 Simulation Software – HFSS

HFSS is a high-performance full-wave electromagnetic(EM) field simulator for arbitrary 3D volumetric passive device modeling that takes advantage of the familiar Microsoft Windows graphical user interface. It integrates simulation, visualization, solid modeling, and automation in an easy-to-learn environment where solutions to your 3D EM problems are quickly and accurately obtained. Ansoft HFSS employs the Finite Element Method(FEM), adaptive meshing, and brilliant graphics to give you unparalleled performance and insight to all of your 3D EM problems. Ansoft HFSS can be used to calculate parameters such as SParameters, Resonant Frequency, and Fields.

HFSS is an interactive simulation system whose basic mesh element is a tetrahedron. This allows you to solve any arbitrary 3D geometry, especially those with complex curves and shapes, in a fraction of the time it would take using other techniques.

The name HFSS stands for High Frequency Structure Simulator. Ansoft pioneered the use of the Finite Element Method(FEM) for EM simulation by developing/implementing technologies such as tangential vector finite elements, adaptive meshing, and Adaptive Lanczos-Pade Sweep(ALPS). Today, HFSS continues to lead the industry with innovations such as Modes-to-Nodes and FullWave Spice.

Ansoft HFSS has evolved over a period of years with input from many users and industries. In industry, Ansoft HFSS is the tool of choice for high-productivity research, development, and virtual prototyping.

Features of HFSS :

- Computes s-parameters and full-wave fields for arbitrarily-shaped 3D passive structures.
- Powerful drawing capabilities to simplify design entry.
- Field solving engine with accuracy-driven adaptive solutions.
- Powerful post-processor for unprecedented insight into electrical performance.
- Calculate far-field patterns.
- Wideband fast frequency sweep .
- Create parameterized cross section models- 2D models.

3.2 Simulation of 6.15 GHz Circular Patch Antenna

3.2.1 Introduction

The software part of our project revolved around determination of the radiation pattern, return loss curve (s11 vs frequency) and VSWR with and without slots of circular patch antenna.

One of the antennas that we simulated was the 6.15 GHz patch antenna. 6.15 GHz antenna is a commonly used frequency for satellite communications, fixed wireless links, defense, science, and the promising 5G applications. Our objective was to design a probe feed patch antenna that resonates at 6.15GHz and then vary the parameters of the antenna such that the working of the patch is optimized.

This design consists of a circular patch of radius 6.45mm. This circular patch is placed on a substrate named FR4_epoxy whose dielectric constant is 4.4. In this design there are no slots used on circular patch. It is preferred to design microstrip patch antenna because of its low dielectric constant.

Dielectric constant	4.4
Thickness of the substrate	1.6mm
Radius of the patch	6.45mm
Radius of the probe	1.59mm
Radius of the coaxial cable	0.47mm
Feeding location	(2.18mm,0mm)

Table 1.2 - Parameters of proposed single band design

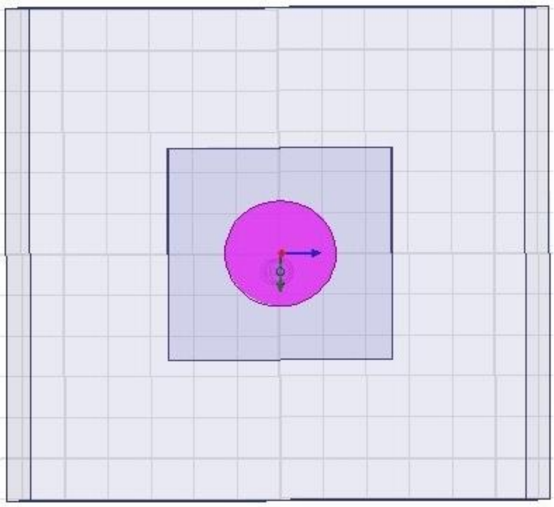


Figure 3.1-Top view of the circular patch of proposed design

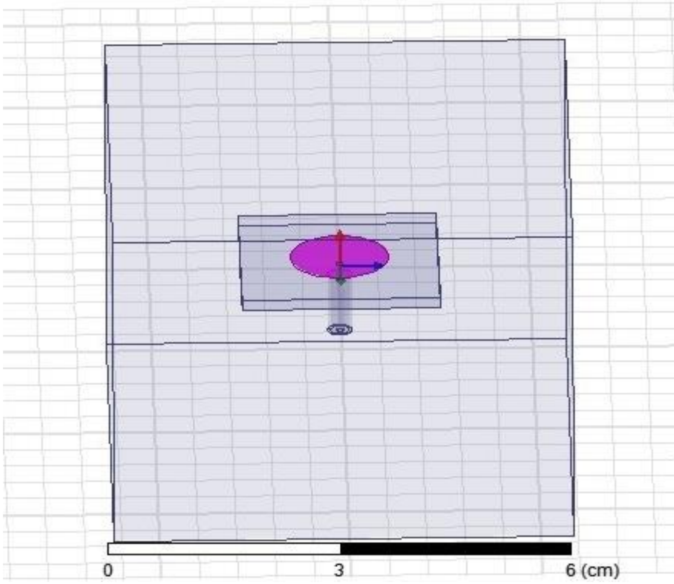


Figure 3.2 - Antenna structure of proposed design

3.2.2 Effect of variation of probe feed on the patch

A coaxial probe type feed is to be used in this design. As shown in Figure 3.1the center of the patch is taken as the origin and the feed point location is given by the co-ordinates (X_f ,Y_f) from the origin.The trial and error method is used to locate the feed point. For different locations of the feed point, the return loss (RL) is compared and that feed point is selected where the Return loss is most negative. There exists a point along the length of the patch where the Return loss is minimum. Hence in this design, Y_f was kept constant at zero and only X_f was be varied to locate the optimum feed point.

The Return Loss is measured from the frequency plot i.e it is a plot of frequency versus s11 parameter. The return loss of the proposed antenna design is shown in Figure 3.3.The Return Loss obtained at 6.15GHz is19.5dB.

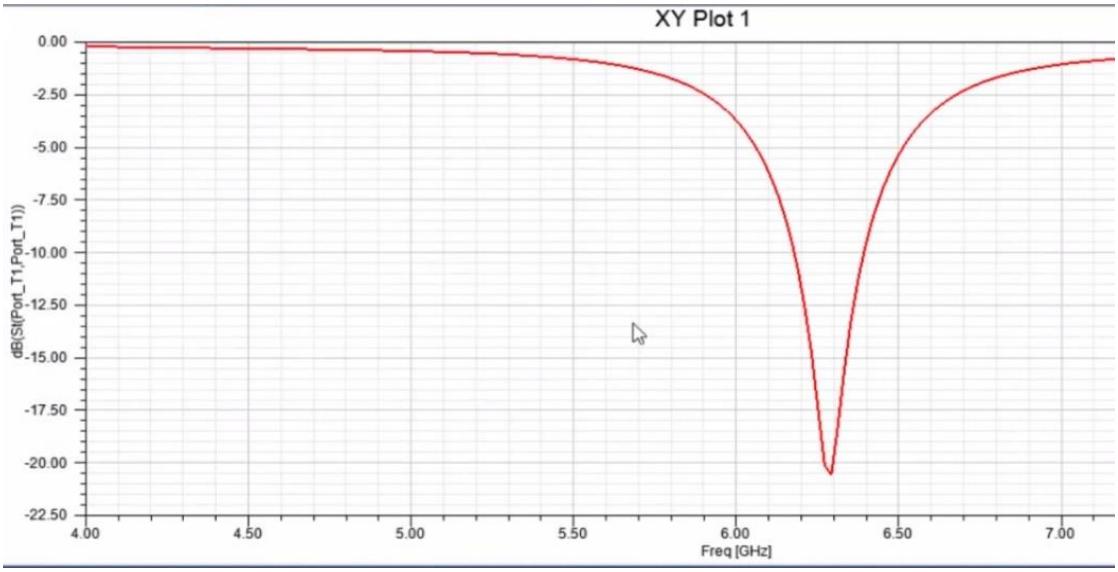


Figure 3.3 - Return Loss of proposed antenna

VSWR stands for Voltage Standing Wave Ratio. It is defined as ratio of maximum voltage to that of minimum voltage in antenna. First, the reflection coefficient ρ can be written as the absolute value of the magnitude of a voltage reflection coefficient at the input terminals of the antenna. It is obtained from frequency plot. It is a plot of frequency versus VSWR.

From the Figure 3.4, the VSWR obtained at 6.15GHz is 1.2,

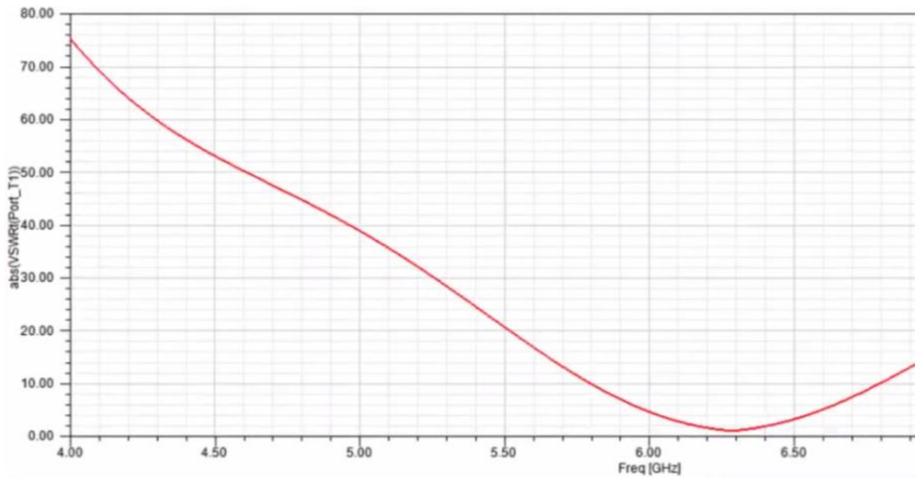


Figure 3.4-VSWR of the proposed antenna

Gain is one of the realized quantities in antenna theory. In general, gain is less than directivity. It introduces ohmic and other losses. It is defined as the ratio of the radiation intensity in a given direction from the antenna to the total input power accepted by the antenna divided by 4π. The gain of the antenna is calculated from radiation pattern i.e by obtaining radiation pattern for phi=0 deg and phi=90 deg for a particular frequency. As the proposed design is utilized for triple band application, the gain can be estimated by acquiring radiation pattern for each frequency band as demonstrated in fig.

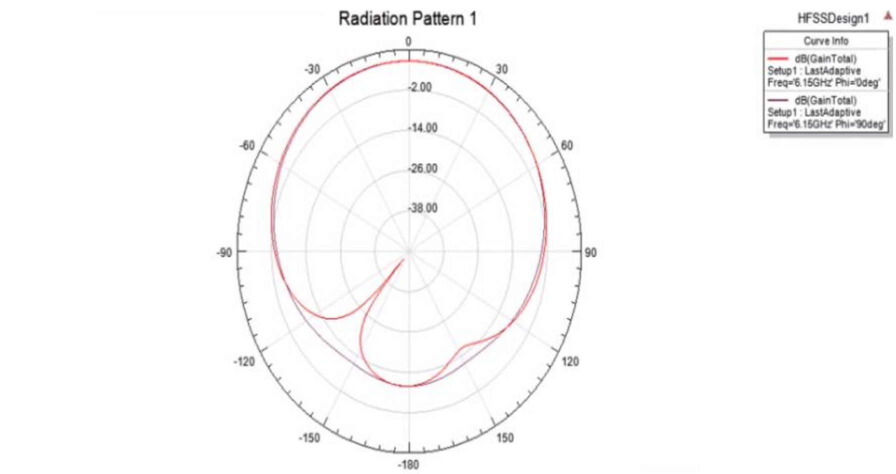


Figure 3.5 - Radiation pattern of proposed antenna at 6.15GHz

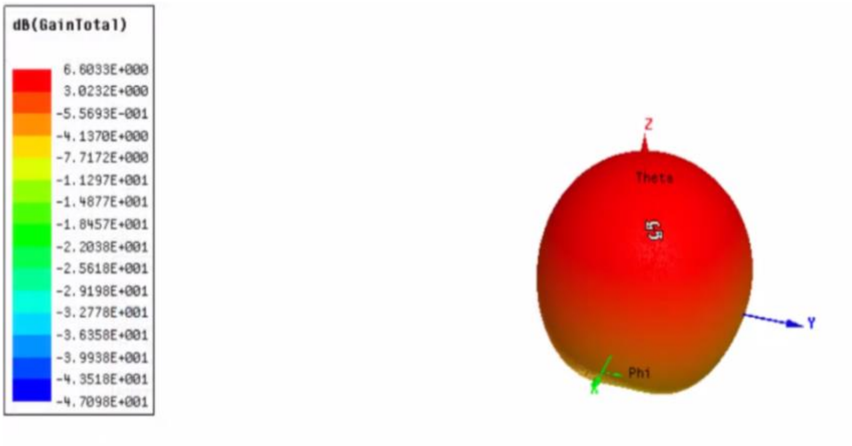


Figure 3.6 - Gain of proposed antenna at 6.15GHz

3.3 Simulation of Triple Band Circular Patch Antenna

3.3.1 Introduction

A microstrip patch antenna comprises of a patch on one side of a dielectric substrate and the other side is having a ground plane. Microstrip patch antennas are utilized in numerous applications like Radio frequency identification, wireless communications, Global positioning systems, Radar systems, Remote detecting and so on. Because of the unique and alluring properties of microstrip patch antenna, it will keep on discovering numerous applications later on. Furthermore, due to the increasing demand in wireless communication system, MSA have attracted much interest due to their properties like light weight, low profile, low cost, easy to fabricate and many more. However these MSA also have drawbacks like limited power handling capacity, low gain spurious feed radiation, narrow bandwidth[3].

The operation and performance of MSA is driven mainly by the geometry of the patch and material charactaristics of the substrate onto which the antenna is printed. Hence by making proper manipulations to the substrate, one can improve performance of microstrip antenna.

Several methods have been developed by the Researchers , in order to upgrade the bandwidth of the patch antenna. A large number of methods includes increasing substrate thickness and utilizing of low dielectric constant substrate. This increases efficiency and BW i.e efficiency as much as 90% and BW upto 35%[4].

While increasing the substrate thickness, antennas size also increases. So, simultaneously we should maintain the antennas size because it is also an important consideration in the design of patch antenna. These techniques used to upgrade the BW by expanding the size of the antenna . However in these techniques the surface waves must be included. From the radiation pattern, the surface waves extract power and results in increased antenna loss, side lobes, diminished efficiency. Consequently, as the substrate thickness increments, the probability of formation of surface wave also increments.

In order to give the input to the microstrip patch antenna, some feeding mechanisms are used. The well known feeding mechanisms are microstrip line, coaxial probe, proximity coupling and aperture coupling. In this design we are using a coaxial probe feeding technique. The benefit of using this scheme is that the feed can be placed at any ideal area inside the patch to coordinate with its input impedance i.e microstrip patch antenna is associated with the inner conductor of coaxial cable and external one is associated with the ground plane[5].

This feed technique is not difficult to manufacture, gives effective feeding and has low deceptive radiation. From the microstrip patch, most of the feed networks are confined, but in this technique it is not like that.

In this design a triple band H-shape slotted circular patch antenna is designed. This design consists of a circular patch of radius of 20.4mm. The circular patch is placed on a substrate named Roggers RT/Duroid 5880(tm), whose dielectric constant is 2.2. It is preferred to design a microstrip patch antenna because of its low dielectric constant[10].

Dielectric constant	2.2
Thickness of the substrate	4mm
Radius of the patch	20.4mm
Radius of the probe	0.6mm
Radius of the coaxial cable	1mm
Feeding location	(-11.5,-10)
Location of slot 1	(-6.44,-7)
Length and width of slot 1(L,W)	(26,2.5)
Location of slot 2	(-2,-4.5)
Length and width of slot 2(L,W)	(10.5,4.5)
Location of slot 3	(-18,6)
Length and width of slot 3(L,W)	(24,2.5)

Table 1.3 - Parameters of proposed Triple band design

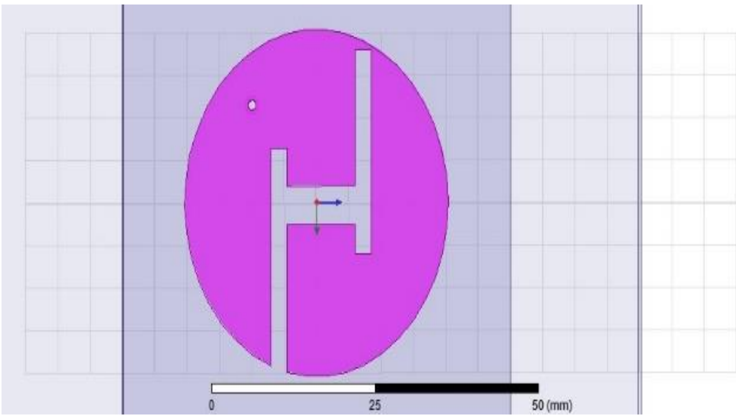


Figure3.7-: Proposed antenna structure

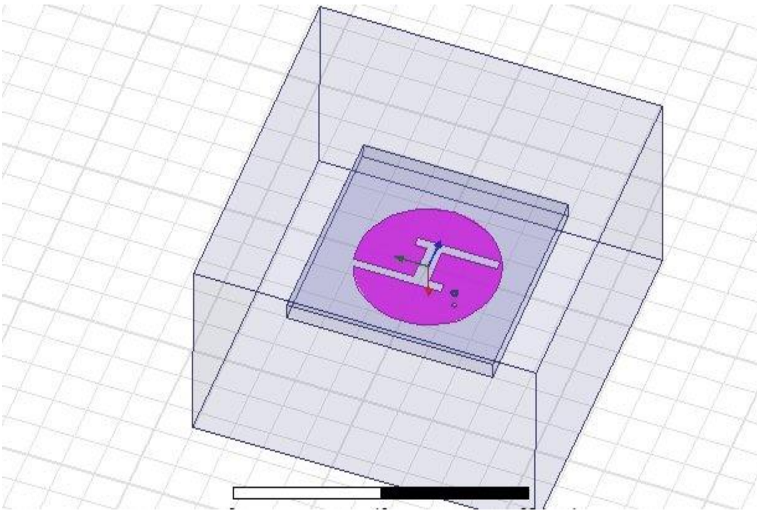


Figure 3.8 - Proposed antenna design using HFSS

3.3.2 Effect of variation of probe feed on the patch

A coaxial probe type feed is to be used in this design. As shown in Figure 3.7, the center of the patch is taken as the origin and the feed point location is given by the co-ordinates (Xf ,Yf) from the origin.The trial and error method is used to locate the feed point. For different locations of the feed point, the return loss (RL) is compared and that feed point is selected where the Return loss is most negative. There exists a point along the length of the patch where the Return loss is minimum. Hence in this design, Yf was kept constant at zero and only Xf was be varied to locate the optimum feed point.

Initially we have designed a microstrip patch antenna with circular patch by giving a coaxial probe feed. And then introduced a H-shaped slot onto the patch and by adjusting the dimensions of slot and position of feed line to patch. We got better results of Return Loss, Vswr, Gain.

The Return Loss is measured from the frequency plot i.e it is a plot of frequency versus s11 parameter. The return loss of the proposed antenna design is shown in figure 3.9.

From the fig. 3.9, the Return Loss obtained at 2.4GHz is -36.05dB, 4.5GHz is -19.43dB, and 6.5GHz is -42.58dB.

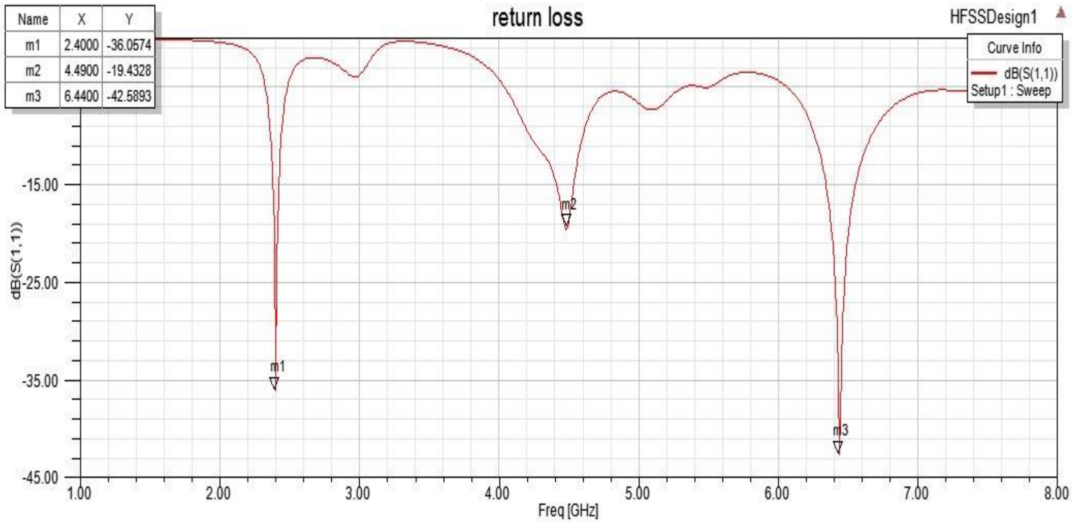


Figure 3.9 - Return Loss of proposed antenna

VSWR stands for Voltage Standing Wave Ratio. It is defined as ratio of maximum voltage to that of minimum voltage in antenna. It is obtained from frequency plot. It is a plot of frequency versus VSWR.

From the Figure 3.10, the VSWR obtained at 2.4GHz is 1.03, 4.5GHz is 1.23, 6.5GHz is 1.01.

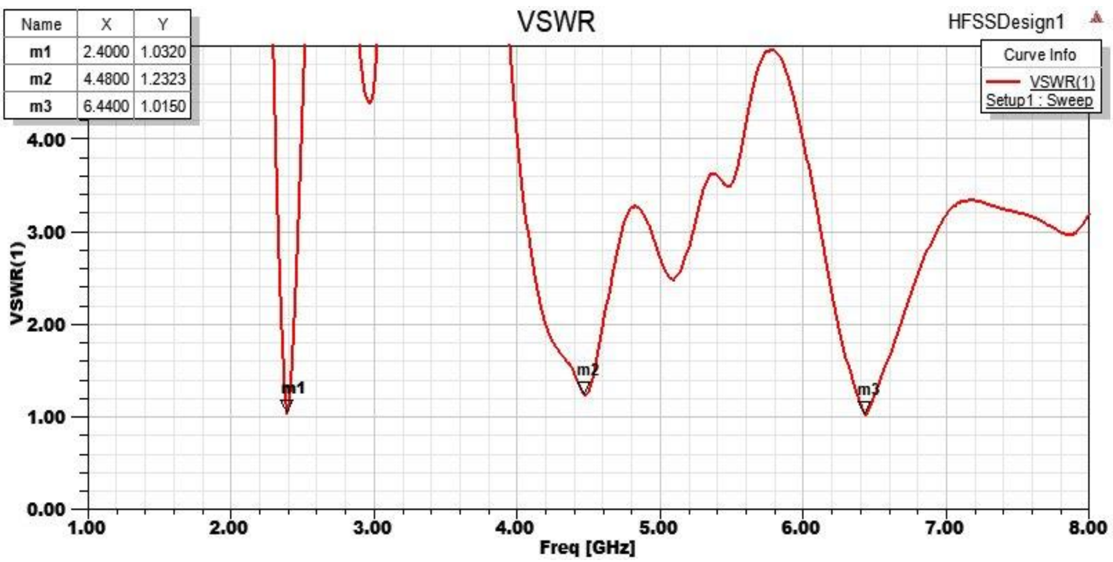


Figure 3.10 - VSWR of proposed antenna

The gain of the antenna is calculated from radiation pattern i.e by obtaining radiation pattern for phi=0 deg and phi=90 deg for a particular frequency. As the proposed design is used for triple band application, the gain can be measured by obtaining radiation pattern for each frequency band as shown in fig.

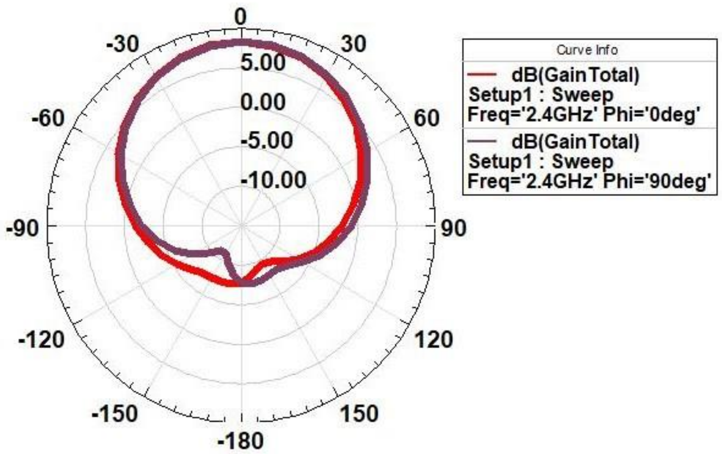


Figure 3.11 - Radiation pattern of proposed antenna at 2.4GHz

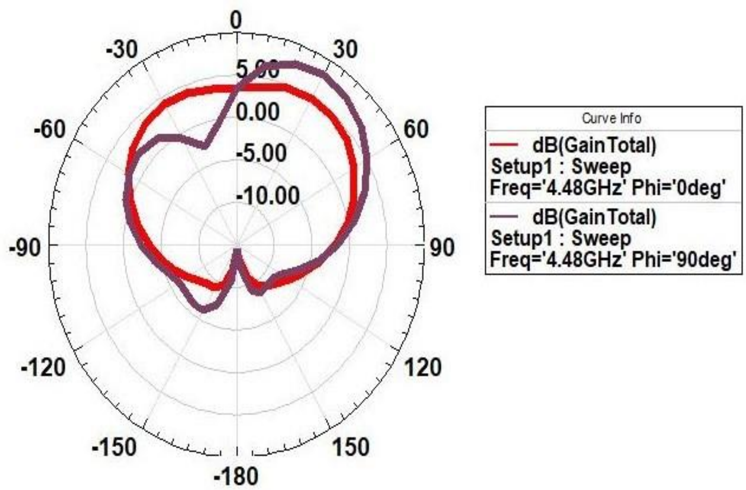


Figure 3.12: Radiation pattern of proposed antenna at 4.5GHz

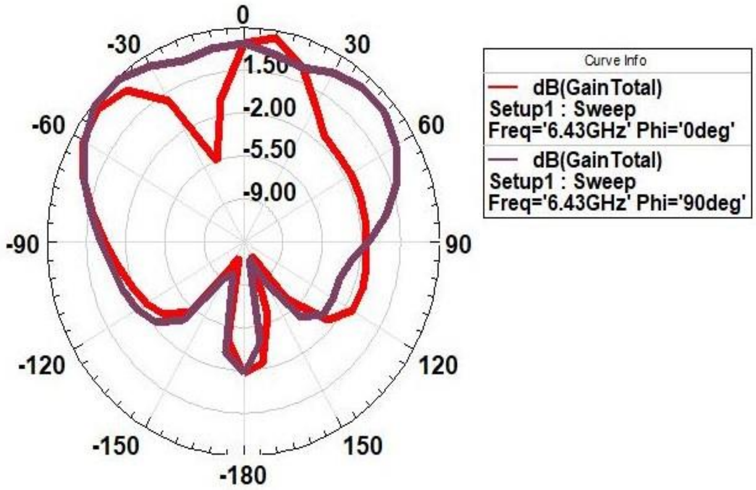


Figure 3.13- Radiation pattern of proposed antenna at 6.5GHz

From the Figures 3.15, 3.16, 3.17 - the gain obtained at 2.4GHz is 7.1dBi, 4.5GHz is 8.1dBi and 6.5GHz is 6.2dBi.

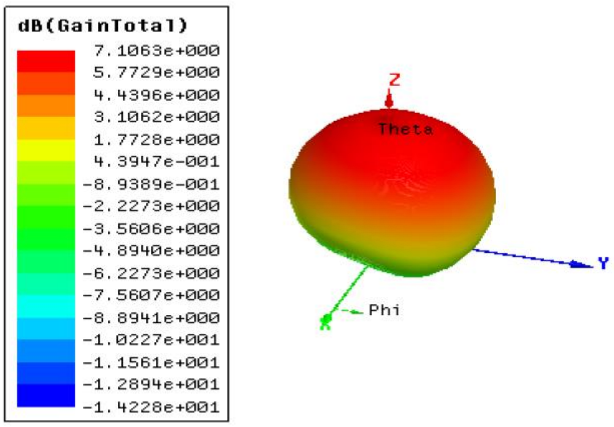


Figure 3.14 - Gain of proposed antenna at 2.4GHz

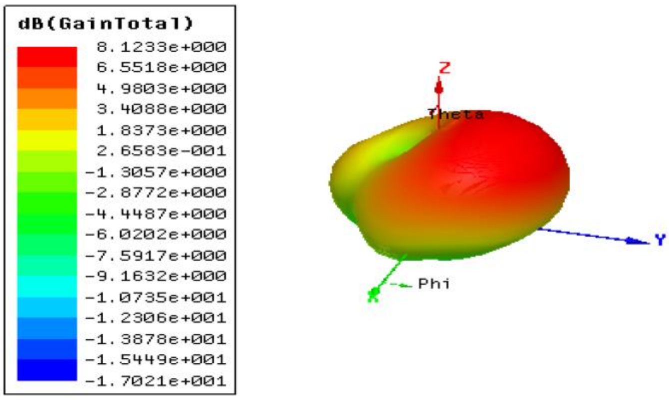


Figure 3.15 - Gain of proposed antenna at 4.5GHz

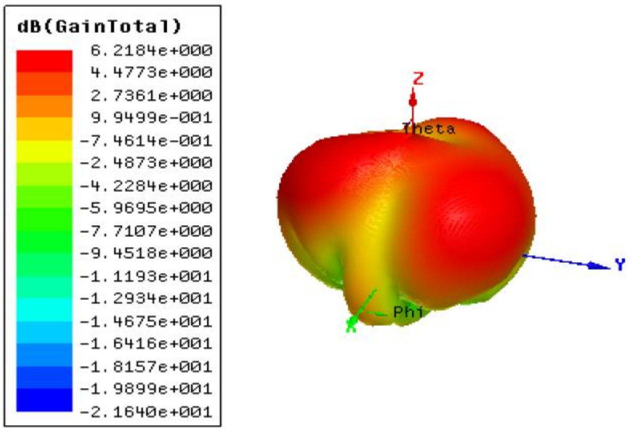


Figure 3.16 - Gain of proposed antenna at 6.5GHz

CHAPTER 4

Conclusions and Scope for Improvement

4.1 Conclusions

Upon the conclusion of our project we made the following assessment of our work: The overall working of antennas was understood. The major parameters such as Return Loss curves, Radiation Patterns, VSWR that affect design and applications were studied and their implications understood.

A triple band H-shape slotted circular patch antenna is designed and simulated using HFSS software. Thus, this design is resonated at 3 different frequencies - 2.4GHz, 4.5GHz, 6.5GHz. The Return Loss obtained at these frequencies are -36.05dB, -19.43dB, -42.58dB. The VSWR obtained at these frequencies are 1.03, 1.23, 1.01 and gain at these frequencies are 7.1dBi, 8.1dBi, 6.2dBi.

4.2 Scope for Improvement

There were some areas we felt we did not address. They were :

- Though we were able to simulate several patch antennas, we were unable to fabricate one and compare the practical and simulated results.
- A more complete study of different field solvers and simulators (such as Sonnet, AWR,etc) could not be made. We were only able to focus on HFSS.
- In the future, the multiple shape slots are combined together onto the patch and results were obtained and compared with this proposed design, in order to get better results.

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