

DESIGN OF MICROSTRIP ANTENNA FOR X-BAND APPLICATIONS

Submitted in partial fulfillment of the requirements for the award of
Bachelor of Engineering Degree in Electronics and Communication Engineering

by

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DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING
SCHOOL OF ELECTRICAL AND ELECTRONICS

SATHYABAMA

INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)

Accredited with Grade "A" by NAAC

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APRIL-2023



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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of **DINESH M (39130117)** and **DINESH S (39130118)** who carried out the project entitled "**DESIGN OF MICROSTRIP ANTENNA FOR X-BAND APPLICATIONS**" under our supervision from November 2022 to April 2023.

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DECLARATION

We **DINESH M (39130117)** and **DINESH S (39130118)** hereby declare that the Project Report entitled “**DESIGN OF MICROSTRIP ANTENNA FOR X-BAND APPLICATIONS**” is done by us under the guidance of **Dr .L. MAGTHELIN THERASE M.E.,Ph.D.**, is submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering degree in Electronics and Communication.

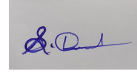
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ABSTRACT

A novel design compact antenna is proposed for communication applications. The Microstrip Patch Antenna is having advantage of compact design, light weight, easy fabrication method and low profile over the conventional antennas. In this work, a circular slot is cut in the conventional rectangular microstrip antenna and microstrip line feeding technique is used. The antenna is designed using FR4 substrate and the software used for analyzing is high frequency simulator software (HFSS). This antenna has been designed for the broadband frequency range in X-band (8-12GHz). The characteristics of the antenna such as return loss, VSWR, impedance bandwidth, gain, directivity and relative efficiency are measured. The aim is to achieve a high directivity with better gain and reduced losses particularly for X band applications.

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LIST OF ABBREVIATIONS

- HFSS-Computer Simulation Technology
- FR4 Epoxy – Flame Retardant 4
- VSWR – Voltage Standing Wave Ratio
- SWR – Standing Wave Ratio

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CHAPTER-1

INTRODUCTION

Antennas are major part of any wireless communication system. In today's scenario, although, antenna as a device is not new to common man, but the level of understanding the background concept involved in the working of this device will certainly help in designing new types of antennas, in order to meet the necessary requirements in wireless domain.

1.1 ANTENNAS

In any wireless communication system, after a radio frequency (rf) signal has been generated in a transmitter, some means must be used to radiate this signal through space to a receiver. The device that does this job is the antenna. The transmitter signal energy is sent into space by a transmitting antenna, the rf signal is then picked up from space by a receiving antenna.

The Rf energy is transmitted into space in the form of an electromagnetic field. As the travelling electromagnetic field arrives at the receiving antenna, a voltage is induced into the antenna (usually a conductor). The rf voltages induced into the receiving antenna are then passed into the receiver and converted back into the transmitted rf information.

So, antennas can be thought of as a “transducer” that converts radio waves into electrical currents and voltages and vice versa. More specifically, these are devices designed to radiate or receive electromagnetic energy efficiently in a prescribed manner.

1.2. TYPES OF ANTENNAS

Wire antennas

- dipole, monopole, loop antenna, helix.
- Usually used in personal applications, automobiles, buildings, ships, aircrafts and spacecrafts.



Fig:1.1: dipole antenna

1.2.1.Aperture Antennas

- Horn antennas, waveguide opening.
- Usually used in aircrafts and space crafts, because these antennas can be flush mounted.

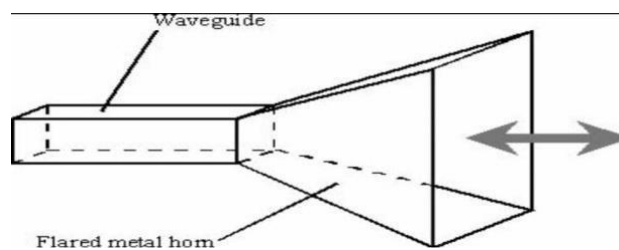


Fig:1.2: Horn antenna

1.2.2.Reflector Antennas

- Parabolic, corner reflectors
- These are high gain antennas usually used in Radio astronomy, Microwave communication and Satellite Tracking.



Fig:1.3: reflector antenna

1.2.3.Lens Antennas

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

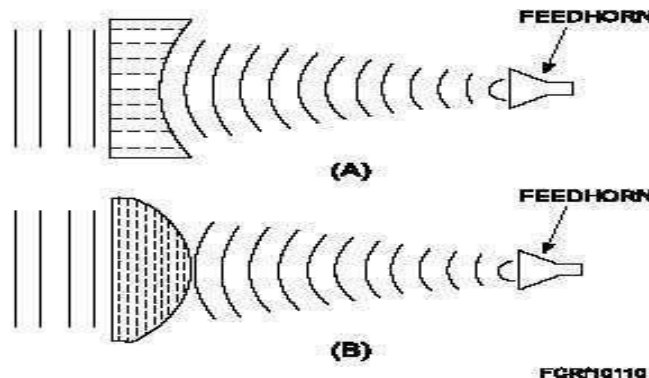


Fig:1.4: lens antenna

1.2.4. Microstrip Antennas

- Rectangular, Circular etc shaped metallic patch above a ground plane. Used in aircraft, spacecraft, satellites, cars, mobile phones etc.

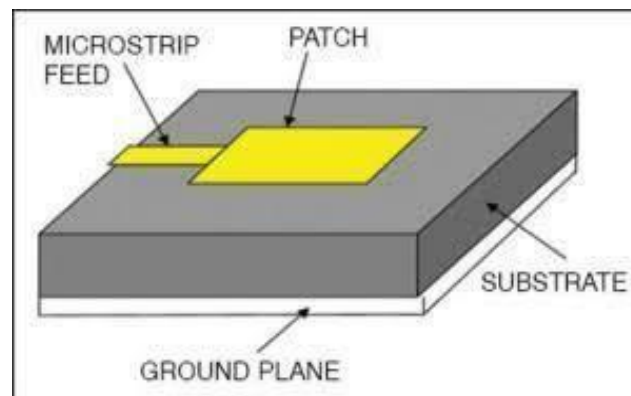


Fig:1.5: microstrip antenna

1.2.5.Array Antennas

- Yagi-Uda antenna, Microstrip patch array, Aperture array, Slotted waveguide array.
- Used for high gain applications with added advantage such as controllable radiation.

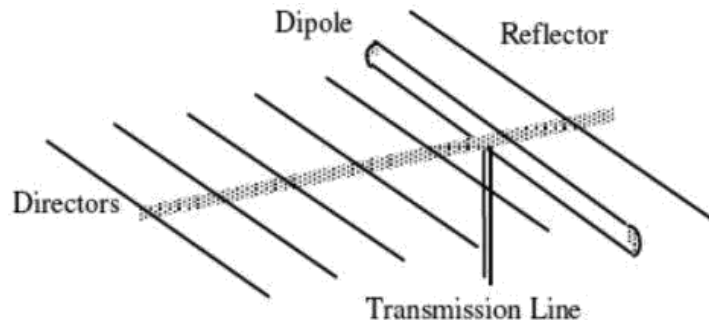


Fig:1.6: yagi-uda antenna

1.3.Feed Techniques in Microstrip patch antennas

Microstrip patch antennas can be fed by variety of methods. These methods can be classified into two categories

- Contacting
- 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).

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 below figure 3.4. 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.

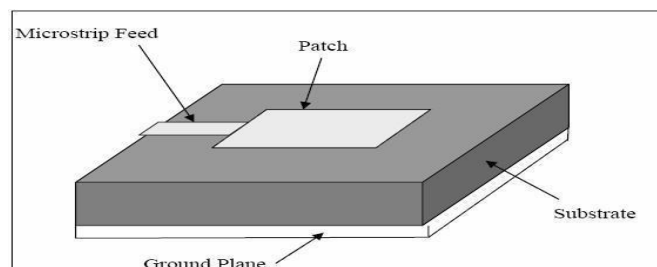


Fig:1.7: Microstrip feedline

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.

Coaxial Feed

The coaxial feed or probe feed is a very common technique techniques used for feeding Microstrip patch antennas. As seen from Figure 3.5, 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 ($h > 0.02\lambda_0$). Also, for thicker broad bandwidth, the microstrip line feed and the coaxial feed suffer from numerous disadvantages. The non-contacting feed techniques discussed below, solve these problems.

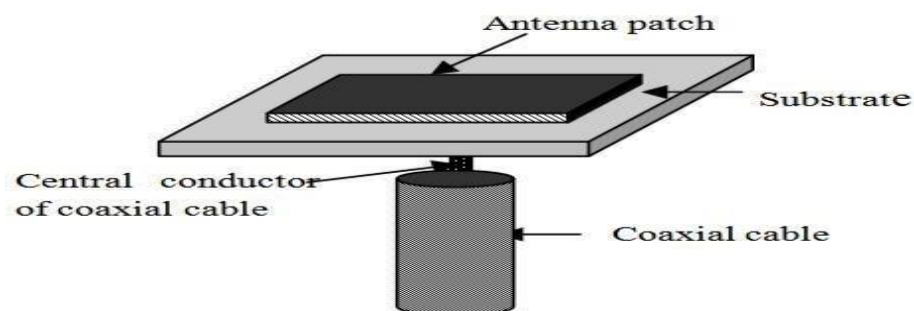


Fig:1.8: coaxial feed

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 3.6. 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.

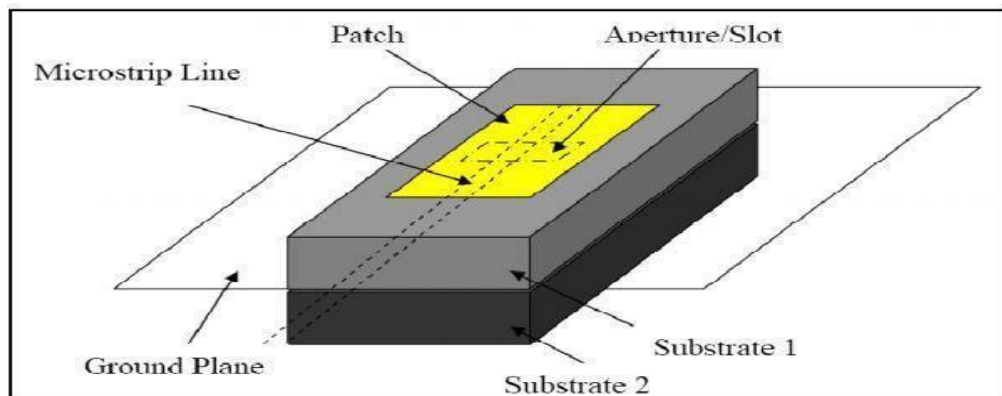


Fig:1.9: Aperture coupled feed

Proximity coupled feed

This type of feed technique is also called as the electromagnetic coupling scheme. As shown in Figure 3.7, 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.

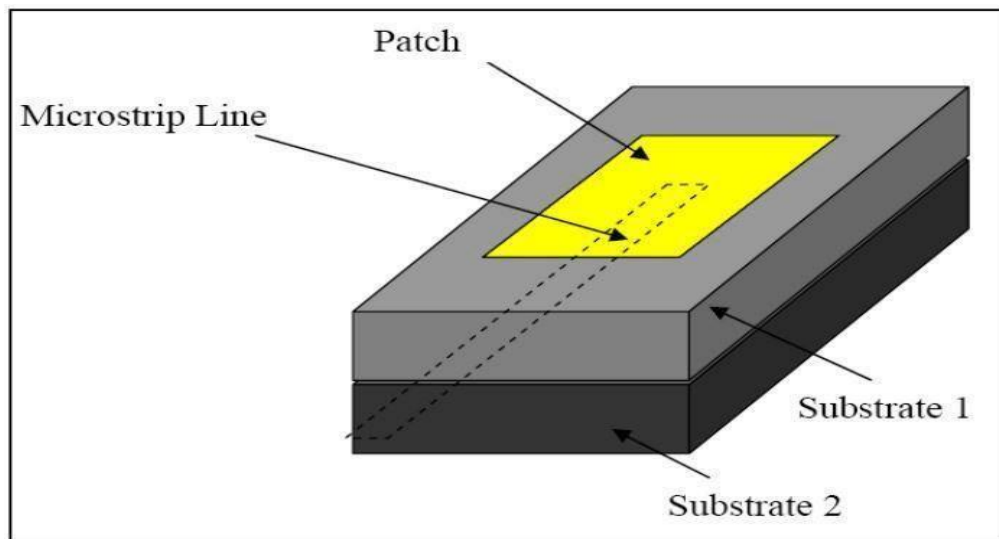


Fig:1.10: proximity coupled feed

Coplanar Wave Guide feed

A Coplanar line is a structure in which all the conductors supporting wave propagation are located on the same plane that is generally on the top of a dielectric substrate. Coplanar Waveguide is a type of electrical planar transmission line which can be fabricated using printed circuit board technology and is used to convey microwave- frequency signals. On a smaller scale, coplanar waveguide transmission lines are also built into monolithic microwave integrated circuits These resonators as crucial elements that allow for high field strength coupling to a super conductivity confining a microwave photon to a volume that is much smaller than the cube of the wavelength.

The main advantage of this type of feeding technique is that the broadband performance can be taken place as it does not need via holes for shunt and series elements. It also consists of simple realization due to etching on one side. This also have Low dispersion. The disadvantage of this coplanar waveguide is costlier and relative thick substrates are needed.

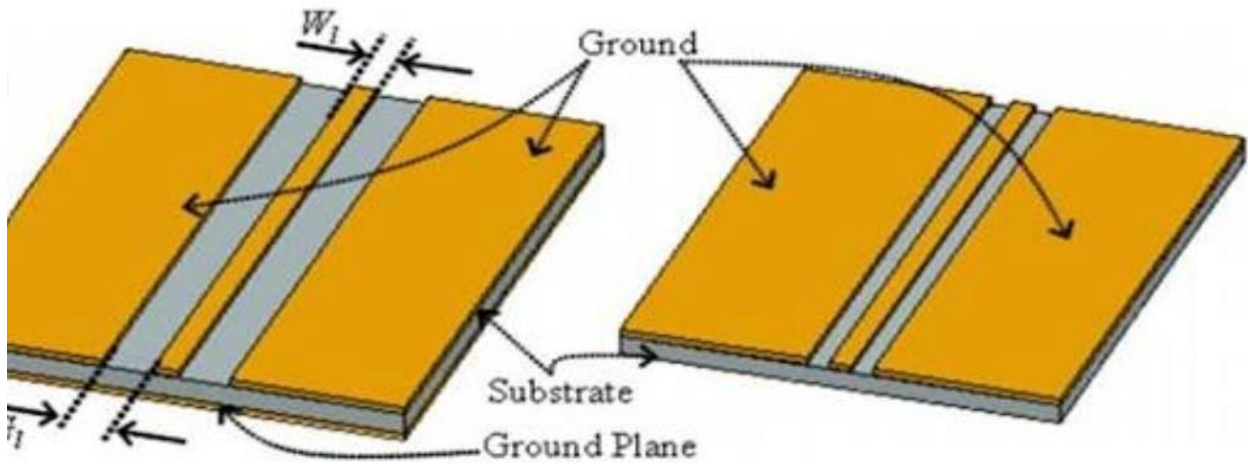


Fig:1.11: Coplanar Wave Guide feed

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 4.1: Comparison of different feed methods

1.4.ANTENNA PARAMETERS

1.4.1.Return Loss

The return loss is another way of expressing mismatch. It is a logarithmic ratio measured in dB that compares the power reflected by the antenna to the power that is fed into the antenna from the transmission line. The relationship between SWR and return loss is the following

$$RETURN LOSS(in db) = 20 \log_{10} \frac{SWR}{SWR-1} \quad (1.1)$$

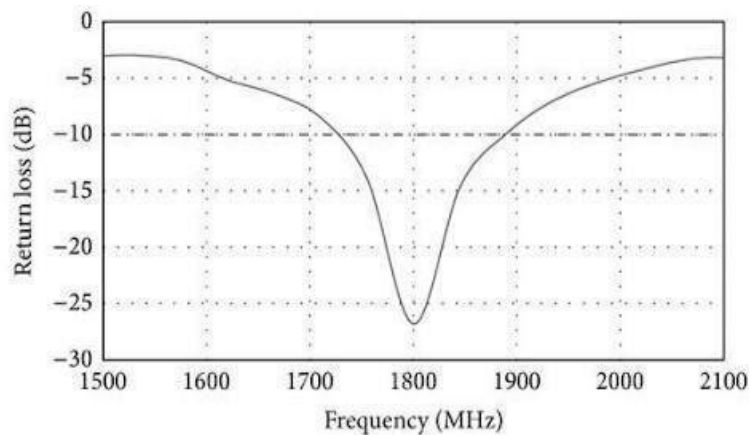


Fig:1.12: example plot for return loss

1.4.2.Band Width

The bandwidth of an antenna refers to the range of frequencies over which the antenna can operate correctly. The antenna's bandwidth is the number of Hz for which the antenna will exhibit an SWR less than 2:1.

The bandwidth can also be described in terms of percentage of the center frequency of the band.

$$BW = 100 * \frac{F_H - F_L}{F_c} \quad (1.2)$$

Where, F_H -Highest frequency in the band

F_L is the lowest frequency in the band

F_c is the center frequency in the band

In this way, bandwidth is constant relative to frequency. If bandwidth was expressed in absolute units of frequency, it would be different depending upon the center frequency. Different types of antennas have different bandwidth limitations.

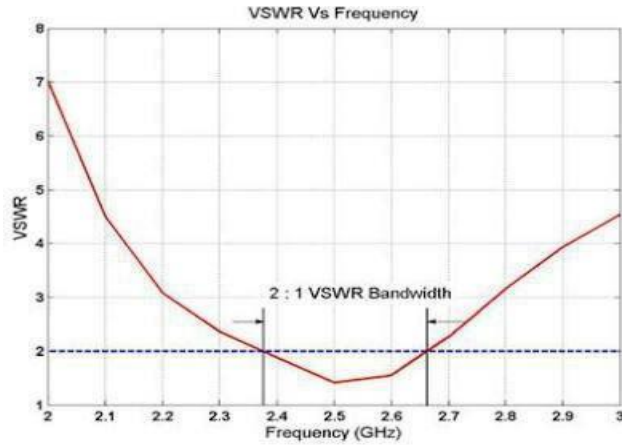


Fig:1.13: example plot for band width

1.4.3.Directivity

Directivity is the ability of an antenna to focus energy in a particular direction when transmitting, or to receive energy better from a particular direction When receiving. In a static situation, it is possible to use the antenna directivity to concentrate the radiation beam in the wanted direction. However, in a dynamic system where the transceiver is not fixed, the antenna should radiate equally in all directions, and this is known as an omni-directional antenna.

$$D = \frac{1}{\frac{1}{4\pi} \int_0^{2\pi} \int_0^{\pi} |F(\theta, \varphi)|^2 \sin \theta d\theta d\varphi} \quad (1.3)$$

Where, D=Directivity of Antenna

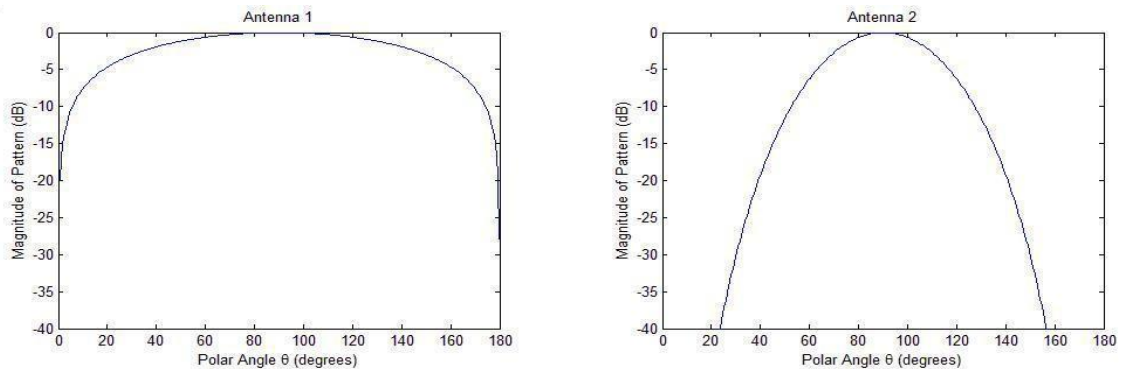


Fig:1.14: example plots of radiation pattern of antennas with higher directivity

1.4.4. Gain

Gain is not a quantity which can be defined in terms of a physical quantity such as the Watt or the Ohm, but it is a dimensionless ratio. Gain is given in reference to a standard antenna. The two most common reference antennas are the isotropic antenna and the resonant half-wave dipole antenna. The isotropic antenna radiates equally well in all directions. Real isotropic antennas do not exist, but they provide useful and simple theoretical antenna patterns with which to compare real antennas. Any real antenna will radiate more energy in some directions than in others. Since it cannot create energy, the total power radiated is the same as an isotropic antenna, so in other directions it must radiate less energy. The gain of an antenna in a given direction is the amount of energy radiated in that direction compared to the energy an isotropic antenna would radiate in the same direction when driven with the same input power.

Usually we are only interested in the maximum gain, which is the gain in the direction in which the antenna is radiating most of the power. An antenna gain of 3 dB compared to an isotropic antenna would be written as 3 dB. The resonant half-wave dipole can be a useful standard for comparing to other antennas at one frequency or over a very narrow band of frequencies. To compare the dipole to an antenna over a range of frequencies requires a number of dipoles of different lengths. An antenna gain of 3 dB compared to a dipole antenna would be written as 3 dB.

The method of measuring gain by comparing the antenna under test against a known standard antenna, which has a calibrated gain, is technically known as a gain transfer technique. Another method for measuring gain is the 3 antennas method. where the transmitted and received power at the antenna terminals is measured between three arbitrary antennas at a known fixed distance.

$$G = \epsilon_r D \quad (1.4)$$

Where ϵ_r =Relative permittivity

D=Directivity

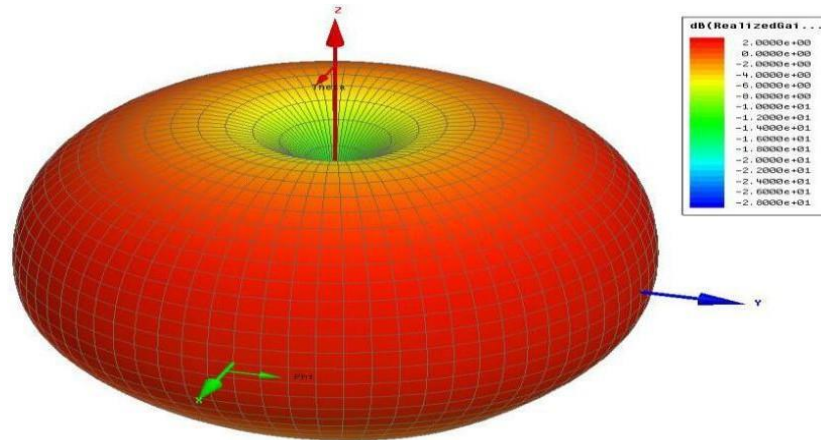


Fig:1.15: example gain pattern of an antenna

1.4.5.Radiation Pattern

The radiation or antenna pattern describes the relative strength of the radiated field in various directions from the antenna, at a constant distance. The radiation pattern is a reception pattern as well, since it also describes the receiving properties of the antenna. The radiation pattern is three-dimensional, but usually the measured radiation patterns are a two-dimensional slice of the three-dimensional pattern, in the horizontal or vertical planes. These pattern measurements are presented in either a rectangular or a polar format.

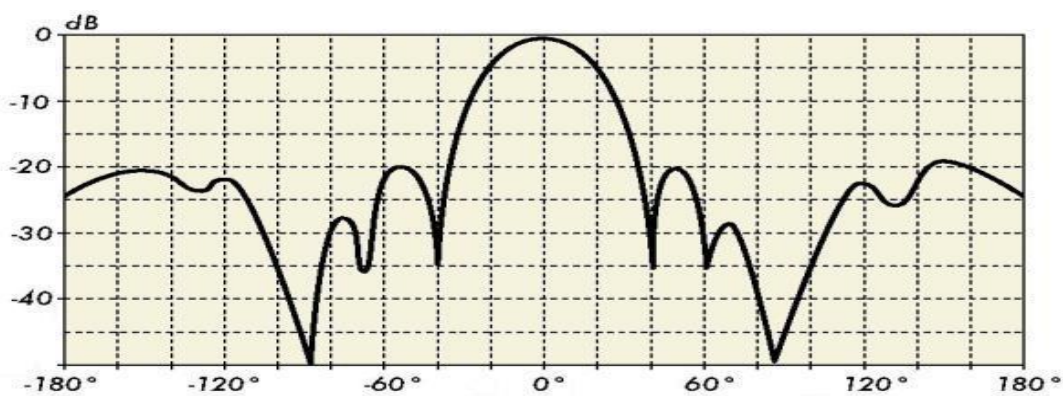


Fig:1.16: example for rectangular plot representation of radiation pattern

Polar coordinate systems are used almost universally. In the polar coordinate graph, points are located by projection along a rotating axis (radius) to an intersection with one of several concentric circles.

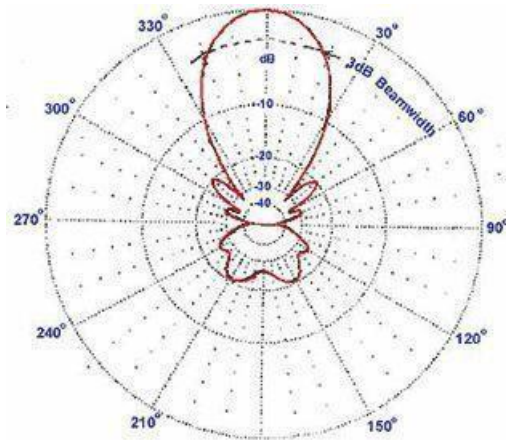


Fig:1.17: example for polar plot representation of radiation pattern

Polar coordinate systems are divided generally in two classes:

1. Line
2. Logarithmic

In the linear coordinate system, the concentric circles are equally spaced and are graduated. Such a grid may be used to prepare a linear plot of the power contained in the signal.

In the logarithmic polar coordinate system the concentric grid lines are spaced periodically according to the logarithm of the voltage in the signal. Different values may be used for the logarithmic constant of periodicity, and this choice will have an effect on the appearance of the plotted patterns.

- Polarization

Polarization is defined as the orientation of the electric field of an electromagnetic wave. Polarization is in general described by an ellipse. Two special cases of elliptical polarization are linear polarization and circular polarization. The initial polarization of a radio wave is determined by the antenna.

In linear polarization the electric field vector stays in the same plane all the time but in circular polarization the electric field vector appears to be rotating with circular motion about the direction of propagation, making one full turn for each RF cycle. This rotation may be righthand or left hand. Choice of polarization is one of the design choices available to the RF system designer.

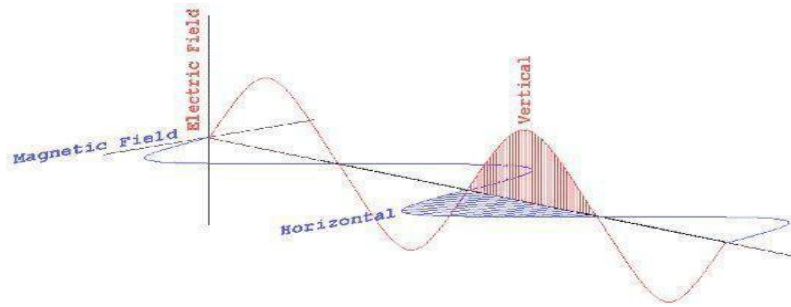


Fig:1.18: example figure for polarization

➤ Polarization Mismatch

In order to transfer maximum power between a transmit and a receive antenna, both antennas must have a same spatial orientation, the same polarization same polarization sense and the same axial ratio.

When the antennas are not aligned or do not have the same polarization, there will be a reduction in power transfer between the two antennas. This reduction in power transfer will reduce the overall system efficiency and performance.

When the transmitter and receiver antennas are both linearly polarized, physical antenna misalignment will result in a polarization mismatch loss.

CHAPTER-2

LITERATURE SURVEY

Byungje Lee et al have designed Miniature microstrip antenna with a partially filled high-permittivity substrate in 2002. A new technique to reduce the overall dimension of a microstrip antenna using a partially filled high-permittivity substrate is proposed. The miniaturized microstrip antenna for a repeater system in a mobile communication cellular band (824-894 MHz) is designed with the proposed technique and manufactured with light weight and small size. The disadvantage of the published paper is high return loss.

The title of the paper published in the year 2004 by Aditya s et al is High-gain 24-GHz CPW-fed microstrip patch antennas on high-permittivity substrates. Simulation and measurement results are presented for two designs of high-gain linearly polarized microstrip patch antennas, operating at 24 GHz on two high-permittivity substrates: Taconic CER-10 and high-resistivity silicon. In both designs, a multilayer construction is used and the patch is coupled to a coplanar waveguide (CPW) feed through a slot. The problem of surface waves is avoided by introducing an air gap between the slot and the patch with the help of micromachining or spacer layer in one of the designs, the superstrate effect is also employed. For the design, the measured gain value in the forward direction exceeds 6 dBi. The disadvantage of the published paper is it is not cost effective.

Nasimuddin et al have designed Compact circularly polarized enhanced gain microstrip antenna on high permittivity substrate in 2005. A new combination of proximity coupled circular microstrip antenna and a square quasi-planar surface mounted short horn is proposed on the high permittivity substrate (10.2) to increase the gain of a compact circularly polarized patch by 4.46 dB. This antenna structure has gain 9.0 dBi and over 3 dB beamwidth (70/spl deg/) the axial ratio (AR) is 0.11 dB. The AR bandwidth is 1.31%. The surface mounted horn provides flat gain over AR ratio bandwidth. The horn improves the side lobe level and the back lobe level between 7 dB to 10 dB. The patch structure has 12% area reduction over normal circular microstrip patch antenna. Total

thickness of structure is only 13 mm. The disadvantage of the published paper is high directivity.

The title of the paper published in the year 2011 by Dey s et al is Design and performance analysis of narrow band textile antenna for three different substrate permittivity materials and bending consequence. In this paper the design of textile antennas for materials with three different substrate permittivity $\epsilon_r = 3, 2.2, 1.25$ are realized. Different substrates having different permittivity affect the antenna performance in various ways. Here, Microstrip patch antenna is designed for narrow band WBAN (Wearable Body Area Network) at the frequency level of 2.45GHz. In this case, Dacron fabric, woven fiberglass fabric and Fleece fabric are used as antenna substrates and woven copper threads are used as the conductive part of the antenna patch. This paper demonstrates the effects of antenna bending at five different angles. Here, resonance frequency fluctuations due to impedance matching as well as effects of radiation pattern deformation due to bending at different angles are focused. The disadvantage of the published paper is impedance mismatching.

Yahya R et al have designed Effect of Rainwater and Seawater on the Permittivity of Denim Jean Substrate and Performance of UWB Eye-Shaped Antenna in 2014. The effect of rainwater and seawater on the permittivity of denim jean substrate and performance of an ultrawideband (UWB) eye-shaped textile antenna is investigated in this paper. For the simulated and measured reflection coefficients in dry condition, it was found that the antenna operates at 2.4-10.9 and 1.6-12 GHz, respectively, with the simulated gain between 3.2 and 5.8 dBi from 2 to 12 GHz with efficiencies greater than 50%. The antenna can operate at the entire range in dry conditions when $S_{11} \leq -10$ dB. From the investigation, it can be shown that the permittivities of denim jean substrate under wet and immersed conditions are proportional to the permittivities of the absorbed medium (rainwater or seawater) at 2-12 GHz. The disadvantage of this paper is it has limited performance under wet conditions and it cannot be used when it is immersed in rainwater and seawater.

The title of the paper published in the year 2004 by D. C. Thompson, O. Tantot, H. Jallageas, G. E. Ponchak, M. M. Tentzeris, and J. Papapolymerou is Characterization of liquid crystal polymer (LCP) material and transmission lines on LCP substrates from

30 to 110 GHz. Liquid crystal polymer (LCP) is a material that has gained attention as a potential high-performance microwave substrate and packaging material. This investigation uses several methods to determine the electrical properties of LCP for millimeter-wave frequencies. Microstrip ring resonators and cavity resonators are measured in order to characterize the dielectric constant and loss tangent of LCP above 30 GHz. The measured dielectric constant is shown to be steady near 3.16, and the loss tangent stays below 0.0049. In addition, various transmission lines are fabricated on different LCP substrate thicknesses and the loss characteristics are given in decibels per centimeter from 2 to 110 GHz. Peak transmission-line losses at 110 GHz vary between 0.88-2.55 dB/cm, depending on the line type and geometry. The disadvantage of this paper is it is hard in real time applications.

G. DeJean, R. Bairava subramanian, D. Thompon, G. E. Ponchak, M. M. Tentzeris, and J. Papapolymerou have designed Liquid Crystal polymer (LCP): a new organic material for the development of multilayer dual-frequency/dual-polarization flexible antenna arrays in 2005. The development of dual-frequency (14 and 35 GHz), dual-polarization microstrip antenna arrays is presented for the first time on liquid crystal polymer (LCP) multilayer technology. Some of the properties of LCP, such as multilayer (three-dimensional) vertical integration capability, good electrical and mechanical properties, and near-hermetic nature, make this substrate a practical choice for the design of low-cost antenna arrays that can be integrated with remote sensing applications operating in the Ku and millimeter-wave frequency bands. This work illustrates the potential of LCP as a low-cost, "all-package" solution for developing compact, flexible, antenna arrays that can be used in future communication and remote sensing systems. The disadvantage of this paper low gain.

CHAPTER-3

AIM AND SCOPE

3.1.AIM

To design a microstrip ring shaped antenna with less return loss and high gain for X-band communication.

The objective of this work is to simulate and analyze the performance of Microstrip ring shaped antenna for wireless communication. Mathematical calculation of various parameters of Microstrip patch antenna such as width, length, Microstrip feed line, thickness of copper. Effective dielectric constant etc., are calculated. Simulation of Microstrip patch antenna is done by using simulation software such as HFSS. Analysis of various characteristics of Microstrip patch antenna such as Return loss, Voltage StandingWave Ratio (VSWR), Gain, Radiation pattern are done.

3.2.SCOPE OF THE DESIGN

The main scope is to yield good result in return loss, bandwidth and gain parameters. The usage of single substrate makes the design simple and decreases the cost of fabrication and hence trying to meet the requirements in communication system.

3.3.DEVELOPMENT OF THE DESIGN

3.3.1.TOP VIEW OF ANTENNA

A rectangular patch with circular slot is placed on the top of the substrate.

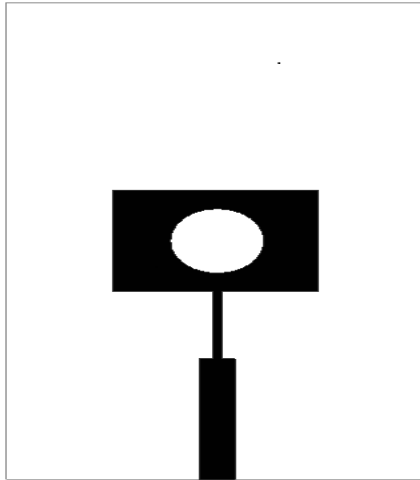


Fig:3.1: Top view of the antenna

3.3.2.BOTTOM VIEW OF ANTENNA



Fig:3.2: Bottom view of the antenna

3.4.PROPOSED SYSTEM DESIGN

A rectangular patch with circular slot is placed on the top of the substrate. The antenna is designed using single substrate to yield good results. Here coplanar waveguide feed technique is used in order to achieve better impedance matching.

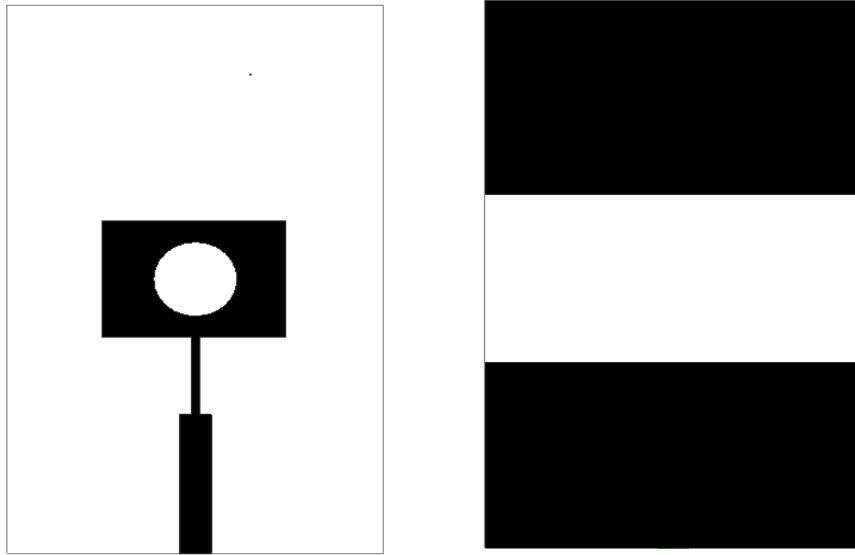


Fig:3.3: Proposed Antenna Design

CHAPTER-4

DESCRIPTION OF PATCH ANTENNA

4.1.SOFTWARE ASPECTS: - DESIGN AND SIMULATION OF MICROSTRIP PATCH ANTENNAS

4.1.1.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 substances to produce low-cost and repeatable antennas in a low profile. The antennas fabricated on complaint substrates withstand tremendous shock and vibration environments. Manufactures 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. 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.

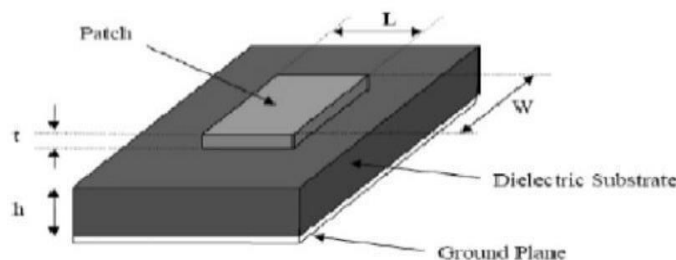


Fig:4.1: typical microstrip patch antenna

In order to simplify analysis and performance prediction, the patch is generally square, rectangular, circular, triangular, elliptical or some other common shape as shown in Figure 3.1. For a rectangular patch, the length L of the patch is usually $0.3333\lambda_0 < L < 0.5\lambda_0$, where λ_0 is the free-space wavelength. The patch is selected to be very thin such that $t \ll \lambda_0$ (where t is the patch thickness). The height h of the dielectric substrate is usually $0.003\lambda_0 \leq h \leq 0.05\lambda_0$. The dielectric constant of the substrate (ϵ_r) is typically in the range $2.2 \leq \epsilon_r \leq 12$.

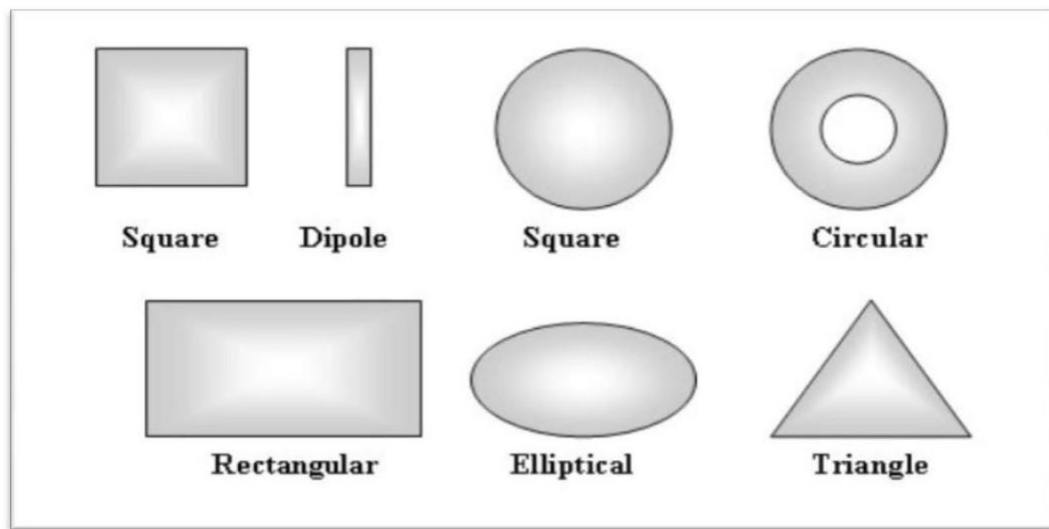


Fig:4.2: typical patch shapes

A patch radiates from fringing fields around its edges. The situation is shown in figure 3.3. 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.

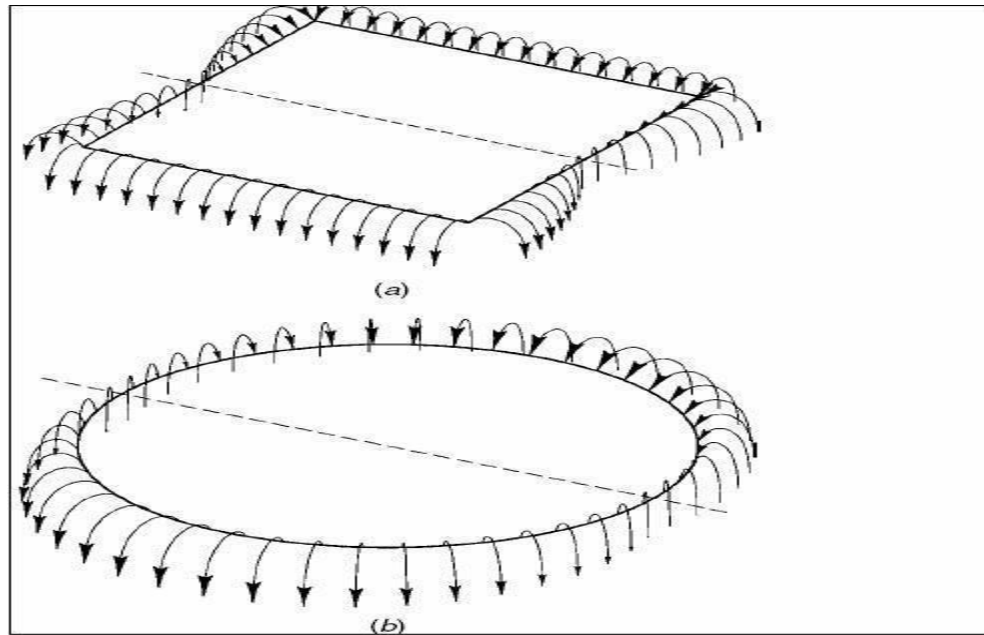


Fig:4.3: fringing fields in patch antenna

4.1.2.Applications of microstrip patch Antenna

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.

4.1.3. Advantages and Disadvantages of Patch Antenna

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 band width 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 the surface wave. This surface wave contribute 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.

4.1.5.Design Calculations

The software part in project revolved around determination of the radiation pattern and return loss curve of several simple rectangular patch antennas. For designing a rectangular microstrip patch antenna the essential parameters are:

- Frequency of operation (f): The resonant frequency of the antenna must be selected appropriately.
- Dielectric constant of the substrate (r): A substrate with a high dielectric constant reduces the dimensions of the antenna.
- Height of dielectric substrate (h): For the microstrip patch antenna to be used in certain applications (such as cell phones) it is essential that it is not bulky and to ensure this the height of the dielectric substrate can't be more than a few mm.

This patch is intended for satellite links and wireless communication and hence its frequency of operation was chosen to be 8 GHz. Its parameters are

➤ Patch Calculations:

$$C=3*10^{11} \text{ mm/s} \quad h=1.6\text{mm} \quad f=8 \text{ GHz}$$

C=Velocity of light

f=Frequency in GHz

h=Thickness of material

r=Dielectric constant of material (FR4 epoxy)

where $r=4.4$

$$f = c/\lambda \tag{4.1}$$

$$\lambda=60\text{mm}$$

$$W = \frac{c}{2f} \sqrt{\frac{2}{s_r+1}} \tag{4.2}$$

$$w=17.56\text{mm}$$

r_{eff} =Effective Dielectric Constant

$$\epsilon_{reff} = \frac{s_{r+1}}{2} + \frac{s_{r-1}}{2} \left[1 + \frac{12h}{w} \right]^{-1/2} \quad (4.3)$$

$r_{eff}=3.8867$

Δl = Normalized extension in length

$$\Delta l = \frac{0.412h(s_{reff}+0.3)\left(\frac{w}{h}+0.264\right)}{(s_{reff}-0.258)\left(\frac{w}{h}+0.8\right)} \quad (4.4)$$

$\Delta l = 0.7272 \text{ mm}$

L_{eff} = Effective length

$$l_{eff} = \frac{c}{2f\sqrt{s_{reff}}} \quad (4.5)$$

$l_{eff} = 15.217$

$$L = l_{eff} - 2\Delta l \quad (4.6)$$

$$L = 12.53 \text{ mm}$$

Using the above parameters and the equations of the transmission line model we obtain

Length of the patch=12.53 mm

Width of the patch=17.56mm

Substrate Calculation:

$$h = \frac{0.0606\lambda}{s_r} \quad (4.7)$$

$h=1.7334 \text{ mm}$

$$L_g = L + 6h \quad (4.8)$$

$$L_g = 24.163 \text{ mm}$$

$$W_g = W + 6h \quad (4.9)$$

$$W_g = 28.6578 \text{ mm}$$

The substrate calculations values are given as

Length of the substrate=58.94mm

Width of the substrate=35.9mm

➤ Feed Line Calculation:

$$\lambda_g = \frac{\lambda}{\sqrt{s_{ref}}} \quad (4.10)$$

$$L_f = \frac{\lambda_g}{4} \quad (4.11)$$

$L_{f1}=14.896\text{mm}$

$L_{f2} = 8.294\text{mm}$

$$W_f = \frac{L_f}{2} \quad (4.12)$$

$W_{f1}=3.59\text{mm}$

$W_{f2}=0.723\text{mm}$

Length of the feedline1=14.896mm

Width of the feedline1=3.59 mm

Length of the feedline 2=8.24mm

Width of the feedline 2=0.723 mm

NAME	LENGTH	WIDTH	HEIGHT
Substrate	58.94mm	35.9mm	1.6mm
Ground	58.94mm	35.9mm	-
Patch	12.53mm	17.56mm	-
Circular slot	Radius =3.9mm	-	-

Table 4.2: Dimensions of Antenna

4.1.6.Simulation Software- Ansys HFSS (High Frequency Simulation Software)

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 software to design high-frequency, high-speed electronics found in communications systems, advanced driver assistance systems (ADAS), satellites, and internet-of-things (IoT) products.

The Six general Steps in an Ansys HFSS

There are six main steps to creating and solving a proper Ansys HFSS. They are:

1. Create model/geometry
2. Assign boundaries
3. Assign excitations
4. Set up the solution
5. Solve
6. Post-process the results

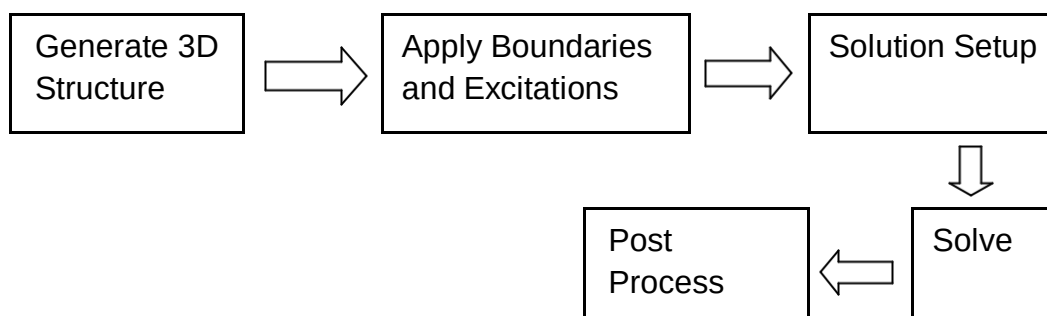


Fig:4.9: General Steps in an HFSS

Every HFSS simulation will involve, to some degree, all six of the above steps. While it is not necessary to follow these steps in exact order, it is good modeling practice to follow them in a consistent model-to-model manner.

Step One: 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 SolidWorks®, 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.

Step Two: 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 provides; therefore, users are encouraged to closely review the section on Boundaries in this document.

Step Three: After the boundaries have been assigned, the excitations (or ports) should be applied. As with boundaries, the excitations have a direct impact on the quality of the results that HFSS will yield for a given model. Because of this, users 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 HFSS results, there are several convenient rules of thumb that a user can follow. These rules are described in the excitations section.

Step Four: Once boundaries and excitations have been created, the next 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 what particular solution and frequency sweep

Step Five: 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 is highly dependent upon the model geometry, the solution frequency, and available computer 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.

Step Six: Once the solution has finished, a user can post-process the results. Postprocessing 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 examine the far fields created by an antenna. In essence, any field quantity or S, Y, Z parameter can be plotted in the post-processor. Additionally, if a parameterized model has been analyzed, families of curves can be created.

4.2.ANTENNA FABRICATION

The antennas are fabricated using the photolithographic technique. This is a chemical etching process by which the unwanted metal regions of the metallic layer are removed so that the intended design is obtained. Depending upon the design of the antenna as biplanar or uniplanar dual or single side substrates are used. The selection of a proper substrate material is the essential part in antenna design.

4.2.1.Characteristics of Substrate Materials

Recent developments in the microelectronic industry demand high performance microwave materials for substrate and packaging applications. Materials for such applications should have low relative permittivity and low dielectric loss to reduce the propagation delay and to increase the signal speed. In addition the materials should have high thermal conductivity for dissipating heat. Other important substrate characteristics include the thickness, homogeneity, isotropic and dimensional strength of the substrate.

The selection of dielectric constant of the substrate depends on the application of the antenna and the radiation characteristics specifications. High Dielectric constant

substrates causes surface wave excitation and low bandwidth performance. Also as the frequency of operation increases, the loss tangent of the material used for substrates slightly increases, which in turn adversely affects the efficiency of the antenna. Also increasing the thickness of the substrate increases the band width of the antennas at the expense of efficiency owing to increase in surface waves. FR4 with $\epsilon_r=4.4$, $\tan \delta=.02$, $h=1.6$ mm and RT Duroid substrate with $\epsilon_r=4.4$, $\tan \delta=.002$, $h=1.5$ mm are used for the study. FR4 substrate are commonly used for initial studies. The final antennas are fabricated on RT Duroid to enhance the antenna efficiency.

Various methods have been devised to accurately measure the dielectric properties of substrates available in market.

The microwave dielectric properties of the sample were measured by the cavity perturbation technique using a vector Network Analyzer. This technique is widely used for the determination of the dielectric characteristics of thin samples of low and medium dielectric loss.

A rectangular S or X-band slotted wave-guide cavity with optimum iris coupling is used for the measurement of dielectric properties of the samples at the microwave frequencies. The resonant frequency and quality factor of the empty cavity were determined for different cavity modes. Then the extremely thin sample having known dimensions is inserted and positioned at the E-field antinode. The new resonant frequency and Q of the sample were again measured. The complex dielectric constant of the sample was calculated using the following equations.

4.2.2. Photo Lithography

After the proper selection of the substrate material a computer aided design of the geometry is initially made and a negative mask of the geometry to be generated is printed on a transparent sheet. A single- or double-sided substrate with copper metallization of suitable dimension is properly cleaned using acetone to free from impurities.

A thin layer of negative photo resist solution (1:1 mix of negative photo resist solution and thinner) is coated using spinning technique on copper surfaces and is dried. The mask is placed onto the photo resist and exposed to UV light. After the proper UV

exposure, the layer of photo-resist material in the exposed portions hardens when it is treated with developer solution.

The board is then dipped in dye ink solution in order to clearly view the hardened photo resist portions on the copper coating. The board is then washed in water. After developing phase the unwanted copper portions are etched off using Ferric Chloride (FeCl_3) solution to get the required antenna geometry on the substrate. The etched board is rinsed in running water to remove any etchant. FeCl_3 dissolves the copper parts except underneath the hardened photo resist layer after few minutes. The laminate is then cleaned carefully to remove the hardened photo resist using acetone solution.

4.2.3.Fabricated Antenna

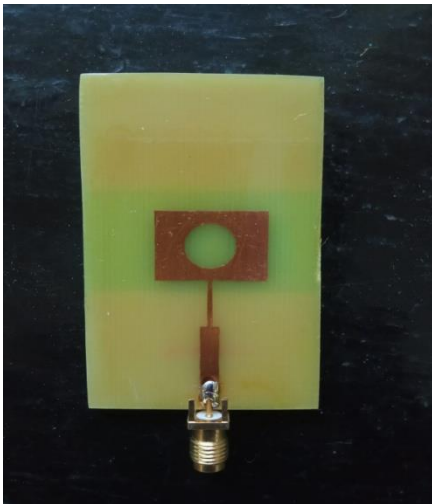


Fig:4.10 Top view of fabricated antenna

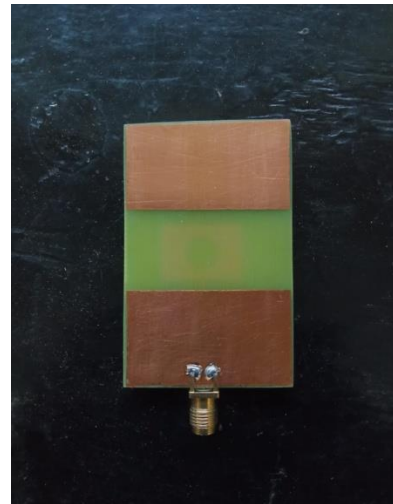


Fig 4.11 Bottom view of fabricated antenna

CHAPTER-5

RESULTS AND DISCUSSION

5.1.SIMULATION RESULTS OF THE DESIGNED ANTENNA

5.1.1.Return Loss

Return loss is a measure of the effectiveness of power delivery from a transmission line to a load such as an antenna. If the power incident on the antenna under test is P_{in} and the power reflected back to the source is P_{ref} , the degree of mismatch between the incident and reflected power in the travelling waves is given by the ratio P_{in}/P_{ref} . The higher this power ratio is, the better the load and line are matched. Return loss is the negative of the magnitude of the reflection coefficient in dB. The frequency (measured in GHz) and Return Loss (measured in db) values are plotted on X and Y axis respectively as shown below. The return loss of the proposed antenna is obtained in fig 4.1.

The markers are placed at depression points of the waveform below the 3 dB line in order to get resonating frequencies. The values of gain and directivity are obtained at these resonating frequencies, as these parameters plays a major role in describing the efficiency of antenna.

From the figure it is observed that the antenna exhibits in dual resonance at 7.8GHz and 8.9 GHz with return loss of -25.37dB and -16.627dB.

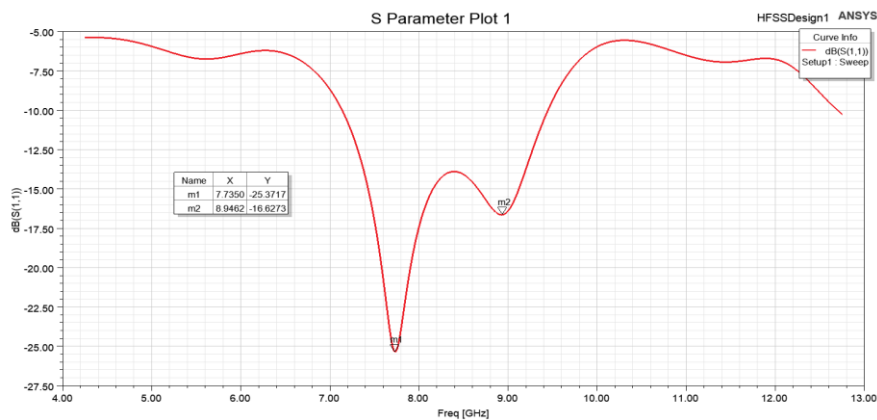


Fig:5.1: Return Loss of proposed system

5.1.2.VSWR

When a transmission line (cable) is terminated by an impedance that does not match the characteristic impedance of the transmission line, not all of the power is absorbed by the termination. Part of the power is reflected back down the transmission line. The forward (or incident) signal mixes with the reverse (or reflected) signal to cause a voltage standing wave pattern on the transmission line. The ratio of the maximum to minimum voltage is known as VSWR, or Voltage Standing Wave Ratio.

From the figure it is observed that the antenna exhibits in dual resonance at 7.7GHz and 8.9 GHz with VSWR of 1.11 and 1.34.

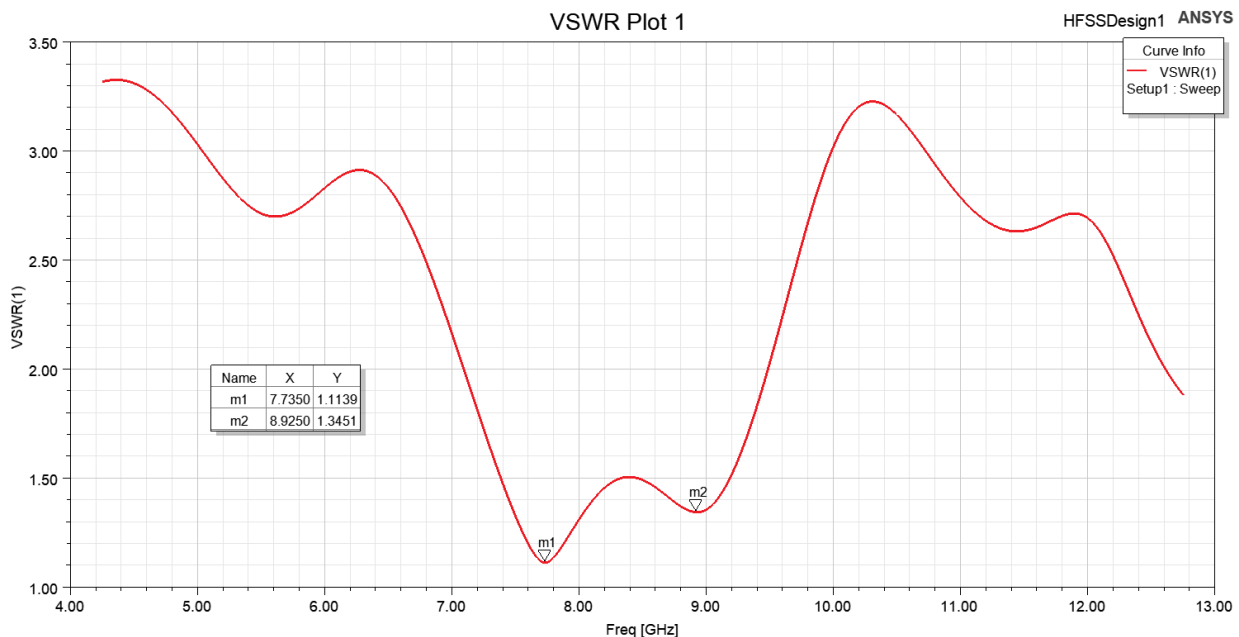


Fig:5.2: VSWR Plot of Proposed system

5.1.3. Gain

The term antenna gain describes how much power is transmitted in the direction of peak radiation to that of an isotropic source.

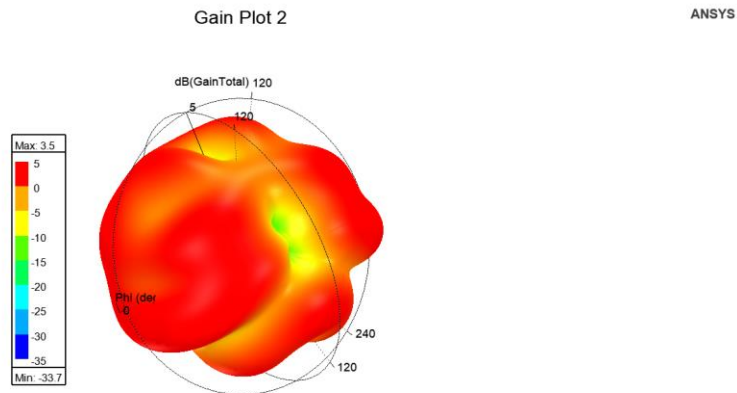


Fig:5.3: Gain plot

Overall System Gain:

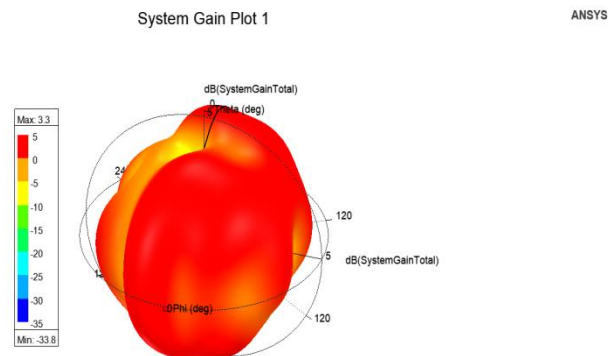


Fig:5.4: System Gain Total

5.1.4. Directivity

It is a measure of how 'directional' an Antenna's radiation pattern.

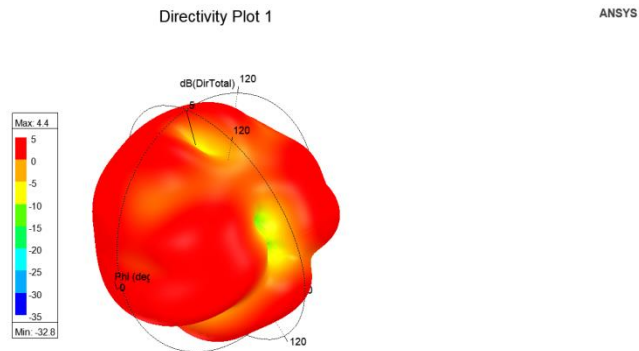


Fig:5.5: Directivity Plot.

5.1.5. SMITH CHART

The Smith chart is a graphical tool for determination of the reflection coefficient and impedance along a transmission line. It is an integral part of microwave circuit performance visualization, modern computer-aided design (CAD) tools, and RF/microwave test instrumentation. Basically, a Smith chart is a polar graph of normalized line impedance in the complex reflection coefficient plane.

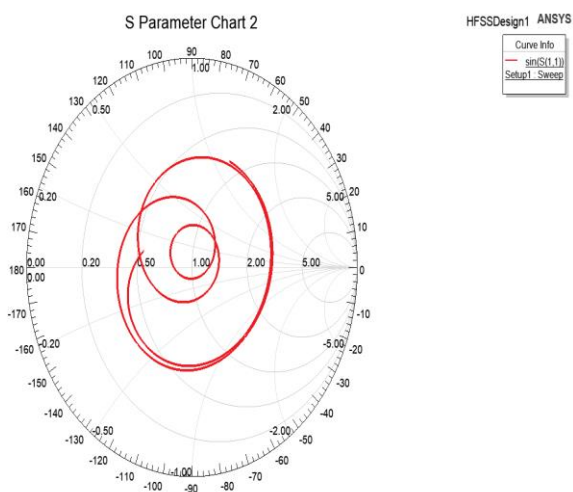


Fig:5.6: Smith Chart.

5.1.6.Electric Field Flow in the Patch:

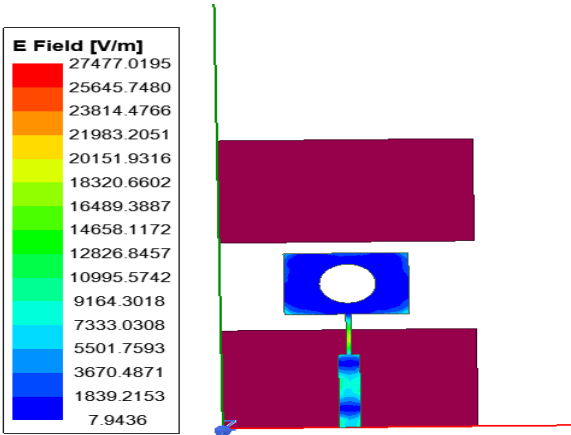


Fig:5.7: Electric field of an antenna.

5.1.7.Magnetic Field Flow in the Patch

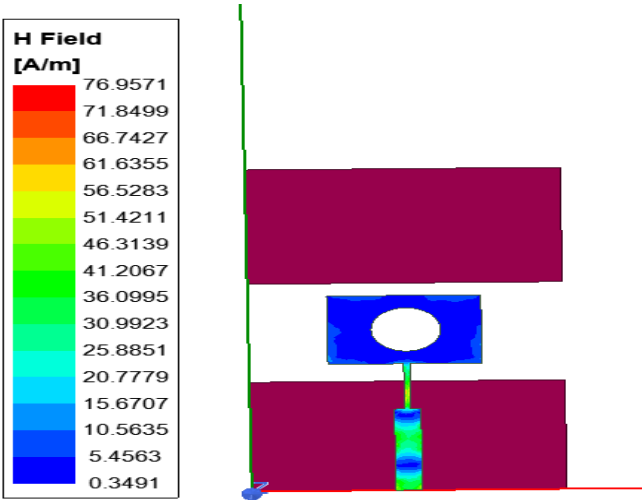


Fig:5.8: Electric field of an antenna.

ANTENNA PARAMETER	SIMULATED VALUES
VSWR	1.1 at 7.7 GHz 1.3 at 8.9 GHz
GAIN	Max: 3.5 dB Min: -33.7 dB
DIRECTIVITY	Max:4.4 dB Min: -32.8 dB
BANDWIDTH	2.1 GHz
RETURN LOSS	-25.37 dB at 7.7GHz -16.6 dB at 8.9GHz

Table 5.1: Simulated results

5.2.TESTING RESULTS OF FABRICATED ANTENNA

5.2.1.S - Parameter

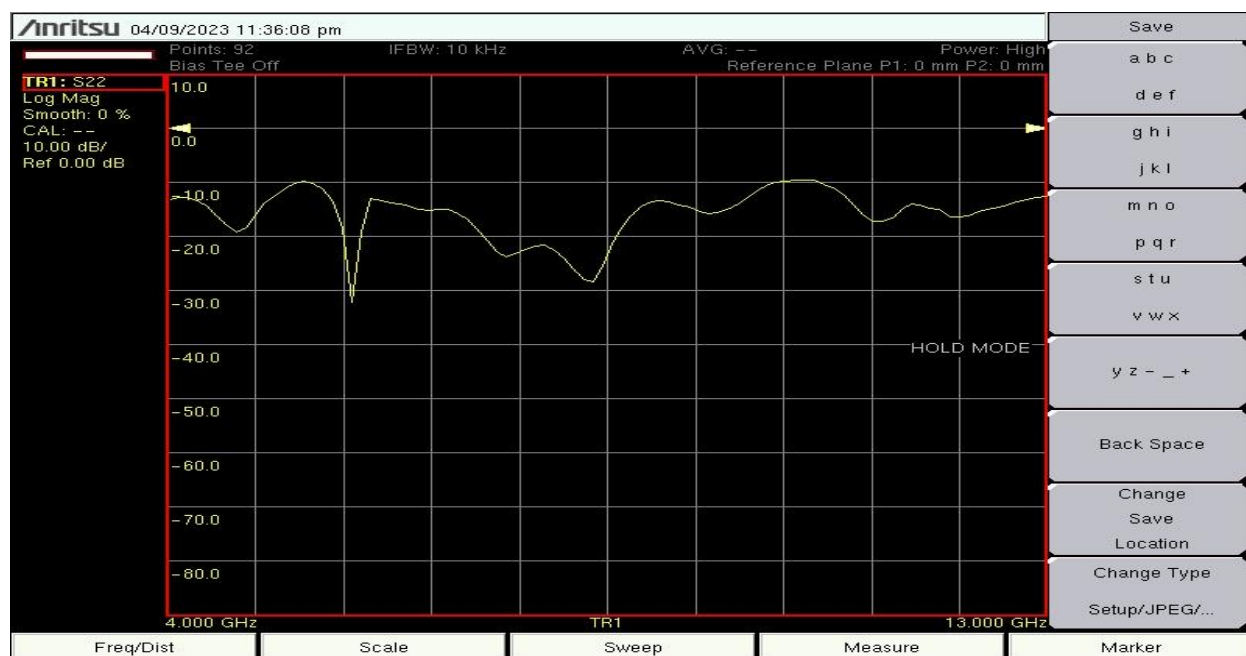


Fig :5.9: S-parameter Plot

5.2.2.SWR PLOT

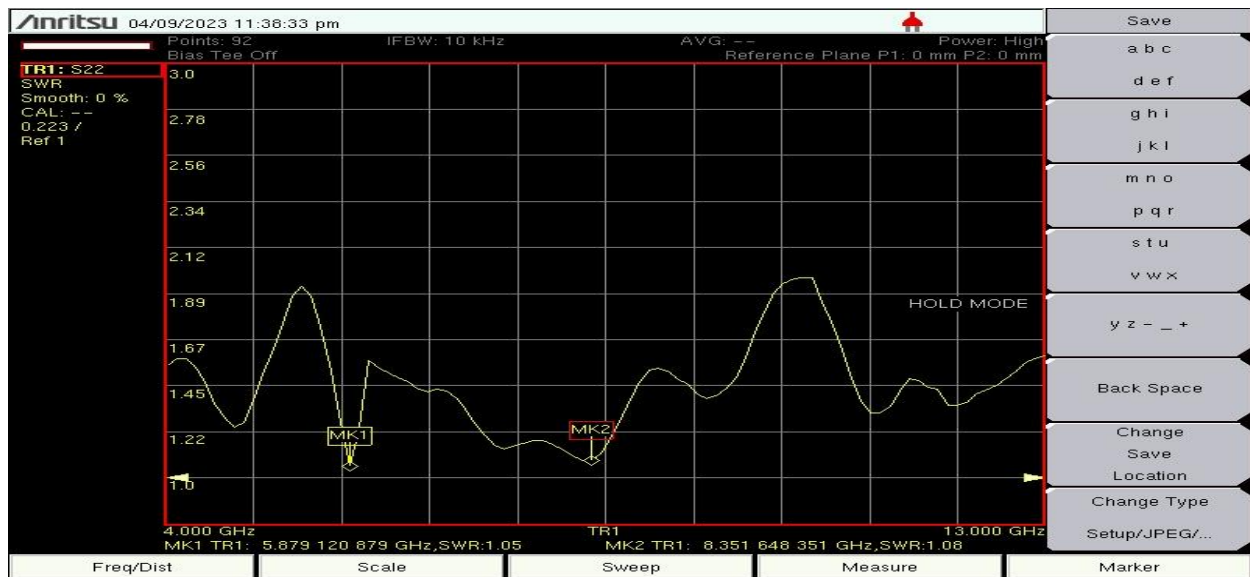


Fig :5.10: VSWR Plot

5.2.3.SMITH CHART

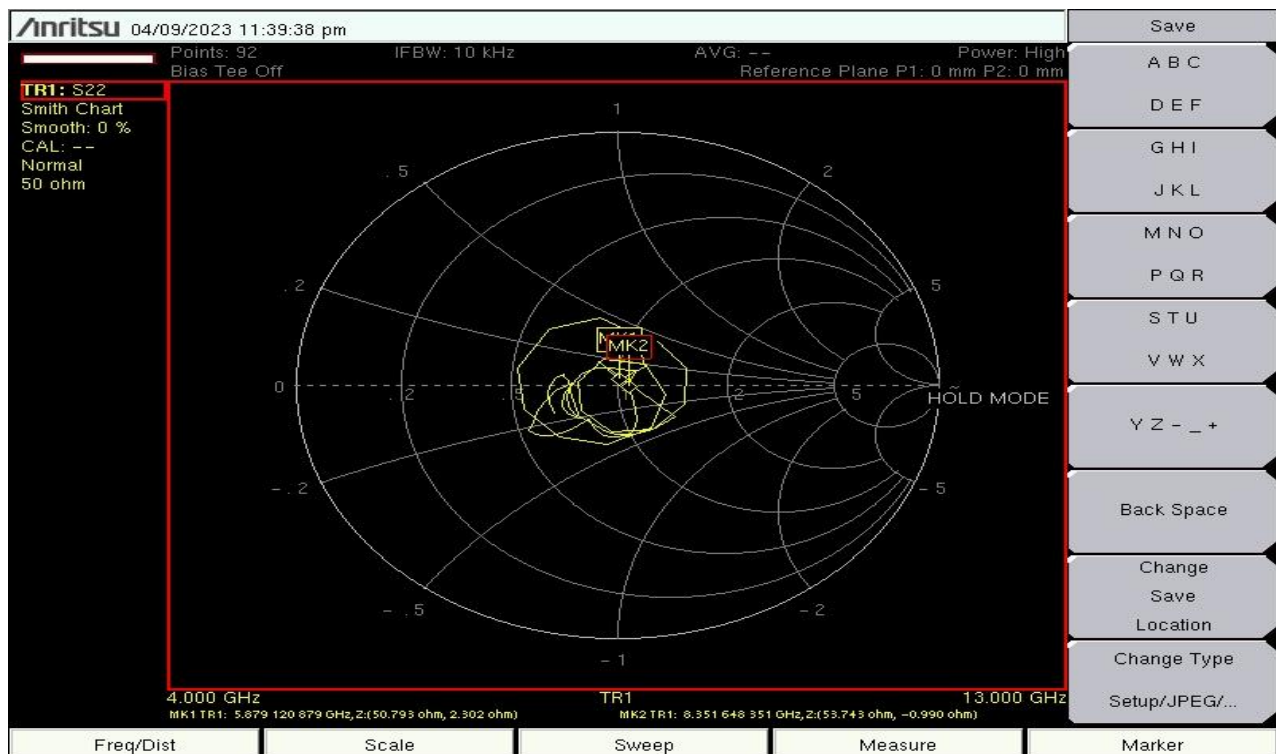


Fig: 5.11: Smith Chart

CHAPTER-6

SUMMARY AND CONCLUSIONS

6.1.OVERALL SUMMARY

The overall working of antenna was understood. The major parameters (such as Return Loss curves, Radiation Patterns, Directivity and Beamwidth) that affect design and applications were studied and their implications understood. The rectangular patch with circular slot antenna is operated at the desired frequency. The patch antenna was simulated (using HFSS) and the desired level of optimization was obtained. It was concluded that the software results we obtained matched the theoretically predicted results.

6.2.CONCLUSIONS

The proposed rectangular patch Antenna with circular slot is designed with FR4 glass epoxy substrate having thickness 3mm and relative permittivity is 4.4. The proposed Microstrip Antenna has a compact size of 58.94mm ×35.9mm ×1.6mm having dual band characteristics covering various bands for wireless communications. The Proposed antenna has return loss of -25.37 and -16.7 dB at resonating frequency of 7.7 and 8.9 GHz respectively and gain of 3.5 dB. This antenna is designed and simulated in HFSS Software and calculated different antenna parameters. This proposed antenna is feed by microstrip line feed technique and it gives satisfactory results of return loss, gain, directivity and radiation pattern.

Hence, it can be used in many applications like wireless communication, satellite communication, space communication, military systems and air traffic control

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