DESIGN OF MICROSTRIPLINE FEED RECTANGULAR MICROSTRIP ANTENNA AT 60/77 GHz FOR DEFENSE APPLICATIONS

Dissertation submitted in fulfillment of the requirements for the Degree of

MASTER OF TECHNOLOGY

IN

ELECTRONICS AND COMMUNICATION

BY

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Enrollment No. 142004

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MAY 2016

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DECLARATION

I hereby declare that the work reported in the M-Tech thesis entitled **"Design of Microstripline Feed Rectangular Microstrip Antenna at 60/77GHz for Defense Purpose"** submitted at **Jaypee University of Information Technology, Waknaghat, India,** is an authentic record of my work carried out under the supervision of **Prof. Ghanshyam Singh.** I have not submitted this work elsewhere for any other degree or diploma.

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CERTIFICATE

This is to certify that the work reported in the M-Tech. thesis entitled "**Design of Microstripline Feed Rectangular Microstrip Antenna at 60/77GHz for Defense Purpose**", submitted by **Deepa Negi** at **Jaypee University of Information Technology, Waknaghat, India,** is a bonafide record of his / her original work carried out under my supervision. This work has not been submitted elsewhere for any other degree or diploma.

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ACKNOWLEDGEMENT

Firstly, I would like to express my deep gratitude to my supervisor **Prof. Ghanshyam Singh** for his encouragement, valuable suggestions and support throughout the project work. Moreover, his discussion on current research issues encouraged me in innumerable ways.

I am also thankful to all my panel members **Prof. S.V Bhooshan, Mr. Salman Raju Talluri, Mr. Mohammed Wajid, Mrs. Meenakshi Sood, Dr. Rajeev Kumar and Miss Pragya Gupta** for their valuable advice, suggestions and hard questions to improve my intellectual maturity.

Finally, I am very much thankful to God for the shower of warm blessings and my parents for their moral support and continuous encouragement while carrying out this study

Date Deepa Negi

ABSTRACT

In this dissertation, the microstripline feed Rectangular Microstrip Antenna is designed at 60/77GHz operating frequency for defence applications by using the U and circular slots for bandwidth enhancement. Firstly we designed our antenna at 60GHz operating frequency in which different parameters are analysed and optimized. In addition to this, to further increase the bandwidth of this antenna we introduced the slots. It has been observed that the slots resulted in the enhancement of the bandwidth and we further observed how different parameters and related to each other. Furthermore, we optimized the results obtained by U and circular slots in the given antenna. The given antenna will prove very useful not only for the military purpose but also for the next generation communication systems. Further use of 60GHz frequency makes this antenna more useless as its being unlicensed all over world and providing very high data rates.

LIST OF ACRONYMS & ABBREVIATIONS

ABC	Absorbing Boundary Conditions
AiP	Antenna in Package
CNC	Computer Numerical Control
CST	Computer Simulation Technology
CFL	Courant Friedrichs-Lewy
DGS	Defected Ground Structure
FDTD	Finite Difference Time Domain
GPS	Global Positioning System
HFSS	High Frequency Structural Simulator
HF	High Frequency
ISI	Intersymbol Interference
MMW	Millimetre-Wave
MIC	Microwave Integrated Circuits
MMIC	Monolithic Microwave Integrated Circuit
PML	Perfect Matched Layer
PIEA	Planar Inverted E Shaped Antenna
RF	Radio Frequency
VSWR	Voltage Standing Wave Ratio
WLAN	Wireless Local Area Network

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CHAPTER 1

INTRODUCTION

1.1 ANTENNAS

Antennas are an indispensable part of any wireless communication system. 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. So, antennas can be thought of as a “transducer” that converts radio waves into electrical currents and voltages and vice versa [41].More specifically, these are devices designed to radiate or receive electromagnetic energy efficiently in a prescribed manner. There are many types of antennas but we used micros trip here because of its light weight, low profile, mechanically robust and low fabrication cost. We further used 60 GHz operating frequency because it is unlicensed, interference immune, high data rates and availability of large bandwidth of 7 GHz. We are designing it, particularly for defence purpose because despite of its many advantages it has a disadvantage of high attenuation due to oxygen absorption and therefore used for short range applications. So the defence troops can use this frequency to communicate among themselves. The only problem we came across this design was its reduced bandwidth, therefore we introduced the U and circular slots to enhance its bandwidth. Moreover military applications are focused on integrating these devices into military clothing in an attempt to enhance their soldier performance, awareness and survivability on the battle field. As the demands for higher data rates and wireless connectivity is increasing day by day, it will result in development of millions of 60 GHz communication devices in future. This designed antenna can be used for the next generation communication systems as well.

1.2 LITERATURE REVIEW

1.2.1 Antenna Definition

A transducer that converts electrical currents and voltages into radio waves and vice versa. A metallic device for radiating and receiving radio waves. According to IEEE definition of antenna, “Antenna is that part of transmitting or receiving system that radiate or receive radio waves” [41]. Regardless of antenna type, all involve the same basic principle that radiation is produced by accelerated (or de-accelerated) charges.

1.2.2Antenna Parameters

It is a graphical representation of the radiation properties of the antenna as a function of the space coordinates.

A field pattern is a graph that describes the relative far field values .E or H, with direction at a fixed distance from the antenna. A field pattern includes a magnitude pattern and a phase pattern.

A power pattern is a graph that describes the relative radiated power density of the far-field with direction at a fixed distance from the antenna.

A radiation pattern shows only the relative values but not the absolute values of the field or power quantity .Hence the values are usually normalised by the maximum value

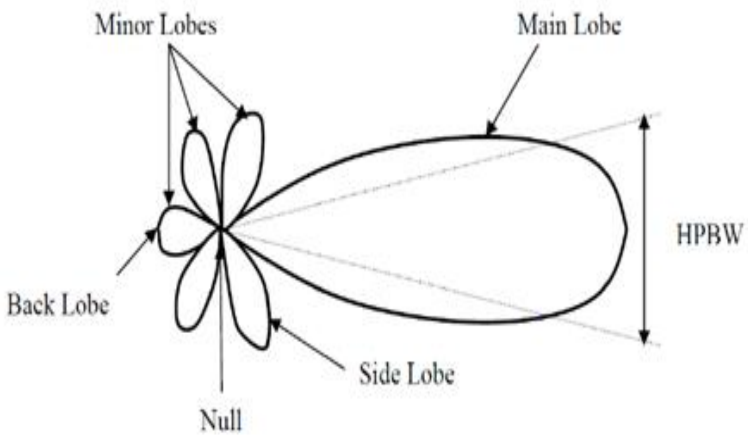

Figure 1.1: Radiation pattern of a generic directional antenna

The radiation pattern can be displayed with a 3D representation; but is common to show it in sections that follow the meridians (constant φ) or parallels (constant θ). These sections can be represented in polar diagram that provides clearer information about the distribution of power in different spatial directions, or Cartesian coordinates that allow us to see important details in antennas with high values of directivity.

The quantity that describes the power of electromagnetic waves is known as Poynting vector:

$$W=E*H \tag{1.1}$$

W = instantaneous Poynting Vector (W/m^2)

E = instantaneous Electrical field intensity (V/m)

H = instantaneous Magnetic field intensity (A/m)

The Poynting vector is power density and the total power crossing over a closed surface is obtained by integrating the Poynting vector over the closed surface given as:

$$P= \oiint W.ds \tag{1.2}$$

Where, P = instantaneous total power (Watts)

Radiation intensity U of antenna is power radiated per unit angle. Its units are watts per steradian. This parameter, in large distances, has the property of being independent of the distance. It is related to the radiated power density as follows:

$$U= r^2 W \tag{1.3}$$

The polarization of an antenna in a given direction is defined as the polarization of the plane wave transmitted by the antenna in that direction. The polarization of a wave transmitted (or received) by an antenna is the locus of the tip of the instantaneous electric field vector E traces out with time at a fixed observation point [41].

- It the locus is a straight line – linear polarization
- If the locus is a circle- circular polarization
- If the locus is an ellipse – elliptical polarization

According to IEEE Standard Definition for Terms for antennas, directivity is the ratio of the radiation intensity of an antenna in a given direction and the radiation intensity averaged over all directions.

$$D = \frac{4\pi U}{p_{rad}} \tag{1.4}$$

D = Directivity (dimensionless)

p_{rad}= Total radiated power (Watts)

The directivity of an antenna can be easily estimated from the radiation pattern of the antenna. An antenna that has a narrow main lobe would have better directivity, then the one which has a broad main lobe, hence it is more directives. Another important performance parameter of antenna is its gain. Though it is quite similar to directivity of antenna but unlike directivity it takes into account of the efficiency of antenna and its directional capabilities. Both are directly proportional to each other.

Absolute Gain of an antenna is defines as "the ratio of radiation intensity of the antenna to the radiation intensity that is obtained by the input power to the antenna."

$$G= \frac{4\pi U}{Pin} \tag{1.5}$$

Where P_{in} is the input power to the antenna

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

$$Z_{in}=R_{in}+jX_{in} \tag{1.6}$$

Z_{in} = the antenna impedance at the terminals

R_{in} = the antenna resistance at the terminals

X_{in} = the antenna reactance at the terminals

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

If the antenna is not perfectly matched to the transmission line and the generator than the electromagnetic waves are reflected back from the antenna and form the standing wave ratio. The quantity that describes the amount of the power that is reflected back is known as reflection coefficient Γ.

The Return Loss (RL) is however a parameter that indicates the amount of power that is “lost” to the load (antenna) and returns back as a reflection [41]. Hence the RL is a parameter similar to the reflection coefficient to indicate how well the matching between the transmitter and antenna has taken place. The RL is given as by

$$RL= -20\log(\Gamma)\ \text{dB} \tag{1.7}$$

For perfect matching between the transmitter and the antenna, Γ = 0 and RL = 0dB which means no power would be reflected back, whereas a Γ = 1 has a RL =infinity dB, which implies that all incident power is reflected. For practical applications, a VSWR of 2 is acceptable, since this corresponds to a RL of -9.54. Its possible values are from 0dB to ∞dB and it is always a positive number.

The total antenna efficiency takes into account the ohmic losses of the antenna through the dielectric material, conduction losses, the reflective losses at the input terminals and losses within the structure of the antenna. [1]

$$e_0= e_r e_c e_d \tag{1.8}$$

Where:

e_0= Total antenna efficiency (dimensionless)

e_r= Reflection efficiency = (1-Γ^2) (dimensionless)

e_c= Conduction efficiency (dimensionless)

e_d= Dielectric efficiency (dimensionless)

The antenna bandwidth is defined as the "range of frequencies with in which the antenna conform to the specific standard with respect to some characteristics". The antenna characteristics that are used to determine the bandwidth can be input impedance, radiation pattern Beam width polarization, side lobe level or gain. The bandwidth of a broadband antenna can be defined as the ratio of the upper to lower frequencies of acceptable operation. The bandwidth of the antenna is inversely proportional to the Beamwidth of the antenna.

$$BW_{broadband} = f_H f_L \quad (1.9)$$

The bandwidth of a narrowband antenna can be defined as the percentage of the frequency difference over the centre frequency.

$$BW_{narrowband}\ (\%) = \frac{f_H - f_L}{f_c} \quad (1.10)$$

f_H =-upper frequency

f_L = lower frequency

f_c = center frequency

One method of judging how efficiently an antenna is operating over the required range of frequencies is by measuring its VSWR or RL. A RL ≤ −10dB) ensures good performance.

For a linearly polarized antenna, performance is often described in terms of its principal E- and H-plane patterns. The E-plane is defined as "the plane containing the electric field vector and the direction of maximum radiation," and the H-plane as "the plane containing the magnetic-field vector and the direction of maximum radiation.

- The magnitude of reflection coefficient is from 0 to 1.
- When the transmitting antenna is not match, that is, Z_A is not equal to Z_0, there is a loss due to reflection (return loss) of the wave at the antenna terminals. When expressed in dB ,it is always a negative number
- Sometimes we use S11 also for representation.

Voltage standing wave ratio (VSWR) is also a common parameter used to characterize the matching property of a transmitting antenna. The VSWR results in the standing waves which are still and these do not carry any energy.

- Possible values of VSWR are from 1 to ∞.
- VSWR = 1 means perfectly matched, VSWR = ∞ completely mismatched.

The space surrounding an antenna is usually divided into two regions:

- Near field region
- Far field region

  Far field is defined as that region of the field of an antenna where the angular field distribution is independent of the distance from the antenna. This region is also called as the Fraunhoufer Region .In this region, the field components are essentially transverse and the angular distribution is independent of the radial distance where the measurements are made.

  The fields immediately surrounding the antenna and the far field region is known as the near field region. This is again divided into two sub regions as reactive near field and radiating near field according to their characteristics.

1.3 RELATED WOK

1.3.1 Related Work on 60GHz Frequency

This paper presents a high-gain grid array antenna (GAA) on FERRO A6M low temperature co-fired ceramic (LTCC) for 60-GHz antenna-in-package (AiP) applications. It has proved to be a capable candidate for 60GHz AiP applications [1]. This paper proposes a cost-effective antenna-package suitable for the mobile terminal of the wireless file-transfer system. The antenna-package has the end-fire radiation from the open-end post-wall waveguide built in the side of the package [2].In this paper, we present a high efficiency antenna for 60 GHz low-cost packaged modules. This antenna is fabricated using IPD™ technology which is flip-chipped on a PCB Taclamplus substrate [5].In this paper, the novel ladder-like directors are proposed and investigated for antenna gain and bandwidth enhancement. The proposed design with compact size and high gain is highly promising as a good candidateforthe60-GHzwireless applications [6].This study developed a dual-resonant slot-patch antenna design that functions at 60 GHz on an LTCC substrate. The inverted microstrip centre-fed structure was designed for easy feeding and impedance matching. Themeasuredresultsshowthattheunlicensed60-GHz band can be fully covered with a maximal gain of 9 dBi and a wide bandwidth of 23% [8].A low cost technology based on FR4 and thin flexible Pyralux substrate to develop membrane antennas/array with high efficiency and wide bandwidth for high speed V-band communication systems is proposed in this paper [36].A new wide band magneto-electric dipole antenna is proposed for 60-GHz millimetre-wave applications. This antenna features wideband and stable gain characteristics. The low cross polarization and low back radiation are obtained owing to its complementary antenna structure [10]. This paper aims to give the most up-to-date status of the 60 GHz wireless transceiver development, with an emphasis on realizing low power consumption and small form factor that is applicable for mobile terminals [38].

1.3.2 Related Work on 77GHz Frequency

In this paper, switch array antenna is designed at 77GHz for automotive FMCW radar to detect the moving targets and NFR targets. The outdoor test is also performed successfully, which shows that multiple false targets are eliminated with the proposed method thus enhancing the detection performance of the radars [28].In this paper the co-integration of the antenna and the silicon-based monolithic microwave integrated circuit (MMIC) is discussed and to simplify the design and the manufacturing of radio frontends significantly. The proposed SiP is focused on 77-GHz [29].In this paper, the reported phased-array receiver, combined with the phased-array transmitter forms the first fully integrated silicon based phased-array transceiver with on-chip [30].In this paper a low cost multilayer antenna is designed for the next-generation automotive radar systems at millimetre waves. A total efficiency higher than 50% has been reported and a very promising radiation performance [31].A 77GHz lens antenna is designed for automotive radar applications. As compared to the previous lens antennas, the presented design has the advantages of excellent electrical performance and a low profile in combination with a thin lens. The electrical performance is also better than any other lens antennas found in the literature [32]. In a complete LTCC antenna concept for highly integrated millimetre-wave radar systems including the housing is presented. With the presented housing design, the antenna radiation pattern is optimized for radar measurements in short distances in a minimum range of half a wavelength due to the reduced phase error and the small beam width in E- and H-planes [33]. In this paper, a 3-D integrated 77-GHz automotive radar front-end is presented using EMWLP process and TMV as the vertical interconnect.[35] A high-gain Bull's-Eye leaky-wave horn antenna working at 77 GHz with sinusoidal profile has been designed. The influence of the number of periods on the gain and beam width is numerically investigated. Experimental measurements show a high gain of 28.9 dB, with low side lobe level and a very narrow beam width in good agreement with results obtained from simulations [34].

1.3.3 Related Work on Introducing Slots in Microstrip Antenna

In this paper, the design and analysis of circular microstrip patch antenna with different slot for the WLAN & Bluetooth Application is presented and out of all square slot gave the best results at operating frequency 2.17GHz, without changing the permittivity and height of the substrate [11].In the present work the rectangular micro strip antenna is loaded by triple rectangular slot and dual circular slot. This slot loaded antenna provides dual frequency band.

Since the micro strip antenna suffers from narrow bandwidth hence the present work provide an alternative solution to increase the bandwidth. The proposed slot loaded Micro strip antenna is fed by 50? Micro strip feed line [12].Design and development of slotted rectangular microstrip antenna is proposed for hepta band operation with notch-band property. Two rectangular slots are placed on the radiating patch from its vertical edges for providing different surface current paths so as to produce six resonant modes [13]. A new broadband and dual band circular slot cut modified circular microstrip antenna is analysed and proposed. The parametric study to analyse the effects of circular slot which realizes broader bandwidth is presented. The circular slot creates two additional resonant modes near the fundamental TM11 mode resonance frequency of the equivalent circular patch and yields bandwidth of 202 MHz (8%) [14].The broadband E-shaped microstrip antenna is realized by cutting pair of rectangular slots on one of the radiating edges of rectangular microstrip antenna. While designing an E-shaped antenna at given frequency, the slot length is taken to be nearly quarter wave in length. The proposed analysis gives an insight into the functioning of widely used E-shaped antenna, and it will help in designing them in given frequency band [17]. In this paper a multifunctional microstrip antenna is designed, fabricated and experimentally verified for operation in AWS, GSM, WiMAX and WLAN bands. This microstrip patch antenna has two U-shaped slots to achieve the dual wideband operation required to meet these specifications [19].This paper presents a novel dual-band planar inverted-e-shaped antenna (PIEA) using defected ground structure (DGS) for Bluetooth and wireless local area network (WLAN) applications [39].In this paper, an asymmetric U-slot patch antenna with low probe diameter is presented. It will be shown that reduction in probe diameter causes in reduction in bandwidth. One of the characteristics of this antenna is keeping the bandwidth in 30% in spite of reduction in antenna size [40].

1.4 PROBLEM STATEMENT

In this we have designed the rectangular microstrip antenna using microstrip line feeding technique at 60/77 GHz for defence applications .We have particularly used the microsrtip antenna in this because of its small size and light weight ,it also supports both linear and circular polarization, therefore providing polarization diversity. Microstrip antenna is considered to be conformal in the nature, which means it easily adapts to the given shape of the material because of this reason it is used in the fighting aircrafts. Mainly we have developed it for the defence purpose because despite of having lots of advantages it suffers from the problem of low gain and bandwidth. Therefore to increase the bandwidth of the antenna we have introduced the slots in it .These slots have introduced the dual band in the present antenna namely V and W band. We are mainly using it for the defence purpose because at 60 GHz, we suffer from the problem of the oxygen absorption because of which it cannot travel large distance and has weak penetration. Therefore we have developed it for defence applications where the troops can deploy their communication without giving their position to the enemy. The signal cannot travel far beyond its intended user because of oxygen absorption.60 GHz is also considered totally interference immune because of its interference immune nature [45]. Further both 60 and 77 GHz are unlicensed and provides very high data rates. Therefore this antenna proves to be very helpful not only for the defence purposes but also for the next generation communication.

1.5 OBJECTIVE OF DISSERTATION

We are designing the microstrip patch antenna at 60 GHz for defence applications. The main idea of using microstrip antenna at 60 GHz is because of its small profile, light weight and mechanically robust nature. We selected 60 GHz because the bands around this are worldwide available, provides high data rates, unlicensed and has a very important property of oxygen absorption which makes it ideal for short range communication and totally immune to interference. In defence it will help troops to deploy their communication in totally interference immune environment and at higher speed. Our main goals are:

- To design a rectangular microstrip patch antenna at 60GHz operating frequency for defence applications.
- To achieve specific and desired performance characteristics at a specified operating frequency.
- To correctly calculate the antenna parameters in different environmental conditions according to our requirements.
- To design an antenna which is cost effective, mechanically robust, strengthens our defence system and fulfils the increasing demand for higher data rates.
- To validate and verify our calculated parameters using Computer Simulation Technology (CST)
- To utilize the limited natural RF spectrum in our best possible manner
- To solve the problem of lower bandwidth in 60GHz microstrip antenna by introducing U and circular slots in the antenna structure.

1.6 ORGANISATION OF DISSERTATION

The rest of the dissertation is organised in the following manner.

Chapter 2

The chapter 2 deals with the microstrip antenna details. Its feeding techniques, advantages, disadvantages, different method of analysis and its designing parameters. In this we have also explained the importance of 60 GHz and its various features, we further explained the 77 GHz frequency.

Chapter 3

The chapter 3 deals with overall designing of the 60 GHz microstrip antenna. It operates on the single band of the 57-64 GHz of the V band. It further includes the parameters calculated, the simulation results and finally the conclusion.

Chapter 4

The chapter 4 deals with the dual band microstrip antenna, in which we have introduced the slots in the given patch namely the U slot and the circular slot. These two slots resulted in the overall bandwidth improvement. Designing parameters and simulation results of the dual band antenna are discussed, further the parameters are optimized for better results. At last conclusion is written.

Chapter 5

It includes the overall conclusion and future scope of the dissertation. Future work which can be done to further increase the performance of the given antenna.

CHAPTER 2

MICROSTRIP ANTENNAS

2.1 INTRODUCTION

Microstrip antennas are planar resonant cavities that leak from their edges and radiate. Printed circuit techniques can be used to etch the antennas on soft substrates to produce low-cost and repeatable antennas in a low profile [43]. The antennas fabricated on compliant substrates withstand tremendous shock and vibration environments. Manufacturers for mobile communication base stations often fabricate these antennas directly in sheet metal and mount them on dielectric posts or foam in a variety of ways to eliminate the cost of substrates and etching. This also eliminates the problem of radiation from surface waves excited in a thick dielectric substrate used to increase bandwidth. Basic antenna radiates due to current distribution but in case of microstrip antennas it is the advantageous voltage distribution due to fringing fields which results in the patch radiation.

Microstrip patch antenna consists of a radiating patch on one side of a dielectric substrate which has a ground plane on the other side as shown below [43]. 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 photo etched on the substrate, along with their feeding networks. Microstrip circuits make a wide variety of antennas possible through the use of the simple photo etching techniques. The patch antenna is also called as the “voltage radiator”.[48], [50], [24].

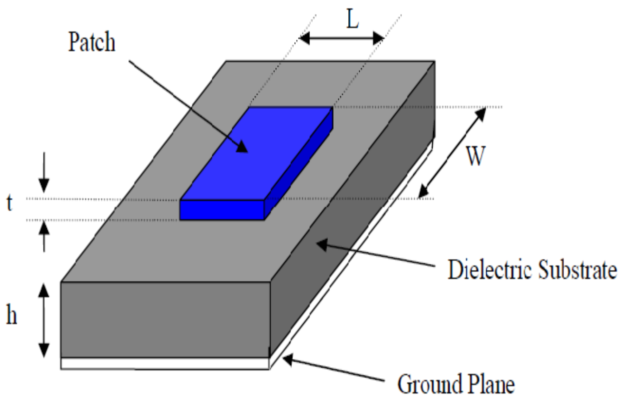

Figure 2.1: Microstrip Patch Antenna

In order to simplify analysis and performance predictions we use rectangular patch , the patch can be square, circular, triangular, and elliptical in shape .For a rectangular patch, the length

L of the patch is usually $0.3333\lambda o < L < 0.5\lambda o$, where λo is the free-space wavelength. The patch is selected to be very thin such that $t << \lambda o$ (where t is the patch thickness). The height h of the dielectric substrate is usually $0.003\,\lambda o \leq h \leq 0.05\lambda o$. The dielectric constant of the substrate is typically in the range $2.2 \leq \varepsilon r \leq 10$.

2.1.1 Advantages of Microstrip Antenna

Important advantages are:

- 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.[59], [60],[56].
- 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.

2.1.2 Disadvantages of Microstrip Antennas

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

Microstrip patch antennas have a very high antenna quality factor (Q). Q represents the losses associated with the antenna and a large Q leads to narrow bandwidth and low efficiency [43], [59]. Q can be reduced by increasing the thickness of the dielectric substrate. But as the thickness increases, an increasing fraction of the total power delivered by the source goes into a surface wave. This surface wave contribution can be counted as an unwanted power loss since it is ultimately scattered at the dielectric bends and causes degradation of the antenna characteristics. However, surface waves can be minimized by use of photonic band gap structure. Other problems such as low gain and low power handling capacity can be overcome by using an array configuration for the elements.

2.1.3 Applications

- Used in telecommunication
- Used in aircraft, spacecraft & missiles

- GPS system
- Telemetry

2.1.4 Remedies

- Low power and low gain can be overcome by using array configuration.
- Surface wave associated limitations such as poor efficiency,
  Increased mutual coupling, reduced gain and radiation pattern can be overcome by using photonic crystals
- The band width can increased by using some special feeding techniques, introducing slots and increasing the height and width.

2.2 DIFFERENT FEEDING TECHNIQUES

Microstrip antenna are resonators whose fields have to be excited by using the feed lines [42].Microstrip patch antennas can be fed by a variety of methods. These methods can be classified into two categories-

1) Contacting
2) 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).

2.2.1 Microstrip-line Feed

In this type of feed technique, a conducting strip is connected directly to the edge of the microstrip patch as shown below. 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. 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 [41], [43], [44]. 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 modelling as well as impedance matching. However as the thickness of the dielectric substrate 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.

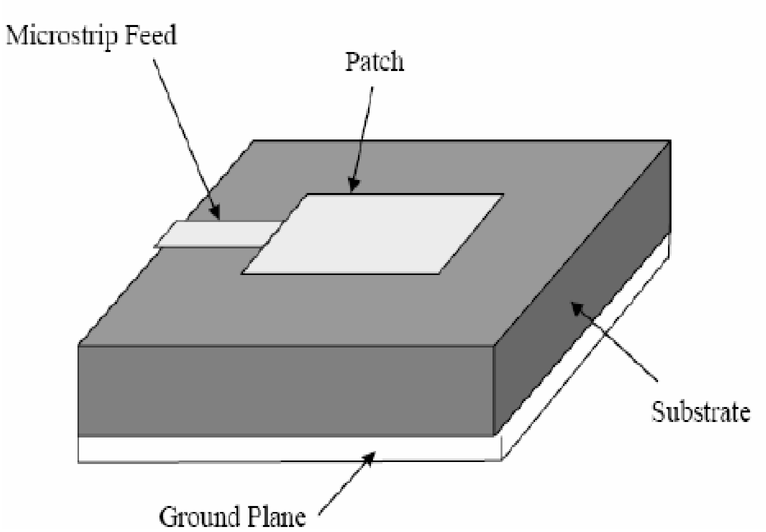

Figure 2.2: Microstripline Feed

2.2.2 Coaxial Feed

The Coaxial feed or probe feed is a very common technique 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 [22]. However, its major disadvantage is that it provides narrow bandwidth and is difficult to model since a hole has to be drilled.

This feed method is easy to fabricate and has low spurious radiation. However, its major disadvantage is that it provides narrow bandwidth and is difficult to model since a hole has to be drilled in the substrate and the connector protrudes outside the ground plane, thus not making it completely planar for thick substrates ($h > 0.02\lambda_o$). Also, for thicker substrates, the increased probe length makes the input impedance more inductive, leading to matching problems. It is seen above that for a thick dielectric substrate, which provides broad bandwidth, the microstrip line feed and the coaxial feed suffer from numerous disadvantages.

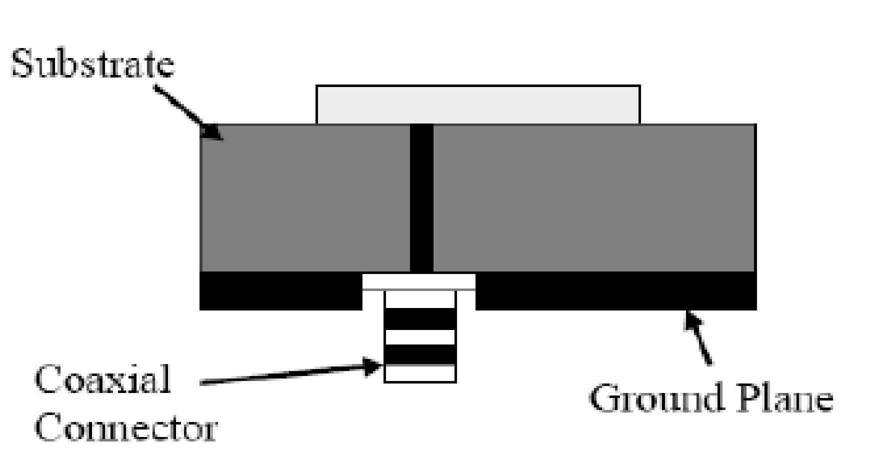

Figure 2.3: Coaxial Feed

2.2.3 Proximity Coupled Feed

This type of feed technique is also called as the electromagnetic coupling scheme. 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.

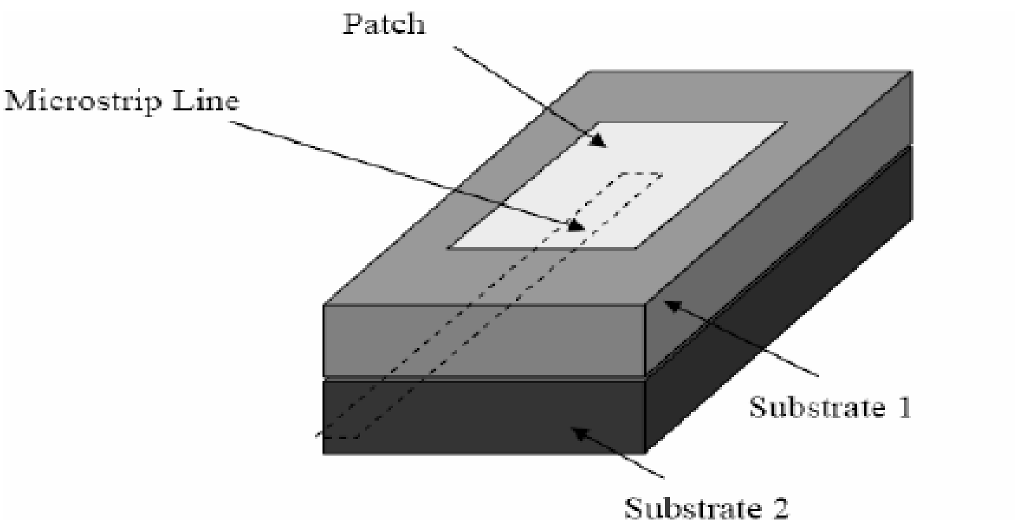

Figure 2.4: Proximity Coupled Feed

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.

2.2.4 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 below. 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 centred 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.

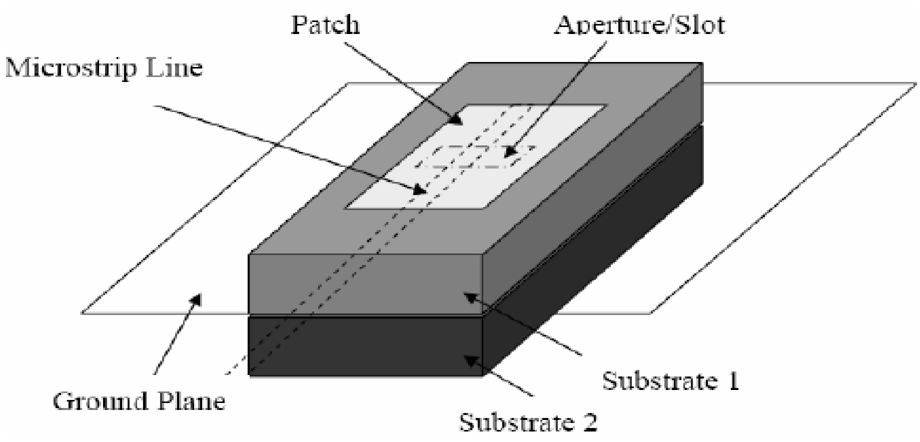

Figure 2.5: Aperture Feed

2.3 DIFFERENT METHODS OF ANALYSIS

- Transmission line model
- Cavity model
- Finite Difference Time Domain Method

- Method Of Moments
- Spatial and Spectral Domain

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

2.3.1 Transmission Line Model

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

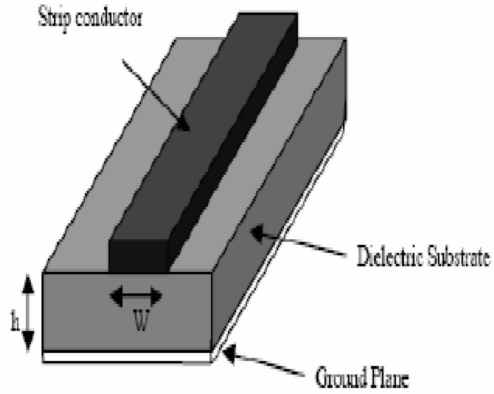

Figure 2.6: Microstrip Line

Most of the electric field lines reside in the substrate and parts of some lines in air. As a result, this transmission line cannot support pure transverse electric- magnetic (TEM) mode of transmission, since the phase velocities would be different in the air and the substrate. Instead, the dominant mode of propagation would be the quasi-TEM mode [44], [43]. Hence, an effective dielectric constant must be obtained in order to account for the fringing and the wave propagation in the line.

2.3.2 Cavity Model

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

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

2.3.3 Full Wave Analysis

Full wave method have received increasing attention due to their rigor and higher accuracy. This is based on Somerfield type integral equation and solution of Maxwell equation in time domain. Prominent numerical methods include integral equation analysis in spectral domain, integral equation analysis in space domain and the finite difference time domain (FDTD) approach [44]. The methods based on integral equation make one important assumption: the dielectric substrate and the ground plane are infinite in extent. The solution are therefore more accurate when the substrate and ground plane are several wavelength long. The FDTD technique is more efficient for finite sized antenna. Various important features of Full Wave Analysis are:

- Predicts the characteristics of Microstrip antennas at higher frequencies.
- It reduced the order of the coefficient matrix and computations as well.
- Used for calculation of resonant frequency and radiation characteristics and pattern.
- Versatile as it is used for all types of antenna structures.
- It provides more accuracy than any other method.
- Completeness, as it includes the effects of all types of losses.
- These are numerically intensive, therefore requires careful programming to reduce computation cost.

2.3.4 Finite Difference Time Domain

FDTD is the most suitable numerical analysis techniques for printed antennas. FDTD is found to be versatile because any embedded semiconductor device in the antenna can be included in the analysis at the device-field interaction level. This leads to an accurate analysis of active antennas. Maxwell's equations are solved as such in FDTD, without analytical pre-processing, unlike the other numerical techniques. Therefore, almost any antenna geometry can be analysed. However, this technique is numerically intensive, and therefore require careful programming to reduce computation cost.

The FDTD analysis of open region problems such as antennas necessitates the truncation of the domain to conserve computer resources. The truncation of the physical domain of the antenna is achieved through absorbing boundary conditions, either analytical ABC or material ABC. Material ABC in the form of PML can achieve a substantial truncation of domain with very low reflection. The design of PML should be compatible with the FDTD scheme employed for the rest of the antenna. A number of PML formulations are available. These are split-field and non-split-field PML [44], [43]. Non split-field types are convenient for coding and are therefore preferred. Of the various PML formulations available now, uniaxial PML looks promising. All the FDTD algorithms suffer from computational error, and the amount of error is related to the space and time step sizes employed. The error is quantified in the form of numerical dispersion.

The FDTD method belongs in the general class of grid-based differential numerical modelling methods (finite difference methods). The time-dependent Maxwell's equations (in partial differential form) are discretized using central-difference approximations to the space and time partial derivatives. The resulting finite-difference equations are solved in either software or hardware in a leapfrog manner: the electric field vector components in a volume of space are solved at a given instant in time; then the magnetic field vector components in the same spatial volume are solved at the next instant in time; and the process is repeated over and over again until the desired transient or steady-state electromagnetic field behaviour is fully evolved.

Some of important features are:

- FDTD is a popular numerical method, because of relatively easy implementation.
- No analytical pre-processing and modelling is required.
- Applied to all shapes of geometries.
- E and H fields are calculated everywhere in the computational domain.
- Uses absorbing boundary conditions to simulate unbounded computational domain.
- FDTD belongs to grid-based differential numerical modelling methods.
- Time and space steps must satisfy CFL condition
- To make computational domain finite we use ABCs and special absorbing materials like PML, which are used to implement absorbing boundary conditions.
- E and H fields are time-stepped or updated resulting in a marching-in-time process
- Allows users to specify the materials at all points within the computational domain.

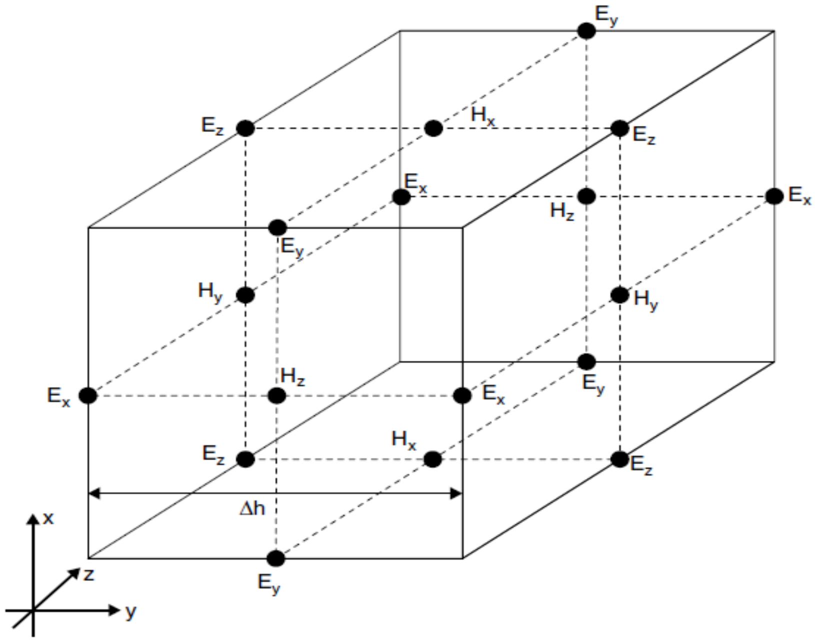

Figure 2.7: Geometry of Yee's cell used in FDTD analysis

2.4 IMPORTANCE OF 60GHz FREQUENCY

Millimeter-wave (MMW) technology for the 60-GHz band is one of the most exciting opportunities for circuit, antenna, and communication system engineers over the next decade [37]. [36]. 60 GHz is, in fact, the beginning of a trend of escalating carrier frequencies that will deliver unprecedented data rates, several tens of gigabits per second, allowing uncompressed high-definition media transfers, sensing and radar applications, and virtually instantaneous access to massive libraries of information. Consumer demand for these applications will result in millions of 60-GHz communication devices produced and sold in future.

The millimeter-wave band, especially the unlicensed spectrum at the 60 GHz carrier frequency, is at the spectral frontier of high-bandwidth commercial wireless communication systems. Compared with microwave band communication, spectrum at 60 GHz is plentiful (frequencies of 57–64 GHz are available in North America and Korea, 59–66 GHz in Europe and Japan), but attenuation is more severe (20 dB larger free space path loss due to the order of magnitude increase in carrier frequency, 5–30 dB/km due to atmospheric conditions, and higher loss in common building materials). These characteristics make 60 GHz communication most suitable for close-range applications of gigabit wireless data transfer. In addition to providing massive bandwidth for future WPANs and WLANs, adoption of wireless connectivity will soon be necessary, which is evident from the consideration of skin and proximity effects, substrate losses, and dispersion of wired interconnects at carrier frequencies of 60 GHz to hundreds of GHz.Various important features of 60GHz are:

- 60-GHz millimeter-wave (57-64GHz)band for unlicensed use and worldwide available
- Has path loss and used for short range applications
- High data rates of around 25Gbps
- It has dense frequency reuse pattern
- Higher frequency leads to smaller size of components
- It uses high gain and wide area coverage antennas
- MMW band has large spectral capacity, compact antenna structure and allows large data transfers than any other antenna and also provides 20 times more bandwidth than any other
- Signals are attenuated due to oxygen absorption, this feature gives it interference immunity and high security.
- Used for indoor and underground communications
- Used in dense populations, radio astronomy, microwave and defense
- Large spectrum of 7GHz is available
- MMW waves travel solely by line of sight, are blocked by building walls and gets attenuated.
- It comes in the V band of the Millimeter wave band which ranges from 50 to 75 GHz
- It suffers from the problem of weak penetration.

5.1 Various Challenges

5.1.1 Antennas

60 GHz chipsets exploit the short-carrier wavelength by incorporating antennas or antenna arrays directly on-chip or in-package. For the simplest and lowest-cost solutions, single antennas are attractive [45], [37]. Single-antenna solutions, however, must overcome the challenges of low on-chip efficiencies (typically 10% or less) and in-package antennas must overcome lossy package interconnects (standard wire-bonds are limited to under 20 GHz).

5.1.2 Highly Integrated Tx and Rx for 60 GHz

The mm-scale wavelength of 60 GHz (5 mm in free space, and smaller on semiconductors and substrates having permittivity greater than 1.0) allows unprecedented levels of integration of analog and microwave components such as transmission lines and disparate monolithic microwave integrated circuits (MMICs) onto a single chip or package.

5.1.3 Modulation and Equalization

Digital communications at 60 GHz provides unique design trade-offs due to millimeter-wave hardware limitations and channel propagation characteristics. The wide operating bandwidth results in tight digital processing constraints and severe frequency-selective signal distortion known as inter symbol interference (ISI). Millimeter-wave modulation must also consider the increased presence of phase noise relative to microwave frequencies and limited output power, which makes nonlinear operation attractive.

2.5 77GHz FREQUENCY

The 77GHz of frequency also lies in the millimetre wave band. It is the part of the W band which ranges from(75-110)GHz.77GHz is also an unliesenced band which is presently used for the radar and automobile applications[35] .It also provides high data rates like the 60GHz band. Greater capability for distinguishing between objects is the main advantage of the 77 GHz frequency in the radar application, therefore providing high resolution. The 77-GHz band consists of two sub-bands, 76-77GHz for narrow-band long-range radars and 77-81GHz for short-range wideband radar.

2.5.1 Present Uses of 77GHz Band

Wireless technologies are helping to boost the convenience and safety of modern automobiles by taking advantage of unused frequencies [34]. So far, achieving reliable performance at 77 GHz has not been a hurdle for a growing number of IC manufacturers and high-frequency companies supporting automotive RF/microwave applications. The frequency band from 76 to 77 GHz has proven to be attractive for a number of automotive radar-based safety applications, including for adaptive cruise control (ACC), blind-spot detection (BSD), emergency braking, forward collision warning (FCW), and rear collision protection (RCP). Free scale's 77 GHz silicon germanium chipset advances automotive safety by enabling vehicles to sense potential crash situations. This radar solution provides long- and mid-range functionality, allowing automotive systems to monitor the environment around the vehicle to help prevent crashes.

2.5.2 Advantages of 77 GHz Technology

This technology is ideal for automotive safety systems and is also applicable for aerospace, military and industrial markets.

• Multi-mode, multi-application capability [30], [29].

• Simultaneous long and mid-range functionality: It allows one radar to be used for multiple safety systems like Adaptive cruise control, Headway alert, Collision warning, Mitigation and brake support.

• Solid-state technology: It provides highest level integration. Most advanced SiGe technology with multi-channel transmitter and receiver chips. It has no moving parts and extremely reliable.

• Mixed-signal technology

• Class-leading performance and durability

CHAPTER 3

SINGLE BAND MICROSTRIP ANTENNA

3.1 INTRODUCTION

Designing of the rectangular microstrip patch antenna at 60GHz operating frequency, includes the single frequency band. In this we have used the microstripline feeding technique because of its being planar and simpler in its structure. The frequency band we are taking is from 57-64 GHz and 60GHz is our operating frequency. As 60 GHz frequency is unlicensed and provides high data rates, therefore we are using this frequency. It lies in the V-Band of the millimetre band, it is made unlicensed everywhere and therefore it is free from any congestion or traffic. The rectangular patch antenna is approximately a one-half wavelength long section of rectangular microstrip transmission line. The resonant length of the antenna is slightly shorter because of the extended electric "fringing fields" which increases the electrical length of the antenna slightly [43], [41]. The microstrip antennas are inherently linearly polarized. We are particularly interested in the rectangular microstrip antenna because it has highest impedance bandwidth and comparatively easy analysis and fabrication as compared to the others.

3.2 DESIGNING OF 60GHz MICROSTRIP ANTENNA

For a good antenna performance, a thick dielectric substrate having a low dielectric constant is desirable since this provides larger bandwidth and better radiation. But as we increase the thickness of the substrate the size of antenna increases. So there is always a tradeoff between the antenna dimensions and the parameters. We cannot say particular parameters to be ideal, a designer has to achieve his specified and desired performance characteristics at a specified operating frequency [59]. Already known parameters are dielectric constant, thickness of substrate, resonant frequency and loss tangent. While designing this antenna we have optimized the dielectric constant, length of the microstripline. To design a particular microstrip antenna we follow the following steps:

3.2.1 Substrate Selection

We need to select a substrate with appropriate thickness and loss tangent. Dielectric constant value can vary from 1.07 to 10 according to our requirements [43]. Commonly used substrates are Honey comb, Duroid, Quartz and Alumina. Ideally dielectric constant is to be taken less than or equal to 2.5. While designing our antenna it was observed that as we reduce the value of the dielectric constant the given dip or the curve shifts towards the right hand side giving the more accurate result as we have used 2.3 as the substrate material but by reducing the values to 2.28 or less gave more accurate results.

3.2.2 Element Width and Length

These two calculations are very important. As length of antenna is called as the resonant dimension and width of the antenna should be equal to 1.5 of the length dimension [43]. Many other parameters like resonant frequency, radiation pattern, input impedance and bandwidth depends on these two parameters.

$$L = \frac{c}{2f_0\sqrt{\varepsilon_r}} \tag{3.1}$$

The effective dielectric constant

$$\varepsilon_{eff} = \frac{\varepsilon_{r+1}}{2} + \frac{\varepsilon_{r-1}}{2}\left(1 + 12\frac{h}{w}\right)^{-1/2} \tag{3.2}$$

$$W = \frac{C}{f_0\sqrt{(\varepsilon_r+1)/2}} \tag{3.3}$$

Where, c is the velocity of light in free space, f_0 is the resonant frequency and ε_r is the dielectric constant of the substrate. As in this antenna has to be designed in such a way that it operates in 57 GHZ to 64 GHz. A middle value i.e. 60 GHz is chosen as the resonant frequency. The RT/duroid 5870 having dielectric constant 2.3,loss tangent 0.0005 and thermal conductivity o.22 is chosen as the substrate material and a Matlab code is used for its length and width calculations. The results which we finally get are all optimized according, to our own requirements.TM_{010} is the dominant mode in the rectangular patch antenna. In TM pmn p=o because as h is very small and the fields along the height are essentially constant. In case of circular patch antenna TM_{011} is the dominant mode. While designing our antenna we observed that as feed point is shifted towards to the left gave more accurate results. Presently the feed point location we have used is 0.4 .Now the values which we have calculated for microstripline was width equals to 0.11629 and length 1.2 but we observed that by reducing the value of the microstrip line width to 0.05 gave more optimized results and also resulted in the better impedance matching. The effective dielectric constant should be more than air and lesser than the substrate dielectric constant.

3.2.3 Simulation Using CST (computer simulation technology) Microwave Studio

We used this software to verify the numerically calculated antenna parameters. We saw simulation results for different dielectric constants of the substrate and how the various simulated results are changing with respect to the variations in different antenna parameters. CST is a company which develop software's for the simulation of electromagnetic fields in arbitrary three dimensional structures. There are many modules of CST dedicated to specific application areas. It was founded by Thomas Weilan in 1992.In our thesis we have used CST Microwave Studio. It enables fast and accurate analysis of HF devices. It is user friendly and enables you to choose most appropriate method for designing and optimization of devices operating in a wide range of frequencies. It gives you an insight into electromagnetic behavior of your high frequency design. CST is more user friendly than HFSS. Its time domain solver is more accurate, fast and easy. However both CST and HFSS gives almost similar results. CST offers accurate, efficient computational solutions for electromagnetic design and analysis. It is user-friendly and enables you to choose the most appropriate method for the design and optimization of devices operating in a wide range of frequencies. The main product of CST STUDIO SUIT, which comprises various modules dedicated to specific application areas. There are modules for microwave, radio frequency, optical applications, summarized in CST MICROWAVE STUDIO, low frequency (CST EM STUDIO), PCB and packages (CST PCB STUDIO), cable harnesses (CST CABLE STUDIO), temperature and mechanical stress (CST MPHYSICS STUDIO) and for the simulation of the interaction of charged particles and electromagnetic (CST PARTICLE STUDIO). All modules are integrated with a system and circuit simulator (CST DESIGN STUDIO).

3.3 SIMULATION RESULTS

In this we have used CST (computer simulation technology) Microwave Studio for designing microstripline feed rectangular microstrip antenna at 60 GHz operating frequency and 5mm operating wavelength for defense applications. The parameters used in this are optimized according to the requirements of the designer. Various Parameters of the microstripline feed rectangular patch antenna at 60 GHz frequency are:

Table 3.1: Various Dimensions of 60 GHz Rectangular microstrip antenna

Dielectric constant	2.3
Loss tangent	0.0005
Height of substrate	0.04 mm
Length of patch	1.5978 mm
Width of patch	1.9174 mm
Height of patch	0.01 mm
Width of microstripline	0.05 mm
Length of microstripline	1.2 mm
Frequency of operation	60 GHz
Operating wavelength	5 mm

3.3.1 Antenna Designed in CST using microstripline feeding technique at 60GHz

In this we have two co-ordinate systems namely local and the global co-ordinates .The X direction of the co-ordinate shows the length of the patch and Y gives the width of the patch and the Z shows the height of the given patch.

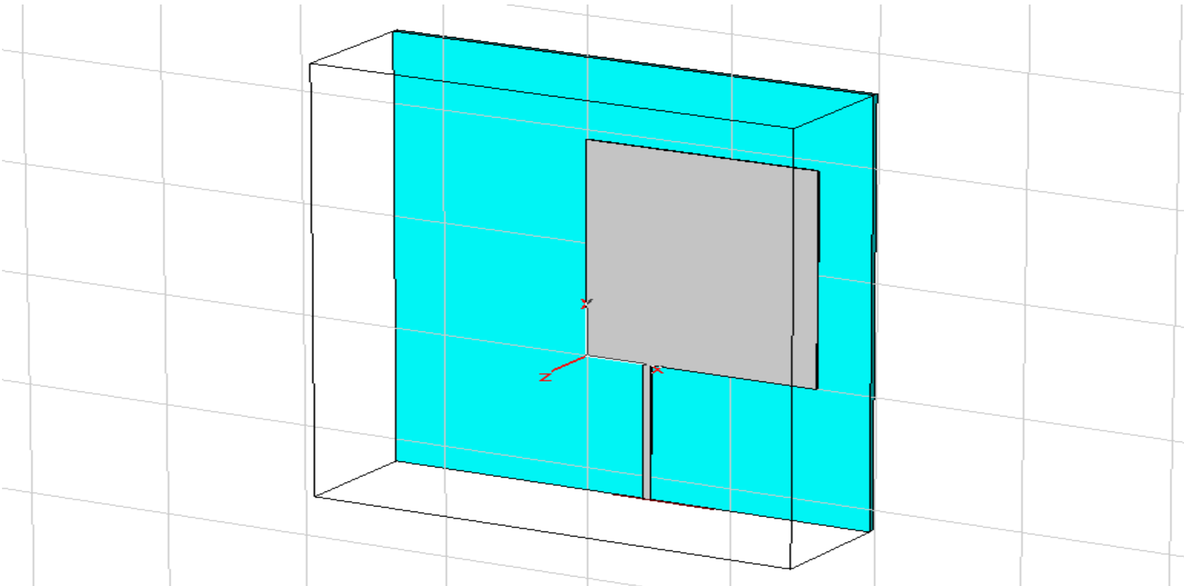

Figure 3.1: Antenna Designed

3.3.2 Return loss of the microstrip antenna at 60GHz

The return loss of the microstrip antenna at 60GHz is -24.77 dB. If the dip is below -10dB , it means 1/10th of the RF energy is being reflected , Usually this is taken as the threshold when most devices are considered to be tuned and have a reasonably good impedance matching and it is equivalent to the VSWR 1.9. Below -20dB is 1/100th of the RF energy is reflected and its equivalent to 1.2 VSWR [41]

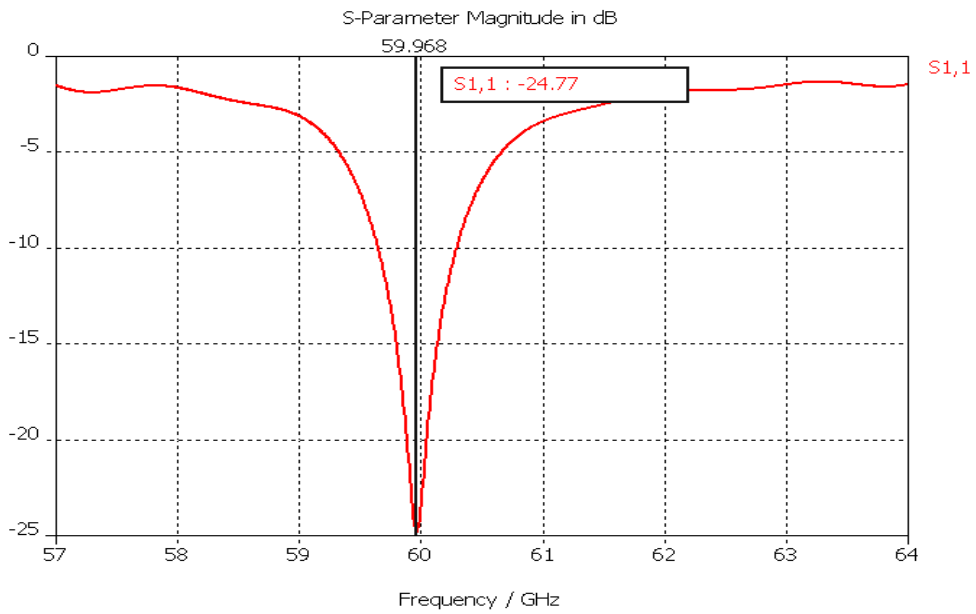

Figure 3.2: Return Loss

3.3.3 Bandwidth of microstrip antenna at 60GHz

The bandwidth of the antenna is the range of frequencies over which the return loss is greater than -10 dB. Thus, the bandwidth of antenna can be calculated from return loss versus frequency plot. The bandwidth of the proposed patch antenna is 1.0716% GHz.

$$\text{Bandwidth} = \frac{(fH - fL)}{fr} * 100$$

Bandwidth = 1.0716%

The bandwidth of the given microstrip antenna is low therefore its value can be increased by decreasing the dielectric constant of the material or by increasing the width of the given patch**.** The bandwidth can also be increased by using different slots in the patch [41]

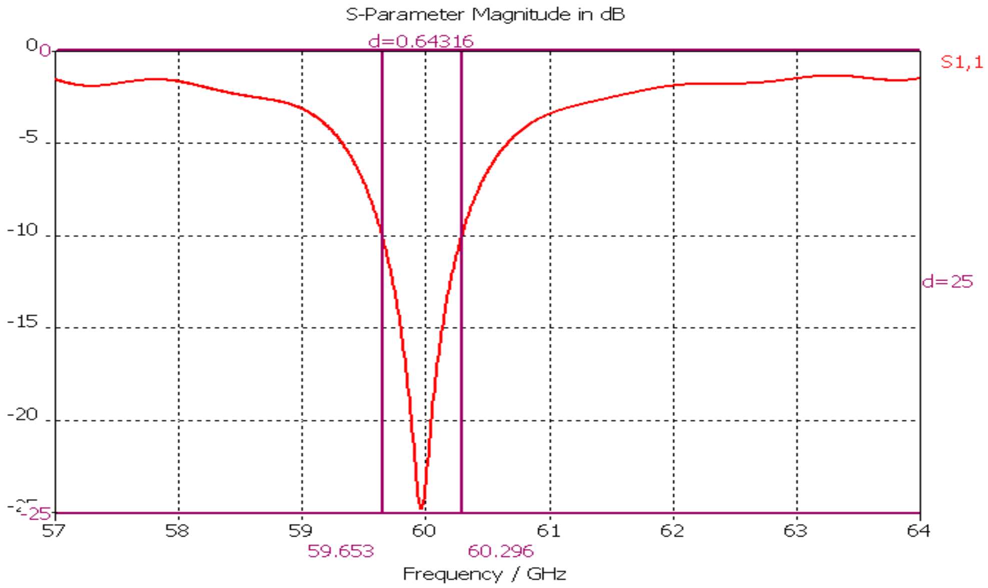

Figure 3.3: Bandwidth

3.3.4 VSWR (voltage standing wave ratio) of microstrip antenna

The VSWR of a good antenna is supposed to be less than equal to 2. The calculated VSWR of the antenna is 1, which shows that it is perfectly matched as the impedance of the source and the load are matched properly for maximum power transfer in the given circuit.

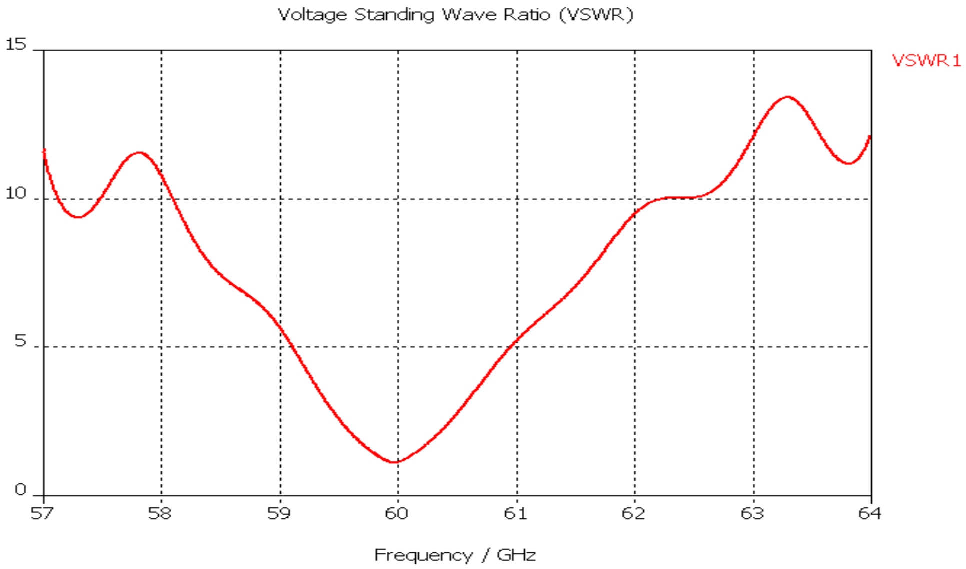

Figure 3.4: VSWR

3.3.5 Smith Chart showing S parameter

It gives the circuit representation of the antenna. Upper side gives the value of inductor , middle one gives the resistor and lower gives the capacitor value.

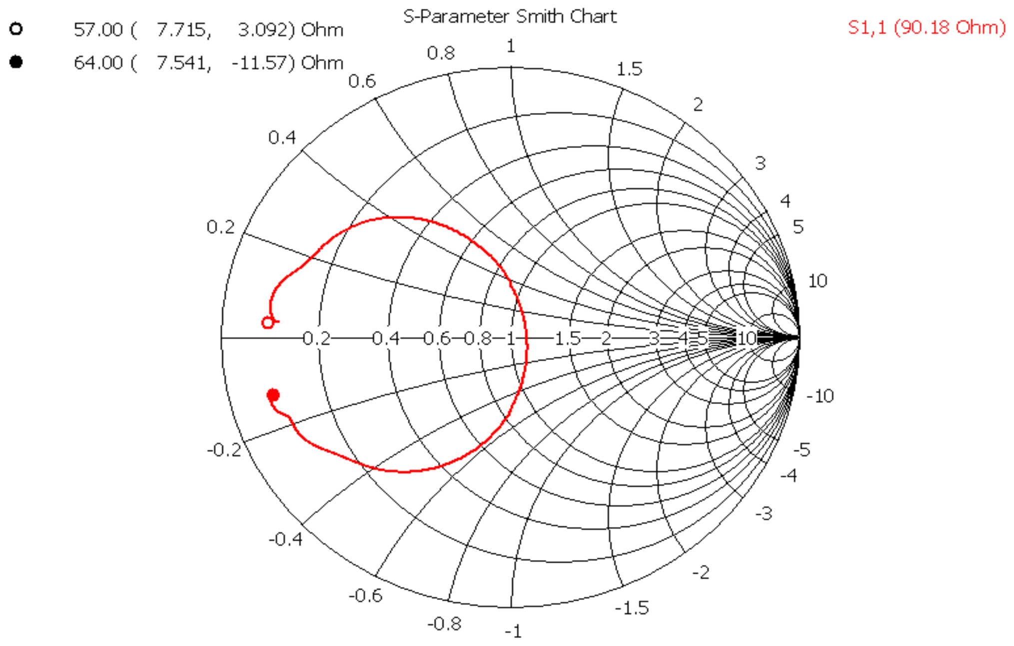

Figure 3.5: Smith Chart

3.3.6 S11 (Reflection Coefficient) parameter in the linear

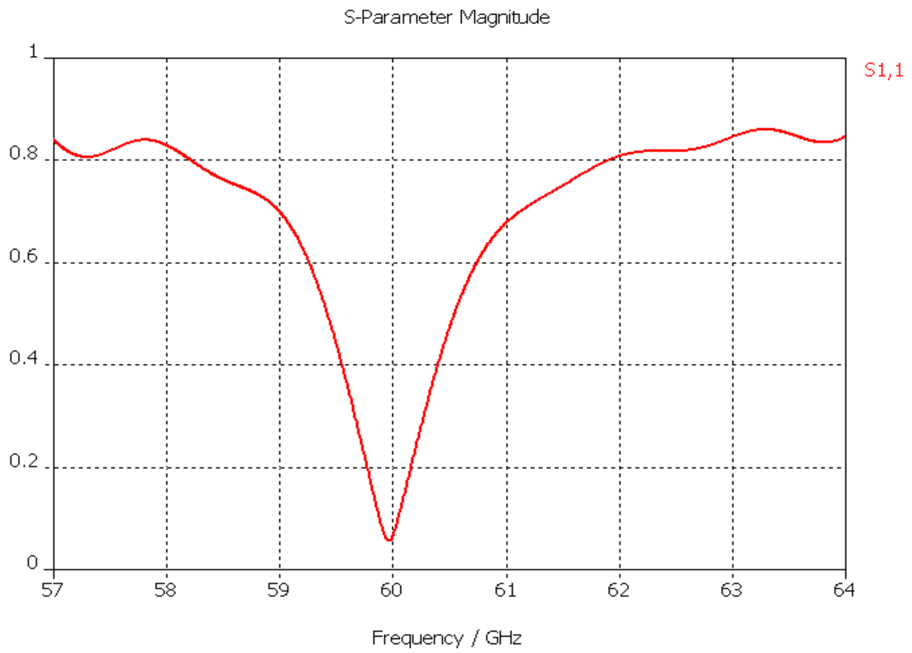

Figure 3.6: Reflection Coefficient

3.3.7 Electric field of the microstrip antenna

As Z is the direction of wave propagation and electric field is oscillating in x direction and magnetic field are oscillating in the Y direction resulting in the power flow in the E×H direction i.e. Z direction.

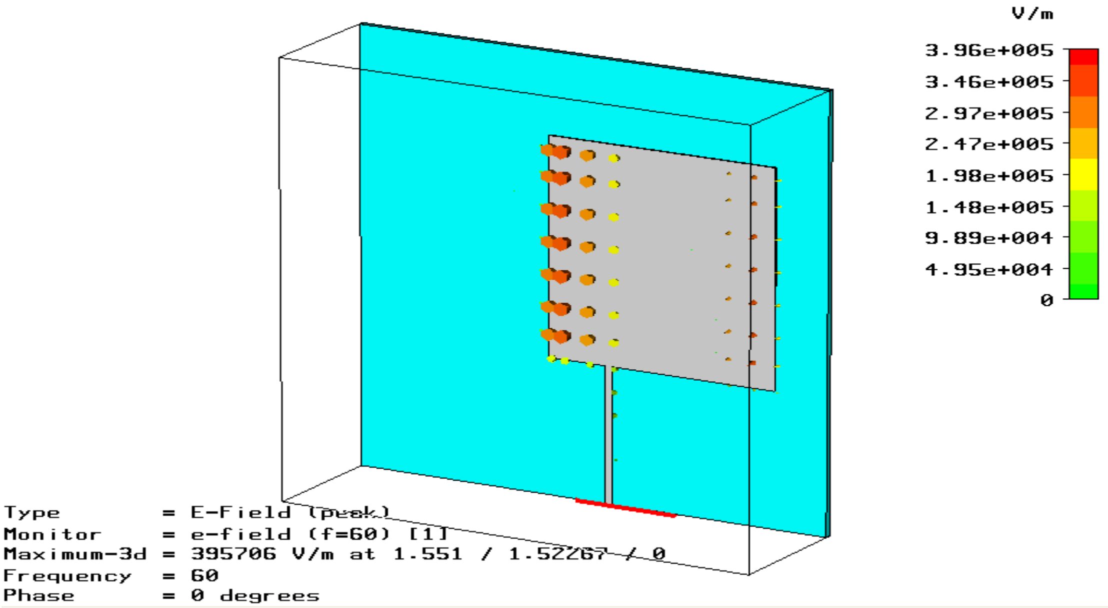

Figure 3.7: Electric Field

3.3.8 Directivity of the microstrip antenna in the far field region

The Directivity of the antenna represents the amount of radiation intensity or the gain intensity i.e. is equal to 7.580 dBi. The simulated antenna radiates more in a particular direction as compared to the isotropic antenna which radiates equally in all directions, by an amount of 7.580 dBi. The total radiation efficiency of the antenna needs to be lesser than the antennas radiation because it is a product of impedance mismatch loss and the antenna efficiency.

In simpler words directionality is the gain intensity. It is always given in the dBi or dBd which means in comparison with the isotropic and the dipole antenna. The directivity of the antenna is directly proportional to the bandwidth of the antenna and it is inversely proportional to the dielectric constant of the given material [59], [60].

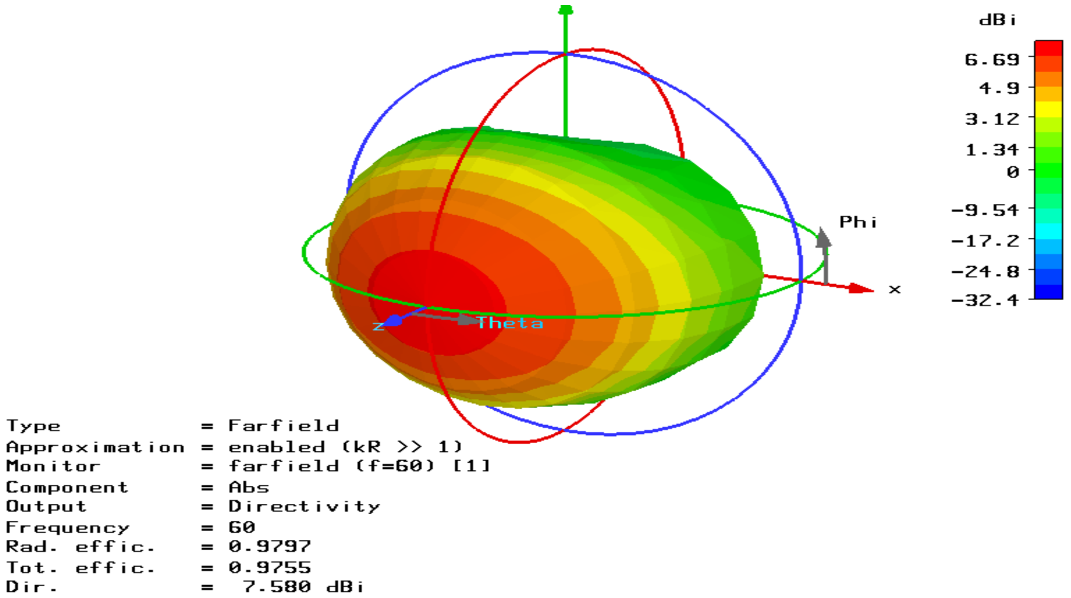

Figure 3.8: Directivity of antenna

3.3.9 Gain of the microstrip antenna in the far field region

The gain of the antenna in a particular direction is more as compared to isotropic antenna radiating in all directions. The antenna gain is passive is nature and is always is comparison to the isotropic or the dipole antenna. The gain of the proposed antenna is 7.491 dB.

Gain of the given antenna is directly proportional to the directivity of the antenna, which is directly proportional to the bandwidth and inversely proportional to the dielectric constant of the given antenna. Gain is the maximum power radiated in the direction of the peak radiation of the given antenna [41]. The microstrip antennas ideally has less gain and bandwidth.

To increase the overall gain of the antenna, the antenna arrays are used which helps to increase the overall gain of the given antenna. The slots of different types are also used to increase the overall gain of the given antenna [25].

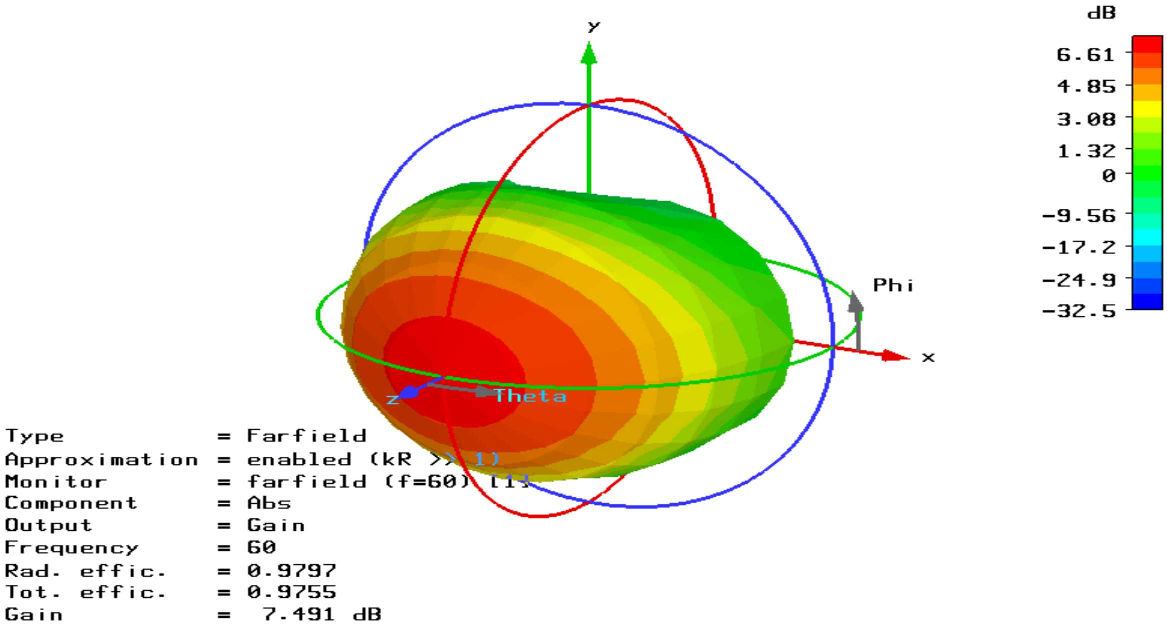

Figure 3.9: Gain of the antenna

3.3.10 Microstrip antenna with waveguide port

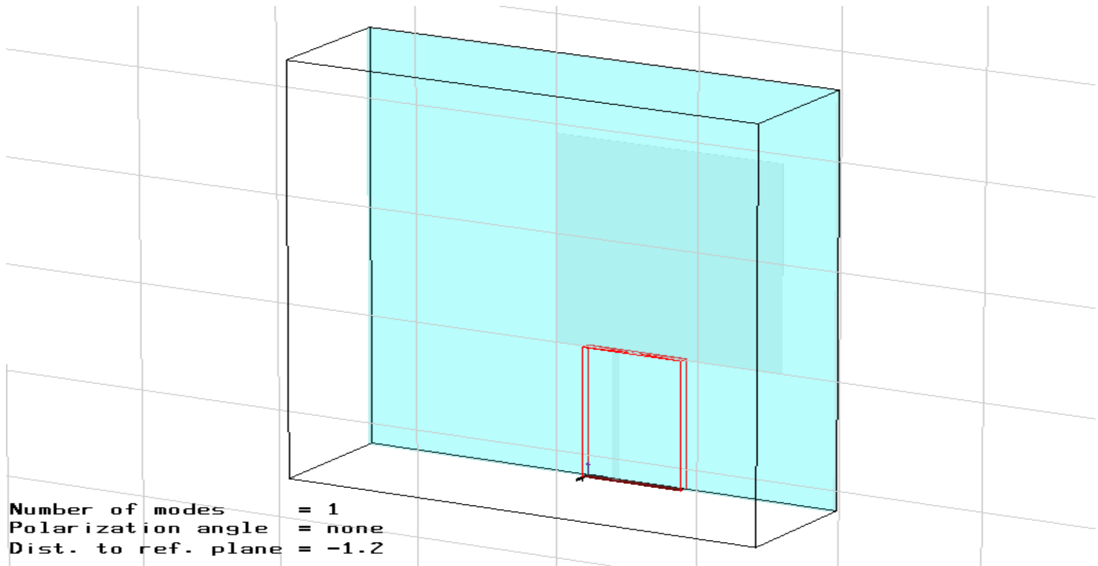

Figure 3.10: Waveguide Port

The port is the point from where we give the input to the device, we have used waveguide port in this as this gives better S parameters as compared to the discrete port. The given antenna is the one port device. The discrete port is mostly used to get radiation pattern of the antenna [41].

3.3.11Gain of antenna in E and H plane

E plane = Angular width is 96.3 degrees and main lobe magnitude is 7.5 dB. H plane = Angular width is 76.4 degrees and main lobe magnitude is 7.5 dB.

The E plane is typically broader than the H plane pattern. The H plane pattern goes zero in the horizon because of the conducting ground plane. The E plane is also called as co-polarization and vertical plane θ and H plane is called as cross polarization and horizontal plane ϕ [41], [43].

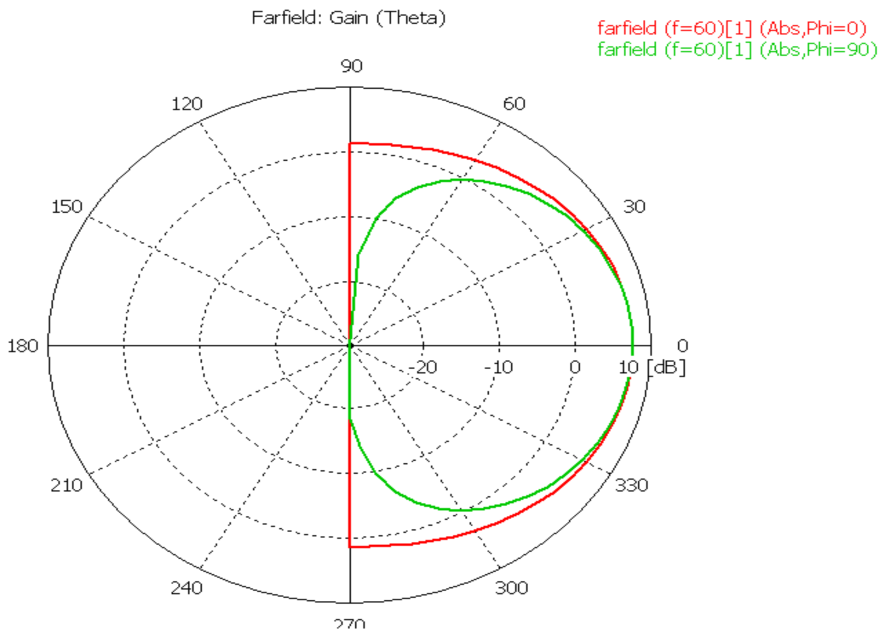

Figure 3.11: Gain in E and H plane

3.3.12 Directivity in E and H plane of microstrip antenna

E plane = Angular width is 96.3 degrees and main lobe magnitude is 7.6 dBi. H plane = Angular width is 76.4 degrees and main lobe magnitude is 7.6 dBi. The E and H plane are the principal patterns of a linearly polarized antenna.

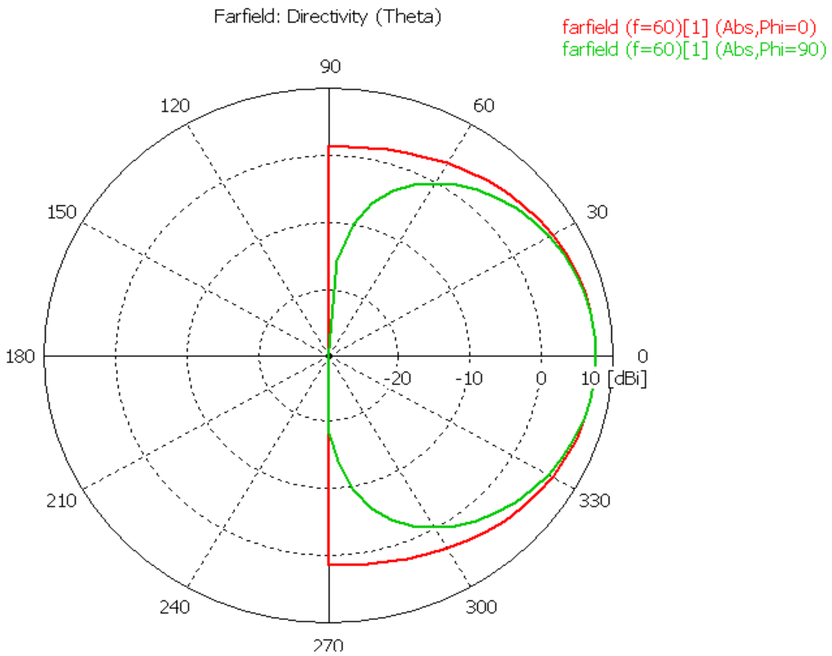

Figure 3.12: Directivity in E and H plane

3.3.13Directivity in the E plane of antenna

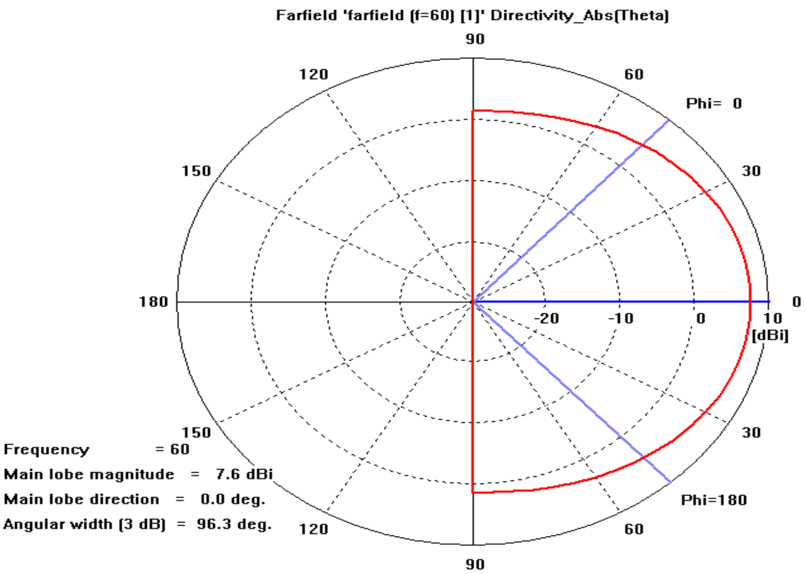

Figure 3.13: Directivity in E plane

3.3.14 E-field in E and H plane of the microstrip antenna

E plane=96.3 degrees

H plane=76.4 degrees

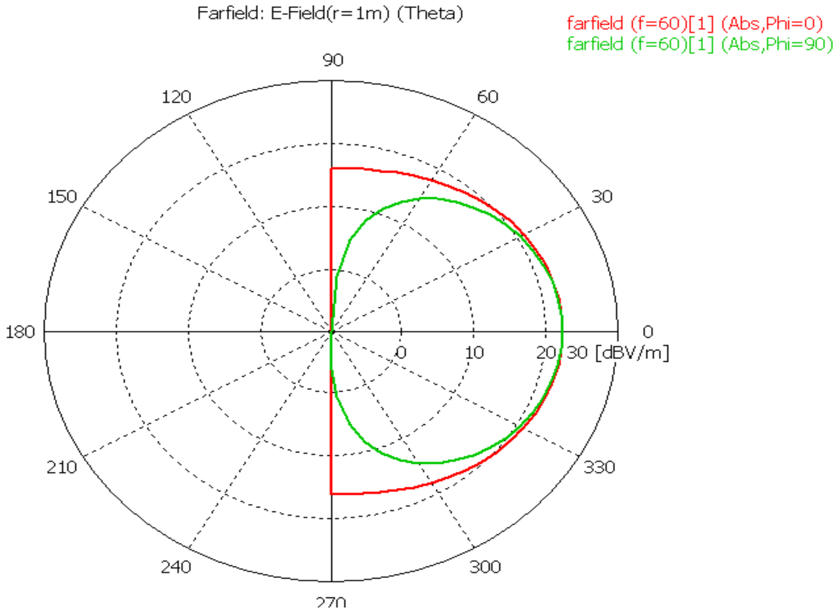

Figure 3.14: E-field in E and H plane

3.3.15 H-field in E and H plane of the microstrip antenna

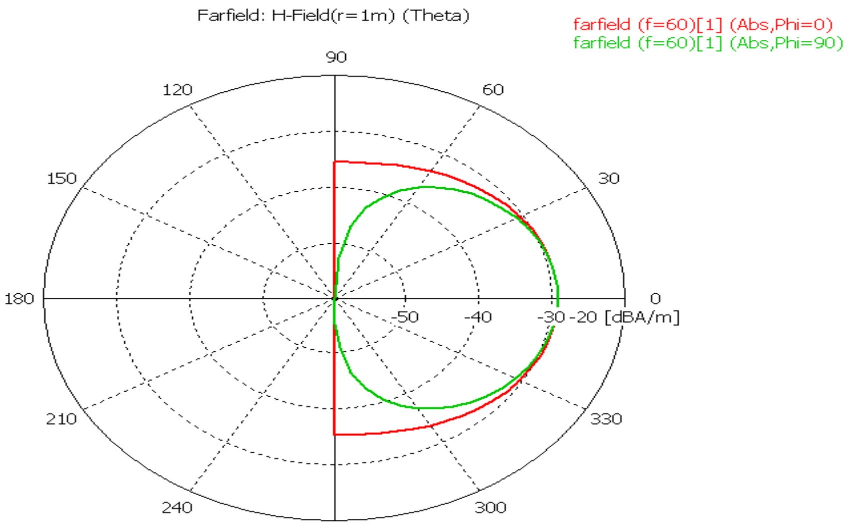

Figure 3.15: H-field in E and H plane.

3.4 CONCLUSION

As designing of this antenna is advantageous at 60 GHz for defence applications but as we know microstrip antenna also suffers from lots of problems like reduced bandwidth and gain. So because of this reason we tried to introduce slots in our patch (U and circular slots).These slots introduced one another frequency band having operating frequency at 77 GHz .Now the bandwidth problem has been solved as the slots have resulted in the enhancement of the bandwidth.

CHAPTER 4

DUAL BAND MICROSTRIP ANTENNA

4.1 INTRODUCTION

The rapid advances in the wireless communication industry demands novel antenna designs that could be used in more than one frequency bands and allow size reduction as well. Many techniques have been proposed for the design of radiating elements of this type, the great majority of which are microstrip antennas. Slots provide polarization diversity to these microstrip antennas. In this to enhance the bandwidth we have introduced the two slots namely U and Circular slots, which gave us dual band operation at 60 and 77 GHz frequency with 50 ohm microstripline feed. These slots gave us two frequency bands one at 60 and other at 77 GHz and now our antenna operates at the two bands namely V and W bands. Slots are used to achieve good impedance matching to increase the bandwidth. Slots force the current to flow through the longer path, increasing the effective dimensions of the patch. Slots can be of various shapes like toothbrush, double bend, cross, U, E, L and circular.

Slot loaded patch antennas have lower resonant frequencies and therefore results in smaller size, it also increases the current length and the impedance bandwidth. The slots can be introduced parallel or inside the given patch. The length, width, height and gap of the slot affects the overall resonant frequency of the antenna. The VSWR parameter of the given antenna remains almost invariant with the slot length and width. The input impedance increases linearly with width of the slot but inversely with length. The original resonant circuit of the parallel RLC circuit combines with the resultant of the above two resonant circuits which finally gives the dual frequency operation at 60 and 77 GHz. Therefore we get the dual tuned resonant circuit (patch + slot) [41], [43].

4.2 U-SHAPED SLOT

The introduction of the U shaped slot in the given patch can give the significant increase in the bandwidth of the given antenna (10%-40%).This mainly happens due to a double resonance effect, with two different modes [25]. The microstrip antennas etched with U-slots could be rectangular or triangular in shape .These have been proved to be versatile radiating elements as these can be designed not only for wideband applications but also for dual- and triple-band as well as for circular polarization operations. It has been found that the U-slot loaded patch can provide impedance bandwidth in excess of 30% for an air substrate thickness of 0.08λo and in excess of 20% for material substrate of similar thickness [40], [65], [101]. U-slot consists of two parallel vertical rectangular slots and a horizontal rectangular one. The parameters that affect the broadband performance of the patch antenna are the slot length, width and the position of the slot [43]. It is noted that the slot width should be small relative to the slot length and the higher resonant mode is sensitive to the length variation of the horizontal slot, whereas the lower resonant mode strongly depends on the perimeter of the U-slot.

4.3 DESIGNING OF U SLOT LOADED MICROSTRIP ANTENNA

The design procedure is a set of simple design steps for the designing of rectangular U-slot mircostrip patch antenna. The designing is same as the previous one only the slot dimensions are introduced now for the dual band operation. Firstly determine the centre frequency and then set the lower and upper bounds of centre frequency.

Slot width W:

$$W = \frac{c}{2\,Lower\,\sqrt{\varepsilon_{reff}}} - 2\,(L + 2\Delta L - E) \tag{4.1}$$

Where E is the thickness of the slot, L is the length of the slot and W is the width of the slot.

Hence by using the optimization, the designer can set the lower bound and upper bound frequency to derive the bandwidth, while the dielectric constant is varied, Hence, it is proven by the results that by changing the permittivity and introducing the U slot the optimized results are obtained [70] ,[67]. In this also we started with the Duroid 2.3 as the substrate, our main aim was to design the antenna which can now operate on two resonant frequencies that is 60 and 77 GHz thus providing the dual band and improving the overall bandwidth of the proposed antenna. The given parameters are optimised at last to get the desired results. Some of the design rules are:

Resonant Frequency: For different resonant frequencies a particular mode will exist in the antenna.

Dielectric Constant of Substrate: This affects directly the bandwidth and radiation efficiency of the antenna. The lower the value of permittivity, the wider is the impedance bandwidth and also results in reduced surface wave excitation and more fringing fields.

Substrate Thickness: This affects the bandwidth and coupling level. A substrate which is thicker results in wider bandwidth, but also in surface wave loses.

Microstrip Patch Length: The length of the microstrip patch determines the resonant frequency of the antenna.

Microstrip Patch Width: The width of the microstrip patch has relationship with the resonant resistance of the antenna. The wider size of the patch gives a lower value of resistance [64]. The width of the antenna is directly proportional to the bandwidth and directivity of the antenna. The width of the patch also controls the input impedance and radiation pattern.

Slot Length: The coupling level is determined by the length of the coupling slot. There are two types of the slot resonant and non-resonant. If the length of the slot is comparable to the half of the wavelength of the antenna, it is called resonant slot. If it is less, it is called non-resonant slot. As the length of the slot is decreased, there is effect on various parameters like input resistance decreases, decrease in the coupling between patch and feed line and decrease in back radiation level [63]. Therefore the slot must be made no larger than is required for the impedance matching.

Slot Width: The width of the slot affects the coupling level, but to a much less degree than the slot length. The relation between slot length and width is given by [62]

L_s/L_w= 1/10 Where, L_s= slot length and L_w = slot width

Feed Line Width: It controls the characteristic impedance and the coupling level. According to the study, to a certain degree, thinner feed lines couple more strongly to the slot.

Feed Line Position Relative to Slot: Maximum coupling takes place, if the feed line is positioned at right angles to the centre of the slot. Slanting direction of the feed line from the slot will reduce the coupling.

Position of the Patch relative to the Slot: Maximum coupling takes place, if the patch is positioned to the centre of the slot, one layer above [43]. For maximum coupling, moving the patch relative to the slot in the H plane direction has very less effect, on the other hand moving the patch relative to the slot in the E-plane direction will decrease the coupling level. While designing the given slot we have observed that by reducing the given slot dimensions we can obtain the better results even by reducing the slot length and the thickness gave us better results. The height from the base though do not have any considerable effect on the results and like in the designing of the 60 GHz results we have observed that by reducing the microstripline width and the given dielectric constant up to the value of 2.12 of the substrate results in better result and optimization same thing is also observed while designing the U slot loaded microstripline feed antenna for the dual band operation operating at the 60/77 GHz frequency.

4.4 SIMULATION RESULTS

In this we have used microwave studio for designing U slot loaded rectangular microstrip antenna with 50 ohm microstripline feed at 60/77 GHz frequency. To get the required results we have optimized the results of the antenna by varying the dielectric constant and width of the microstripline. Various parameters of U slot loaded microstrip antenna are:

Table 4.1: Various Dimensions of the Rectangular U Slot loaded microstrip antenna

Height of slot from base	0.2663 mm
Slot thickness	0.007 mm
Slot width	0.9587 mm
Slot length	0.4326 mm
Dielectric constant	2.3
Loss tangent	0.0005
Height of substrate	0.04 mm
Length of patch	1.5978 mm
Width of patch	1.9174 mm
Height of patch	0.01 mm
Width of microstripline	0.05 mm
Length of microstripline	1.2 mm
Operating wavelength	5 mm
Feeding Impedance	50 Ω
Operating Frequency	60 and 77 GHz

4.4.1 Antenna designed using U slot for dual band operation

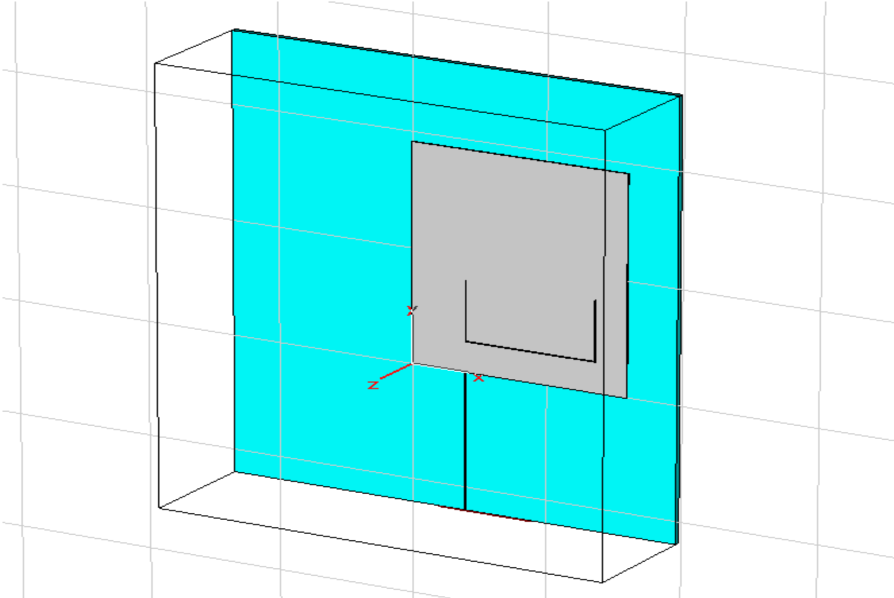

Figure 4.1: Antenna designed

4.4.2 Return loss of the U slot loaded microstrip patch antenna

The return loss of the microstrip antenna at 60GHz is -15dB. If the dip is below -10dB , it means 1/10th of the RF energy is being reflected , Usually this is taken as the threshold when most devices are considered to be tuned and have a reasonably good impedance matching and it is equivalent to the VSWR 1.9. Below -20dB is 1/100th of the RF energy is reflected and its equivalent to 1.2 VSWR [41].

The return loss is a common parameter used to characterize the matching property of a transmitting antenna. So better the impedance matching between the load and the source better the return loss parameter will be.

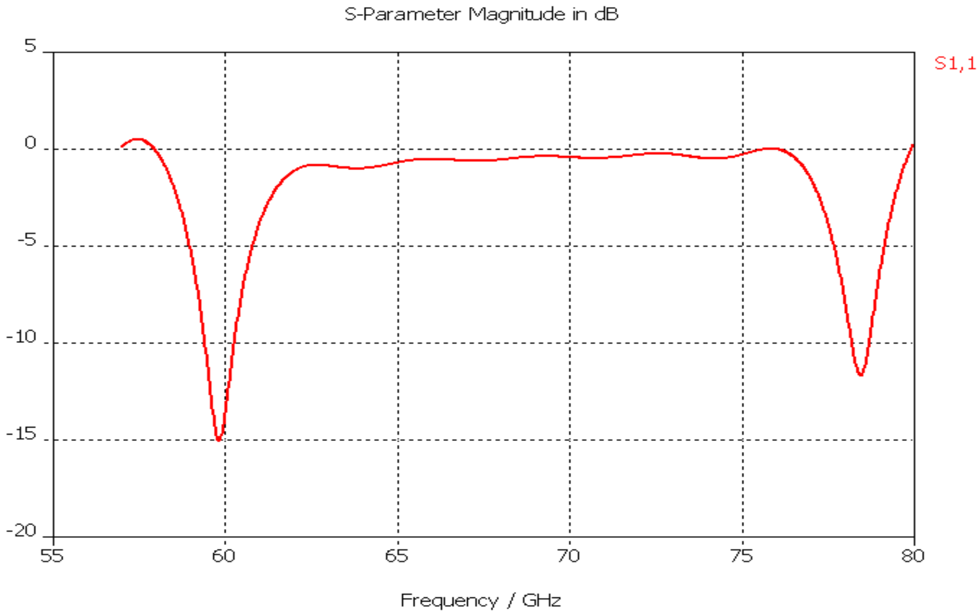

Figure 4.2: Return Loss

4.4.3 Directivity of the U slot loaded microstrip patch antenna

The directivity of the antenna is increased from 7.5 to 7.842 dBi.

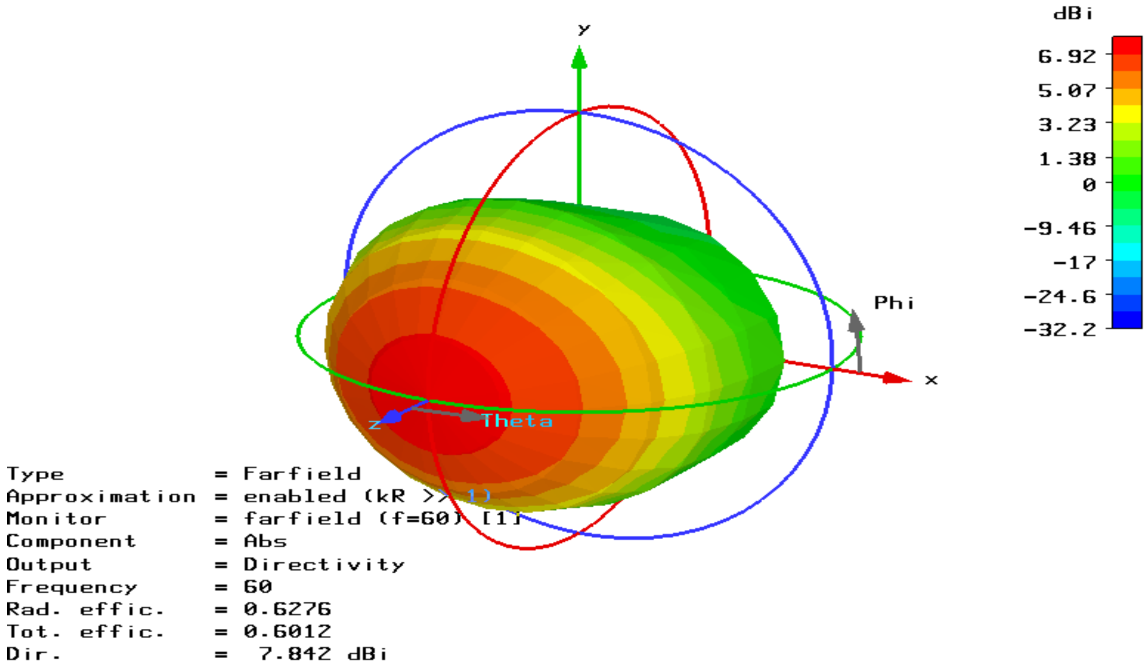

Figure 4.3: Directivity

4.4.4 Band width of the U slot patch antenna

The given bandwidth of the antenna has increased from 1.071% to 1.461 % GHz at 60 GHz operating frequency and 0.81% at 77GHz operating frequency. The main reason behind the use of the slot is only the enhancement of the given antennas bandwidth.

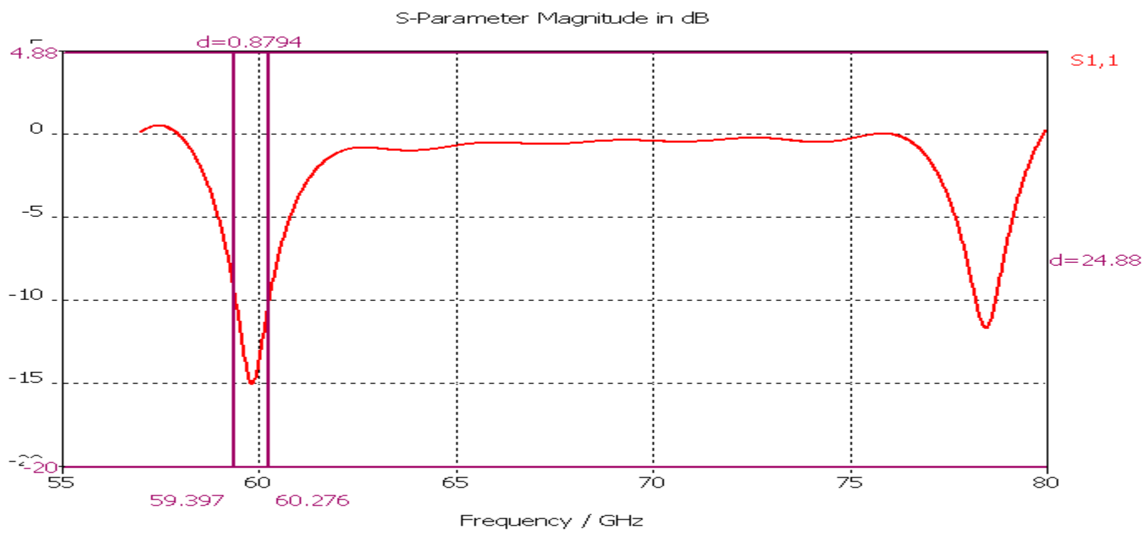

Figure 4.4: Bandwidth

4.4.5 Gain of the U slot patch antenna

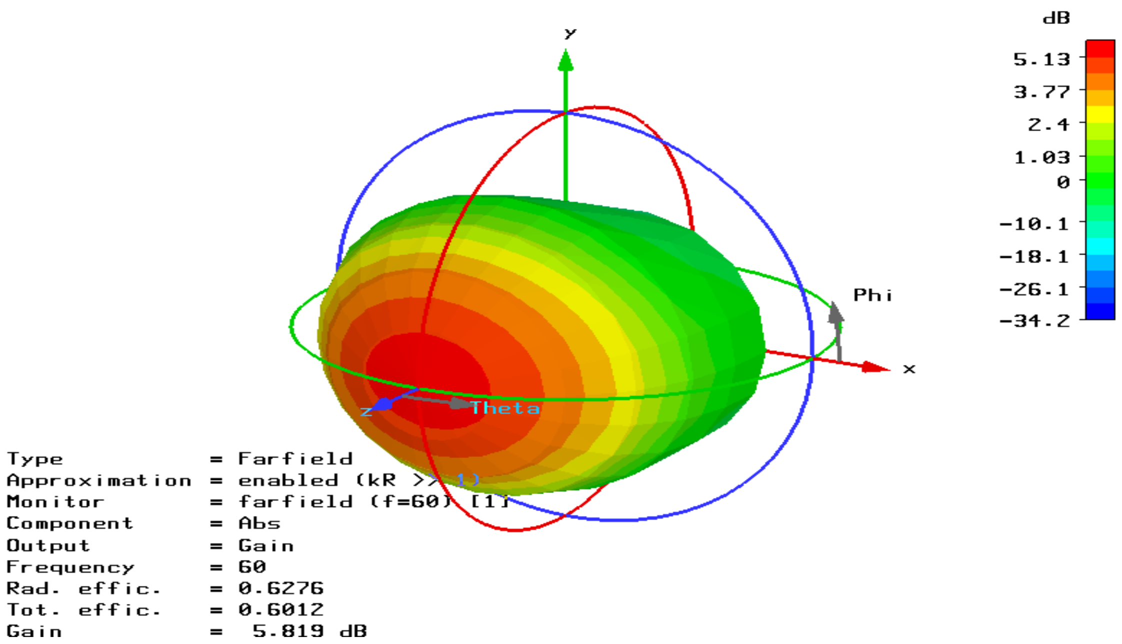

Figure 4.5: Gain of the antenna

4.4.6 VSWR of the antenna

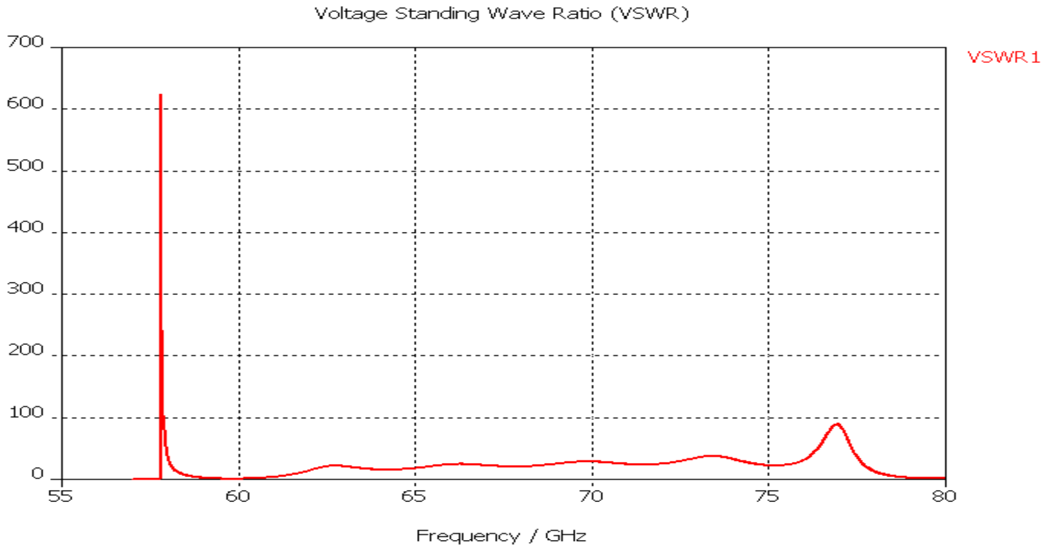

Figure 4.6: VSWR

4.4.7 Axial Ratio of the U slot loaded patch antenna

The polarization state of an EM wave can also be indicated by Axial Ratio (AR). It is defined as ratio of major and minor axes of the polarization ellipse.

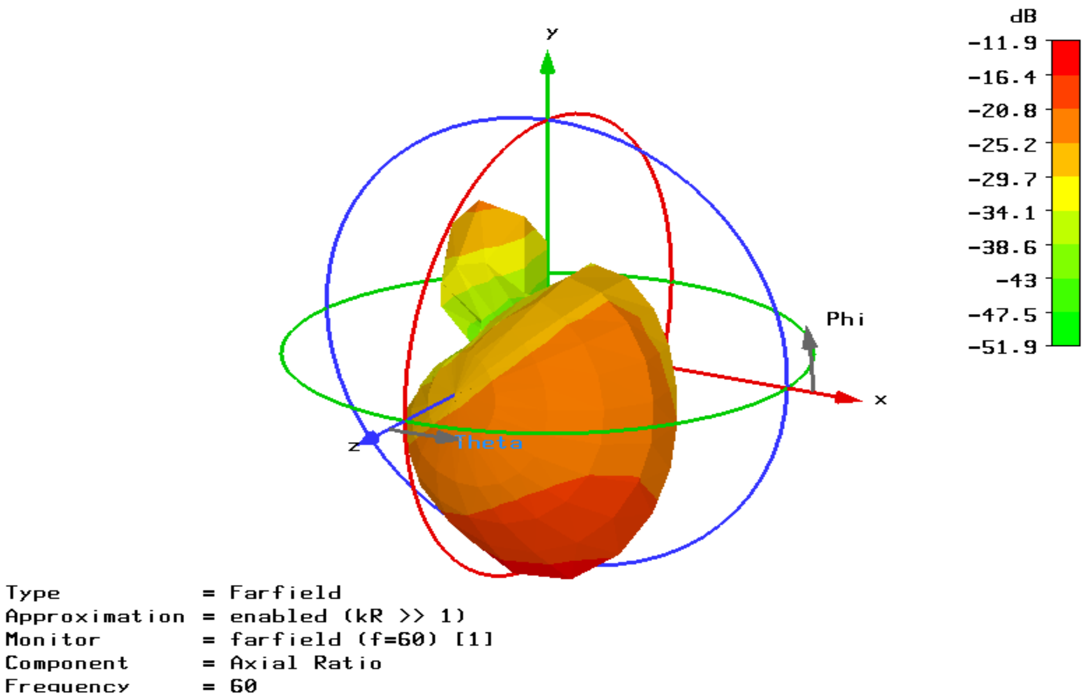

Figure 4.7: Axial Ratio

4.4.8 Gain in the E and H plane of the rectangular U slot patch antenna

E plane = Angular width is 89.0 degrees and main lobe magnitude is 5.8 dB. H plane = Angular width is 77.9 degrees and main lobe magnitude is 5.8 dB.

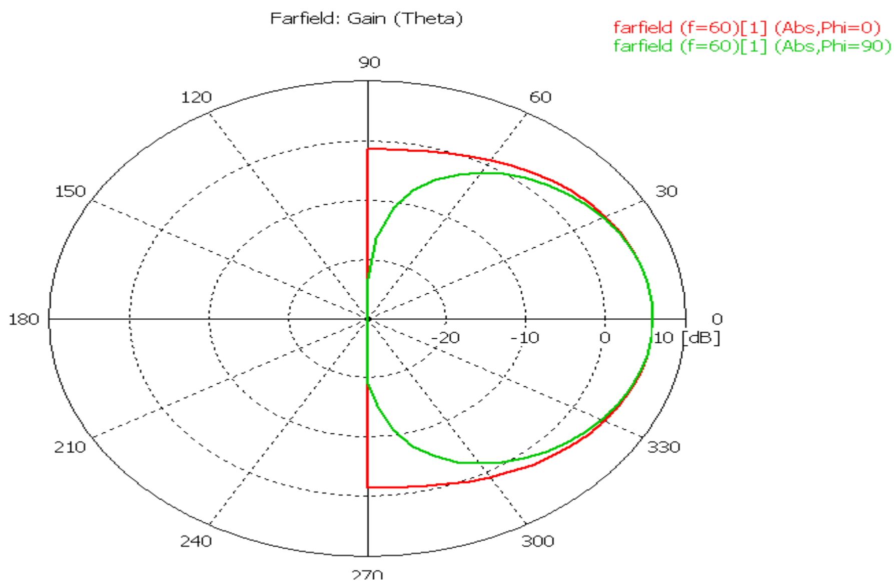

Figure 4.8: Gain in the E and H Plane

4.4.9 Directivity of the antenna in the E and H plane

E plane = Angular width is 89.0 degrees and main lobe magnitude is 7.8 dBi. H plane = Angular width is 77.9 degrees and main lobe magnitude is 7.8 dBi.

The E and H plane are the principal patterns of a linearly polarized antenna. The E plane is typically broader than the H plane pattern. The H plane pattern goes zero in the horizon because of the conducting ground plane. The E plane is also called as co-polarization and vertical plane θ and H plane is called as cross polarization and horizontal plane ϕ [41], [43].

The directivity of the antenna is the gain intensity. For a good antenna its directivity should be 1. It is always taken in comparison to the isotropic and the practical dipole antenna. As the directivity of this antenna is 7.8 dBi, it means in a particular direction it is radiating 7.8dB more power as compared to the isotropic antenna which shows it is a non-isotropic or the directional antenna.

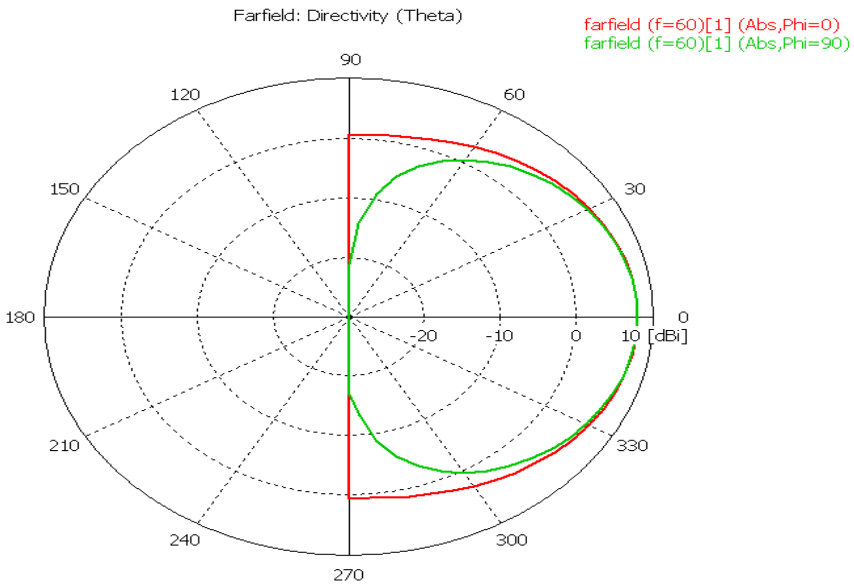

Figure 4.9: Directivity in the E and H plane

4.5 CIRCULAR SLOT IN THE RECTANGULAR PATCH ANTENNA

There are many different types of slots which can be used to enhance the bandwidth of the given designed antenna. Slot antennas are useful in different fields like S and H shape slots are used basically for Bluetooth applications. E AND U shape is basically used for Wi-max, WLL and WLAN [100]. L shape slot antenna finds its application in field of wireless and mobile communication. Study has proved that the E-shaped patch antennas has the highest bandwidth followed by U-shaped patch antenna and H-shaped patch antenna [12].

In this a dual band printed antenna is designed by introducing circular slot in the patch. By this, two bandwidth, covering V and W band, are achieved. The circular slots has two radius namely inner and outer radius. In the designing, the slot dimension controls the lowest frequency of the bandwidth. Indeed, the larger the slot radius, the lower the low cut frequency is. In this the circular slot is fed by a 50-Ω microstripline feed for proper impedance matching. Usually Circular slots are designed by introducing two circular ring cuts from the patch. This method is similar to the slot loading technique. The two radius of circles namely inner and the outer are estimated by circular patch antenna formulas [75]. Width of the circular patch is given by r2-r1, where r1 is the radius of the inner circle and r2 is the radius of the outer circle. The parameters like radius, the position of the circular slot and the width of the given strip line has been optimised to get the desired results.

In this two circles with radius 0.05 and 0.044 mm are designed for controlling the radiation characteristics of the given rectangular antenna. The main function of any slot is to increase the bandwidth, directivity and also the return loss. The advantages of the circular shaped slot over other slots is that it has are only one degree of freedom, that means it doesn't have two dimension parameters like length and width in rectangular or other slots which needs to be adjusted again and again to get the optimized results [100], [12], [43]. So, for parametric study the parameter that we have adjusted is only the radius as compared to the width and length of the U slot antenna. After parametric study the optimize dimension is 0.05 and 0.044 mm, respectively.

The right dimension of these two radius can affect the location of the resonant frequency of the antenna. While designing we have observed that the dimensions and the feed width needs to be small for better results. In this we need to take different values of the radius and see which are giving the most optimized and desired results, it is kind of iterative process.

4.6 SIMULATION RESULTS

In this we have used microwave studio for designing circular slot loaded rectangular microstrip antenna with 50 ohm microstripline feed at 60/77 GHz frequency. To get the required results we have optimized the results of the antenna by varying the dielectric constant and width of the microstripline. Various parameters of circular slot antenna are:

Table 4.2: Various Dimensions of the Circular Slot loaded rectangular microstrip antenna

Height of slot from base	0.9 mm
Radius of outer circle	0.05 mm
Radius of inner circle	0.044 mm
Dielectric constant	2.3
Loss tangent	0.0005
Patch length	1.5978 mm

Patch width	1.9174 mm
Height of the patch	0.01 mm
Height of substrate	0.04 mm
Length of substrate	1.5978 mm
Width of microstripline	0.05 mm
Length of microstripline	1.2 mm
Operating Wavelength	5 mm
Feeding Impedance	50 Ω
Operating Frequency	60 and 77 GHz

4.6.1 Antenna designed using circular slot for dual band operation

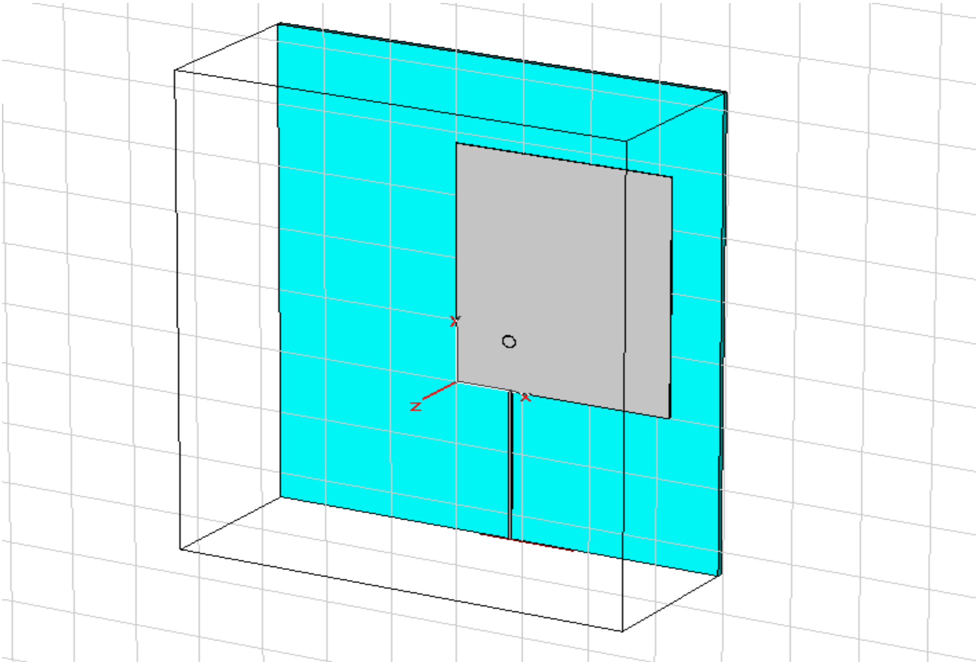

Figure 4.10: Antenna Designed

4.6.2 Return loss of the circular slot antenna

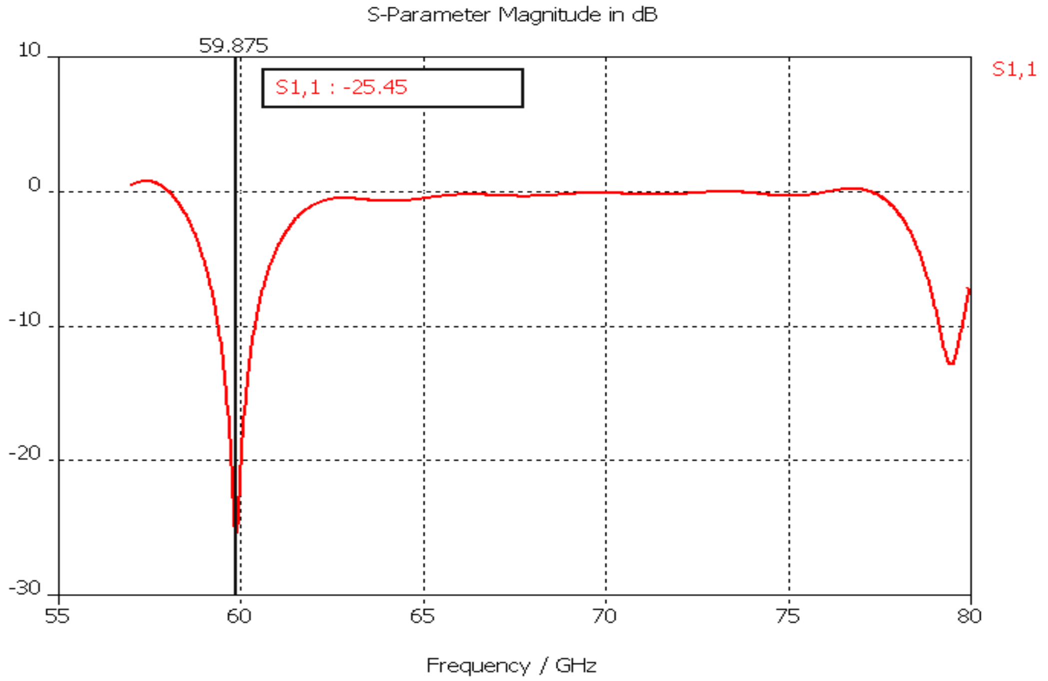

Figure 4.11: Diagram showing Return Loss

4.6.3 Bandwidth of the Circular Slot antenna

The bandwidth of the circular antenna has been increased to the 1.7185% GHz and the 77GHz operating frequency is giving 0.97% bandwidth.

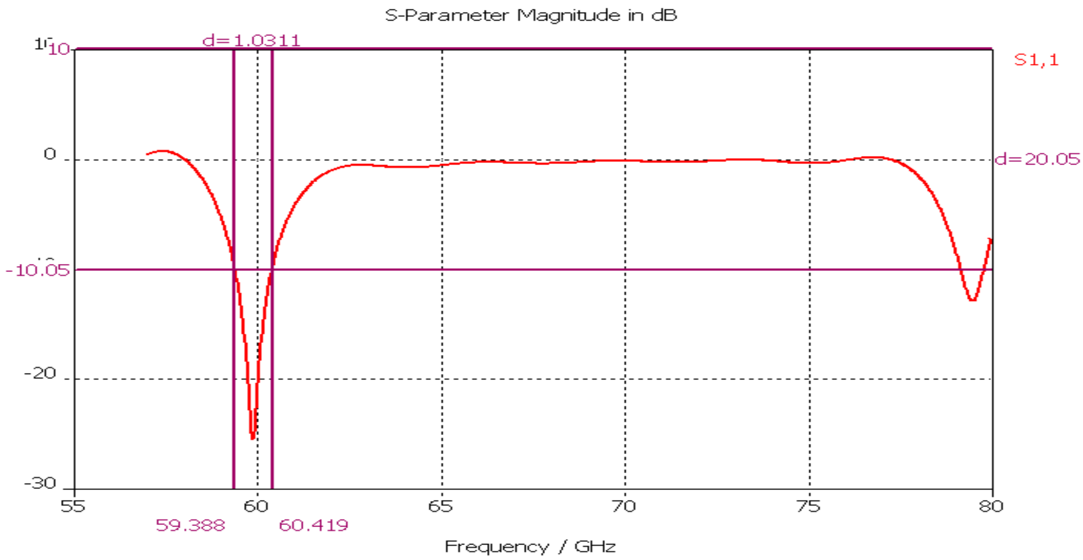

Figure 4.12: Diagram showing Bandwidth

4.6.4 Directivity of the given antenna in the far field region

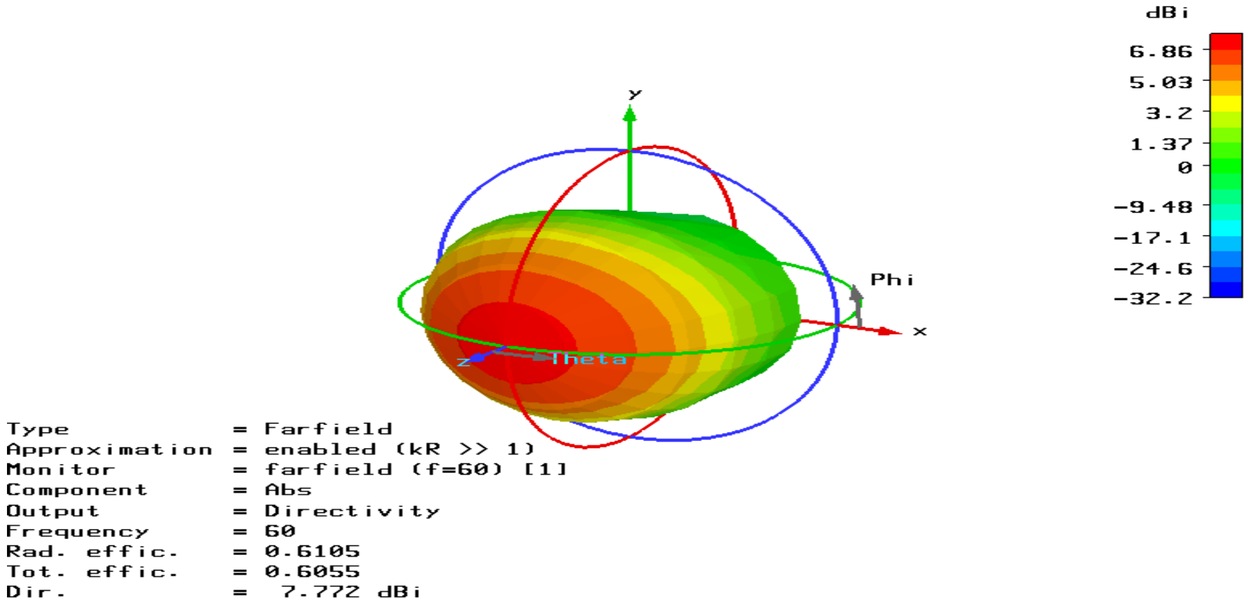

Figure 4.13: Directivity of the antenna

4.6.5 Gain of the antenna in the far field region

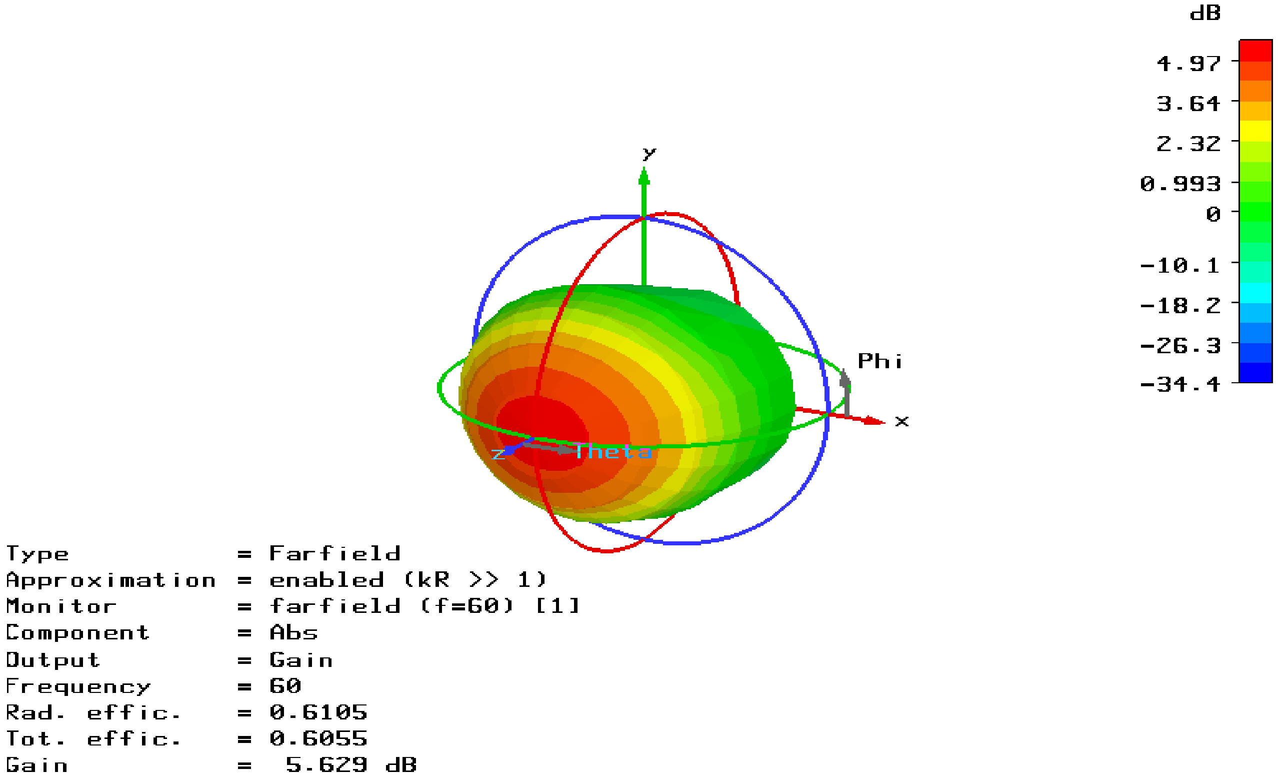

Figure 4.14: Gain of the antenna

4.6.6 Gain in the E and H plane of the antenna

E plane = Angular width is 92.0 degrees and main lobe magnitude is 5.6 dB. H plane = Angular width is 78.2 degrees and main lobe magnitude is 5.6 dB.

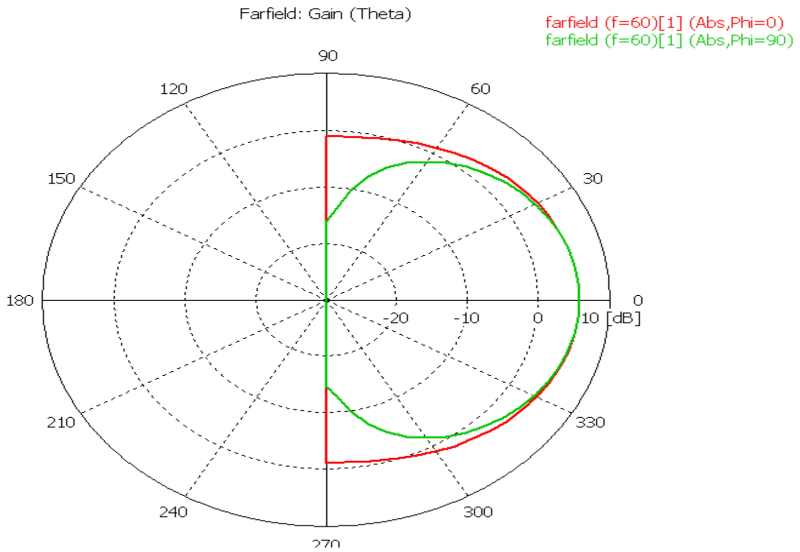

Figure 4.15: Combined gain

4.6.7 Directivity in the E and H plane of the antenna

E plane = Angular width is 92.0 degrees and main lobe magnitude is 7.8 dBi. H plane = Angular width is 78.2 degrees and main lobe magnitude is 7.8 dBi.

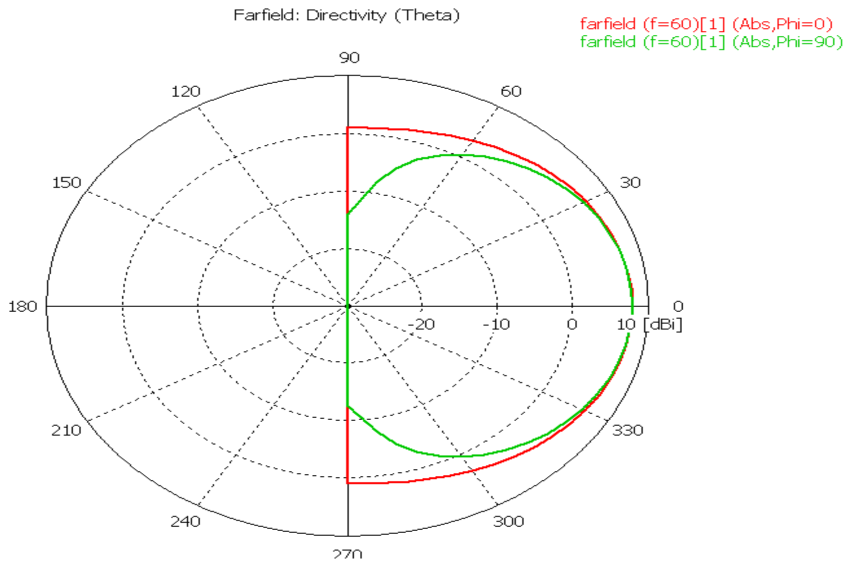

Figure 4.16: Combined Directivity

4.6.8 Axial Ratio of the antenna

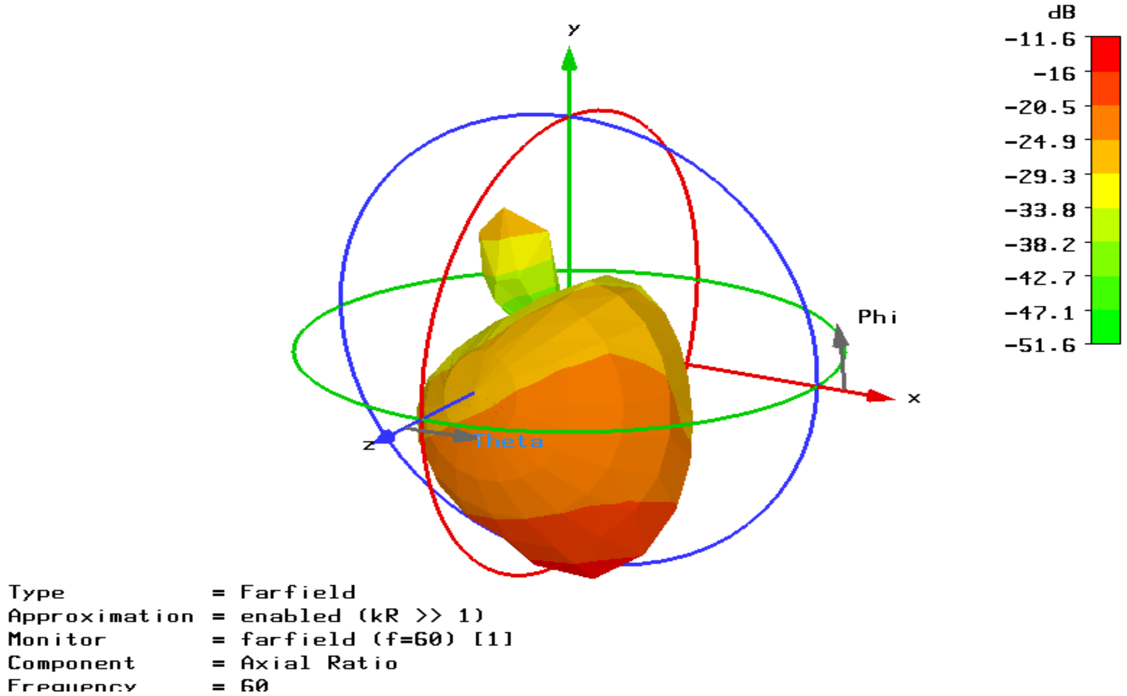

Figure 4.17: Axial Ratio of the antenna

4.6.9 VSWR of the circular slot antenna

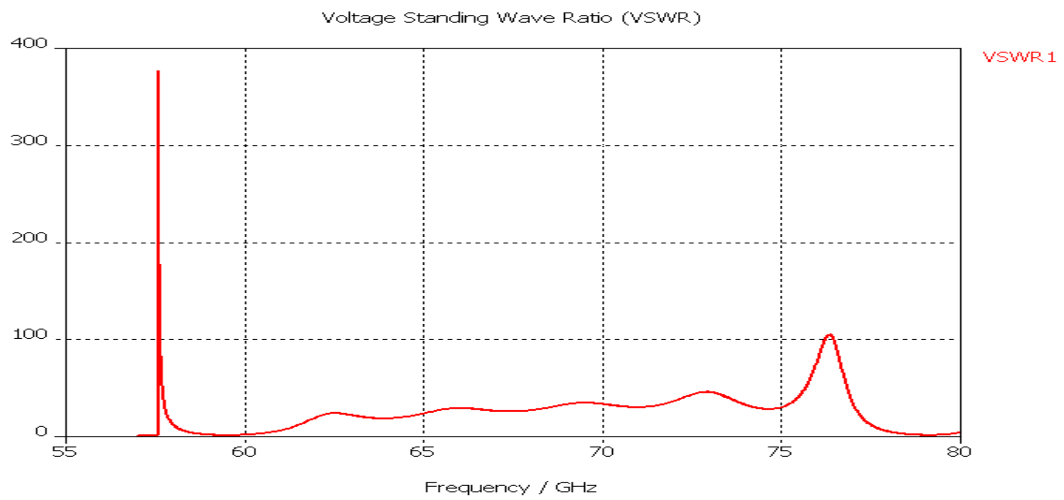

Figure 4.18: VSWR of the antenna

4.7 CONCLUSION

We have enhanced our bandwidth requirement to a great extent by using these slots. In communication field the bandwidth is very important parameter which needs to be maximized therefore we have increased the overall importance of our antenna by increasing its bandwidth. As we have increased the bandwidth it has further increased the directivity and gain of the antenna. As according to the Shannon's theorem with the increasing bandwidth the overall channel capacity also increases .Therefore we have concluded that the introduction of slots have resulted in the overall enhancement of the bandwidth. To overcome their inherent limitation of narrow bandwidth and low gain, many techniques have been proposed and investigated, one of them is the use of slots in the antenna.

CHAPTER 5

CONCLUSION AND FUTURE SCOPE

5.1 CONCLUSION

60 GHz is, in fact, the beginning of a trend of escalating carrier frequencies that will deliver unprecedented data rates, several tens of gigabits per second, allowing uncompressed high-definition media transfers, sensing and radar applications, and virtually instantaneous access to massive libraries of information. As RF spectrum is a limited natural resource, so we must use it judiciously, it's wise to use a frequency which is free. As it has a disadvantage of high attenuation which makes it, not so good for commercial applications. But it can be used in defence applications because of its peculiar property of oxygen absorption, where small troops can use this interference immune frequency to deploy their communication. As the demands for higher data rates and wireless connectivity is increasing day by day, it will result in the development of millions of 60 GHz communication devices in future. So, as in our thesis we have used particularly microstrip antenna, which makes it more useful and cost effective.

There is always a trade-off between the antenna parameters and dimensions, as when we increase the thickness of substrate for better radiations, it results in the large antenna size. So none of the parameters are ideal. A designer has to adjust the parameters according to his requirements. So the goal of a designer is to achieve specific performance characteristics at a specified operating frequency. Introduction of slots in the antenna has helped in the enhancement of the bandwidth of the given antenna, there are many other slots as well which can further increase the overall bandwidth of the given antenna. The antenna designed not only used in the defence but can also be used in the next generation communication system as well. So we concluded that despite of its disadvantages microstrip antenna finds its great importance in defence mainly because of its light weight and conformal nature and further the 60GHz frequency is going to be next big frequency in the world.

5.2 FUTURE SCOPE

In future the results like gain, bandwidth and directivity can be further refined or more optimized for better results. The optimization procedure solely depends on the field where we want to use our antenna, whether it is defence or in communication systems. According to the requirements we do further optimization of the parameters. We can further use some other software's for further validation of our parameters and better results. We can further do experimental testing and the fabrication process as well.

APPENDIX

Matlab code for determining various parameters of Microstrip Patch Antenna.

```
clc
clear all
format long

disp('Design ');
disp('........');
er=input('Enter the dielectric constant:');
h=input('Enter the substrate thickness (in mm):');
f=input('Enter the frequency (GHz):');
z=input('Enter the input impedance(ohms):');
disp('calculating. please wait.');
f=f*1e9;

%calculate the width
wid=(3e8/(sqrt((er+1)/2)*2*f))*1000;            %in mm

%calculate effective dielectric constant
e_eff=((er+1)/2)+(((er-1)/2)*(1+((12*h)/wid))^-0.5);

%calculate extension of length L
del_1=(((e_eff+0.3)*((wid/h)+0.264))/((e_eff-0.258)*((wid/h)+0.8)))*(0.412*h); %in mm

%calculate the effective length
eff_l=(3e8/(2*f*sqrt(e_eff)))*1000;

%calculate the actual length
L=eff_l-(2*del_1);
```

```
i2=(3e8/f)*1000;
k=(2*pi)/i2;
x=k*(wid);
i1=-2+cos(x)+(x*sinint(x))+(sin(x)/x);
g1=i1/(120*pi*pi);    %conductance
syms th
th = 0:pi;
a1= trapz((((sin((x./2).*cos(th))./cos(th)).^2).*(besselj(0,(k.*L.*sin(th)))).*(sin(th)).^3),th);
g12=a1/(120*pi*pi);     %in siemens
r_in=1/(2*(g1+g12));   %in ohms

inset=(L/pi)*(acos(sqrt(z/r_in)));        %in mm

Lg_min=6*h+L;
Wg_min=6*h+wid;

B=60*pi*pi/(z*sqrt(er));
m1=2*B-1;
m=log(m1);
n1=B-1;
n=log(n1);

w=(2*h/pi)*(B-1-m+(((er-1)/(2*er))*(n+(0.39*0.61)/er)));
l=5/(4*(er)^(.5));

g=(3e8*4.65e-9)/(sqrt(2*e_eff)*f*10^-9);

disp('Rectangular Patch:')
disp(['The width of patch (Wp)is:',num2str(wid),'mm'])
```

```
disp(['The length of patch (Lp) is:',num2str(L),'mm'])
disp(['The inset point is:',num2str(inset),'mm'])
disp(['The width of feed line(Wf) is:',num2str(w),'mm'])
disp(['The length of feed line(lf) is:',num2str(l),'mm'])
disp(['The gap of the feed line(Gpf) is :',num2str(g),'mm'])
disp(['The minimum length of the ground plane is:',num2str(Lg_min),'mm'])
disp(['The minimum width of the ground plane is:',num2str(Wg_min),'mm'])
```

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