DESIGN OF DUAL L-SLOT ASYMMETRIC I-SHAPED FREQUENCY RECONFIGURABLE ANTENNA

A Project report submitted in partial fulfillment of the requirements for

the award of the degree of

BACHELOR OF TECHNOLOGY

IN

ELECTRONICS AND COMMUNICATION ENGINEERING

Submitted by

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DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

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

(2021-2022)

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CERTIFICATE

This is to certify that the project report entitled " **DESIGN OF DUAL L-SLOT ASYMMETRIC I-SHAPED FREQUENCY RECONFIGURABLE ANTENNA"** submitted by partial fulfilment of the requirements for the award of the degree of **Bachelor of Engineering V.V.S.SAI KIRAN(318126512118), V.MADHURI(318126512113), B.TARUN(318126512066), V.YERNI KAMESWARI(318126512114)** in **Electronics and Communication Engineering** of Andhra University, Visakhapatnam is a record of bonafide work carried out under my guidance and supervision.

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ABSTRACT

Reconfigurable antennas are advantageous in terms of reduced size and complexity to achieve multiple resonant frequencies or multiple radiation patterns or multiple polarizations. A dual-band frequency reconfigurable antenna with PIN diode switching cases is discussed. The antenna is designed using substrate as FR4_epoxy material of dielectric constant εr=4.4 with size 25 x 15 x 1.6 mm3 . A dual L-slot I-shaped frequency reconfigurable antenna is proposed to switch at different frequency bands between 2 to 4 GHz (S-band) & 4 to 8 GHz (C-band) with the help of a two asymmetric L- slot structures on the I-shaped design. It is planned to achieve frequency reconfigurability using one RF PIN diode (SMP 1346-079LF) as per it's datasheet at appropriate location on the patch. The two operating modes of the PIN diode i.e., ON/OFF states would result different current distribution, causing antenna resonance at different frequencies. The designed antenna is suitable for wireless applications in C and S bands.

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Chapter-1

INTRODUCTION

In this chapter, antenna and it's types were discussed, also how antenna has it's radiation mechanism and different types of parameters that it constitutes. And then microstrip patch antenna and it's advantages were discussed. Different types of feeding methods such as microstrip line feed, coaxial feed, aperture coupled feed and proximity coupled feed were also discussed. And further how reconfigurability helps in achieving multiple frequency bands and different types of reconfigurable antennas were discussed.

1.1 HISTORY OF ANTENNAS

The first radio antennas were built by Heinrich Hertz, a professor at the Technical Institute in Karlsruhe, Germany. Heinrich Hertz‘s end-loaded half-wave dipole transmitting antenna and resonant half-wave receiving loop operating at λ = 8 m in 1886.
Hertz was the pioneer and father of radio, his invention remained a laboratory uriosity until 20-year-old Guglielmo Marconi of Bologna, Italy, went on to add tuning circuits, big antenna and ground systems for longer wavelengths, and was able to signal over large distances. In mid-December 1901 he startled the world by receiving signals at St. Johns, Newfoundland, from a transmitting station he had constructed at Poldhu in Cornwall, England.
Guglielmo Marconi‘s square conical antenna at Poldhu, England, in 1905 for sending transatlantic signals at wavelengths of 1000s of meters is shown in Figure.1.1 below. Rarely has an invention captured the public imagination as Marconi‘s wireless did at the beginning of the 20th century. With the advent of radar during World War II, centimeter wavelengths became popular and the entire radio spectrum opened up to wide usage.
Thousands of communication satellites bristling with antennas now circle the earth in low, medium, and geostationary orbits. The geostationary satellites form a ring around the earth similar to the rings around Saturn. Global Position Satellite (GPS) receiver gives latitude, longitude and elevation to centimeter accuracy anywhere on or above the earth day or night, cloudy or clear.

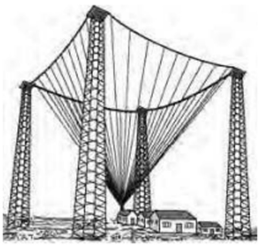


Figure.1.1 Square conical antenna

Very Large Array (VLA) of 27 steerable parabolic dish antennas each 25 m in diameter operating at centimeter wavelengths for observing radio sources at distances of billions of light-years. The array is located at the National Radio Astronomy Observatory near Socorro, New Mexico in 1980. Our probes with their arrays of antennas have visited the planets of the solar system and beyond, responding to our commands and sending back photographs. And our radio telescope antennas operating at millimeter to kilometer wavelengths receive signals from objects so distant that it has taken more than 10 billion years for the signals to arrive.

1.2 INTRODUCTION TO ANTENNAS

An antenna (or aerial) is a metallic device for radiating or receiving radio waves. It is usually used with a radio transmitter or radio receiver. In transmission, a radio transmitter supplies an oscillating radio frequency electric current to the antenna's terminals, and the antenna radiates the energy from the current as electromagnetic waves (radio waves).

In reception, an antenna intercepts some of the power of an electromagnetic wave in order to produce a tiny voltage at its terminals, that is applied to a receiver to be amplified. Antennas are essential components of all equipment that uses radio. They are used in systems such as radio broadcasting, broadcast television, two-way radio, communications receivers, radar, cell phones and satellite communications, as well as other devices such as garage door openers, wireless microphones. Very Large Array (VLA) of 27 steerable parabolic dish antennas each 25 m in diameter operating at centimeter wavelengths for observing radio sources at distances of billions of light-years. The array is located at the National Radio Astronomy Observatory near Socorro, New Mexico in 1980 is shown in Figure.1.2 below. Antennas act as transformers between conducted waves and electromagnetic waves propagating freely in space. Their name is borrowed from zoology, in which the Latin word antennae is used to describe the long, thin feelers possessed by many insects.

In wireless communication systems, signals are radiated in space as an electromagnetic wave by using a receiving, transmitting antenna and a fraction of this radiated power is intercepted by using a receiving antenna. An antenna is a device used for radiating or receiving radio waves. An antenna can also be thought of as a transitional structure between free space and a guiding device (such as transmission line or waveguide).

Figure.1.2 Steerable parabolic dish antennas

1.3 TYPES OF ANTENNAS

1.3.1 WIRE ANTENNAS:

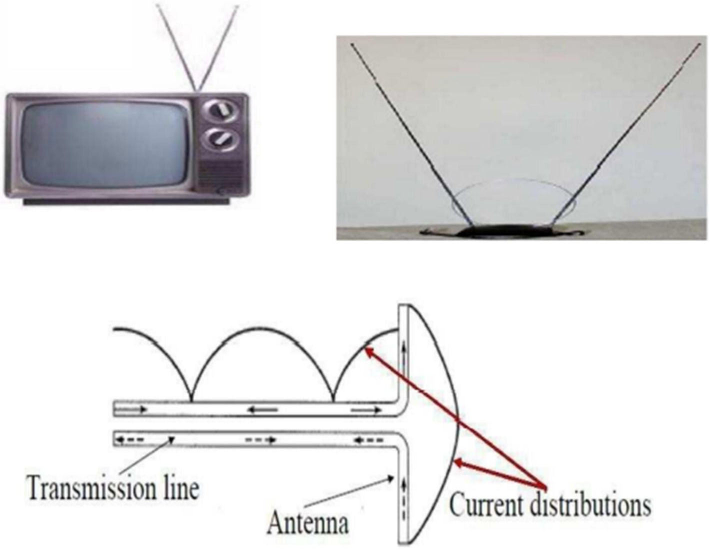


Figure.1.3 Wire antennas

Dipole, monopole, loop antenna, helix antennas:- These were shown in Figure.1.3 and are usually used in personal applications, automobiles, buildings, ships, aircrafts and spacecrafts.

1.3.2 APERTURE ANTENNAS:

Horn antennas, waveguide opening :- Usually aperture antennas are used in aircrafts and space crafts, because these antennas can be flush.. These are shown in Figure.1.4

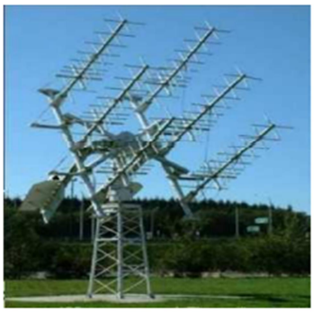


Figure.1.4 Aperture antennas

1.3.3 REFLECTOR ANTENNAS:

Parabolic reflectors, corner reflectors :- These are high gain antennas usually used in radio astronomy, microwave communication and satellite tracking. The reflector antennas are shown in Figure.1.5

Figure.1.5 Reflector antennas

1.3.4 LENS ANTENNAS:

Convex-plane, convex-convex , convex-concave and concave-plane lenses o These antennas are usually used for very high frequency applications.

1.3.5 MICROSTRIP ANTENNAS:

Rectangular, circular etc. shaped metallic patch above a ground plane :- Micro strip antennas are low-profile antennas. A metal patch mounted at a ground level with a di-electric material in-between constitutes a **Micro strip** or **Patch Antenna**. These are very low size antennas having low radiation. Used in aircraft, spacecraft, satellites, missiles, cars, mobile phones etc and are shown in Figure.1.6.

Figure.1.6 Microstrip antennas

1.3.6 ARRAY ANTENNAS:

Yagi-Uda antenna, microstrip patch array, aperture array, slotted waveguide array :- Used for very high gain applications with added advantage, such as controllable radiation pattern.

1.4 RADIATION MECHANISM:

When electric charges undergo acceleration or deceleration, electromagnetic radiation will be produced. Hence it is the motion of charges, that is current is the source of radiation. Here it may be highlighted that, not all current distributions will produce a strong enough radiation for communication.

Antennas radiate or couples or concentrates or directs electromagnetic energy in the desired or assigned direction. An antenna may be isotropic or non directional (omni-directional) and un isotropic or directional.

There accepts include radiation pattern, gain, efficiency, impedance, frequency characteristics, shape size, weight and look at antenna and above all these makes their economic viability. The cost, size and shape makes the main difference on usage of different frequencies.

High gain and Directivity are the basic requirements for the transmitting antennas. Where as low side lobes and large signal to noise ratio are key selection criteria for receiving antennas. Antenna may vary in size from the order of few millimetres(strip antenna) to thousands of feet (dish antennas for astronomical observations) To give a mathematical flavour to it, as we know

$$A = \frac{\mu I dl}{4\pi r}$$

$$dl\,\frac{dI}{dt} = dlq\frac{dv}{dt} = dlqa$$

$$\boxed{E = -\nabla V - \frac{\partial A}{\partial t} = -\nabla V - \frac{\mu dl}{4\pi r}\frac{\partial I}{\partial t} = -\nabla V - \frac{\mu dl}{4\pi r}qa}$$

As shown in these equations, to create radiation (electric field), there must be a time-varying current dI/dt or an acceleration (or deceleration) a of a charge q. If a charge is moving with an uniform velocity, there is no radiation if the wire is straight, and infinite in extent there is radiation if the wire is curved, bent, discontinuous, terminated. So, it is the current distribution on the antennas that produce the radiation. Usually these current distributions are excited by transmission lines and waveguides as shown in the Figure.1.7.

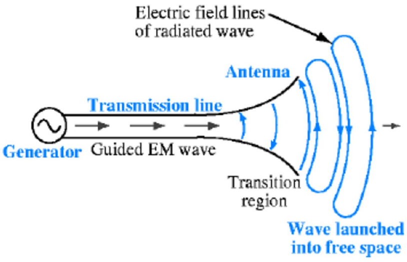


Figure.1.7 Antenna radiation mechanism

1.5 ANTENNA PARAMETERS

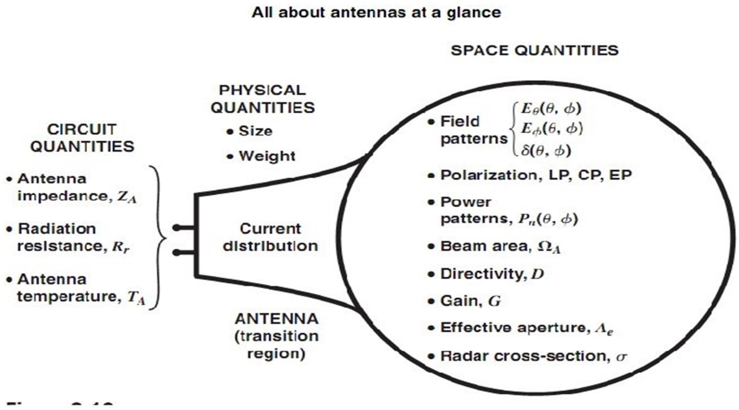


Figure.1.8 Schematic diagram of basic parameters

1) At a given moment, the generator's right side is positive and its left side is negative. A law of physics states that like charges repel each other. Consequently, electrons will flow away from the negative terminal as far as possible while the positive terminal will attract electrons. The distribution curve shows that most current flows in the center and none flows at the ends. The current distribution over the antenna is always the same, regardless of how much or how little current is flowing. However, current at any given point on the antenna will vary directly with the amount of voltage that the generator develops.

2) One-quarter cycle after the electrons begin to flow, the generator develops it; minimum voltage and the current decreases to zero. Although no current is flowing, a minimum number of electrons are at the left end of the line and a minimum number are at the right end. The charge distribution along the wire varies as the voltage of the generator varies.

1.5.1 Gain:

Gain is a parameter that measures the directionality of a given antenna. An antenna with low gain, emits radiation about same power in all directions, whereas a high gain antenna preferentially radiates in particular directions. Specially the gain, directive gain or power gain of an antenna is defined as the ratio of intensity of the signal radiated by the 11 P antenna in a given direction at an arbitrary distance divided by the intensity radiated at the same distance by a hypothetical isotropic lossless antenna. Since the radiation intensity from a lossless isotropic antenna equals the power into the antenna divided by a solid angle of 4π Steradians, The gain formula is defined by equation 1.1.

$$Gain = \frac{4\pi\, radiation\ intensity}{total\ input(transmitted)power} \quad \text{…………(1.1)}$$

Although the gain of an antenna is directly related to its directivity, antenna gain is a measure that considers the efficiency of the antenna as well as its directional capabilities.

1.5.2 Directivity

The directivity of the antenna has been defined as “the radiation intensity in a given direction from the antenna divided by the radiation intensity averaged over all directions”. The average radiation intensity is equal to the total power radiated by the antenna divided by 4π. In other words, the directivity of a non isotropic source is equal to the ratio of its radiation intensity in given direction, over that an isotropic source. The directivity formula is defined by equation 1.2.

$$D = \frac{4\pi U}{P_{rad}} \quad \text{…………(1.2)}$$

1.5.3 Return Loss(S11)

The Return Loss (RL) is a parameter that indicates the amount of power that is lost to the load and does not return as a reflection. Waves are reflected leading to the formation of standing waves, when the transmitter and antenna impedance do not match. Hence the RL is a parameter to indicate how well the matching between the transmitter and antenna has taken place. The RL is given by equation 1.3.

$$S11(dB) = 10log_{10}\frac{Pi}{P_r} \qquad \text{…………(1.3)}$$

1.5.4 Polarization

Antenna polarization is an important consideration when selecting and installing antenna. Because radiation property of an antenna depends on the antenna polarization and if polarization is not synchronized between transmitting and receiving antenna even resonant frequency are perfectly matched still the signals will not be received by receiving antenna. The electric field or “E” plane determines the polarization or orientation of the wave. An antenna is vertically linear polarized when its electric field is perpendicular to the Earth’s surface. Horizontally linear polarized antenna, have their electric field parallel to the Earth’s surface. In a circularly polarized antenna, the plane of polarization rotates in a corkscrew pattern making one complete revolution during each wavelength. A circularly polarized wave radiates energy in the horizontal, vertical plane as well as in every plane in between. If the rotation is clockwise looking into the direction of propagation, the sense is called right-hand-circular (RHC) polarization. If the rotation is counter clockwise, the sense is called left-hand-circular (LHC) polarization. Polarization is an important design consideration. The polarization of each antenna in a system should be properly aligned. Maximum signal strength between stations occurs when both stations are using identical polarization.

1.5.5 Voltage Standing Wave Ratio(VSWR)

As electromagnetic waves travel through the different parts of the antenna system, from the source to the feed line to the antenna and finally to free space, they may encounter differences in impedance at each interface. Depending on the impedance match, some fraction of the wave’s energy will reflect back to the source, forming a standing wave pattern in the feed line. The ratio of the maximum power to the minimum power in the wave can be measured and it is called the voltage standing wave ratio (VSWR). A VSWR of 1:1 is ideal. A VSWR of 1.5:1 is considered to be marginally acceptable in low power applications. Minimizing impedance differences at each interface will reduce the VSWR value and maximize power transfer through each part of the system. The VSWR can be defined as shown in equation 1.4.

$$VSWR = \frac{Vmax}{Vmin} = \frac{1+|\Gamma|}{1-|\Gamma|} \qquad \text{…………(1.4)}$$

1.5.6 Bandwidth

The bandwidth is the antenna operating frequency band within which the antenna performs as desired. The bandwidth of a broadband antenna can be defined as the ratio of the higher to lower frequencies of acceptable operation. In other words, the frequency over which the antenna will perform satisfactorily i.e. it's one or more characteristics have acceptable values between the bandwidth limits. The absolute bandwidth (ABW) is defined as the difference of the two edges and the fractional bandwidth (FBW) is designated as the percentage of the frequency difference over the centre frequency, given as shown in equation 1.5.

$$\text{ABW} = f_L - f_H \qquad \text{…………(1.5)}$$
$$\text{FBW} = 2\frac{f_H - f_L}{f_H + f_L}$$

1.5.7 Radiation Pattern

The radiation pattern of an antenna is defined as "a mathematical function or a graphical representation of the radiation properties of the antenna as a function of space coordinates. In most cases, the radiation pattern is determined in the far field region and is represented as a function of the directional coordinates. Radiation properties include power flux density, radiation intensity, field strength, directivity, phase or polarization." Various parts of a radiation pattern are referred to as lobes. Lobes are sub classified into major lobe, minor lobe, side lobe and back lobe. A major lobe (also called main beam) is defined as "the radiation lobe containing the direction of maximum radiation." A minor lobe is any lobe except a major lobe. A side lobe is "a radiation lobe in any direction other than the intended lobe." (Usually a side lobe is adjacent to the main lobe and occupiesthe hemispherein the direction of the main beam.) 14 A back lobe is "a radiation lobe whose axis makes an angle of approximately 180° with respect to the beam of an antenna. The radiation pattern in 3D plane is shown in the Figure.1.9

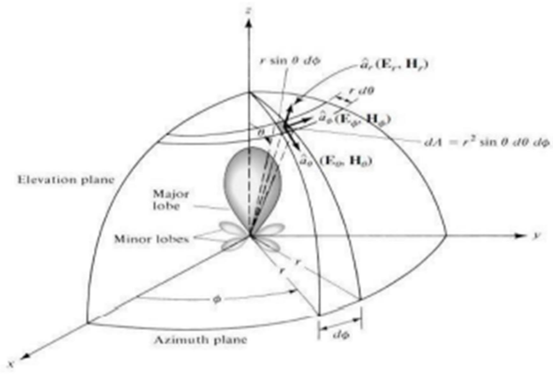


Figure.1.9 Radiation pattern in 3D plane of an antenna

Chapter-2

Microstrip Patch Antenna

In this chapter, an introduction of Microstrip Patch Antenna is followed by its advantages and disadvantages and also feeding techniques were discussed. Finally, Microstrip Patch Antenna analysis theory is discussed. Working mechanism is also discussed.

2.1 Introduction

A Microstrip patch antenna consists of a radiating patch on one side of a dielectric 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 feed lines are usually photo etched on the dielectric substrate.

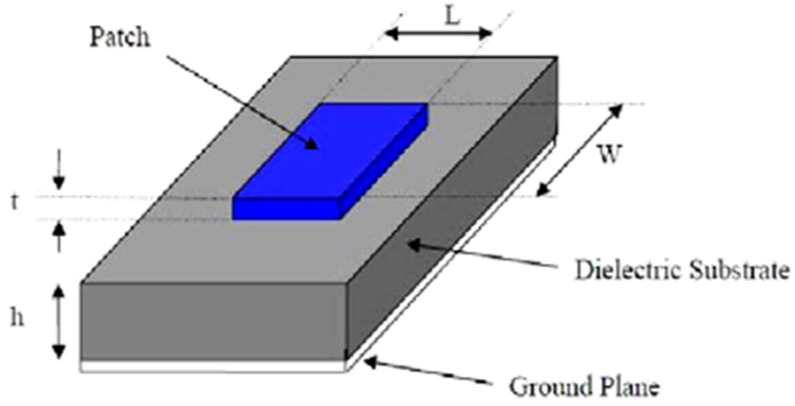


Figure 2.1 Structure of a Microstrip Patch Antenna

In order to simplify analysis or performance prediction, the patch is generally square, rectangular, dipole, circular, triangular, elliptical, disc sector, circular ring, ring sector are shown in Figure 2.2.

For rectangular patch, the length L of the patch is generally $0.3333\lambda_o < L < 0.5\lambda_o$ where λ_o is free space wavelength. The patch is very thin such that $t << \lambda_o$ where t is the thickness of the patch. The height h of the dielectric substrate is generally $0.003\lambda_o < h < 0.05\lambda_o$. The dielectric constant of the substrate(ε_r) is in the range $2.2 < \varepsilon_r < 12$.

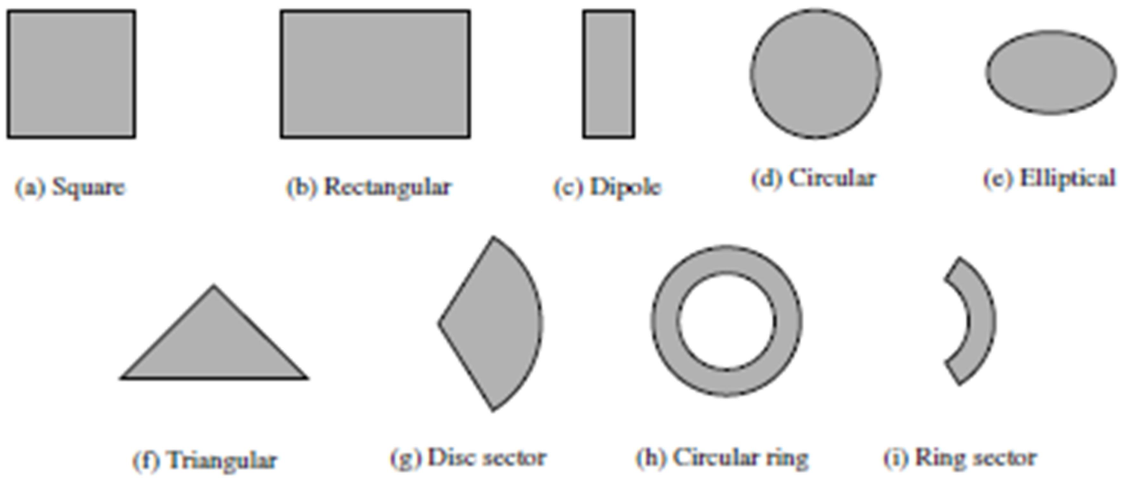


Figure 2.2 Common shapes of microstrip patch antenna

Microstrip patch antenna radiate because of fringing fields between patch edge and the ground plane. For good antenna performance, a thick dielectric substrate having a low dielectric constant is required since this provides better efficiency, larger bandwidth and better radiation. However such configuration leads to a larger antenna size. In order to compact Microstrip Patch Antenna, higher dielectric constants must be used which are less efficient and result in narrower bandwidth.

2.2 FR4 Substrate

"FR" stands for flame/fire retardant. FR-4 is a designation assigned to glass-reinforced epoxy laminate sheets, tubes, rods and printed circuit boards. It is a composite material composed of fibre glass clot an epoxy resin binder that is flame resistant. FR-4 glass epoxy is famous and flexible high-pressure thermoset plastic laminate material with high strength to weight ratios.

If the material has to be flame or fire retardant, there are certain requirements to be fulfilled for the material to be certified as FR. When an equipment using FR4 grade PCB and if there is some kind of overvoltage or short circuit in the equipment, then the PCB made of organic material can catch fire but it should have the ability to retard the fire by itself; that means, it should have a self-extinguishing property.

The FR4 substrate is manufactured by compressing an epoxy resin at high pressure and a glass fibre mat is embedded within the structure. The glass fibre gives strength to the substrate and increases the dielectric constant of the composite material. The weave is generally more densely packed in one direction and so material is anisotropic with small variation in dielectric constant in different planes. At microwave frequencies, the bulk dielectric constant value is similar to value at 1MHz, decreasing slightly at frequencies above GHz.

FR4 epoxy glass substrates are the material of choice for most PCB applications. The material is of low cost and has excellent mechanical properties, making it ideal for a wide range of electronic equipments. As more and more microwave systems are developed for consumer market, there is a considerable interest in minimizing the cost of these systems.

Commercial substrate materials are promptly available for the use at RF and microwave frequencies for the design of microstrip and printed antennas. The substrate can be preferred based on the desired material characteristics for optimal performance over the specific frequency range. Dielectric constant, thickness and loss tangent are the commonly used parameters. Normally the dielectric constant ranges from 2.2 to 12 for the operations at frequencies ranging from 1 100 GHz.

The microstrip patch antenna design depends upon substrate thickness. The thick substrates with low dielectric constants are required one to obtan the larger bandwidth and higher efficiency due to loosely bound fringing fields. While thin substrates with large dielectric constants reduce overall size of antenna, due to high loss tangents thin substrates are less efficient that results with narrow bandwidth. Therefore substrate plays an important role while designing an antenna.

2.3 FR4 Advantages and Disadvantages

Microstrip patch antenna are increasing in popularity for use in wireless applications due to their low profile structure. They are compatible for embedded antennas in wireless devices such as cellular phones, 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. Some of their principal advantages are given below:

2.3.1 Advantages

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

2.3.2 Disadvantages

- Narrow bandwidth
- Low efficiency
- Low Gain
- Extraneous radiation from feeds and junctions
- Poor and fire radiator except tapered slot antennas

- Low power handling capacity
- Surface wave excitation

Microstrip patch antennas have a high antenna quality factor(Q). Q represents 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 thickness increases , an increasing fraction of the total power delivered by source goes into a surface wave.

2.4 Feeding Techniques

Microstrip patch antenna can be fed by variety of methods. These methods can be classified into 2 types-contacting and non-contacting. In contacting method, the RF power is fed directly to the radiating patch using a connecting element such as microstrip line. In non-contacting method, electromagnetic field coupling is done to transfer power between microstrip line and radiating patch. The four most feeding techniques used are microstrip line, coaxial probe (both are contacting methods), aperture coupling and proximity coupling(both are non-contacting methods) .

2.4.1 Microstrip line feed

In this type of feeding technique, the conducting strip is directly connected to the edge of the microstrip patch as shown in Figure 2.3. The conducting strip is smaller in width as compared to patch and this kind of feed arrangement has advantage that the feed can be etched on same substrate to provide planar structure.

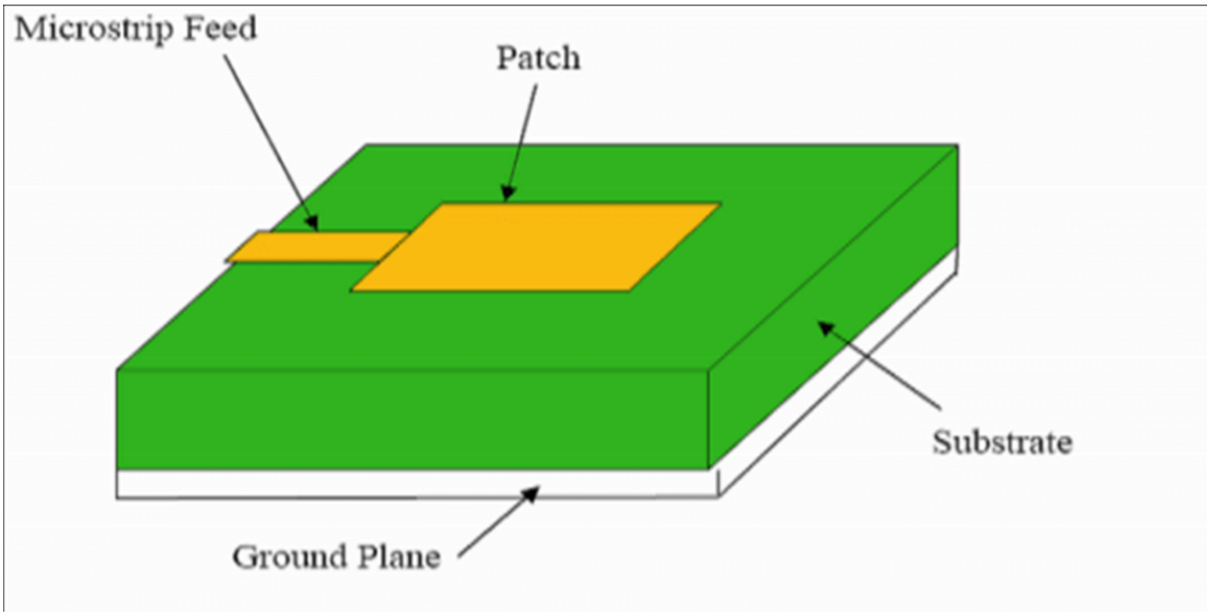


Figure 2.3 Microstrip Line Feed

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 case of fabrication and simplicity in modelling 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 2.4, 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.

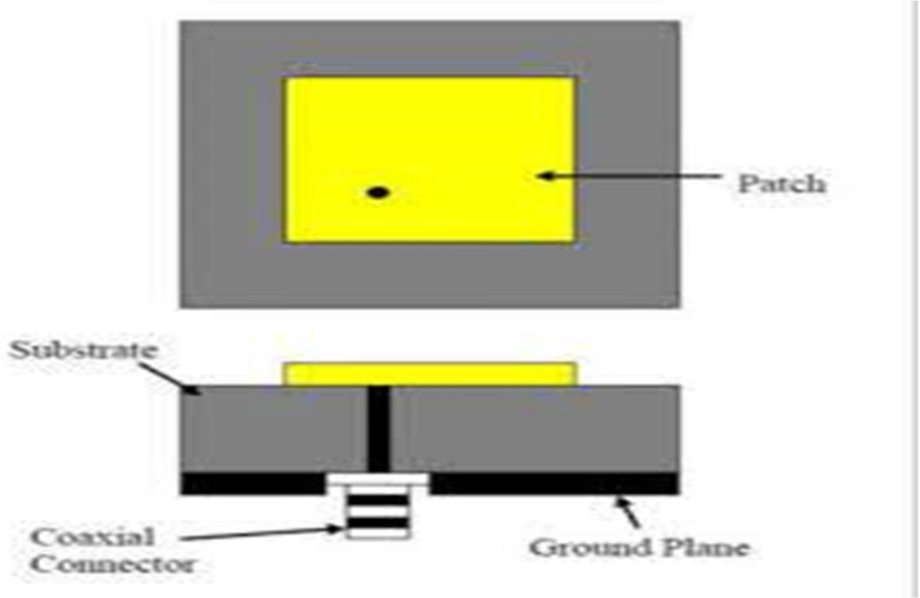


Figure 2.4 Probe Feed rectangular Microstrip Patch Antenna

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 . 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 which have been discussed below, solve these problems.

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 2.5. Coupling between the patch and the feed line is made through a slot or an aperture in the ground plane.

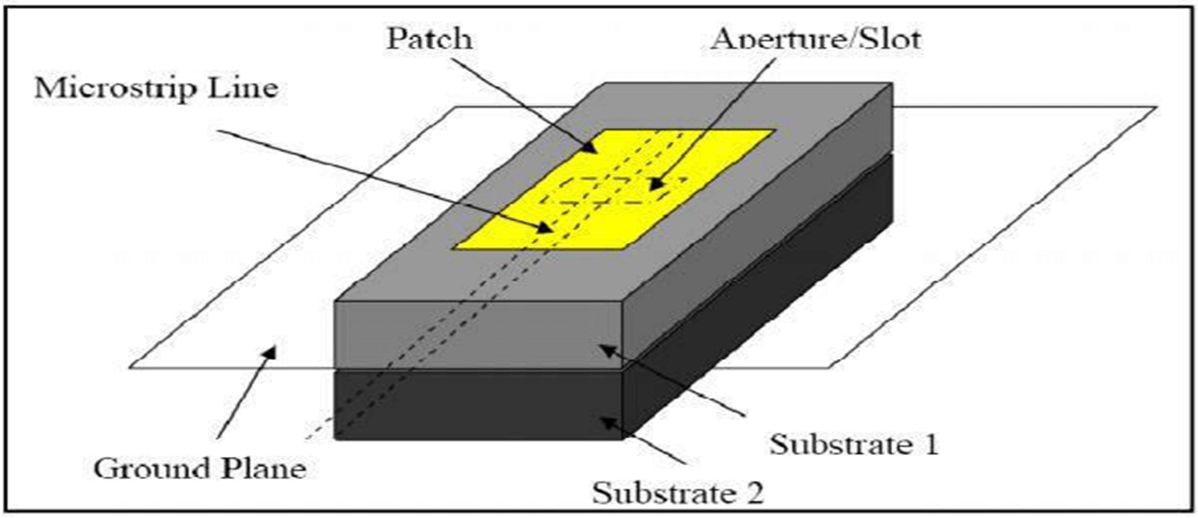


Figure 2.5 Aperture Coupled Feed

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.

2.4.4 Proximity Coupled Feed

This type of feed technique is also called as the electromagnetic coupling scheme. As shown in Figure 2.6, two dielectric substrates are used such that the feed line is between the two substrates and the radiating patch is on top of the upper substrate. 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.

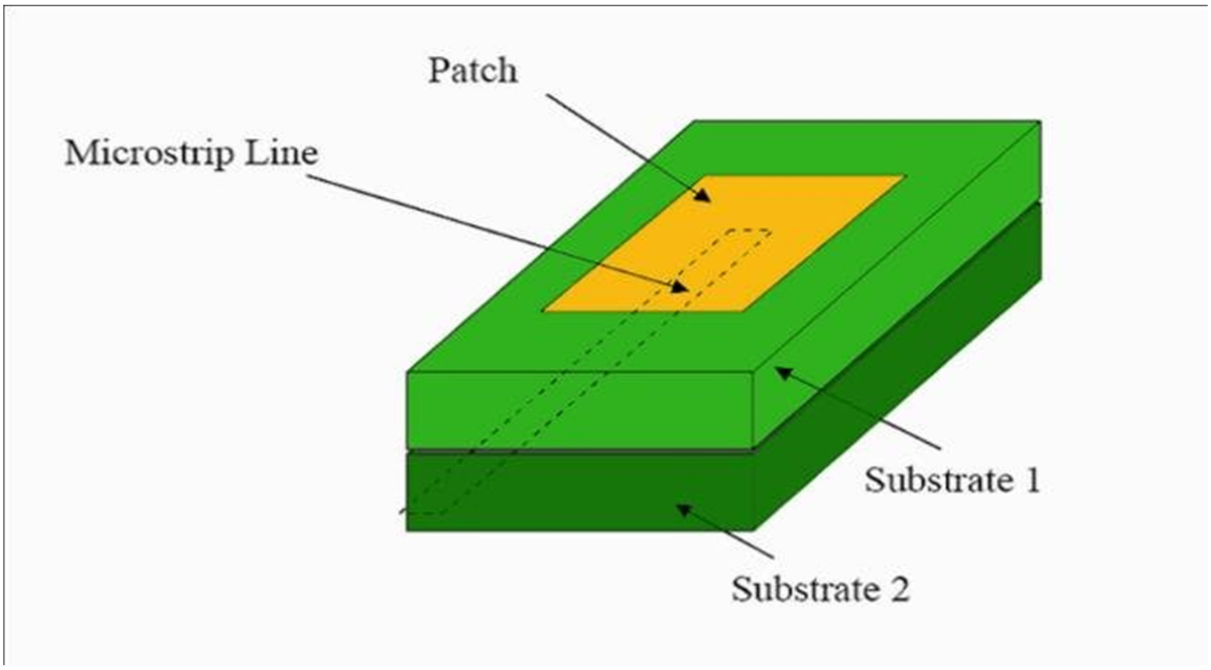


Figure 2.6 Proximity Coupled Feed

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. Table 2.1 below summarizes the characteristics of the different feed techniques.

Table 2.1 Comparing 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%

2.4.5 Methods of Analysis

There are many methods of analysis for microstrip antennas. The most popular models are the transmission model and cavity model and full wave (which include primarily integrations/methods). The transmission line model is the easiest of all, it gives good physical insight, but is less accurate and it is more difficult to model coupling. Compared to transmission line model, the cavity model is more accurate at the same time more complex. However it gives also physical insight and is rather difficult to model coupling, although it has been used successfully. In general, when applied properly, the full wave models are accurate, very versatile and can treat single elements, finite and infinite arrays, stacked elements, arbitrary shaped elements, and coupling. However they are the most complex models and usually give less physical insight. In this section we will cover the transmission-line model only.

2.4.5.1 Rectangular Patch Antenna

The rectangular microstrip patch is by far the most widely used configuration. It is very easy to analyze using both the transmission-line and cavity models, which are most accurate for thin substrates. We begin with the transmission-line model because it is easier to illustrate.

2.4.5.1.1 Transmission Line Model

The transmission line model treated rectangular microstrip as a part of transmission line As the rectangular microstrip antenna consists two radiating slots, transmission line modeller presents each radiating slots by an equivalent admittance which are separated by a distance equal to the length. The resistive part of them represents the radiation loss from the each slot. At the resonance the reactive part of the input impedance cancelled out and the input impedance become pure resistive Transmission line model consider the elects of various parameters described below.

a. Fringing Field

The fringing field in rectangular microstrip antenna as shown in Fig.2.7, arises from the radiating edges shown in the figure below. Fringing field are mainly depends on the dielectric constant and length L to height h ratio. Since in most of the cases the L/h ratio is <<1 therefore the fringing fields are less.

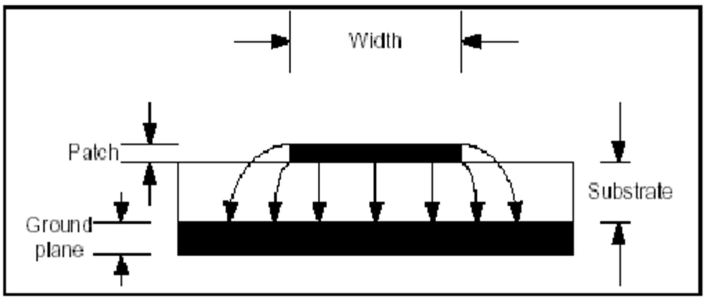


Figure 2.7 Fringing Field Effect

Higher dielectric constant substrate leads to bounded electric fields more enclosed in the substrate as used in the microstrip lines. While the lower dielectric constants substrates results in loosely bounded electric fields means they will go more further from the patch. Lesser the dielectric constant material used in substrate more bowed the fringing fields .We know that the fringing fields are responsible for the radiations from microstrip antenna. Therefore lower dielectric constants more the fringing fields and more the radiation leads to better efficiency and better antenna performance. From figure it can be seen that fringing field lines are not only enclosed in substrate but also further out in the air. As the field lines travel in substrate and air also we have to calculate an Effective Dielectric constant by taking the air also in account as shown in Fig 2.8

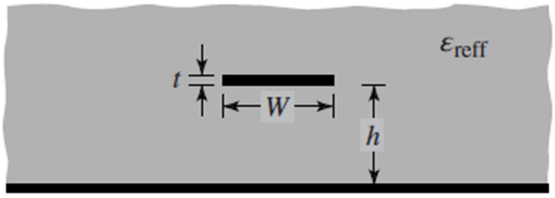


Figure 2.8 Effective Dielectric Constant

The effective dielectric constant is a dielectric constant of the material for which the antenna characteristics are same as for the real one. The range of effective dielectric constant varies from 1>Ereff<Er. In most cases the Ereff value is close Er. If the air is used as a substrate then the effective dielectric constant is equal to dielectric constant Ereff=Er. The Ereff is also depends on frequency. As the operating frequency increases the value of effective dielectric constant reaches to the real value of dielectric material used. Fig. 2.9 below showing the variation of effective dielectric constant with the frequency below.

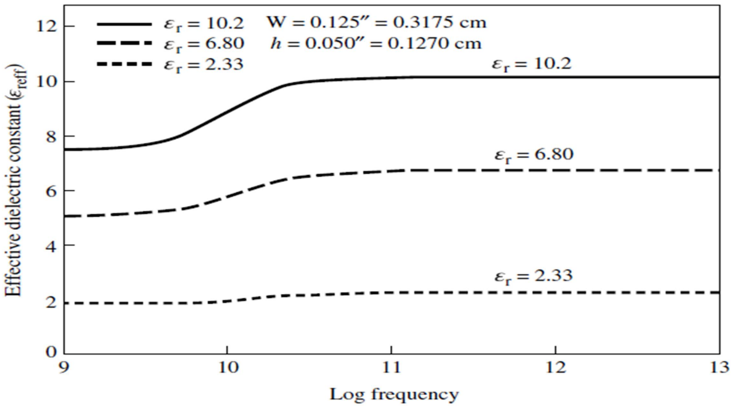


Figure 2.9 Effective dielectric constant vs Frequency

For the lower frequency the effective dielectric constant does not varies but as the frequency increases the effective dielectric constant approaches towards the actual dielectric constant of substrate material.

The Ereff for W/h>I can be given by equation 2.1

$$E_{\mathrm{eff}} = \frac{\varepsilon r+1}{2} + \frac{\varepsilon r-1}{2}\left[1+12\frac{h}{w}\right]^{-1/2} \quad \ldots\ldots\ldots\ldots 2.1$$

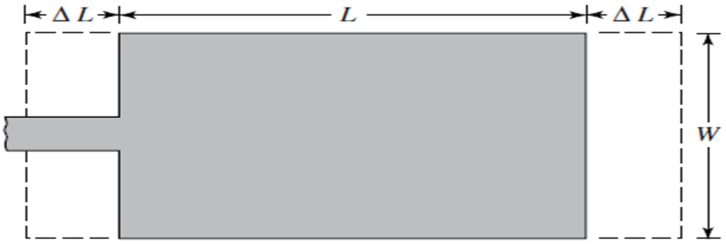
b. Effective length, Resonant Frequency, and Effective Width:

Because of the fringing effects, electrically the patch of the microstrip antenna looks greater than its physical dimensions. Where the dimensions of the patch along its length have been extended on each end by a distance delta L, which is a function of the effective dielectric constant Ereff and the width-to-height ratio (W/h). A very popular and practical approximate relation for the normalized extension of the length is given by equation 2.2.

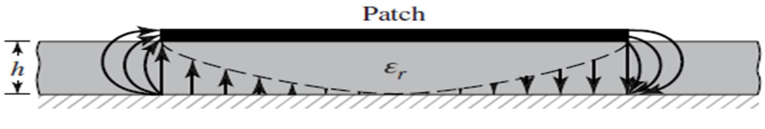
$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{\mathrm{reff}}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{\mathrm{reff}}-0.258)\left(\frac{W}{h}+0.8\right)}$$

$$\ldots\ldots\ldots\ldots..2.2$$

Since the length of the patch has been extended by ΔL on each side, the effective length of the patch as shown in Fig. 2.10.



(a) Top view



(b) Side view

Figure 2.10 Length Extension

This delta L value mainly depends on the effective dielectric constant and the width to height ratio. Due to this length extension length of patch is about 0.48lambda rather than 0.5lambda. Therefore to get the actual physical length of the patch equal to lambda/2. we have consider the extension on both the ends and that is, the length of the patch is given by equation 2.3.

$$L = L_{\mathrm{eff}} - 2\Delta L \quad \ldots\ldots\ldots\ldots 2.3$$

As we know for dominant mode the length of the patch is equal to lambda/2 therefore the L_{eff} is given by equation 2.4.

$$L_{eff} = \frac{c}{2fo\sqrt{\varepsilon eff}} \quad \ldots\ldots\ldots\ldots 2.4$$

Where C is the velocity of light in free space and f, is the resonance frequency for which antenna is to be design. For the dominant mode TM010 there is no fringing fields along the width therefore there is no need to consider the effective dielectric constant. Width of the patch can be calculated by this formula is given by equation 2.5.

$$W = \frac{c}{2fo\sqrt{\frac{\varepsilon r+1}{2}}} \quad \ldots\ldots\ldots\ldots\ldots 2.5$$

For the dominant mode TM010 the antenna resonates (without taking fringing into account) at the frequency given by the equation 2.6.

$$f_{10} = \frac{c}{\sqrt{\varepsilon r}}\left(\frac{1}{2L}\right) \quad \ldots\ldots\ldots\ldots\ldots 2.6$$

and when considering the effective length and effective dielectric constant the antenna will radiate at the frequency.

2.4.5.2 Circular Microstrip Antenna

Circular patch is the second most widely used geometry for the microstrip patch antenna. As in rectangular microstrip antenna we have two degree of freedom (length and width) to control the antenna characteristics, here we have only radius of circular patch. A circular microstrip antenna is shown in the Fig.2.11 below.

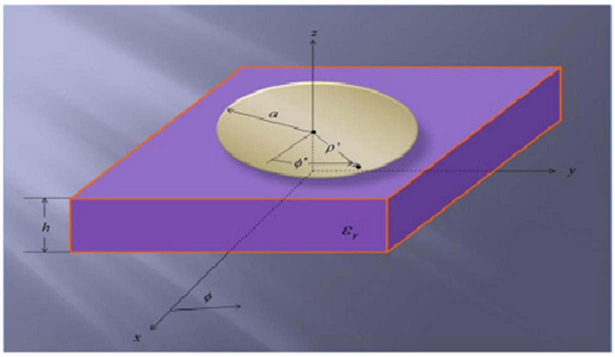


Figure 2.11 Circular Patch Antenna

As shown in figure Metallic circular patch with radius 'a' is placed a height 'h' above the ground plane. Dielectric substrate separates the patch is fed at appoint r distance from the centre at an angle phi from the x-axis. The circular patch antenna can be analysis considering the patch as a cavity with two perfect conductor electric wall above and below (patch and ground plane) and magnetic walls along the edges.

The modes supported by the circular patch antenna can be found by treating the patch, ground plane, and the material between the two as a circular cavity whose substrate height is small ($h<<\lambda$) are TM^2 where z is taken perpendicular to the patch. As far as the dimensions of the patch, there are two degrees of freedom to control (length and width) for the rectangular microstrip antenna. Therefore the order of the modes can be changed by changing the relative dimensions of the width and length of the patch (width-to-length ratio). However, for the circular patch there is only one degree of freedom to control (radius of the patch). The cavity is composed of two perfect electric conductors at the top and bottom to represent the patch and the ground plane, and by a cylindrical perfect magnetic conductor around the circular periphery of the cavity. The dielectric material of the substrate is assumed to be truncated beyond the extent of the patch.

Chapter-3

Reconfigurable Antenna

3.1 Introduction

Antennas are necessary and critical components of communication and radar systems. Nine different types of antennas have proliferated during the past 50 years in both wireless communication and radar systems. These nine varieties include dipoles, monopoles. loop antennas, slot/horn antennas, reflector antennas. Microstrip antennas, log periodic antennas, helical antennas, dielectric/lens antennas and frequency-independent antennas, Each category possesses inherent benefits and detriments that make them more or less suitable for particular applications. When faced with new system design guidelines as starting points to develop new structures that often produce acceptable results.

Making antennas reconfigurable so that their behaviour can adapt with changing system requirement or environmental conditions can ameliorate or eliminate these restrictions and provide additional levels of functionality for any system. The reconfigurable antennas have a capacity to change an individual radiator's fundamental operating characteristics through electrical, mechanical or other means.

3.2 Necessity of Reconfigurability

Let us consider two general application areas, single-element scenarios and array scenarios, In single element scenarios an antenna used in portable wireless vices, such as a cellular telephone, a personal digital assistant, or a laptop computer. Single antennas typically used in these devices are monopole or microstrip antenna based and may or may not have multiple-frequency capabilities. Moreover, the portable device is often used in unpredictable and/or harsh electromagnetic conditions, resulting in antenna performance that is certainly less than optimal. Antenna reconfigurability in such a situation could provide numerous advantages. If the antenna's radiation pattern could be changed, it could be redirected toward the access point and use less power for transmission, resulting in a significant savings in battery power. The antennas are mostly used in array configuration, feed structures with power dividers/combiners and phase shifters. This restriction comes from mutual coupling effect on one hand, appearance on grating lobe on other hand. Many of these established applications assume that the antenna element pattern is fixed, all of the elements are identical, and the elements lie on a periodic grid.

There are several antenna structures that are suitable for implementation of reconfigurable antennas, Among them microstrip patch antennas are very attractive structures for various types of reconfigurable antennas, all such antennas are usually equipped with switches that are controlled by DC bias signals. Upon toggling the switch between on and off states, the antenna can be reconfigured. The following section describes the design procedure of microstrip patch antenna types presented and different feed types used in this dissertation.

3.3 Types of Reconfigurable Antenna

Reconfigurable antenna has an ability to change any one of the antenna parameter (operating frequency, radiation pattern and polarization) without effecting the remaining parameters. Based on the antenna parameter that is dynamically adjusted, the reconfigurable antennas are classified into four types. They

3.3.1 Frequency Reconfigurable Antenna

Frequency reconfigurable antennas can adjust their frequency of operation dynamically. They are particularly useful in situations where several communications systems converge because the multiple antennas required can be replaced by a single reconfigurable antenna. Frequency reconfiguration is generally achieved by physical or electrical modifications to the antenna dimensions using RF switches, impedance loading or tunable materials.

These antennas can be developed by two mechanisms, electrical or mechanical. The electrical mechanism employs discrete tuning and continuous tuning methods. Discrete tuning can be achieved by radio frequency (RF) switches and continuous tuning can be achieved by varactor diodes. The mechanical mechanism employs the impedance loading tunable materials such as liquid crystals to achieve the frequency reconfiguration.

3.3.2 Radiation Pattern Reconfigurable Antenna

Radiation pattern reconfigurability is based on the intentional modification of the spherical distribution of the radiation pattern. Pattern reconfigurable antennas are usually designed using movable/rotatable structures or switchable and reactively-loaded parasitic elements.

3.3.3 Polarisation Reconfigurable Antenna

These antennas use switching between different polarizations, i.e. from linear polarization to left hand circular polarization (LHCP) and right hand circular polarization (RHCP), using multi modes structures. To reduce the polarization mismatch, losses in portable devices, switching between horizontal, vertical and circular polarizations are needed.

3.4 Switchable Devices used for reconfiguration

In order to demonstrate the reconfigurable antennas, various effective implementation techniques have been proposed to be used in different wireless systems such as satellite, multiple-input multiple-output (MIMO) and cognitive ratio communications, which are classified as below:

- Electrical reconfiguration
- Optical reconfiguration
- Physical reconfiguration
- Reconfigurable antennas with smart materials

The most common technique is electrical reconfiguration, which uses active elements such as positive intrinsic-negative (PIN) diodes, varactors and radiofrequency micro-electromechanical system (RFMEMS) switches. Compared to RFMEMS switches, PIN diodes have acceptable performance and a low price. Another technique is called optical reconfiguration, which relies on photoconductive switching elements. The antenna reconfigurable characteristic can also be implemented by altering the structure of the antenna this is called the mechanical reconfiguration method. The antenna can be also reconfigured using smart materials in the antenna configuration.

3.4.1 Electrical Reconfiguration

In this type of reconfiguration method, the antenna characteristics are changed using electronic switching components such as PIN diodes, varactors or MEMS. Using these switches, the antenna structure can be reconfigured, which causes the redistribution of the surface current and alters the antenna's fundamental characteristics in terms of frequency, radiation pattern and polarization. The implementation of such a reconfigurable antenna with switching elements is easy and has received lots of attention in research. Next, different methods along with some examples of electrically reconfigurable antennas to obtain the corresponding reconfigurability function with their own advantages and disadvantages using PIN diodes, varactors or MEMS switches are described.

3.4.2 PIN Diodes

A PIN diode is a diode with a wide, undoped intrinsic semiconductor region between a p-type semiconductor and an n-type semiconductor region. The wide intrinsic region makes the PIN diode an fast switch, photo detectors, and high voltage power electronics applications. PIN diodes are widely used as the switching components in different wireless systems.The PIN diode needs a high tuning speed, a high bias current in the ON-state and a high power-handling capacity. it is very reliable and extremely low-cost which makes it a good choice for the reconfiguration technique. The Pin Diode model is shown in Fig 3.1.

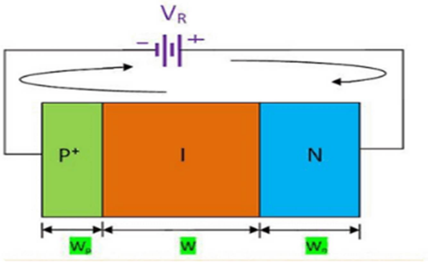


Figure 3.1 PIN Diode

3.4.3 Varactor Diodes

Varactors are used as voltage-controlled capacitors. By changing the voltage levels of the varactor, its capacitance changes, which leads to tune the antenna performance. Usage of varactors in reconfigurable designs helps to achieve the frequency tuning function. The varactor is nonlinear with a low dynamic range. It also requires a complex bias circuitry. When compared with other active elements such as a PIN diode or MEMS, it has a small current flow and continuous tuning characteristics. Voltage-controlled oscillators have many applications such as Phase-locked loops are used for the frequency synthesizers that tune many radios, television sets, and cellular telephones. The Fig 3.2 shows the structure of the Varactor Diode.

The equation for capacitance is:

$$C = (\varepsilon_r \varepsilon_o)A/d$$

C is the capacitance in Farads
A is the area of each plate measured in square meters
Er is the relative permittivity of the insulator
Eo is the permittivity of free space
d is the separation between the plates in meters.

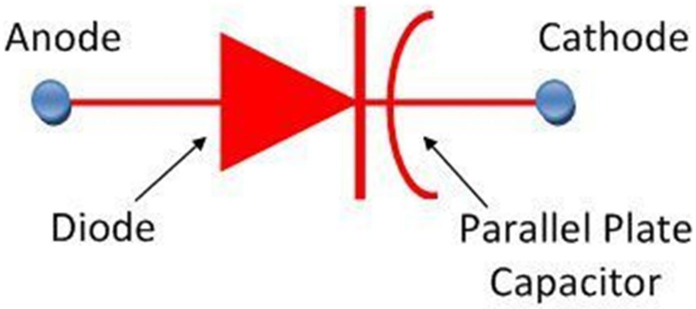


Figure 3.2 Varactor Diode

3.4.4 MEMS

Reconfigurable antennas with MEMS switches are more interested for research. MEMS switches are devices which operate by the use of mechanical movement to achieve a short or open circuit in RF circuits. MEMS switches can be designed in different configurations based on signal path, the required force for mechanical movement can be obtained by different mechanisms for actuation such as electrostatic and magnetostatic. RFMEMS switches that are able to handle up to 20 W. These have applications in radar system, network analyser, satellite communication systems and base stations. An RFMEMS shunt switch is a type of MEMS switch, It is a series switch, which consists of a suspended movable thin metal bridge over the centre conductor. MEMS switches for RF applications operate through short and open circuits to transmit signals. The Fig 3.3 represents the MEMS structure.

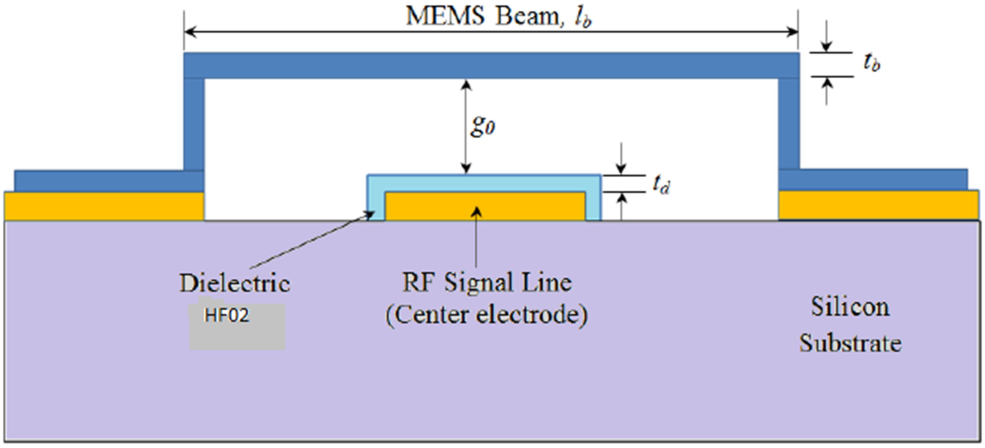


Figure 3.3 MEMS

3.4.5 Optical Reconfiguration

This is based on the use of photoconductive switches, made of a semiconductor material In optical reconfiguration, the photoconductive switches need for metallic wires, and bias lines are used which provide less interference and high isolation compared to electrical switches. In addition, they exhibit extremely fast switching speeds, switching in nanoseconds. Using photoconductive switches allows one to optically control an antenna's operational bandwidths and radiation pattern. In an optically reconfigurable antenna is proposed for cognitive radio applications.

3.4.6 Mechanical Reconfiguration

In mechanical reconfiguration, the main radiator of the antenna can be reconfigured mechanically to provide different characteristics. In contrast to other reconfiguration techniques with the switches, this type of reconfigurable antenna does need active element integration, biasing systems. The performance flexibility of this type of antenna is limited, and it is difficult to provide multi-function reconfigurable characteristics. In a reconfigurable antenna is proposed that uses a liquid metal to mechanically reconfigure its performance. By changing the size of channel filling, the operation frequency and impedance bandwidth of the proposed mechanically reconfigurable antenna can be easily tuned for different frequencies. The performance flexibility of this type of antenna is limited, and it is difficult to provide multi-function reconfigurable characteristics. In a reconfigurable antenna is proposed that uses a liquid metal to mechanically reconfigure its performance.

3.4.7 Reconfigurable Antennas with Smart Materials

Reconfigurable antennas with smart materials are new area of research, In this type of reconfiguration technique, the characteristics of the antennas can be reconfigured by pumping fluid into a hollow placed behind the antenna to change the characteristics of the substrate in terms of relative electric permittivity or magnetic permeability. In a broadband polarization reconfigurable antenna is proposed. The antenna utilizes two water arms and is mounted above a large ground plane for unidirectional radiation. Two water channels are mounted above the ground plane to generate different polarizations. By controlling the water flow along the water channels, the polarization of the antenna can be switched between right-hand and left-hand circular polarizations. The antenna operation band covers a frequency range of 1.2-1.84 GHz.

3.5 Advantages

Reconfigurable antennas have several advantages when compared to multi-band/wideband antennas or multiple antennas. Some of them are

1. Ability to support more than one wireless standard

a) Minimizes cost

b) Minimizes space requirement

c) Allows easier integration.

d) Good isolation between different wireless standards.

2. Lower front-end complexity

a) No need for front-end filtering

b) Good out-of-band rejection

3. Multifunctional capabilities

a) Act as a single element or as an array

b) Provide narrow band or wideband operation

e) Provide narrow band or wideband operation

4. Best candidate for software defined radio

a) Capability to adapt and learn

b) Automated via a microcontroller or a field programmable gate array (FPGA).

3.6 Applications

The reconfigurable antennas are applicable in situations where the operating requirements of a communication system change over time. Major applications of the reconfigurable antenna are

1. Wireless equipment's:

In wireless equipment's where several communication systems will converge and integration of multiple antennas are used. Instead of using multiple single-function antennas, a single frequency reconfigurable antennas can accommodate the multiple requirements. This is a very attractive approach for actual wireless equipment which integrate multiple communication systems, as depicted in Fig 3.1, and would lead to significant size reductions, which is of utmost importance in portable and compact devices.

2. Cognitive Radio:

Frequency reconfigurable antennas play a key role is cognitive radio (CR). Cognitive radio transceivers sense the spectrum usage and the channel characteristics to dynamically select the operating frequency band according to specific performance metrics as illustrated in Fig. 3.2. Cognitive radio can benefit from frequency reconfigurable antennas because of the capability to tune the operating frequency over the required frequency range.

3. SAR level reduction:

Pattern reconfigurable antenna is used to reduce the specific absorption rate (SAR) in the personal wireless devices as shown in Fig 3.3. When the radiation from the wireless devices are travelling into the user's body, in that situation the pattern reconfigurable antenna changes its pattern to other direction rather than in the direction of the body and it reduce the power dissipation in the user's body.

4. Portable devices:

Due to the variable orientations in the portable devices, the polarization of the transmitter and the receiver are not in align which in turn degrades the performance of the device. In this situation, the polarization reconfigurable antenna is useful in order to improve the performance of the portable devices.

Some other interesting applications of reconfigurable antennas are

- In line of sight condition when mobile devices are moving To mitigate in-hand and out-band interference
- Adaptive MIMO systems
- Space applications
- Beam scanning

3.7 Design Equations and Procedure for designing the antenna

The three important parameters while designing the antenna are

1. Operating Frequency (f)

2. Dielectric Constant (ε)

3. Substrate Thickness (h)

By using above three parameters, the dimensions of an antenna can be determined by using the below equations

Width of the patch(W) is given by equation (2.5)

The Length of patch (L) is given by equation (2.3)

Where L_{eff} is the effective length of the patch

E_{eff} is the effective dielectric constant

The effective length of the patch (L_{eff}) is given by equation (2.4)

Where C is the velocity of light in free space

f is the resonant frequency for which case is to be design

The effective dielectric constant (ε_{eff}) is given by equation (2.1)

Chapter-4

HFSS

4.1 Introduction

HFSS (High Frequency Structure Simulator) uses a numerical technique called the Finite Element Method (FEM). This is a procedure where a structure is subdivided into many smaller subsections called finite elements. The finite elements used by HFSS are tetrahedra, and the entire collection of tetrahedron is called mesh A solution is found for the fields within the finite elements are interrelated so that Maxwell's equations are satisfied across inter-clement boundaries Yielding a field solution for the entire, original, structure. Once the field solution has been found, the generalized S-matrix solution is determined.

Ansys HFSS is a 3D electromagnetic (EM) simulation software for designing and simulating high frequency electronic products such as antennas, antenna arrays, RF or microwave components, high speed interconnects, filters, connectors, IC packages and printed circuit boards Engineers worldwide use Ansys HFSS to design high-frequency, high-speed electronics found in communications systems, radar systems, advanced driver assistance systems (ADAS), satellites, internet-of-things (IoT) products and other high-speed RF and digital devices.

HFSS (High Frequency Structure Simulator) employs versatile solvers and an intuitive GUI to give you unparalleled performance plus deep insight into all your 3D EM problems. Through integration with Ansys thermal, structural and fluid dynamics tools, HFSS provides a powerful and complete multi physics analysis of electronic products, ensuring their thermal and structural reliability. HFSS is synonymous with gold standard accuracy and reliability for tackling 3D EM challenges by virtue of its automatic adaptive meshing technique and sophisticated solvers, which can be accelerated through high performance computing (HPC) technology.

The Ansys HFSS simulation suite consists of a comprehensive set of solvers to address diverse electromagnetic problems ranging in detail and scale from passive IC components to extremely large scale EM analyses such as automotive radar scenes for ADAS systems. Its reliable automatic adaptive mesh refinement lets you focus on the design instead of spending time determining and creating the best mesh. This automation and guaranteed accuracy differentiate HFSS from I other EM simulators, which require manual user control and multiple solutions to ensure that the generated mesh is suitable and accurate. With Ansys HFSS, the physics defines the mesh rather than the mesh defining the physics Ansys HFSS is the premier EM tool for R&D and virtual design prototyping. It reduces design cycle time and boosts your product's reliability and performance. Beat the competition and capture your market with Ansys HFSS.

4.2 Requirements

- HFSS consume huge memory if fine result is needed.
- 300M+ Memory and 400M+ processor is recommended.
- Personal Laptop with 8GB RAM and 1.7G processor.

4.3 Features

- 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.
- Advanced materials.
- Model Library-including spiral inductors.
- Model half, quarter, or octet symmetry.
- Calculate far-field patterns.
- Wideband fast frequency sweep.
- Create parameterized cross section models- 2D models.

4.4 Simulation Workflow

The Fig 4.1 shows the design process in HFSS. There are 6 main steps to creating and solving a proper HFSS simulation. They are:

4.4.1 Creating model

The initial task in creating an HFSS model consists of the creation of the physical model that a user wishes to analyze. This model creation can be done within HFSS using the 3D modeler. The 3D modeler is fully parametric and will allow a user to create a structure that is variable with regard to geometric dimensions and material properties. A parametric structure, therefore, is very useful when final dimensions are not known or design is to be "tuned." Alternatively, a user can import 3D structures from mechanical drawing packages, such as Solid Works, Pro E or AutoCAD. However, imported structures do not retain any history of how they were created, so they will not be parameterizable upon import If parameterization of the structure is desired, a user will need to manually modify the imported geometry so that parameterization is possible.

When using HFSS, a user must initially specify what type of solution HFSS needs to calculate. There are three types of solutions available:

1. Driven Modal

2. Driven Terminal

3. Eigen mode

The difference between driven modal and driven terminal is that, simulations that use the driven modal solution type yield S-matrix solutions where as the driven terminal expressed in terms of the incident and reflected powers of waveguide modes. The eigen mode solver will provide results in terms of eigen modes or resonances of a given structure. This solver will provide the frequency of the resonances as well as the fields at a particular resonance.

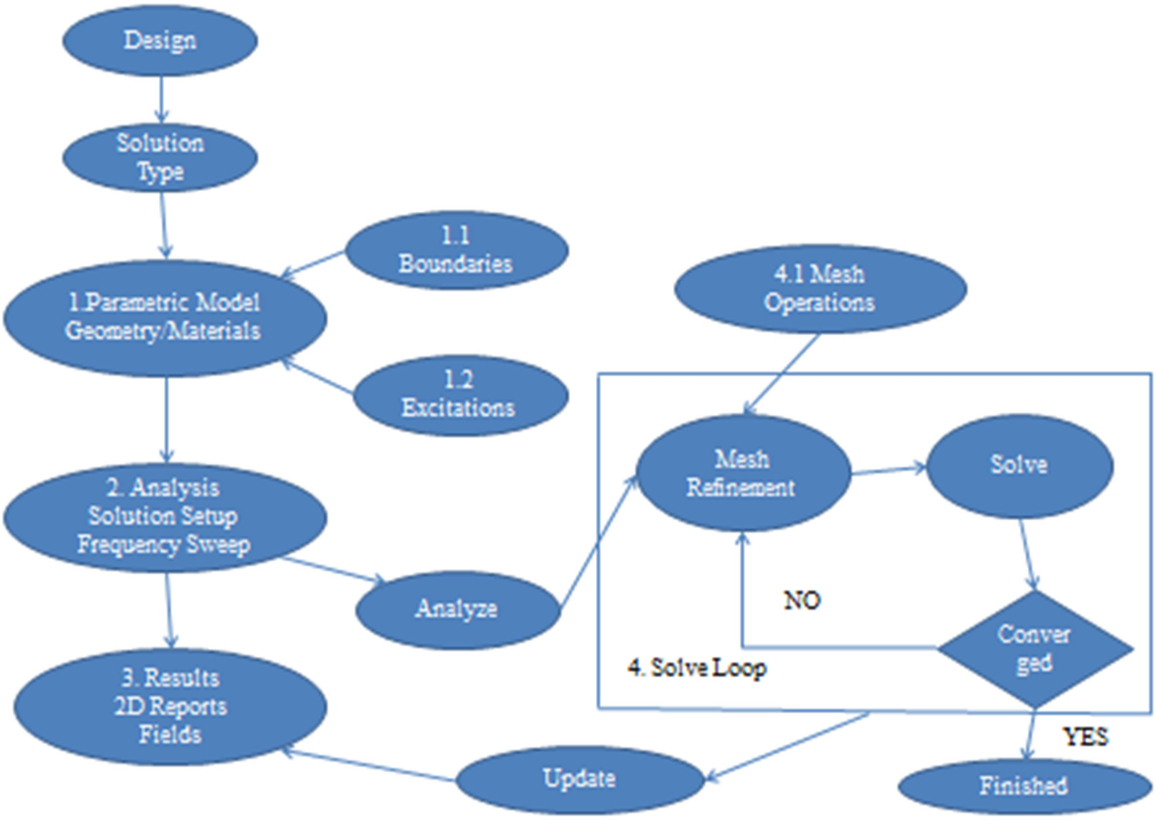


Figure 4.1 Simulation Workflow of HFSS

4.4.2 Assign Boundaries

The assignment of "boundaries" generally is done next. Boundaries are applied to specifically created 2D (sheet) objects or specific surfaces of 3D objects. Boundaries have a direct impact on the solutions that HFSS therefore, users are encouraged to closely review the section on Boundaries in this document.

There are twelve boundaries available within HFSS. Boundaries are applied to specifically created 2D sheet surfaces of 3D objects. The twelve boundaries are:

1. Perfect Electric Conductor (PEC): default HFSS boundary fully encloses the solution space and creates closed model.

2. Radiation: used to create an open model

3. Perfectly Matched layer(PML): used to create an open model and preferred for antenna simulations.

4. Finite Conductivity: allows creation of single layer conductors.

5. Layered Impedance: allows creation of multilayer conductors thin dielectrics.

6. Impedance: allows creation of ohm per square material layers.

7. Lumped RLC: allows creation of ideal lumped components.

8. Symmetry used to enforce a symmetry boundary

9. Master: Used in conjunction with Slave Boundary to model infinitely large repeating array structure.

10. Slave: Used in conjunction with Master Boundary to model large infinitely repeating array structures.

11. Screening Impedance: allows creation of large screens or grids.

12. Perfect H: allows creation of a symmetry plane.

4.4.3 Assign Excitations:

After the boundaries have been the excitations (or ports) should be applied. As with boundaries, the excitations have a direct impact on the quality of the that HFSS will yield for a given model. Because of are again encouraged to closely review the section on excitations in this document. While the proper creation and use of excitations is important to obtaining the most accurate. The Excitations we commonly use in designing antennas are Lumped port and Wave port.

HFSS results, there are several convenient rules of thumb that a user can follow.

4.4.4 Set up the Solution:

Once boundness and excitations have been created, the neat step is to create a solution setup. During this step a user will select a solution frequency, the desired convergence criteria, the maximum number of adaptive steps to perform a frequency band over which solutions are desired, and the particular solution and frequency sweep methodology to use.

4.4.5 Solve:

When the initial four steps have been completed by an HFSS user,, the model is now ready to be analyzed. The time required for an analysis highly dependent upon the model geometry, the solution frequency, and available compute resources. A Solution can take from a few seconds to the time needed to get a coffee, to an overnight run. It is often beneficial to use the remote solve capability of HFSS to send a particular simulation run to another computer that is local to the user's site. This will free up the user's PC so it can be used to perform other work.

4.4.6 Post-process the results:

Once the solution has finished, a user can post-process the results Post processing of results can be as simple as examining the S-parameters of the device modelled or plotting the fields in and around the structure Users can also can the far fields created by an antenna. In essence, any field quantity or S.YZ parameter can be plotted in the post-processor. Additionally, if a parameterized model has been analyzed, families of curves can be created.

In this chapter, we have discussed the methodology and High Frequency Structure Simulator. HFSS is used to simulate the proposed antennas. The antenna designing steps with HFSS has been elaborated step by step.

4.5 Methodology

Symmetry techniques are always helpful to improve the output. Accurate symmetry exhibits better results. So, we have implemented symmetrical cutting while designing the antenna structures. Antenna may have the impedance loss because of improper impedance matching. and this can be overcome by using parameter sweep technique which is also helpful to find the position of the feed point for best impedance matching. While designing the antenna, the cutting either on the fractal shape, patch or ground plane should be done in the appropriate way that it should reduce the cost as well as enhance the bandwidth. Manufacturing cost will get less, as it depends on the material used. The antenna performance also depends on the height and dielectric constant of the substrate.

4.6 Simulation tool used

HFSS The Ansys/Ansoft HFSS (High Frequency Structure Simulator) Version 13 is used for designing and simulating the designed antenna. It is a standard simulation tool used for 3D full wave EM field simulation and is mainly for the high frequency design. It was introduced in the year 1990.

This tool is a combination of simulation, automation, visualization, and solid modelling. This software can be used to accurately solve the three-dimensional electromagnetic problems. This software offers art solver (multiple state) technologies i.e. it uses Finite Element Method (FEM), brilliant graphics and adaptive meshing to provide us superior performance and also provide proper understanding to the problems. User has option to select the solver as per their simulation requirement.

4.7 Designing steps of an Antenna

1. Create the substrate first.

2. Assign the dimensions to the substrate.

3. Assign the material to substrate.

4. Than create the Patch and assign the dimensions to the patch.

5. Assign the boundary to patch.

6. In the Next Step, create the Feed Line and assign dimensions to the feed line.

7. Then unite the feed line.

8. After this, create the Ground Plane.

9. Than Create the Excitation Port to provide the electromagnetic energy to the antenna.

10. After this, create the radiation box and assign the radiation boundary to the radiation box.

4.8 Steps for Simulating and Analyzing the results of Antenna

1. To analyze the different parameters of designed antenna, the analysis setup is created first and desired solution frequency is assigned.

2. After assigning the solution frequency, the next step is to add the frequency sweep which is used to generate the solution frequency across the frequency ranges.

3. Than far field radiation setup is used to analyze the gain and radiation pattern of designed antenna.

4. After this, antenna is validated, analysed band report is created.

4.9 Applications

- Antennas
    - Microwave transiting Waveguide components
    - RF filters
    - Three-dimensional discontinuities
    - Passive circuit elements

- After the simulation, the layout design is generated by using the AutoCAD software. This software is used to create the mask, and this mask is printed on the transparent sheet. Than photolithography process is used to fabricate the desired antenna. Once the antenna is fabricated, it can be tested on the VNA to measure the antenna parameters like reflection coefficient, VSWR, etc.

Chapter-5

Reconfigurable Antenna Design

5.1 Introduction

A compact, confirmable multi operating frequency devices are the requirement of wireless communication systems. Reconfigurable antennas is advantageous as single antenna can be used for multiple frequency bands, multiple radiation patterns and multiple polarisations in terms of reduced size and complexity to achieve different frequency bands. In wireless communication systems S and C band frequencies are widely used in commercial and security applications. Three popularly known reconfigurable antennas are frequency reconfigurable antennas, radiation pattern reconfigurable antennas, and polarisation reconfigurable antennas. These types of antennas can be designed by adopting different switching mechanisms like semiconductor diodes operated at microwave frequencies, MEMS, optical switches, microcontroller based switches, liquid dielectric switches and FPGA control switches.

A Dielectric resonator antenna with a Co-Planar Waveguide structure to achieve frequency reconfigurability is discussed by Danesh et al[2]. Different types of Reconfigurable antennas for space applications is discussed in detail by Christodoulou et al[3]. Acheiving single directional radiation patterns with low cross polarisation for UHF band applications is discussed by Yogesh kumar Choukiker et al[5]. A dual band antenna operating at microwave frequencies for WiMAX and WLAN applications is discussed by Yogesh B.Chaouche et al[6]. A basic and small FRPA using a pair of asymmetric and unique L-slots is discussed by Bhaben Saikia et al[7]. PIN diodes used as switches to reconfiguring the antenna and producing certain frequencies, allowing for multiband operation were discussed by Y.I.Abdul Raheem et al[9]. A slot antenna is designed which are utilised for frequency and pattern reconfiguration is discussed by Wenmei Zhang et al[10]. Various frequency reconfigurable antennas were discussed by Han L C Wang et al[11], J.T.Aberle et al[15], Youcef B. Chouche et al[16]. A dual band MPA for radio frequency applications is discussed by Ibrahim Tekin et al[14]. A two element array antenna introduced with frequency and pattern reconfiguration is discussed by Zainarry et al[17].

An I-shaped antenna is presented which operates in multiple frequencies using a PIN diode. The proposed design causes antenna resonance at two frequency bands i.e., S and C band which includes WiMAX, WLAN and satellite communications. To obtain frequency reconfiguration, I-shaped asymmetric structures are used with one PIN diode which acts as switches. So by using the PIN diode at appropriate location on the patch, required frequency reconfiguration is achieved.

5.2 Defective Ground Structure

The compact geometrical slots embedded on the ground plane of microwave circuits are referred to as Defected Ground Structure (DGS). A single defect (unit cell) or a number periodic and aperiodic defects configurations may be comprised in DGS. Thus, periodic or aperiodic defects etched on the ground plane of planar microwave circuits are referred to as DGS. Earlier Photonic Band Gap (PBG) and Electromagnetic Band Gap (EBG) have been reported with irregular ground planes. The comparison between PBG, EBG, and DGS is depicted.

5.2.1 Working principle

DGS has been integrated on the ground plane with planar transmission line, that is, micro-strip line, coplanar waveguide, and conductor backed coplanar wave guide. The defects on the ground plane disturb the current distribution of the ground plane; this disturbance changes the characteristics of a transmission line (or any structure) by including some parameters (slot resistance, slot capacitance, and slot inductance) to the line parameters (line resistance, line capacitance, and line inductance). In other words, any defect etched in the ground plane under the microstrip line changes the effective capacitance and inductance of microstrip line by adding slot resistance, capacitance, and inductance.

5.3 Design of an Antenna

Simulation steps are as below:

Step 1: Launch the Ansoft HFSS.

Step 2: In an Ansoft HFSS window, from the menu item click file → New.

Step 3: From the Project menu, select Insert HFSS Design.

Step 4: Select the menu item HFSS → Solution Type → Driven Terminal.

Select the menu item 3D Modeller → Units → mm.

Step 5: Go to menu and click on rectangle. Windows popup and define all the specifications of patch that is type, dimensions of the patch name the sheet as patch. Assign boundary as perfect E.

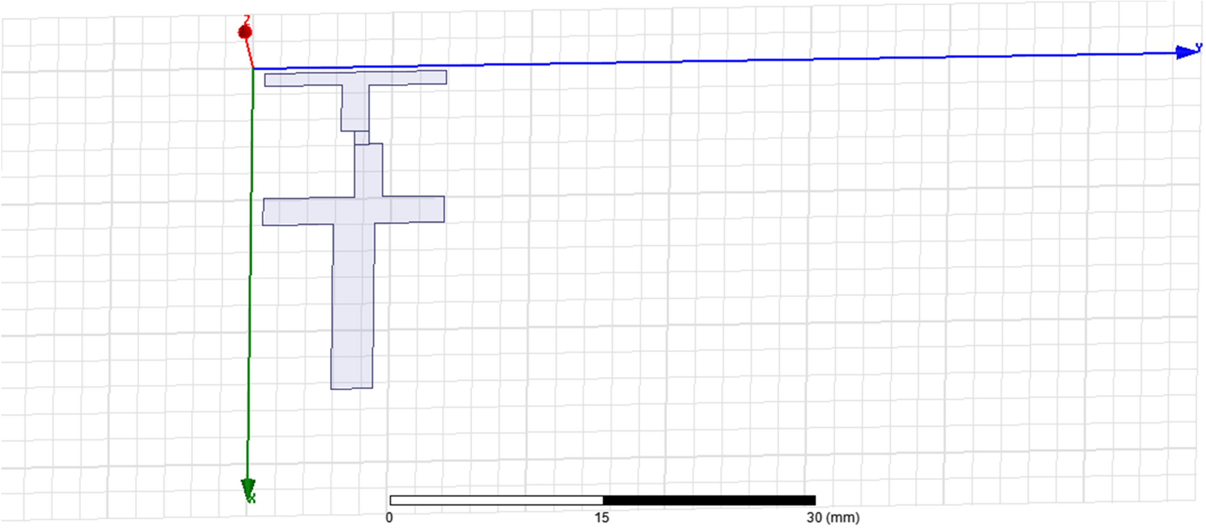


Figure 5.3.1 Patch in HFSS Window

Step 6: Go to menu and click on rectangle. Windows popup and define all the specifications of defected ground that is type, dimensions of the defected ground name the sheet as defected ground.

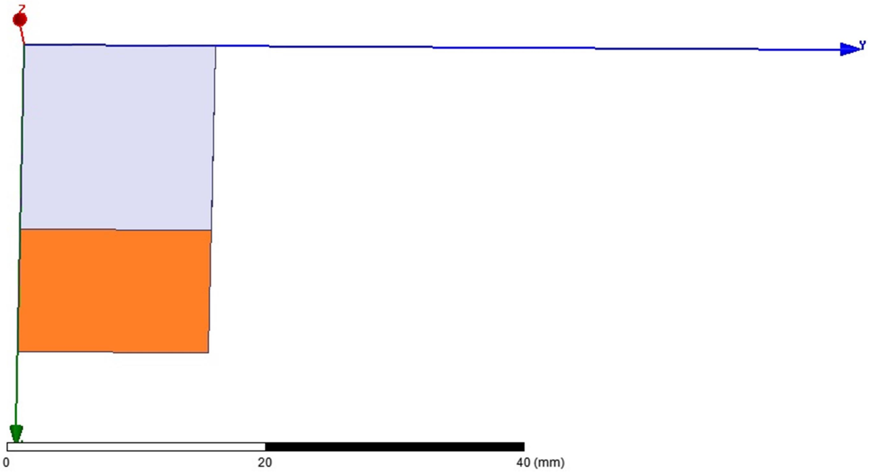


Figure 5.3.2 Defected ground structure in HFSS Window

Step 7: Go to menu and click on rectangle. Windows popup and define all the specifications of PIN diode .Assign the boundary as LUMPED RLC.

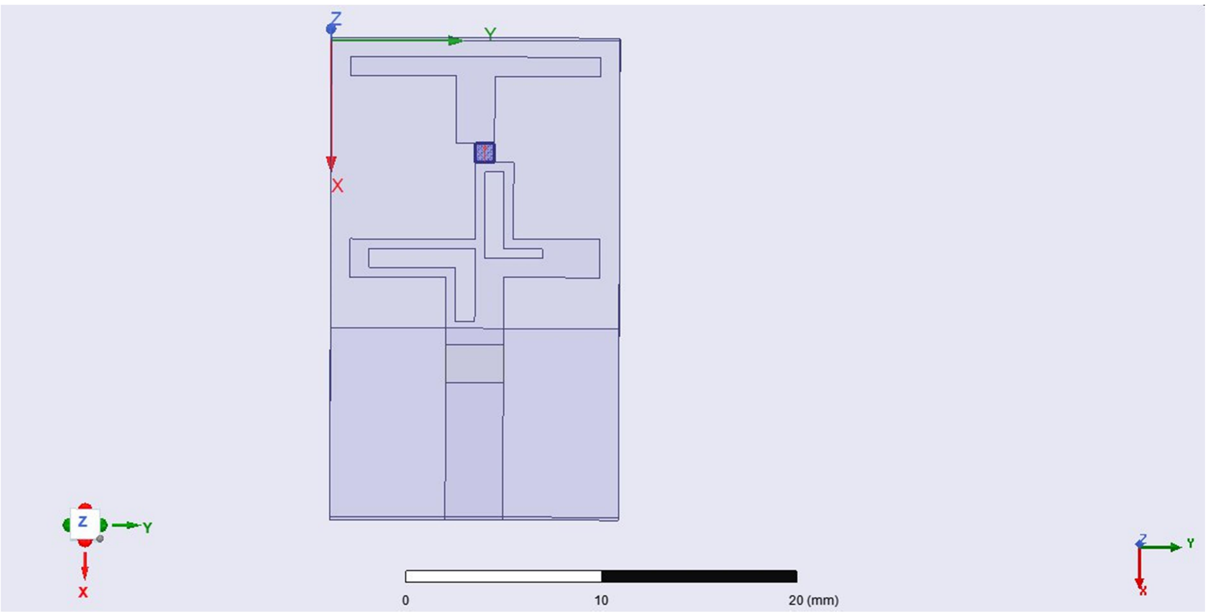


Figure 5.3.3 assigning Lumped RLC in HFSS window

Step 8: Go to menu and click on rectangle. Windows popup and define all the specifications of Capacitor .Assign the boundary as LUMPED RLC with defined Capacitance value.

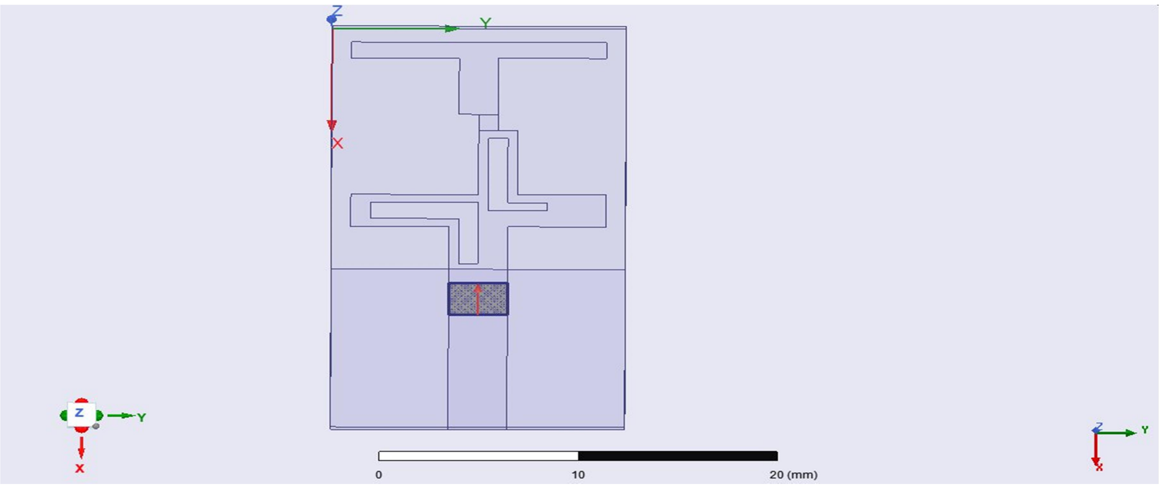


Figure 5.3.4 assigning Capacitor in HFSS window

Step 9: Go to menu and click on rectangle. Windows popup and define all the specifications of lumped port. Give the current direction from ground to substrate.

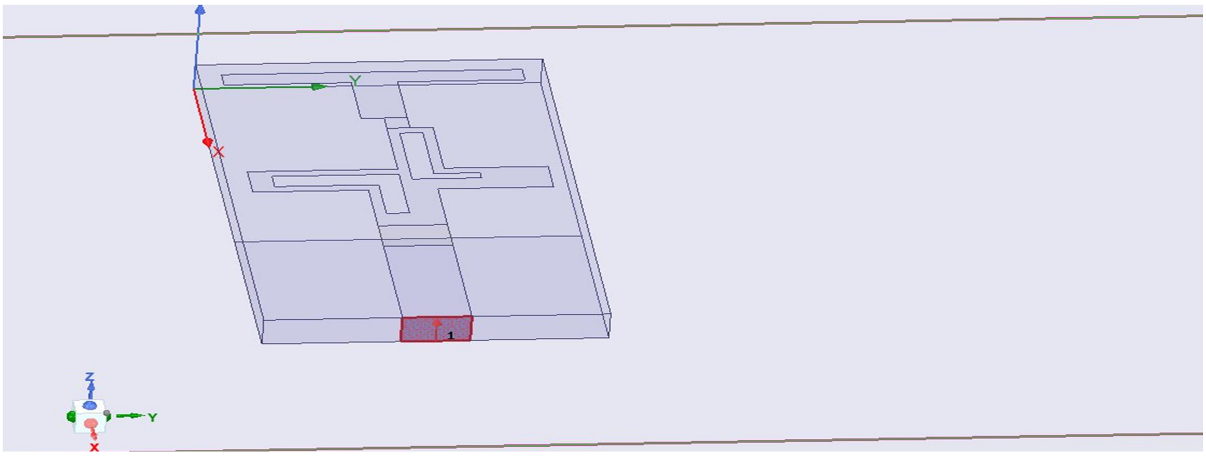
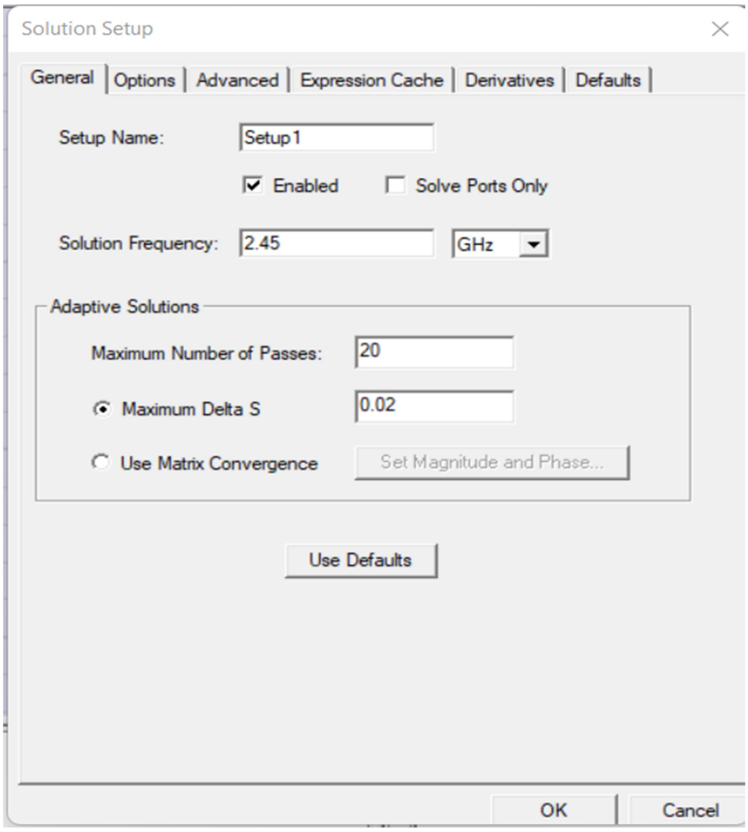


Figure 5.3.5 Lumped port in HFSS window.

Step 10: Go to menu and click on box and assign dimensions of 90mm length, width , height, assign the boundary as radiating box.

Step 11: To simulate the designed antenna, select HFSS then analysis setup as solution setup. A window popup, in that window define the operating frequency. To specify the start and stop frequency of the plot, select HFSS then analysis setup then add frequency sweep.



Setup Name: Setup1

☑ Enabled ☐ Solve Ports Only

Solution Frequency: 2.45 GHz

Adaptive Solutions

Maximum Number of Passes: 20

● Maximum Delta S 0.02

○ Use Matrix Convergence

Figure 5.3.6 Solution setup

Step 12: To view any errors in the design click on HFSS then validation. Check and then to analyze the design click on HFSS then analyze all.

mainproject_1.1 - HFSSDesign1 - Setup1: Interpolating Sweep 'Sweep', Step #4 : Frequency 3.25 GHz - Solving on Local Machine - RUNNING

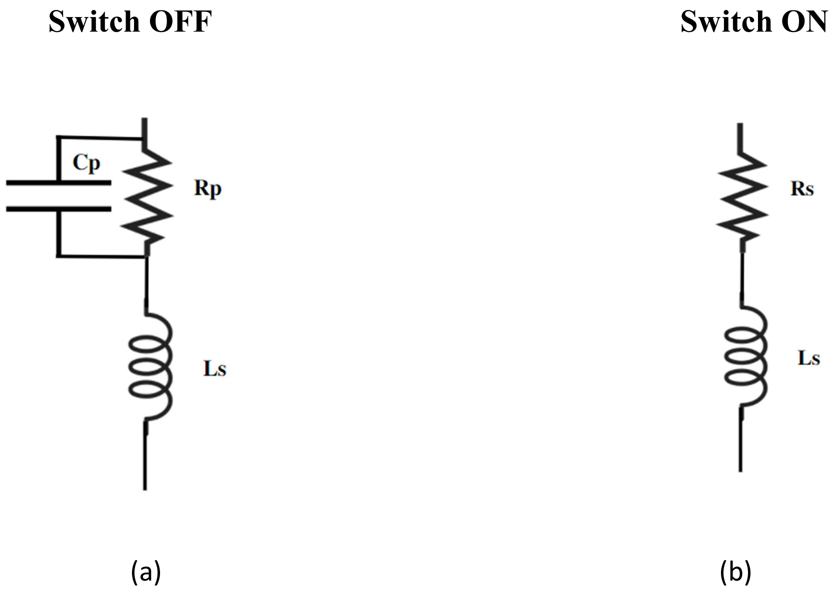
Solving matrix part 1 of 2

Figure 5.3.3 Analysis setup

Step 14: After the completion of simulation process the results are observed through select HFSS then results.

5.4 The PIN Diode and it's biasing circuit

The circuit equivalent to the PIN Diode is shown in Figure 2. When the p-i-n diode is in OFF condition (Reverse Bias Condition) , diode D acts as an Open Circuit with resistance Rp=5kΩ in parallel with capacitance Cp=0.19pF and the combination is in series with inductance Ls=0.7nH as given in Figure 5.4.1(a). When the p-i-n diode is in ON condition (Forward Bias Condition) , The Diode D acts as an Short Circuit and offers very low resistance with Rs=1.5Ωwith a series inductance of Ls=0.7nH as given in Figure 5.4.1(b) . The above values of the elements in RF p-i-n diode when the diode is in ON/OFF condition is taken as shown in datasheet of p-i-n diode of Skyworks solutions of the Diode model(SMP 1345-079LF). The p-i-n diode is introduced in order to acquire frequency reconfigurability of the presented antenna. A 1mm slot is used to introduce RF PIN diode D at appropriate location on the patch. A capacitor C of value 10pF is introduced on the feed line inorder to block the DC voltage and to remove unwanted noise.



Switch OFF

Switch ON

(a)

(b)

Figure 5.4.1 (a) Equivalent circuit of PIN diode when OFF state (b) Equivalent circuit of PIN diode when ON state

5.5 Design parameters of antenna

The proposed antenna with I-shaped has a ground of size 25mm x 15mm and also the size is same for the substrate. The material used for the substrate if FR4_epoxy substrate with dielectric constant εr = 4.4 and thickness of h = 1.6mm. Figure 1 shows the overall view of the preferred antenna. In this preferred antenna, we have used strip line feeding technique in which the the patch is directly attached to the feed line. In this design, we have introduced DGS (Defective Ground Structure) which is used to optimise gain and bandwidth and also to improve characteristics of the micro strip antenna radiation. The length of defective ground structure is Lg = 10mm. In order to achieve frequency re-configurability, we have introduced RF PIN Diode (SMP 1345 079LF) at appropriate location on the patch. The Table 5.1 represents the parameter values that we have used for the proposed antenna design.

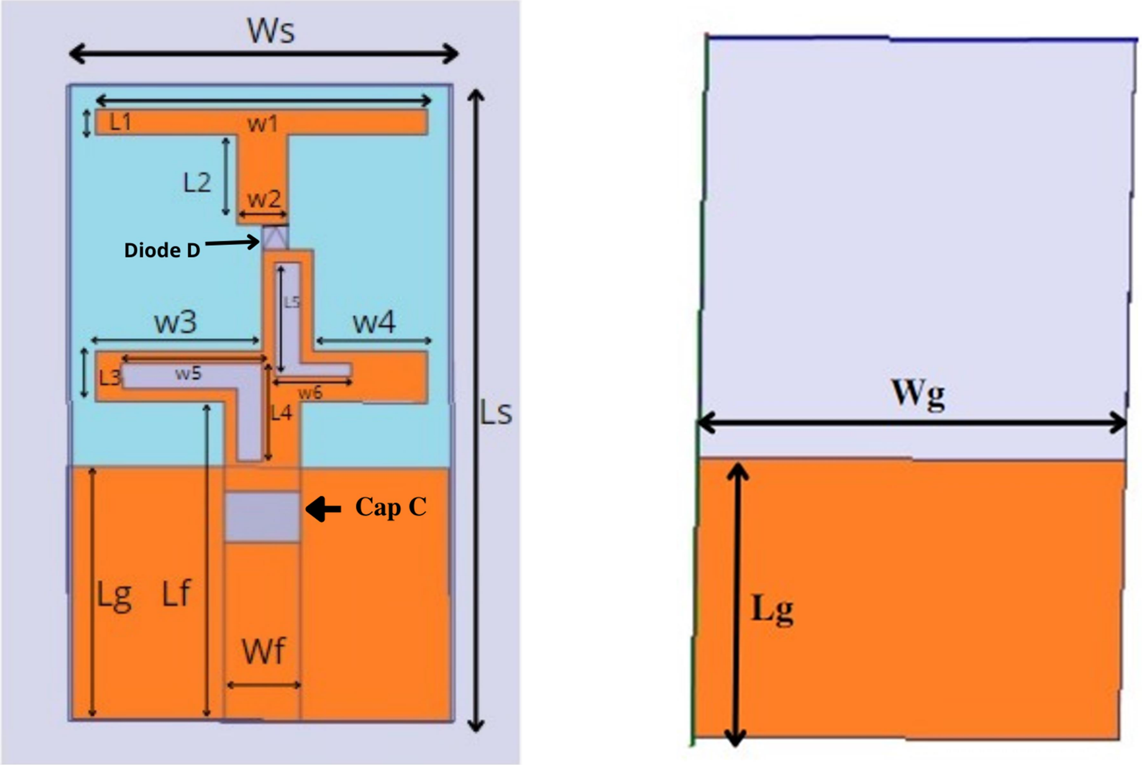


Figure 5.5.1 I-shaped Frequency Reconfigurable Antenna with DGS

The feed line's length and width can be adjusted to achieve appropriate impedance matching at the desired resonant frequency. Two Asymmetric L-slots are introduced on the patch and One RF p-i-n Diode is placed in between upper part of I- Shaped patch and lower part of I-Shaped Patch. The Two L-slots dimensions and feed line's length and width can be optimized for good impedance matching and also for maximisation of -10dB frequency reconfigurable range using High Frequency Structure Simulator(HFSS) software. RF p-i-n Diode works as a switch, change surface current distributions across the slots made in order to attain frequency re-configurability. The two operating modes of the PIN diode i.e., ON/OFF states would result different current distribution, causing antenna resonance at different frequencies.

Table 5.1 Dimensions of I-shaped frequency reconfigurable antenna with DGS

Parameters	Value in mm	Parameters	Value in mm
L_s	25	W_4	4.5
W_s	15	L_4	3.8
L_1	1	W_5	5.5
W_1	13	L_5	4.5
L_2	3.5	W_6	3
W_2	2	L_f	12.5
L_3	2	W_f	3
W_3	6.5	L_g	10

The value of L4 and L5 can be optimised for better impedance matching and for improving return loss in order to acquire the resonant frequency of 3.2GHz when p-i-n Diode D is in OFF condition and 3.4GHz and 6.8GHz when p-i-n Diode D is in ON condition. The chosen value of L4 is 3.8mm and L5 is 4.5mm in order to achieve better frequency re-configurability. We can also optimise the position of the Capacitor C which is on the feed line. After optimising, feed line’s length and width is chosen as 12.5mm and 3mm.

Chapter-6

Results

The Frequency Reconfigurable Patch Antenna (FRPA) is simulated and outputs are observed using HFSS simulation software. One PIN Diode D is inserted in between Upper part and Lower part of I-shaped Patch Antenna in such a way that cathode of Diode D touches to Upper part and Anode of Diode D touches to Lower part i.e., current direction of PIN Diode D is from Lower part to Upper part of I-shaped Patch Antenna which leads to two different reconfigurable modes of operation, i.e., Mode 1(OFF) and Mode 2(ON). The simulated return losses of preferred FRPA under 2 different modes of operation (OFF and ON) is shown in Figure 6.1 and Figure 6.2.

Switching States of the Diode D is shown in Table 6.1. Resonant Frequency, -10dB Bandwidth, S_{11} parameter and gain dBi for the 2 modes of operation is shown in Table 6.1. The Simulated Gains of FRPA for the 2 operating modes (OFF and ON) are 1.5374dB and 1.25dB. From Table 6.2 , it is observed that 2 different reconfigurable modes offers resonant frequency with return loss $S_{11} < -10$dB.

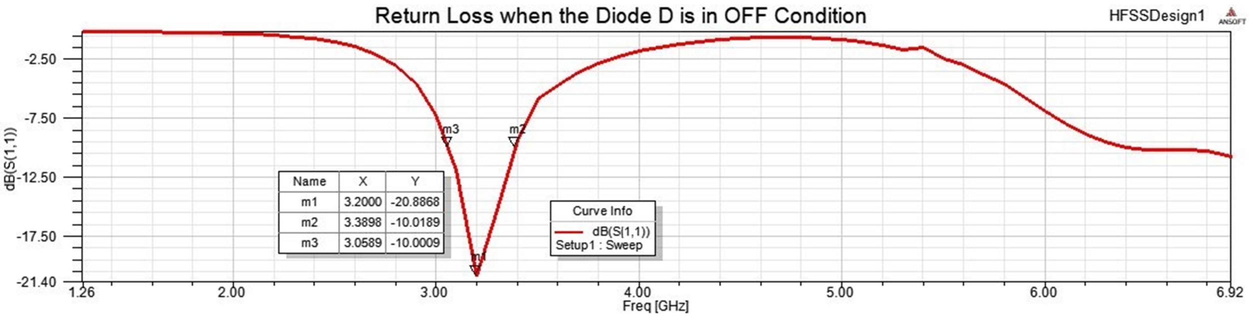
Table 6.1 Switching States

Switching State of Diode D	Resonant Frequency in GHz
Mode 1 (OFF State)	3.2
Mode 2 (ON State)	3.4 and 6.8

It is observed that the resonant frequencies for the 2 operating modes are different and operating in 2 different bands i.e., S Band and C Band.

Table 6.2 Simulated results of proposed antenna

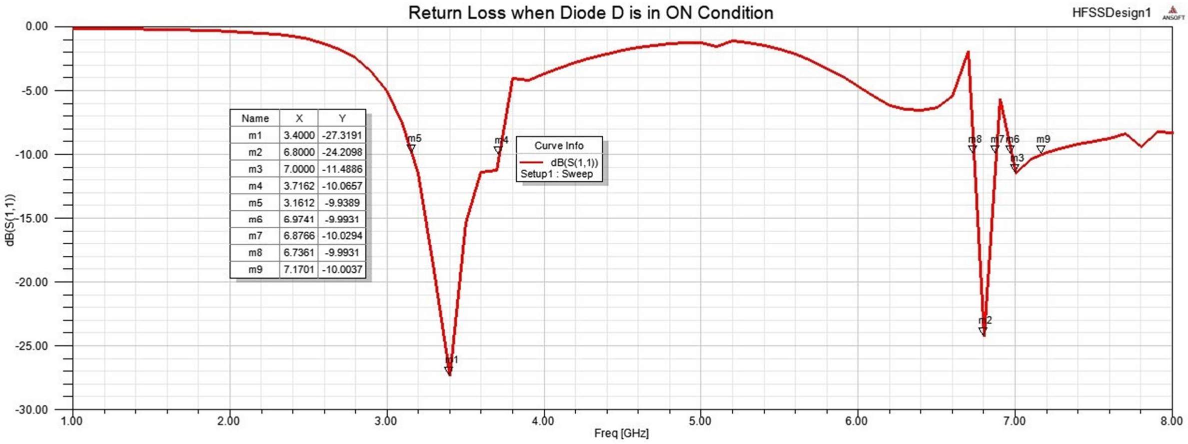
Switching State of Diode D	Resonant Frequency	Frequency Band	Bandwidth	Measured S_{11} (dB)	Measured Gain(dB)
Mode 1 (OFF State)	3.2	3.0589GHz to 3.3898GHz	330.9MHz	-20.8868	1.5374
Mode 2 (ON State)	3.4 and 6.8	PassBand-3.1612GHz to 3.7162GHz StopBand-6.8766GHz to 6.9741GHz	PassBand Bandwidth-555MHz StopBand Bandwidth-97.5MHz	-27.3191 and -24.2098	1.25



Name	X	Y
m1	3.2000	-20.8868
m2	3.3898	-10.0189
m3	3.0589	-10.0009

Figure 6.1 S_{11} plot when D is in OFF State

In Mode 1, when D is in OFF State, the antenna resonates at 3.2GHz frequency which is a single band with impedance matching bandwidth of 330.9MHz (from 3.0589GHz to 3.3898GHz) and the resonant frequency is in S band (2 to 4 GHz).



Name	X	Y
m1	3.4000	-27.3191
m2	6.8000	-24.2098
m3	7.0000	-11.4886
m4	3.7162	-10.0657
m5	3.1612	-9.9389
m6	6.9741	-9.9931
m7	6.8766	-10.0294
m8	6.7361	-9.9931
m9	7.1701	-10.0037

Figure 6.2 S_{11} plot when D is in ON State

For Mode 2, when D is in ON State, the antenna resonates at 2 different frequencies i.e., 3.4GHz and 6.8GHz frequency which is a dual band with pass band bandwidth of 555MHz (from 3.1612GHz to 3.7162GHz) and stop band bandwidth of 97.5MHz (from 6.8766GHz to 6.9741GHz) and the resonant frequencies are in S band (2 to 4GHz) and C Band (4 to 8GHz).

Surface Current Distribution is represented for 2 different switching states of Diode D(OFF and ON) which clearly shows effective resonance lengths responsible for different frequencies in radiating structure which is shown in Figure 6.3 and Figure 6.4.

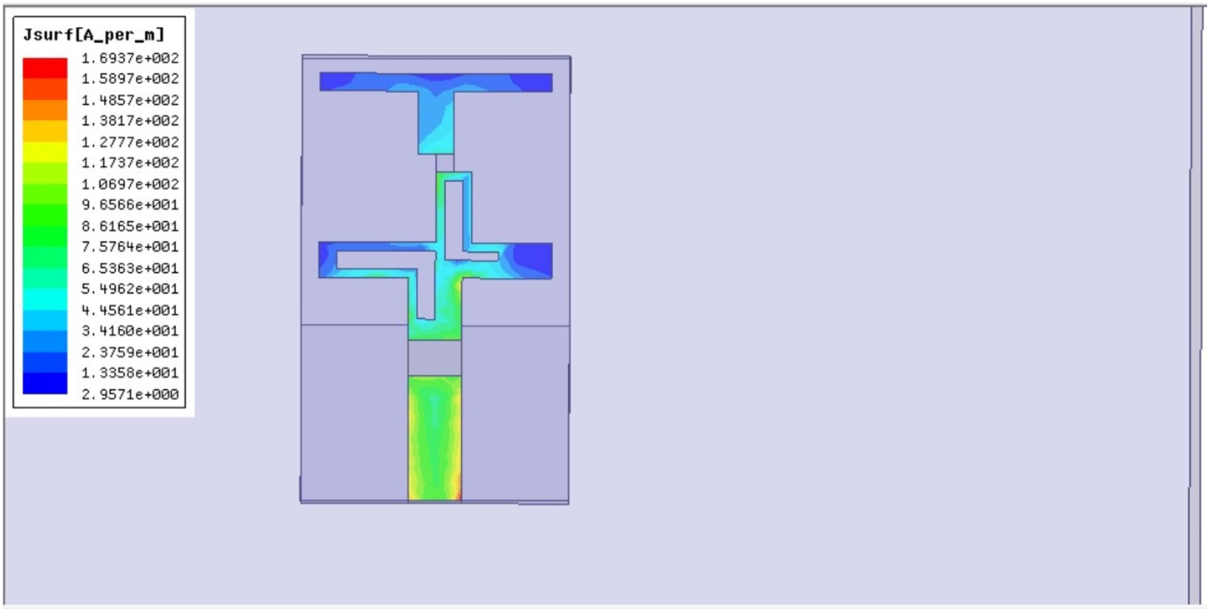


Figure 6.3 Surface Current Distribution when D is in OFF State

When the diode D is in OFF state, the more current is distributing in the feedline that represents the returns loss is improved.

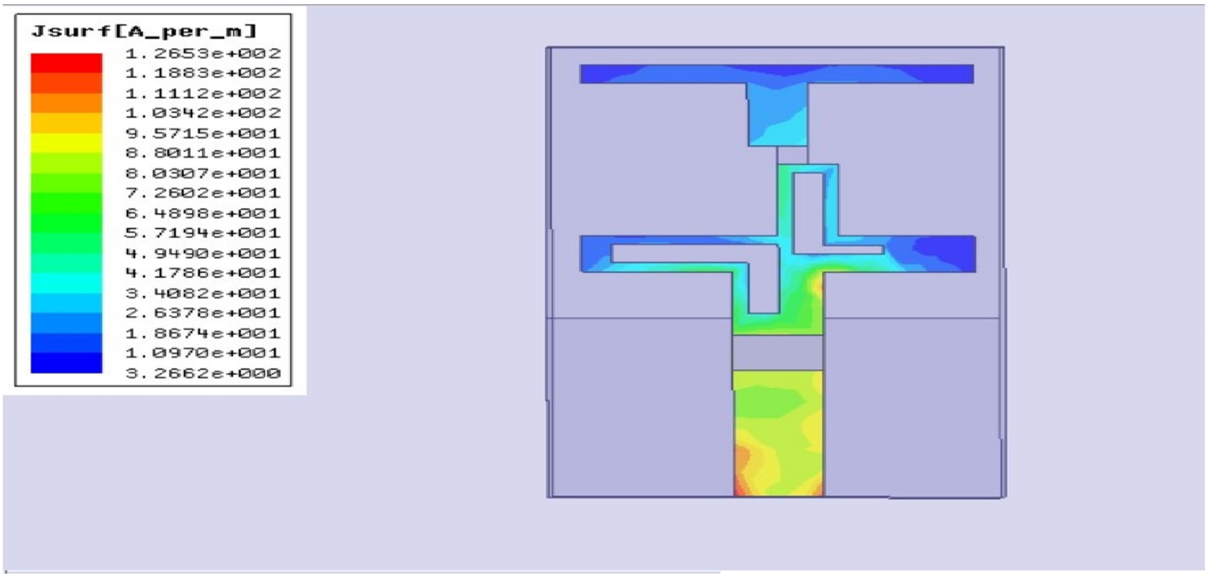
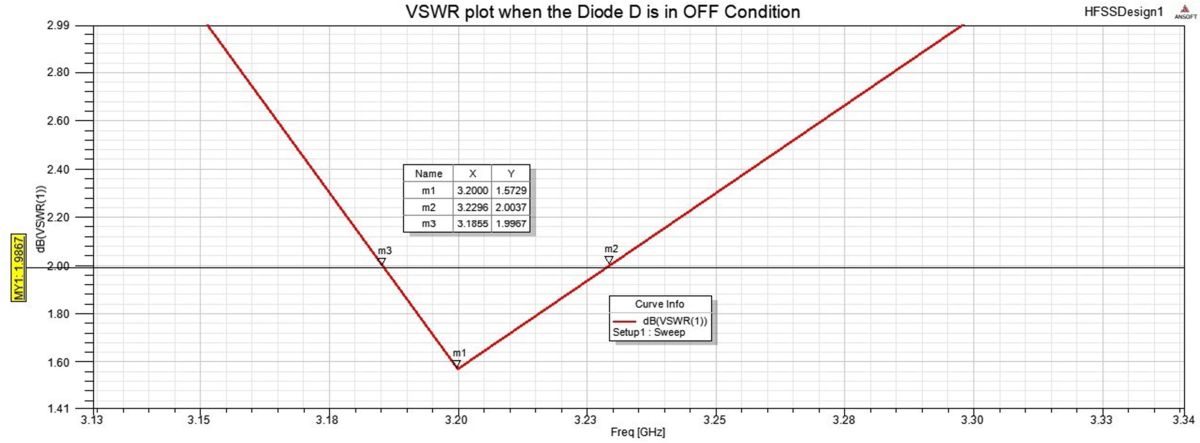


Figure 6.4 Surface Current Distribution when D is in ON State

When the diode D is in ON state, the more current is distributed in the feedline when compared to current distribution in OFF state and also the return loss is improved and bands are changed when switched from OFF state to ON state.

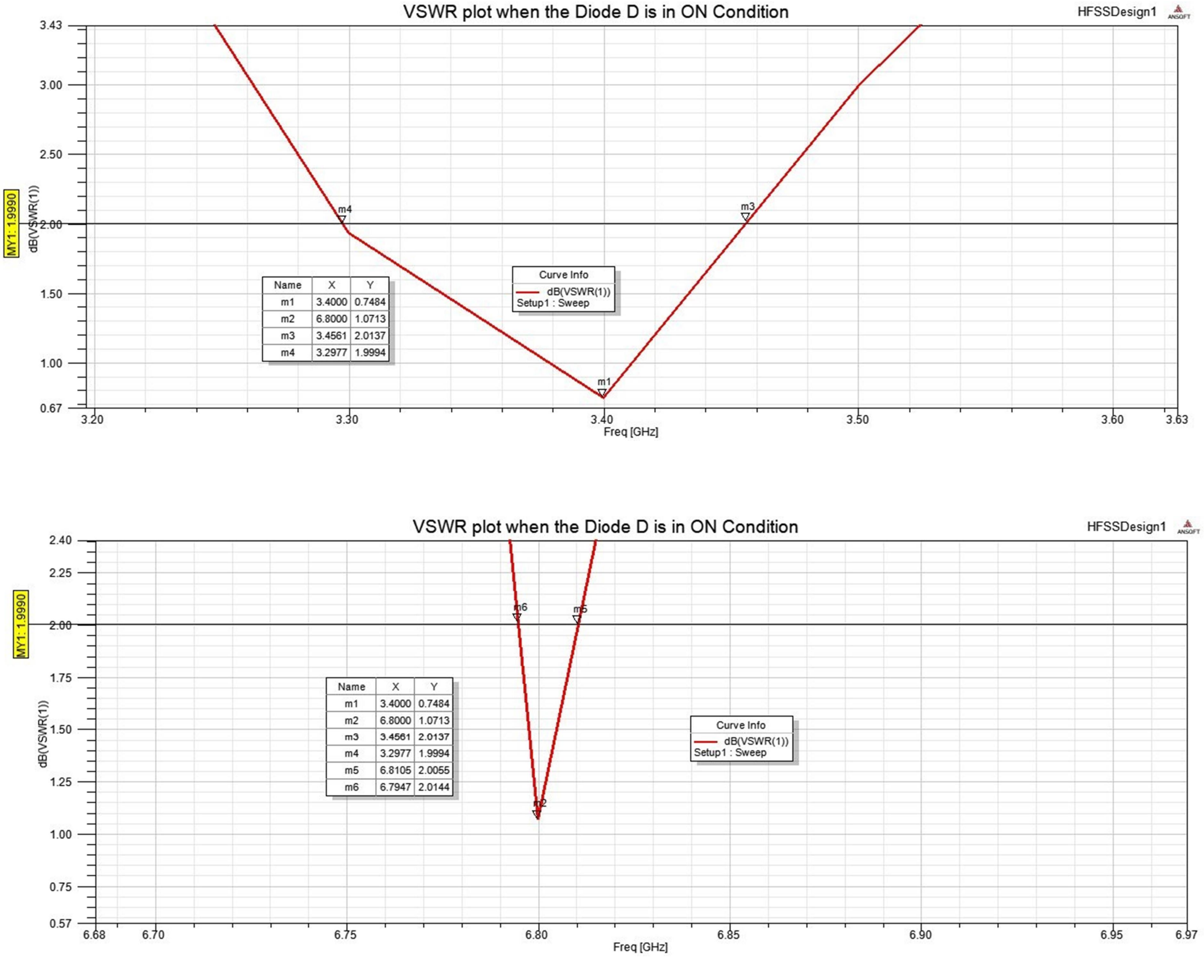
The simulated VSWR in dB of preferred FRPA under 2 different operating modes (OFF and ON) is shown in Figure 6.5 and Figure 6.6.



Name	X	Y
m1	3.2000	1.5729
m2	3.2296	2.0037
m3	3.1855	1.9967

Figure 6.5. VSWR in dB when D is in OFF State

When the PIN Diode is in reverse bias condition (OFF State), the antenna is radiating nearly with a VSWR of 1.5729dB at 3.2GHz for S-band frequency range with partial S-band of bandwidth 44.1MHz.



Name	X	Y
m1	3.4000	0.7484
m2	6.8000	1.0713
m3	3.4561	2.0137
m4	3.2977	1.9994

Name	X	Y
m1	3.4000	0.7484
m2	6.8000	1.0713
m3	3.4561	2.0137
m4	3.2977	1.9994
m5	6.8105	2.0055
m6	6.7947	2.0144

Figure 6.6. VSWR in dB when D is in ON State

When the PIN Diode is in forward bias condition (ON State), the antenna is radiating nearly with a VSWR of 0.7484dB for S-band frequency range with partial S-band of bandwidth 158.4MHz and 1.0713dB for C-band frequency range with partial C-band of bandwidth 15.8MHz.

The simulated 3D Polar Plot in dB of preferred FRPA under 2 different operating modes (OFF and ON) is shown in Figure 6.7 and Figure 6.8.

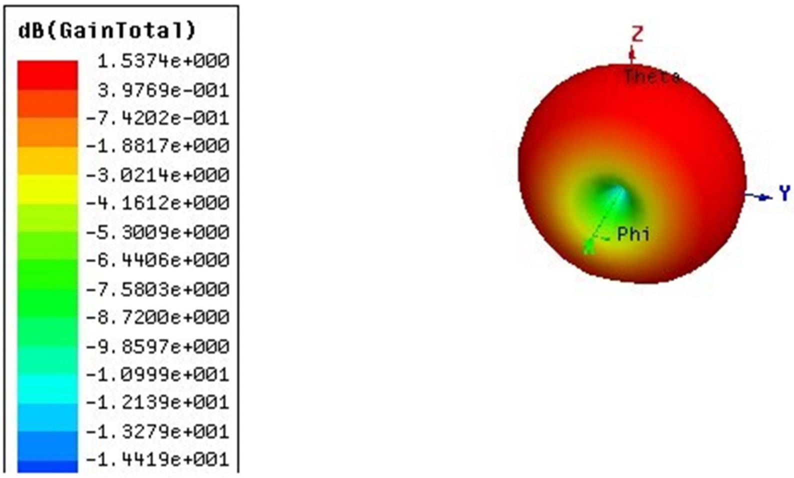


Figure 6.7 3D polar plot in dB when OFF State

The antenna is radiating with a gain of 1.5374dB when the diode D is in OFF state.

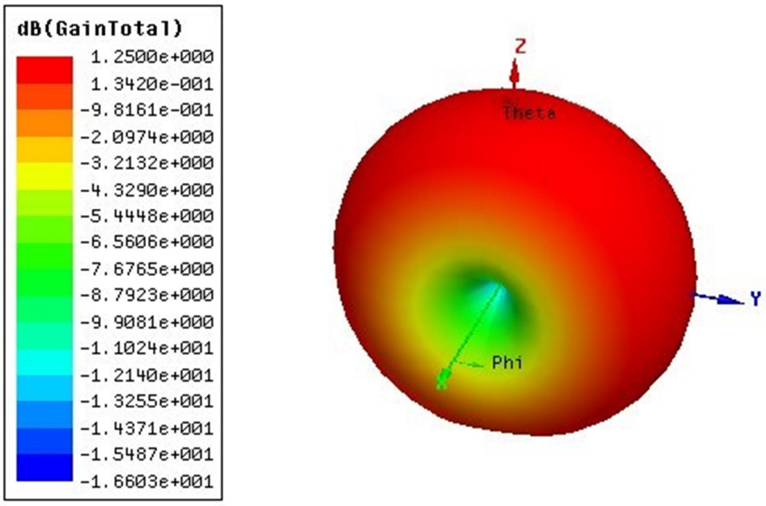


Figure 6.8. 3D polar plot in dB when ON State

The antenna is radiating with a gain of 1.25dB when the diode D is in ON state.

Conclusion

The proposed Dual L-Slot Asymmetric I-Shaped Frequency Reconfigurable Antenna is simulated in HFSS. One PIN Diode is used to achieve frequency reconfigurability. In different operating modes, When the diode D is in OFF state, the antenna is resonating in a single band at 3.2GHz with the pass band bandwidth of 330.9MHz. When the diode D is in ON state, the antenna is resonating in a dual band one is at 3.4GHz with the pass band bandwidth of 555MHz and other is at 6.8GHz with the stop band bandwidth of 97.5MHz. Then antenna is radiating with gain of 1.5374dB and with a VSWR of 1.5729dB at 3.2GHz frequency when diode is in OFF state. The antenna is radiating with a gain of 1.25dB and with a VSWR of 0.7484dB at 3.4GHz frequency and 1.0713dB at 6.8GHz frequency when diode is in ON state. The achieved modes of operation will be used for applications in S and C Band like Weather Radar, Air Traffic Control, WiFi applications.

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