DESIGN AND OPERATION OF DUAL/TRIPLE BAND SLOTTED MICROSTRIP MONOPOLE ANTENNA FOR WIRELESS APPLICATIONS

A thesis submitted in partial fulfilment of the requirements

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MASTER OF ENGINEERING

In

Wireless Communication Engineering

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CERTIFICATE

I hereby declare that the work which is being presented in the thesis entitled, **"Design and Operation of Dual/Triple Band Slotted Microstrip Monopole Antenna for Wireless Applications"** in partial fulfilment of the requirement for the award of degree of M.E in Wireless Communication Engineering submitted in Electronics and Communication Engineering Department of Thapar University, Patiala is an authentic record of my own work carried out under the supervision of Ms. Jaswinder Kaur, Lecturer, ECED, Thapar University, Patiala.

The matter presented in this thesis has not been submitted in any other University/Institute for the award of degree.

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(Gourav Hans)

ABSTRACT

Wireless communications have been developed widely and rapidly in the modern world especially during two decades. The future development of the personal communication devices will aim to provide speech, image and data communication at anytime and any where around the world. This indicates the future communication terminal antenna must meet the requirement of multi-band or wide band to sufficiently cover the possible operating bands. However, the difficulty of antenna design increases when the number of operating frequency band increases. In addition for miniaturization the wireless communication system, the antenna must also be small enough to be placed inside the system. However in order to transmit and receive more information large bandwidth are required and bandwidth enhancement is currently a popular research area.

The aim of thesis is to design a broad band Dual/Triple frequency rectangular microstrip patch antenna for wireless communication system and study the effect of various antenna parameters like patch length (L), Patch (P), Width (W), substrate parameters viz relative dielectric constant, substrate thickness etc. Here, coplanar waveguide feed is used to excite the patch antenna.

In this thesis, three designs have been proposed for broad banding of patch antenna. The proposed antennas have been modelled, designed and simulated using Computer Simulation Technology Microwave Studio Version 2010 (CST MWS V 10.0). The designs include slotted patch, reduced ground plane and defected ground structures. The maximum impedance bandwidth is achieved by reducing the size of ground plane and embedding a slot in ground.

First design is presented for dual banding of microstrip antenna for wireless applications. The resonating applying behaviour of MPA proposed antenna depend upon embedding multiple slots length in the patch and by applied coplanar feed line the performance of proposed patch antenna improved as compared to rectangular patch without coplanar waveguide (CPW) feeding mechanism. The dual band antenna covers WLAN and WiMAX bands viz 2.4 GHz to 2.7 GHz and 5.2 GHz to 6.3 GHz and its fabrication and measurement has been attempted in this thesis. The antenna parameters like operating frequency, Voltage Standing Wave Ratio (VSWR), bandwidth, return loss, directivity and gain are analysed for each antenna configuration. The return loss of dual band antenna is -

21.88 dB and -36.99 dB at resonant frequencies. The directivity of antenna is 2.15 dBi and 2.88 dBi and the gain of antenna is 2.21 dBi and 2.54 dBi respectively.

Second design is slotted and stubbed antenna for triple band in this antenna H and two U Shape slots embedded in radiating patch which offer a wide bandwidth which is suitable for WLAN and WiMAX applications. The design offers a bandwidth 259 MHz, 889 MHz and 185 MHz at resonate frequencies 2.01 GHz, 3.59 GHz and 5.70 GHz. The return loss of antenna is -15.44 dB, -22.63 dB, -23.50 dB. The gain and directivity of antenna is 2.29 dBi, 2.68 dBi, 4.66 dBi and 2.21 dBi, 2.76 dBi, 4.13 dBi respectively.

Third design is Trident shaped triple band monopole antenna which have three resonating path through which three resonances are occurring at 2.74 GHz, 3.96 GHz and 6.03 GHz which are reserved for WLAN, WiMAX and IMT applications. The triple band covering the frequency bands (2.55 GHz-2.90 GHz), (3.77 GHz-4.11 GHz) and (5.68 GHz-6.45 GHz). The directivity of antenna 4.41 dBi, 3.31 dBi and 3.94 dBi and gain of antenna 4.47 dBi, 2.93dBi and 3.63 dBi respectively.

The fabrication and testing of the dual band slotted microstrip antenna has also been accomplished using VNA model No: E5071C. A Comparison between simulated and measured results has also been demonstrated in this thesis.

INDEX

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

MPA	Microstrip Patch Antenna
WLAN	Wireless Local Area Network
WiMAX	Worldwide interoperability for microwave access
CST	Computer Simulation Technology
CPW	Coplanar Waveguide
VNA	Vector Network Analyzer
IMT	International Mobile Telecommunications

CHAPTER 1
INTRODUCTION

1.1 Introduction

In high performance aircraft, spacecraft and missiles applications where size, weight, cost, performance, ease of installation and aerodynamic profile are constraints, low profile antenna may be required. Presently there are many other government and commercial applications such as mobile radio and wireless communication that have similar specifications. To meet these requirements, microstrip antenna can be used. These antennas are low profile, conformable to planar and non planar surface, simple and inexpensive to manufacture using modern printed circuit technology. Mechanically robust when mounted on rigid surface, compatible with MMIC design. When the particular patch shape and mode are selected they are very versatile in term of resonant frequency, polarization pattern and impedance. In addition by adding the load between patch and ground plane such as pins, adaptive elements with variable resonant frequency, impedance, polarization and pattern can be designed. The concept of microstrip patch antenna was proposed by Deschamps in 1953. A patent was issued in France in 1955 in the name of Gutton and Baissinor. However 20 year passed before practical antennas were fabricated. Development during the 1970's was accelerated by the availability of good substrate with low loss tangent and attractive thermal and mechanical properties. The first practical antenna was developed by Howell [27] and Munson [28].

Wireless local area network (WLAN) and Worldwide interoperability for microwave access (WiMAX) technology is most rapidly growing area in the modern wireless communication. This gives the mobility to move around within a broad coverage area and still be connected to the network. This provides greatly increased freedom and flexibility. For the home user, wireless has become popular due to ease of installation and location freedom. Naturally these applications require antennas. This being the case portable antenna technology has grown along with mobile and cellular technologies. It is important to have the proper antenna for a device. The proper antenna will improve transmission and reception, reduce power consumption, last longer and improve marketability of the communication device.

Microstrip antennas have some good features like low cost, low profile, easy to fabricate, capable for dual and triple frequency operations. Due to the microstrip antennas are well suited for WLAN/WiMAX application systems. Microstrip antennas have some disadvantages like narrow bandwidth, low gain etc. Broad banding is the a main problem, for solving the problems we propose new structures for that require more than one frequency band operation [29]. Recently dual band wireless phones have become popular recently because they allow using the same phone in two networks that have different frequencies. Tri band phones have also gained popularity but there exist more than three frequency bands that can be used for wireless applications. Table 1.1 list a few useful wireless applications and their operating frequencies. Recently coplanar waveguide (CPW) antenna has been more popular because of its many attractive features such as wider bandwidth, better impedance matching and simplest structure of a single metallic layer, no soldering points and easy integration with active device or monolithic microwave integrated circuits. A Coplanar Waveguide structure consists of a median metallic strip of deposited on the surface of a dielectric substrate slab with two narrow slits ground electrodes running adjacent and parallel to the strip on the same surface. CPW is one of these antennas having these qualities. A coplanar line is a structure in which all the conductors supporting wave propagation are located on the same plane, i.e. generally the top of a dielectric substrate [35].

1.2 Wireless Standards

1.2.1 GSM

GSM networks operate in a number of different carrier frequency ranges (separated into GSM frequency ranges for 2G and UMTS frequency bands for 3G), with most 2G GSM networks operating in the 900MHz or 1800 MHz bands. Where these bands were already allocated, the 850 MHz and 1900 MHz bands were previously used for first-generation systems and most 3G networks in Europe operate in the 2100 MHz frequency band.

Regardless of the frequency selected by an operator, it is divided into timeslots for individual phones to use. This allows eight full-rate or sixteen half rate speech channels per radio frequency. These eight radio timeslots (or eight burst periods) are grouped into a TDMA frame. Half rate channels use alternate frames in the same timeslot. The channel date rate for all 8 channels is 270.833 Kbit/s, and the frame duration is 4.615 ms.

The transmission power in the handset is limited to a maximum of 2 Watt in GSM850/900 and 1Watt in GSM 1800/1900.

1.2.2 IMT (International Mobile Telecommunications)

In the mid 1980's the ITU started work to define the next "generation" of mobile radio standards to move existing mobile networks from specific National and Regional standards onto a global basis. This necessitated finding a new globally available frequency band as well as attempting to maximize convergence within the many existing second generation mobile wireless technologies.

Due to the rapid growth of 2G mobile during the 1990's it became necessary for the ITU to offer a number of possible routes from the various existing 2G systems to a 3G capability. Fortunately it also became economically realistic to offer multi-mode/multiband mobile equipment to smooth the transition from 2G to 3G operations. Mobile radio technologies are proving to be the only economical approach for making telecom service available to the underserved regions in developing countries and globally mobile users. In developed countries mobile use is near saturation and so driving force in these areas is new "broadband" multimedia services. These new services will be provided through enhancement to IMT-advanced (4G) in the future. IMT is the generic ITU name for 3G/4G. Radio spectrum below 1GHz is optimum for the needs of developing countries, due to the ability to serve larger rural areas from a single cell site compared to spectrum above 2 GHz. The 2007 World Radio conference made valuable strides in identifying additional spectrum for IMT, both below 1 GHz and above 2 GHz.

1.2.3 IEEE standard for WLAN

The IEEE 802.11 standard was proposed in 1997 for WLAN applications. After few years new standard was proposed, operating on the 2.4 GHz ISM band (2.4-2.484 GHz), called 802.11b or 802.11 HR (High Rate), which provides a data rate up to 11 Mbps. The IEEE 802.11a standard was approved in 1999, operating on the 5 GHz ISM bands (5.15-5.35 GHz and 5.725-5.825 GHz). The change of operating band showed that 802.11a and 802.11b products are not compatible. Therefore, the IEEE propose 802.11g standard was accepted in 2003. Since 802.11b and 802.11g are using 2.4 GHz frequency band while 802.11a uses 5 GHz frequency band so a dual band antenna was designed for WLAN applications. The popularity of WLAN was increased due to high-speed transfer rate. This increased the development of broadband antennas [31].

1.2.4 IEEE standard for WiMAX

WiMAX technology is based on the IEEE 802.16 standard also called Broadband Wireless Access. The name WiMAX was created by the WiMAX forum which was formed in June 2001 to promote conformity and interoperability of the standard. The forum describes WiMAX as "a standards-based technology enabling the delivery of last wireless broadband mile wireless broadband access as an alternative to cable and DSL". There is no uniform global licensed spectrum for WiMAX, although the WiMAX Forum has published three licensed spectrum profiles: 2.5 GHz (2.5-2.69 GHz), 3.5 GHz (3.4-3.69 GHz) and 5.5 GHz (5.25-5.85 GHz). WiMAX provide the data rate up to 70 Mbps over 50 Km. IEEE 802.16-2004 is often called IEEE 802.16d, since that was the working party that developed the standard. It is also frequently referred to as "fixed WiMAX" since it has no support for mobility. It replaced IEEE standards 802.16-2001, 802.16c-2002, and 802.16a-2003. 802.16e-2005 is an amendment to 802.16-2004 and is often referred to in shortened form as 802.16e. It introduced support for mobility, amongst other things and is therefore also known as "mobile WiMAX" [31].

Table 1.1: Various wireless standards and their frequency band [31]

Wireless Applications		Frequency Band (MHz)	Bandwidth (MHz)
GSM	GSM 900	890-960	70
	GSM 1800	1710-1805	95
	GSM 1900	1850-1990	140
IMT		2300-2400	100
		2700-2900	200
		3400-4200	800
		4400-4900	500
WLAN		2400-2484	84
		5150-5350	200
		5725-5825	100
BLUETOOTH		2400-2500	100
WiMAX		2500-2690	190
		3400-3690	290
		5250-5850	600

1.3 Antenna Overview

1.3.1 Need of Antennas

In each and every case, the transmitters and receivers involved require antennas, even if some are hidden like inside laptop computers equipped with Wi-Fi, or inside radio. According to the IEEE standards definition of terms for antennas, antenna is basically defined as the means of transmitting and receiving radio waves. It can also be defined as the transitional structure between the free space and the guiding space [1]. Antennas are required by any radio receiver or transmitter to couple its electrical connection to the electromagnetic field. Radio waves are electromagnetic waves which carry signals through the air or through space, at the speed of light. Radio transmitters and receivers are used to convey signals/ information in the systems including broadcast radio, Wi-Fi, point to point communication links and many remote controlled devices.

1.3.2 Types of Antennas

Antennas are classified into many types which are described below:

On the basis of radiation:

- **Omni-directional antenna**: also called as weakly directional antennas which radiate and receive more or less in all directions.
- **Directional antenna**: also called as beam antennas which radiate and receive in a particular direction. A directional antenna is intended to maximize its coupling to the electromagnetic field in the direction of the other station or to cover a particular sector.

On the basis of Aperture:

- **Wire Antennas:** these types of antennas are familiar to layman as these antennas are seen every where like on automobiles, buildings, Ships, aircrafts etc.
- **Aperture Antennas:** these antennas are more familiar to the layman today than in the past because of the increasing demand for more sophisticated form of antennas and also for utilization of higher frequencies. These are more useful in spacecraft and aircraft applications as they can be easily mounted on them.
- **Microstrip Antennas:** these antennas have use in space applications, government and commercial applications. They consist of metallic patch on grounded substrate. These antennas are mounted on the surface of high performance aircraft, spacecraft, satellites, missiles.
- **Array Antennas:** to get the required radiation characteristics, which is not possible with single antenna, then an aggregate of radiating elements called array are used. The arrangement of the arrays should be such that the radiation adds up to give maximum radiation in a particular direction or directions and minimum in other directions.

On the basis of Polarization:

- **Linearly polarized antenna:** if the antenna is transmitting /receiving in the vertical E direction then it is called vertically polarized antenna. If the antenna is transmitting/receiving in the horizontal E direction then it is called horizontally polarized antenna.

- **Circularly polarized antenna:** if the antenna is able to transmit/receive E field vectors of any orientation, then antenna is said to be circularly polarized antenna. The major requirement in the present wireless world is to have the size of antenna as small as possible, so out the available structures when application in terms of WLAN is considered; the microstrip antennas serve as the most optimum choice.

1.4 Introduction to Microstrip Patch Antennas (MPAs):

In high performance point to point and point to multipoint application where size, weight, cost, performance, ease of installation are constraints, low profile antenna is very much required. To meet these requirements, microstrip antenna is preferred. Microstrip antenna is currently one of the fastest growing segments in the telecommunications industry that promise to become the preferred medium of telecommunications in the future [1]. The basic configuration of a microstrip antenna is a metallic patch printed on a thin, grounded dielectric substrate. The thickness of the dielectric substrate 'h' is usually 0 .003λ ≤ h ≤ 0.05λ and the thickness of patch 't' above the substrate is much less than λ (where λ is the free space wavelength). The microstrip antenna radiates relatively broad beam broadside to the plane of the substrate. End-fire radiation can also be accomplished by judicious mode selection. For a rectangular patch, the length L of the element is usually λ/3 <L<λ/2 and the dielectric constants of the substrates are usually in the range of 2.2 ≤ ε ≤ 12 [1].

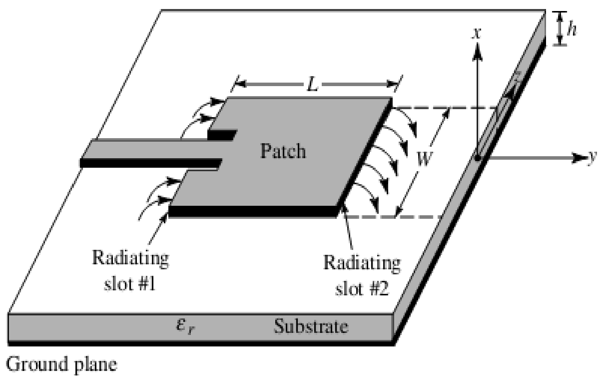


Figure 1.1: Structure of a MPA [1]

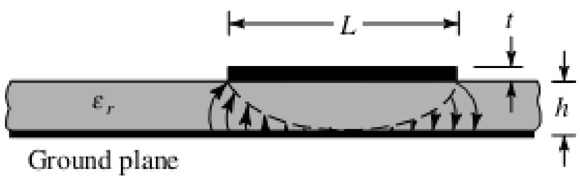


Figure 1.2: Side View of a MPA [1]

1.4.1 Analysis of a Microstrip Patch Antenna Operation

The preferred 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). Basically **the transmission-line model** represents the microstrip antenna by two slots, separated by a low-impedance Z_c transmission line of length L**.**

(A) Fringing Effect

Because the dimensions of the patch are finite along the length and width, the fields at the edges of the patch undergo fringing. This is illustrated along the length in Figures 2.6 (a)-(b) for the two radiating slots of the microstrip antenna. The same applies along the width. The amount of fringing is a function of the dimensions of the patch and the height of the substrate. For the principal E-plane (xy-plane) fringing is a function of the ratio of the length of the patch L to the height h of the substrate (L/h) and the dielectric constant of the substrate. Since for microstrip antennas L/ h >>1, fringing is reduced; however, it must be taken into account because it influences the resonant frequency of the antenna. The same applies for the width. Fringing makes the microstrip line look wider electrically compared to its physical dimensions. Since some of the waves travel in the substrate and some in air, an effective dielectric constant ε_{reff} is introduced to account for fringing and the wave propagation in the line. For a line with air above the substrate, the effective dielectric constant has values in the range of $1 << \varepsilon_{reff} < \varepsilon_r$. For most applications where the dielectric constant of the substrate is much greater than unity ($\varepsilon_r >> 1$), the value of will be closer to the value of the actual dielectric constant of the substrate. The effective dielectric constant is also a function of frequency. According to it, as the frequency of operation increases, most of the electric field lines concentrate in the substrate. Therefore the microstrip line behaves more like a homogeneous line of one dielectric (only the substrate), and the effective dielectric constant approaches the value of the dielectric constant of the substrate [32] The effective dielectric value of the substrate is given by:

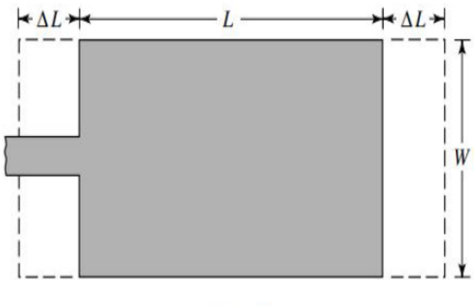
$$W/h > 1$$

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-1/2} \tag{1.1}$$

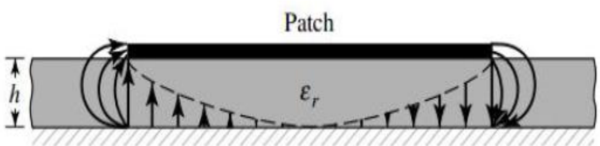
(B) Effective Length, Resonant Frequency and Effective Width

Because of the fringing effects, electrically the patch of the microstrip antenna looks greater than its physical dimensions. For the principal E-plane (xy-plane), this is demonstrated in Figure 2.7 where the dimensions of the patch along its length have been extended on each end by a distance ΔL, which is a function of the effective dielectric constant and the width-to-height ratio (W/h). A very popular and practical approximate relation for the normalized extension of the length is

$$\frac{\Delta L}{h} = 0.412 \frac{(\epsilon_{reff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\epsilon_{reff} - 0.258)\left(\frac{W}{h} + 0.8\right)} \tag{1.2}$$



(a) Top view



(b) Side view

Figure 1.3: physical and effective length of MPA [1]

Since the length of the patch has been extended by ΔL on each side, the effective length of the patch is now (L=λ/2 for dominant TM010 mode with no fringing)

$$L_{eff} = L + 2\Delta L \tag{1.3}$$

For the dominant TM_{010} mode, the resonant frequency of the microstrip antenna is the function of length. Usually it is given by:

$$(f_r)_{010} = \frac{1}{2L\sqrt{\epsilon_r}\sqrt{\mu_0\epsilon_0}} - \frac{v_0}{2L\sqrt{\epsilon_r}} \tag{1.4}$$

Where $\mathbf{V_0}$ is the speed of light in the free space [33]

(C) Design Procedure

In the typical design procedure of rectangular Microstrip patch antenna, three essential parameters are:

Frequency of operation (Fr): The resonant frequency of the antenna must be selected appropriately. The antenna designed should be useful for the wireless communication system. The frequency range is approximately 890 MHz to 5.85 GHz.

Dielectric constant of the substrate (ε_r): The dielectric constant of substrate (εr) material plays an important role in the patch antenna design. A substrate with a high dielectric constant reduces the dimensions of the antenna but it also affects the antenna performance. So, there is a trade-off between size and performance of patch antenna.

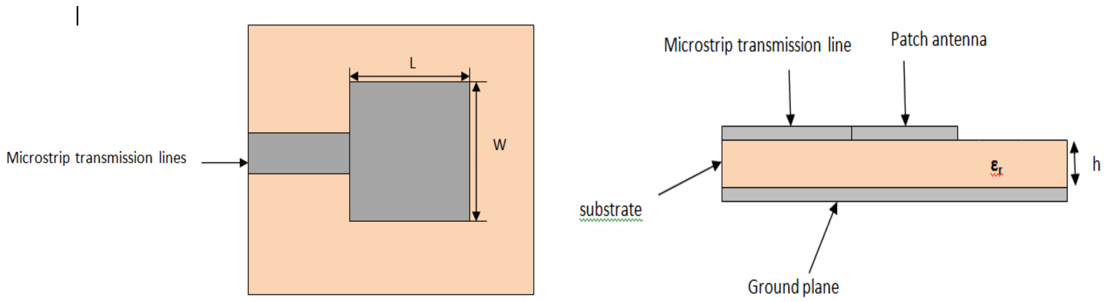


Figure 1.4: MPA with microstrip feed line

Height of dielectric substrate (h): For the Microstrip patch antenna to be used in communication systems, it is essential that the antenna is not bulky. Hence, the height of the dielectric substrate should be less.

After the proper selection of above three parameters, the next step is to calculate the radiating patch width and length. 0.

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Step 1: Calculation of Width (W)

For an efficient radiator, practical width that leads to good radiation efficiencies is [33]

$$W = \frac{1}{2f_r\sqrt{\mu_0\epsilon_0}}\sqrt{\frac{2}{\epsilon_r+1}} \tag{1.5}$$

Step 2: Calculation of Effective Dielectric Coefficient (εr):

The effective dielectric constant can be bettered from equation (1.1)

Step 3: Calculation of Effective Length (L_{eff}):

The effective length is

$$L_{eff} = \frac{c}{2f_0\sqrt{\epsilon_{reff}}} \tag{1.6}$$

Step 4: Calculation of Length Extension (L)

$$\frac{\Delta L}{h} = 0.412 \frac{\left(\epsilon_{reff} + 0.3\right)\left(\frac{W}{h} + 0.264\right)}{\left(\epsilon_{reff} - 0.258\right)\left(\frac{W}{h} + 0.8\right)} \quad (1.7)$$

Step 5: Calculation of actual Length of Patch (L):

The actual length of radiating patch is obtained by

$$L = L_{eff} - 2\Delta L \quad (1.8)$$

Step 6: Calculation of Ground Dimensions (Lg, Wg)

The transmission line model is applicable to infinite ground planes only. However, for practical considerations, it is essential to have a finite ground plane. It has been shown by that similar results for finite and infinite ground plane can be obtained if the size of the ground plane is greater than the patch dimensions by approximately six times the substrate thickness all around the periphery. Hence for this design, the ground plane dimensions would be given as:

$$L_g = 6h + L \quad (1.9)$$

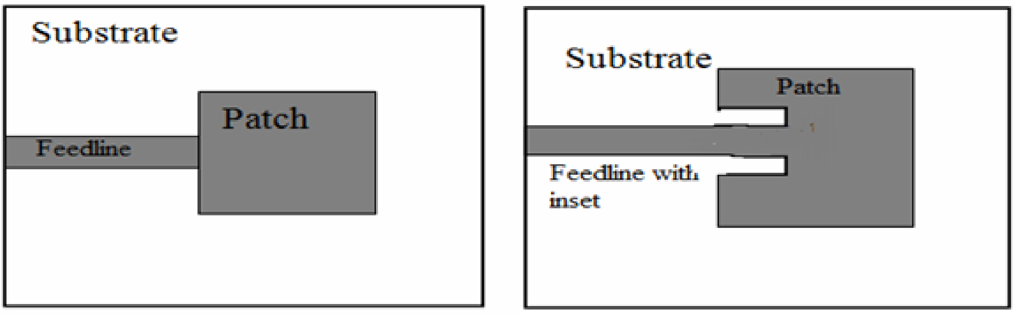
$$W_g = 6h + W \quad (1.10)$$

1.4.2 Feeding Techniques

There are many configurations that can be used to feed microstrip antenna. The most popular feeding techniques are the microstrip feed line, coaxial probe, aperture coupling, proximity coupling and coplanar Waveguide. Out of these five techniques, the first two are very similar in operation and offer essentially one degree of freedom (for a fixed patch size and substrate). The proximity coupled patch has at least two degrees of freedom: the length of the feeding stub and the patch width-to-line width ratio. The aperture coupled patch antenna has at least four degrees of freedom: the slot size, its position the feed substrate parameters and the feed line width.

(1) Microstrip feed line

The microstrip feed line is a conducting strip, usually of much smaller width compared to the patch. The microstrip-line feed is easy to fabricate, simple to match by controlling the inset position and rather simple to model. However as the substrate thickness increases, surface waves and spurious feed radiation increase, which for practical designs limit the bandwidth. Such antennas are limited in bandwidth to about 2-5 %. The equivalent circuit that applies to this feeding technique is the parallel RLC network representing the resonant patch and the series inductor represents feed inductance of the microstrip feed line. Electromagnetic field lines are focused between the microstrip line and ground plane to excite only guided waves as opposed to radiated or surface waves [2].



(a) **(b)**

Figure 1.5: Geometry of Microstrip Feed line (a) directly feed (b) Inset feed [1]

(2) Coaxial probe

It can be used to feed patch elements through the ground plane from the parallel feed substrate. The inner conductor of the coax is attached to the radiation patch while the outer conductor is connected to the ground plane. The coaxial probe feed is easy to fabricate and match and it has low spurious radiation. However, it has narrow bandwidth and it is more difficult to model, especially for thick substrates (h > 0. 02 λ). But in the array design having thousands of elements, such a large number of solder joints makes fabrication difficult and lowers reliability. Its equivalent circuit is same as the microstrip feed line. Although, probe and microstrip line feeds primarily stimulate the dominant mode of the patch, the native unevenness of these feeds generates some higher-order modes which produce cross-polarized radiation.

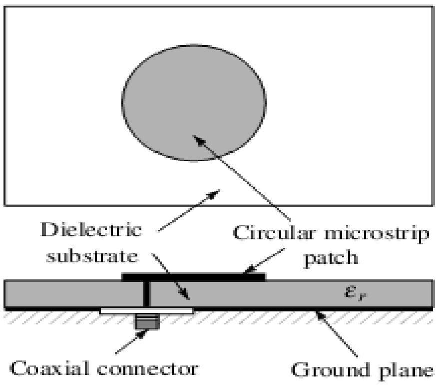


Figure 1.6: Geometry of Coaxial Probe Feed patch antenna [1]

(3) Aperture coupling technique

This configuration uses two parallel substrates separated by a ground plane. A microstrip feed line on the bottom substrate is coupled through a small aperture in the ground plane to a microstrip patch on the top substrate. This feeding technique allows independent optimization to both the feed and the radiation functions by keeping thin, high dielectric constant substrate to be used for the feed and thick, low dielectric constant for the antenna element. The key factor of this feeding technique is that the aperture is usually smaller than resonant size, so the back lobe radiated by the slot is 15-20dB below the forward main beam. Aperture coupled antennas are advantageous in arrays because they electrically isolate the feed and phase shifting circuitry from the patch antennas. The disadvantage is the required multilayer structure which increases fabrication complexity and cost . 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. The equivalent circuit appears as a series RLC network, with a shunt inductance representing the coupling slot.

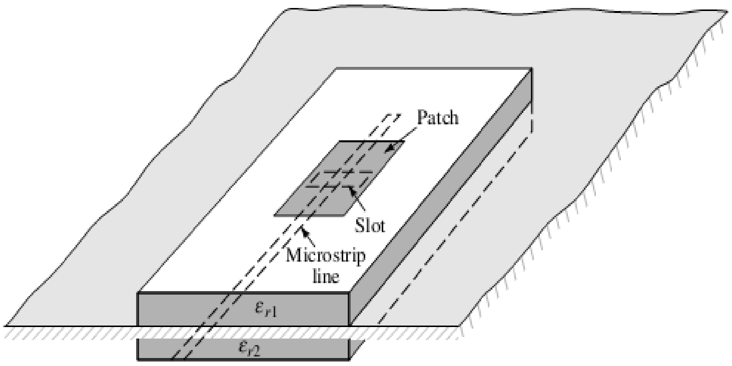


Fig 1.7: Geometry of Aperture Coupled Microstrip Patch Antenna [1]

(4) Proximity coupling feed antenna

It uses a two-layer substrate with a microstrip line on the lower substrate, terminating in an open stub below the patch which is printed on the upper substrate. It is a type of non-contacting feed. Proximity coupling has the advantage of allowing the patch to exist on a relatively thick substrate for improved bandwidth; on the contrary the feed line is on an effectively thin substrate, which reduces spurious radiation and coupling. The major problem in this feeding technique is its fabrication, which is bit more difficult because of the requirement for accurate alignment between substrates, but soldering is eliminated. The coupling in proximity is of capacitive nature. The equivalent circuit of this feeding technique has a capacitor in series with the parallel RLC resonator that represents the patch. It provides bandwidth up to 21%.

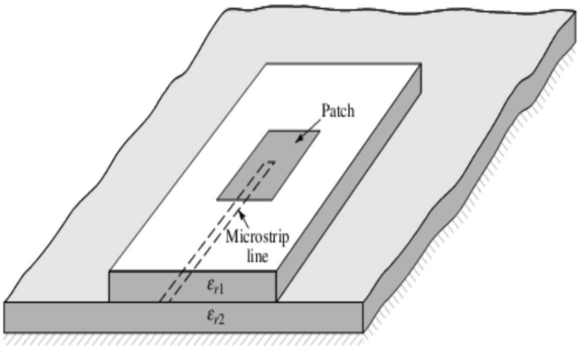


Figure 1.8: Geometry of Proximity Coupled Microstrip Patch Antenna [1]

(5) Coplanar waveguide feeding

The coplanar waveguide was proposed by C.P. Wen in 1969. A coplanar waveguide structure consists of a median metallic strip of deposited on the surface of a dielectric substrate slab with two narrow slits ground electrodes running adjacent and parallel to the strip on the same surface. This transmission line is uniplanar in construction, which implies that all of the conductors are on the same side of the substrate. They have many features such as low radiation loss, less dispersion, easy integrated circuits and simple configuration with single metallic layer, and no via holes required. The CPW fed antennas have recently become more and more attractive because of its some more attractive features such as wider bandwidth, better impedance matching, and easy integration with active devices or monolithic microwave integrated circuits.

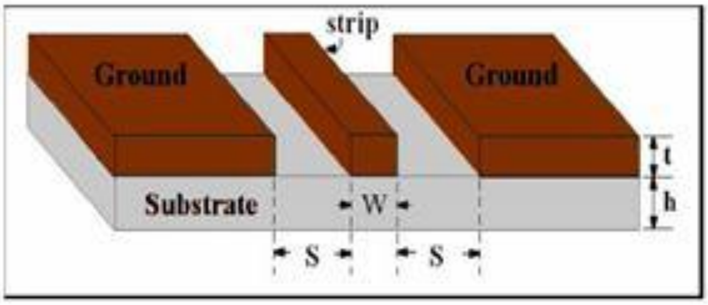


Figure 1.9: Geometry of Coplanar Waveguide Feed

Table 1.2 The comparisons between the feeding methods for MPA

Characteristics	Microstrip Feed line	Coaxial Feed	Aperture coupling Feed	Proximity Feed	Coplanar Waveguide
Spurious Feed Radiation	**More**	**More**	**More**	**More**	**More**

Reliability	**Better**	**Poor due to soldering**	**Good**	**Good**	**Good**
Impedance Matching	**Easy**	**Easy**	**Easy**	**Easy**	**Easy**
Bandwidth	**2-5%**	**2-5%**	**13%**	**21%**	**40%**

Due to more spurious radiation, more reliability and easy impedance matching, aperture coupled feeding techniques is used. Also, it provides better bandwidth as compared to Microstrip feed line and Coaxial coupled techniques.

1.4.3 Advantages and Disadvantages of Microstrip Antennas

Advantages of Microstrip Antennas

- They are very low profile, and can be fabricated using printed circuit techniques.
- Light weight and low volume.
- Low fabrication cost, hence can be manufactured in large quantities.
- Supports both, linear as well as circular polarization
- Can be easily integrated with microwave and millimetre wave integrated circuits (MMICs).
- Capable of dual and triple frequency operations.
- Mechanically robust when mounted on rigid surfaces

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.

Applications of Microstrip Antennas

- Aerospace vehicles including high-performance aircraft, spacecraft, satellites and missiles
- Mobile radios, phones and pagers
- Base stations for personal communications
- Large ground-based phased array antennas

Microstrip patch antennas have a very high antenna quality factor (Q). Q represents the losses associated with the antenna and a large Q leads to narrow bandwidth and low efficiency. Q can be reduced by increasing the thickness of the dielectric substrate. But as the thickness increases, an increasing fraction of the total power delivered by the source goes into a surface wave. However, surface waves can be minimized by use of photonic band gap structures [34]. Other problems such as lower gain and lower power handling capacity can be overcome by using an array configuration for the elements.

1.5 Antenna Parameters

Before discussing the simulated results of a microstrip patch antenna, it is important to discuss some parameters in details that are to be analysed in simulation.

- **Return Loss:** It is the difference between forward and reflected power, in dB, generally measured at the input to the coaxial cable connected to the antenna. If the power transmitted by the source is Pt and the power reflected back is Pr , then the return loss is given by Pr. For maximum power transfer the return loss should be as small as possible. This means that the ratio Pr/Pt should be as small as possible, or expressed in dB, the return loss should be as large a negative number as possible [1]. Return Loss is determined in dB as follows:

$$RL = -20\log_{10}|\Gamma| \tag{1.11}$$

  Where | Γ | = is the reflection coefficient,

- **Directivity:** It is defined as the ratio of radiation intensity in a given direction from the antenna to the radiation intensity averaged over all the directions. The average radiation intensity is equal to the total power radiated by the antenna divided 4π. If the direction is not specified, the direction of maximum radiation intensity is implied. The directivity of the non-isotropic source is equal to the ratio of its radiation intensity in a given direction over that of an isotropic source. In numerical form, directivity is given by [32]:

$$D = \frac{U}{U_0} = \frac{4\pi U}{P_{rad}} \tag{1.12}$$

  Where U=radiation intensity (W/unit solid angle)

  U_o = radiation intensity of an isotropic antenna (W/unit solid angle)

  Prad = total power radiated (W)

- **Gain:** It is defined as the ratio of the intensity, in a given direction, to the radiation intensity that would be obtained if the power accepted by the antenna is radiated isotropically. The radiation intensity corresponding to the isotropically radiated power is equal to power accepted (input) by the antenna divided by 4π.when the direction is not stated, the power gain is usually taken in the direction of maximum radiation.[1] It is given as:

$$Gain = 4\pi.\frac{radiation\ intensity}{total\ input}$$

$$Gain = \frac{4\pi U(\theta,\varphi)}{P_{in}} \qquad (1.13)$$

- **Bandwidth:** It is defined as "the range of frequencies within which the performance of the antenna, with respect to some characteristic, conforms to a specified standard." The bandwidth can be considered to be the range of frequencies, on either side of a centre frequency (usually the resonance frequency for a dipole), where the antenna characteristics (such as input impedance, pattern, beam-width, polarization, side lobe level, gain, beam direction, radiation efficiency) are within an acceptable value of those at the centre frequency [1].
- **Beam width:** It is defined as the angular separation between two identical points on opposite side of the pattern maximum [1].
- **Efficiency:** It is used to take into account losses at the input terminals and within the structure of the antenna. Such losses may be due, to

1. Reflections because of the mismatch between the transmission line and the antenna
2. *I* 2*R* losses (conduction and dielectric)

In general, the overall efficiency can be written as

$$\mathbf{e_o = e_r \times e_c \times e_d} \qquad (1.14)$$

Where e_o = total efficiency (dimensionless)

e_r = reflection(mismatch) efficiency = (1 - |?|2) (dimensionless)

e_c = conduction efficiency (dimensionless)

e_d = dielectric efficiency (dimensionless)[3]

1.6 Microstrip Slot Antenna

Microstrip antennas can be divided into two basic types by structure, namely microstrip patch antenna and microstrip slot antenna. The slot antennas can be fed by microstrip line, slot line and CPW. Microstrip slot antenna is very simple in structure: it consists of microstrip feed that couples electromagnetic waves through the slot above and slot radiates them. A microstrip-fed slot antenna offers a better isolation between the feed and the material under measurement compared to the microstrip-fed microstrip antenna. They are more flexible in integration with other active and passive devices in a hybrid MIC and MMIC design [40]. Furthermore, they are capable of producing omni-directional radiation patterns by simply inserting quarter-wave thick foam and reflector. To improve the antenna performance by improving the coupling between the patch and feed line, different size and shapes of slots are experimented. H-shaped, bowtie, dog bone shaped slots had been studied. All these slot shapes provide better input impedance compared to a rectangular slot. They also have smaller dimensions compared to rectangular slot, which decreases the amount of back radiation through the aperture. Only disadvantage of these complicated slot geometries is that it is difficult to analyse these structures analytically or even numerically. Besides slot shape, patch and feed shapes are also varied to design a wideband microstrip antenna. Some different shapes of patch and feed, like T-shaped feed, Further more the effects of dielectric constants of the layers are investigated. Studies have shown that it is advantageous to choose a high dielectric constant material for the lower substrate (for feed) and a thick and low dielectric constant material for the upper substrate (for patch).

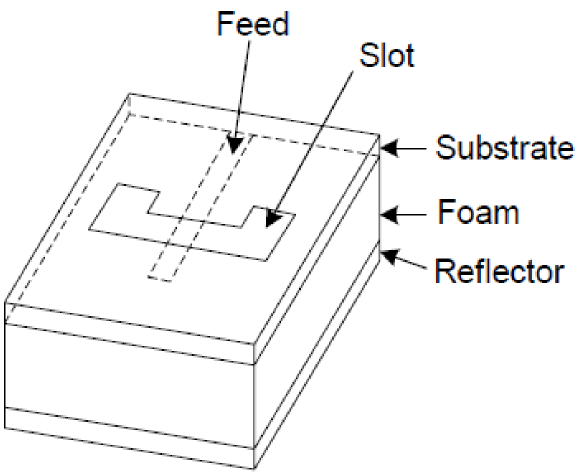


Figure 1.10: Microstrip Slot antenna Structure [40]

1.7 Objective of Thesis

The main objectives were designed as the following:

(A) To design and simulate a Dual band for WLAN and WiMAX frequency bands.

- Parametric studies on the proposed antenna.
- Fabrication and testing of the proposed design.

(B) To design and simulate a Triple band for WLAN and WiMAX frequency bands.

- Parametric studies on the proposed microstrip patch antenna as a foresaid.

(C) To design and simulate a triple band for WLAN, WiMAX and IMT frequency bands

- Parametric studies on the proposed microstrip patch antenna as a foresaid.

1.8 Methodology

- Extensive literature survey is conducted to study the literature available in the field of Dual and Triple Frequency microstrip antennas.
- Detailed study of antenna structures.
- The effects on gain, return loss and radiation pattern are analysed For conducting simulation of proposed antenna designs, Full Wave Electromagnetic Simulation Software, Computer Simulation Technology - Microwave Studio Version 10.0 (CST MWS V10.0) has been used.
- The proposed antenna designs are projected on "Fibre-glass Reinforced epoxy" FR-4 material which is an inexpensive and readily available substrate material.
- The return loss or S_{11} parameters of the proposed antenna will be measured using Vector Network Analyser.

1.9 Organization of Thesis

The Thesis is divided into six Chapters

Chapter 1 is dedicated to the Overview of Wireless Communication and basics of Microstrip Antenna discussing.

Chapter 2 is dedicated to the literature survey on slotted Microstrip antenna. The brief idea about the research work done for bandwidth enhancement, defected ground structure, Coplanar waveguide antenna is also given.

Chapter 3, a Dual band antenna is designed and effect of various physical parameters on the resonating frequency is done. In this proposed antenna various resonant slot lengths is cut on the radiating patch and is feed with coplanar waveguide feeding which give a desired frequency bands, wideband width and better return loss. The antenna is fabricated and result is compared with a simulated results.

Chapter 4, a Novel slotted and stubbed Triple band antenna Microstrip patch antenna for wireless application is proposed in which H shaped and Two U slots are cut in radiating patch and feed with a Microstrip feed line which offers a wide band width, better return loss, gain and omnidirectional radiation characteristics.

Chapter 5, a Triple band Trident shaped monopole antenna is designed with microstrip feed line and studied the various parameters. In this proposed antenna three resonant path are created for which three resonances are occurring with sufficient large band width which covers the WLAN, IMT and WiMAX applications.

Chapter 6, This chapter gives the conclusion to this thesis and the future work continued antenna design by using a different structure configuration, the use of different dielectric substrate material as well as combination of different substrate in one structure.

CHAPTER 2
LITERATURE SURVEY

Prior to stating of my Thesis, it is important to have a deep understanding on the existing pages of antenna. The main source of information for Thesis is books, journals, Thesis and the internet. This chapter give us idea about the evolution of microstrip slot antenna and various developments in the past.

M. Ojaroudi *et al*. (2013) presented a novel, small, printed monopole antenna for ultra wideband (UWB) applications with dual band-notch function. By cutting an inverted fork-shaped slit in the ground plane, additional resonance is excited and hence much wider impedance bandwidth can be produced. To generate dual band-notch characteristics, we use a coupled inverted U-ring strip in the radiating patch. The measured results reveal that the presented dual band-notch monopole antenna offers a wide bandwidth with two notched bands, covering all the 5.2/5.8-GHz WLAN, 3.5/5.5-GHz WiMAX, and 4-GHz C-bands. By cutting an inverted fork-shaped slit in the ground plane, additional resonance is excited. Also, by using coupled inverted U-ring strip with variable dimensions on the radiating patch, dual band-notch function is generated. The proposed antenna displays a good omnidirectional radiation pattern even at higher frequencies [2].

M. Moghadasi *et al.* (2013) presented unique and miniaturized dual-band coplanar waveguide (CPW)-fed antenna is presented. The proposed antenna comprises a rectangular patch that is surrounded by upper and lower ground-plane sections that are interconnected by a high-impedance microstrip line. The proposed antenna structure generates two separate impedance bandwidths to cover frequency bands of GSM and Wi-Fi/WLAN. Using a unique ground structure, this comprises a strip line interconnecting the upper and lower ground sections surrounding the patch, results in an effective dual-mode antenna without compromising its physical size. The antenna exhibits two resonant modes with an excellent impedance performance. The proposed antenna has several advantages such as small size, excellent radiation characteristics, and circular polarization in the GSM operating band. These properties make the antenna suitable for GSM and Wi-Fi/WLAN applications [3].

A. H. Shah *et al.* (2013) discussed A Tri-band G-shaped Microstrip Monopole antenna suitable for the ISM band wireless applications in MIMO environment is presented in this paper. The novelty contributed in this work is the appropriate selection of dielectric substrate, the logical modifications in the existing antenna length and width, and the connection of the ground planes on both sides of the existing G-shaped antenna. The proposed antenna is fed with CPW waveguide and the parameters have been optimized so that resonant modes with wider bandwidths suitable for applications at lower, mid and the upper end of the ISM band achieved. The antenna design parameters are optimized to achieve a bandwidth improvement at 2.4 GHz, 4.2 GHz, and 6.07 GHz as the centre frequencies of the said three frequency bands. It is concluded that there is a bandwidth improvement of 19.6%, 29.4% and 40.79% at 2.4 GHz, 4.2 GHz, and 6.07 GHz respectively. Therefore, the proposed antenna can be used for wireless applications in the ISM band [4].

A. Foudazi *et al.* (2012) presented a small size microstrip-fed multi-band planar mode antenna the base of proposed antenna is a diamond shaped patch that cover the ultra band frequency range to create a multi band antenna, several narrow strip acting as resonance paths can integrated with diamond shape antenna by removing the centre part of the diamond shape antenna without distorting the ultra band behaviour a quarter wavelength can be added to the notch region which cover the frequency band 1.3, 1.8, 2.4 and 3.1-10.6 GHz which includes GPS, GSM, WLAN and UWB. The dual and triple band antennas show stable omnidirectional radiation patterns over all the frequency band as well as relatively consistent group delay across the UWB frequencies [5].

T. Quan *et al.* (2012) discussed on proposed triple band monopole planar antenna for DCS (digital cellular system) and WiMAX (worldwide interoperability for microwave access) system. the antenna is etching an H-shaped and two U-shaped slots on a rectangular patch and resonant frequency can be controlled by adjusting the dimension of the slots which covers 1.8GHz band for DCS and 3.5/5.5GHz band for WiMAX the proposed antenna has a small size and have three operating bandwidth at 1.8GHz, 3.5 GHz, 5.5 GHZ and widely used for wireless communication applications [6].

C. M. Wu *et al* (2012) discussed compact planar ultra wideband (UWB) antenna suitable for wireless universal serial bus (USB) dongle application is presented. By simply cutting notches and embedding types of slots into a rectangular patch, multiple resonances with effective bandwidth enhancement were achieved. A prototype of the proposed antenna was constructed and measured to show an ultra wide operating band with 10-dB return-loss bandwidth of about 10.42 GHz ranging from 2.86 to 13.38 GHz, which sufficiently covers the operating band, 3.1–10.6 GHz, of the new wireless personal area network (WPAN) using UWB technique. With an antenna size of only 11× 15 mm^2, multi resonance having ultra wide bandwidth and suitable radiation performance to cater for the WPAN standard used in a USB dongle device is achieved. Also, the prototype has been constructed and measured to show a good agreement with the simulated results [7].

H. F. Abutarboush *et al* (2012) presented U-slot tri-band monopole antenna on a low-cost paper substrate using inkjet-printed technology is presented for the first time. The U-shaped slot is optimized to enhance the bandwidth and to achieve tri-band operation of 1.57, 3.2, and 5 GHz with measured impedance bandwidths of 3.21%, 28.1%, and 36%, respectively. The antenna is fabricated through a metallic nano particle ink on a standard commercial paper. Thus, the antenna can be used to cover the GPS, WiMAX, HiperLAN/2, and WLAN. U-shaped slot cut on the main radiator is used to generate a low-frequency band for GPS and two other high-frequency bands with much wider bandwidths for many other applications. Although the proposed antenna is optimized to operate at 1.57, 3.2, and 5 GHz, other applications are also possible to be obtained by changing the structural parameters of the U-slot [8].

S. Genovesi *et al.* (2012) discussed a compact printed antenna operating concurrently at three distinct frequencies is presented for sub-GHz wireless communications. The radiation properties of the antenna, realized by using a low-cost PCB process on FR4 substrate, have been measured, and the feasibility of a sub-GHz wireless sensors network in an industrial scenario has been evaluated. The novel design is able to concurrently operate at three different tune able bands within the 300-MHz–1-GHz range providing suitable bandwidth and read range for short-range applications [9].

A. A. Ibrahim *et al.* (2011) proposed a triple band microstrip-fed monopole antenna which is Meta material inspired planar monopole antenna .the proposed structure consist of monopole loaded with composite right/left handed unit cell. It operate at two narrow bands 0.925 and 1.227GHz and one wideband 1.56-2.7GHz it covers several communication standard the design antenna covers the GSM900, DCS, PCS, UMTS, Bluetooth, Wi-Fi(2.4GHz), WiMAX(2.5GHz) and GPS(1.27GHz,1.57GHz) bands with quasi-omnidirectional radiation pattern at all bands [10].

M. Koohestani *et al*. (2011) presented a new microstrip-fed planar monopole antenna is presented for ultra-wideband (UWB) communication systems. The antenna structure consists of a dome-topped, bowl-shaped patch with a truncated ground plane structure.

The ground plane is predominately tapered and includes a notch below the feed-line in the vicinity of the patch. The effects of dimensional parameters on the performance of the antenna have been investigated through a parametric study. Current density distribution it has been shown that the performance of the antenna is mostly dependent on the feed gap, ground plane structure and the dimension of the radiator patch. The ultra-wide bandwidth, small size and low cost make the antenna suitable for the next generation of UWB communication system [11].

S. Jing *et al.* (2011) presented dual-band E-shaped monopole antenna is proposed for wireless applications in the 2.4/5.2GHz bands. To obtain the dual band characteristic, two L-shaped stubs are added to a traditional monopole antenna. The proposed antenna is fed by coplanar waveguide. The measured results show that **t**he impedance bandwidth with S11<-10dB at the lower band reaches 477 MHz (2.29-2.77 GHz) and at the upper band is about 410 MHz (5.02-5.43GHz), which can satisfy the 2.4/5.2 GHz WLAN applications. Meanwhile, the gain and radiation patterns are also studied in this paper. From the results we can see that the proposed antenna is suitable for the WLAN applications [12].

J. H. Yoon *et al.* (2011) proposed dual-band planar monopole antenna for wireless local area network (WLAN) application was designed, fabricated, and measured. The proposed antenna was fabricated on a low-cost, easily available FR4 substrate, which effectively covers both the 2.4GHz and 5.2/5.8 GHz WLAN bands. The proposed antenna consists of two branches, an asymmetric ground plane, a rectangular projection strip, and a rectangular slit in the ground plane. The rectangular projection strip and the rectangular slit in the ground plane were introduced to enhance the performance of the proposed antenna. The configuration can meet the demands of WLAN systems and effectively enhanced the impedance bandwidth to 39.7% for the lower band and 23.1% for the upper band when the impedance bandwidth was -10dB [13].

S. Lin *et al.* (2010) proposed a new dual frequency design of microstrip antenna which have two operating modes of the proposed antenna are associated with various length of two monopole in which larger monopole work for first resonant mode and shorter monopole for the second mode and it reduce the design by 38% and by etching rectangular slot in larger monopole a broadband dual frequency operation was demonstrated and it cover the two frequency band 1.9GHz to 2.2GHz and 2.2GHz to 2.8GHz. The proposed dual band antenna can be used in WCDMA band (1920MHz-1930MHz, 2110MHz-2120MHz) and 2.5-2.69GHz IMT-2000 which are always used in omni directional application [14].

T. D. Hung *et al.* (2010) proposed dual-band microstrip monopole antenna for 3G mobile handsets. This antenna can work in GSM/UMTS bands by generating two resonant modes of 900MHz and 1900MHz frequencies. Antenna is printed on FR4 substrate with the size of 58mm×80mm, thickness of 1.6mm and relative permittivity of 4.4 and the return loss bandwidths of lower and upper modes of the proposed antenna cover the required bandwidth of GSM/UTMS system and which is suitable for application in 3G mobile handsets [15].

L.Y. Cai *et al.* (2010) presented a compact triple band antenna for Bluetooth / WiMAX / WLAN applications using two U-type slot antenna which are very effective in rejecting unwanted frequency in term of its selectivity. This antenna gives bidirectional pattern in the E-plane and omni directional radiation pattern in H-plane over the frequency range and relatively stable. This antenna offer excellent performance with Bluetooth ranging from 2.28GHz to2.9GHz,WiMAX ranging from 3.3GHz to 3.85GHz and WLAN ranging from 4.72GHz to 6.4GHZ and this is compact, planar, three-band ,low cost and its design is simple and straight forward . It can be mounted within the printed circuit boards of notebook computer, mobile terminals and any other wireless device [16].

K. Fuqiang *et al.* (2010) discussed on a triple-band microstrip antenna for WLAN application is made up of quarter wavelength resonating component fed by a 50ohmic microstrip line. The resonating frequencies of the proposed antenna are 2.5GHz and 4.8 GHz, the bandwidth is about 500MHz and 2.63GHz covering the triple band of WLAN system. The lower and higher resonant frequencies can be easily tuned by adjusting few parameters of the presented antenna and the antenna has a simple structure and low profile, making it promising for WLAN applications [17].

B. Vedaprabhu *et al*. (2010) proposed a patch antenna with two U-shaped slots to achieve dual band operation. A thick substrate helps broaden the individual bandwidths. The antenna is designed based on extensive IE3D simulation studies. A prototype antenna is fabricated and experimentally verified for the required. The design of a microstrip patch antenna to operate for several wireless bands with frequency ranges of 1.7-2.2GHz, 2.4-2.5GHz, 5.15-5.35GHz, and 5.45-5.85GHz is proposed here. The primary advantage of this approach is the ease of fabrication as the design does not require alignment between multiple layers of dielectrics and metals. Two U-slots are included to provide the above operating frequency bands. By adjusting the width and aspect ratio of slots and the offset of feed location from the centroid on this thick substrate, the desired bandwidths can be obtained for the antenna [18].

K. Dong *et al.* (2010) proposed a compact dual-band planar monopole antenna for 2.4/5GHz WLAN application is presented. The two resonant modes of the proposed antenna are associate with four slots which contribute to the upper resonant frequency and can reduce the size of the lower resonant length. The proposed antenna show the designed antenna can provide excellent performance for 2.4/5 GHz WLAN systems, including sufficiently wide frequency band, moderate gain and nearly omnidirectional radiation coverage [19].

M. Ojaroudi *et al.* (2009) presented application with frequency band-notch proposed antenna consist of a stepped square radiating patch with two U-shaped slots and a notched ground plane with a T-shaped sleeve that provide a wide fractional bandwidth by modified U-shaped slots dimension the radiating patch, frequency band of 2.85GHz to over 16.73GHz with a rejection band around 5.02-5.97GHz and experimental the proposed antenna is good candidate for ultra wideband applications [20].

J. Y. Park *et al.* (2008) proposed a microstrip line monopole antenna for the wearable applications that can be used as wrist wearable antenna for the UHF band RFID system (911.25MHz) and which have thick monopole structure with quarter wavelength short stubs disposed in parallel on both sides of the microstrip line on the ground plane and the microstrip line extended by 0.14λ and it was design as low profile antenna with a ground plane in order to minimize the effect by the human body and improve its wear ability as the antenna worn in wrist there was little change in resonant frequency and the maximum gain was -7.5dB [21].

X. Song *et al.* (2008) presented a small dual band and broadband microstrip monopole antenna fed by coplanar waveguide. The proposed antenna can generate two separate resonant modes and operate in two frequency bans that used for WLAN. The lower operating band cover from 2.27GHz to 2.49GHz and the upper operating band covers from 4.52GHz to 6.61GHz and the proposed antenna has a compact dimension and easy to construct and integrate with the application specific circuit [22].

R. Zaker *et al.* (2008) discussed a modified microstrip-fed ultra wideband (UWB) planar monopole antenna with variable frequency band-notch characteristic is presented. By inserting two slots in the both sides of microstrip feed line on the ground plane, much wider impedance bandwidth can be produced a modified H-shaped conductor-backed plane with variable dimensions is used in order to generate the frequency band-stop performance and control characteristics such as band-notch frequency and its bandwidth.

The designed antenna has a small size and proposed monopole antenna has the frequency band of 3.1 to over 13.9 GHz with a rejection band around 5.1 to 6 GHz [23].

J. Jung *et al.* (2005) discussed on a small wideband microstrip-fed monopole antenna which consists of a rectangular patch and truncated ground plane is presented for ultra wideband applications. The proposed antenna is designed to operate over 3.1 to 11GHz having a good return loss and radiation pattern characteristics and experimental result show that the proposed antenna could be a good candidate for hand-held UWB application [24].

K. chung *et al.* (2005) proposed a compact ultra-wideband microstrip-fed monopole antenna by using inverted U-slot which increase the impedance bandwidth of antenna and also improve the VSWR performance of monopole antenna .the notch frequency can be controlled by changing the length of U-slot and the proposed antenna has a frequency band of 3GHz to over 11GHz for VSWR less than 2.0 with a rejection band around 5.0 to 5.9GHz [25].

S. I. Latif *et al.* (2005) presented bandwidth enhancement and size reduction of microstrip slot antenna with different slot shapes-straight, L and inverted T, and placed on a small ground plane the variation in the slot shape, from straight to L and T shapes, help in generating additional resonances which when coupled to the original resonances of the slot which further increases impedance bandwidths. This antenna showed wide bandwidth for each of its slot, with orthogonal polarization characteristics the measured impedance bandwidths of about 60%, 84%, and 80% achieved for the straight L and T slot antennas respectively [26].

CHAPTER 3

DUAL BAND CPW FED SLOTTED MONOPOLE ANTENNA FOR WLAN/WiMAX

A novel dual band monopole planar antenna fed by coplanar waveguide (CPW) suitable for wireless applications has been discussed in this chapter. The proposed antenna has two resonant modes which are associated with five slots which contribute the upper resonant frequency and lower resonant frequency. In this chapter the proposed antenna use that is CPW feed mechanism which microstrip antenna consists of parallel conducting layers separating a dielectric medium referred as substrate and provides a wider bandwidth, better impedance matching and easy integration with active devices. The dual frequency behaviour is obtained by etched various resonating lengths in the form of slots in the patch and the frequency tuning is obtained by changing the length of slot and ground plane is etched with a slot which provide a good impedance matching and U slot at the top of the patch which reduces the unwanted resonance occur at upper resonating frequency. The proposed antenna is suitable for Wireless Applications. This Design is simulated using Computer Simulation Technology Microwave studio Version 2010 (CST MWS V 10.0). Finally the result are obtained from the simulations are demonstrated.

3.1 Design of Dual band Microstrip Patch Antenna using CPW

In this design the antenna has two resonating modes which are associated with five resonating lengths in the form of slots on radiating patch. The proposed antenna design is resonating at two frequencies 2.55 GHz and 5.84 GHz and gives a return loss of -21.88 dB and -35.66 dB. The Proposed antenna gives a wide band width of 307 MHz and 1091 MHz which is suitable for WLAN and WiMAX Applications.

Table 3.1: Design specifications of Substrate

Thickness of Substrate	1.2 mm
Dielectric Constant (ε_r)	4.4
Tangent loss (δ)	0.0009

Table 3.2: Optimized parameters of CPW MPA

Parameter	L	W	L_P	W_P	W_1	G
Size (mm)	32	20	22	12	1.65	2
Parameter	L_1	L_2	L_3	L_4	L_5	
Size (mm)	6	9	10	9	5	

3.1.1 Antenna Design

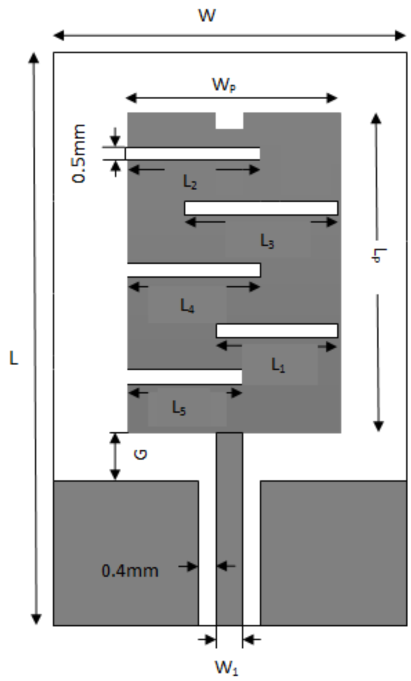


Figure 3.1: Simulated design of Antenna

3.2 Simulated Results:

The simulated results of the proposed CPW fed dual band monopole antenna of various parameters like Return loss, Voltage standing wave ratio (VSWR), Gain, Directivity, Current Distribution and Bandwidth are mentioned in detail as:-

3.2.1 Return loss and Antenna Bandwidth

Return loss is the difference between forward and reflected power, in dB, generally measured at the input of the coaxial cable connected to the antenna, for maximum power transfer the return loss should be as small as possible, this mean return loss should be a large negative number as possible. The above designed antenna shows a good return loss approximately -21.88 dB and -35.66 dB which is an excellent result.

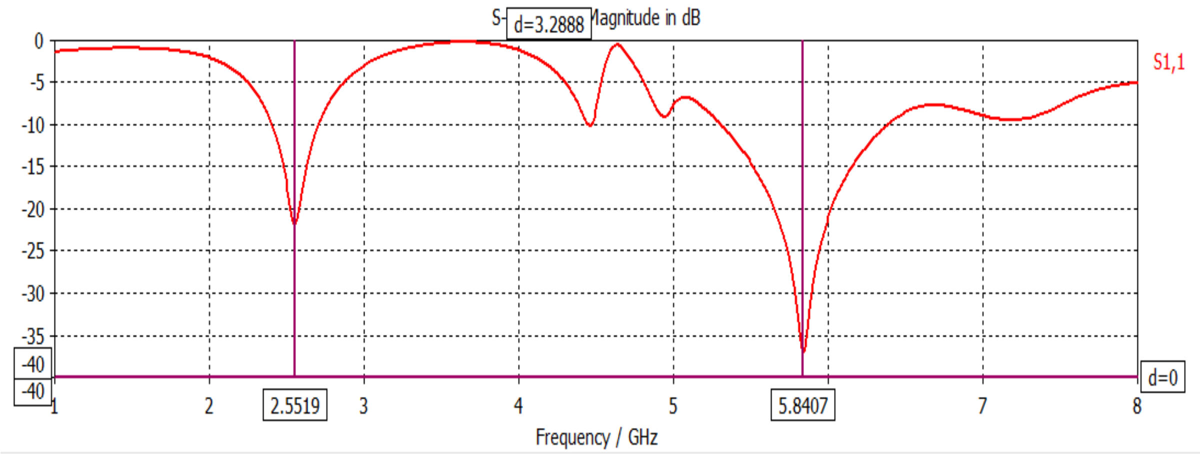
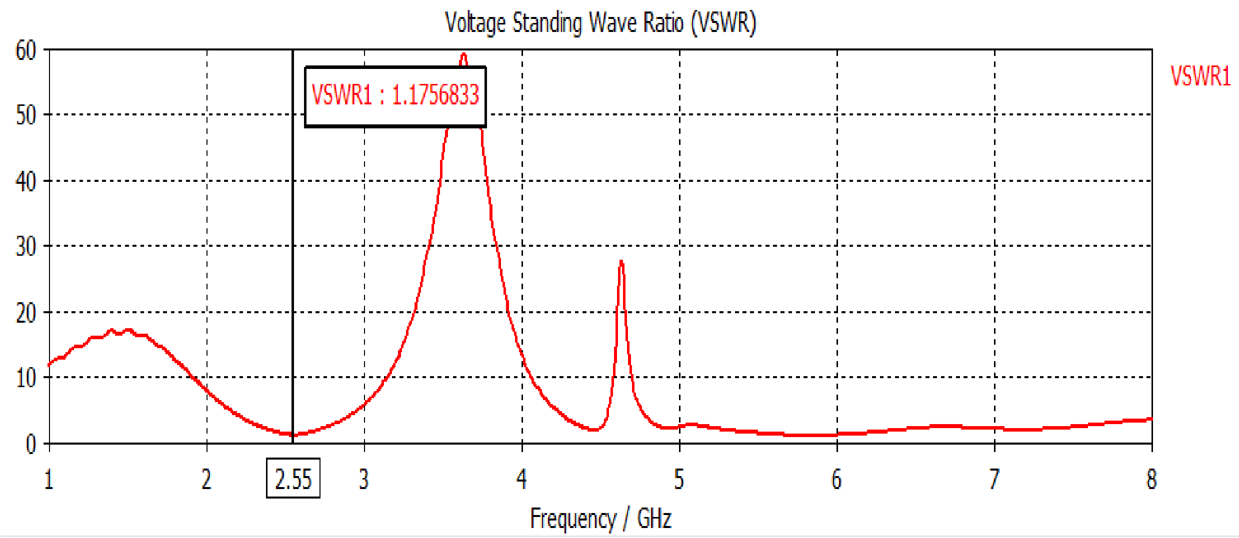


Figure 3.2: Return loss curve of proposed antenna

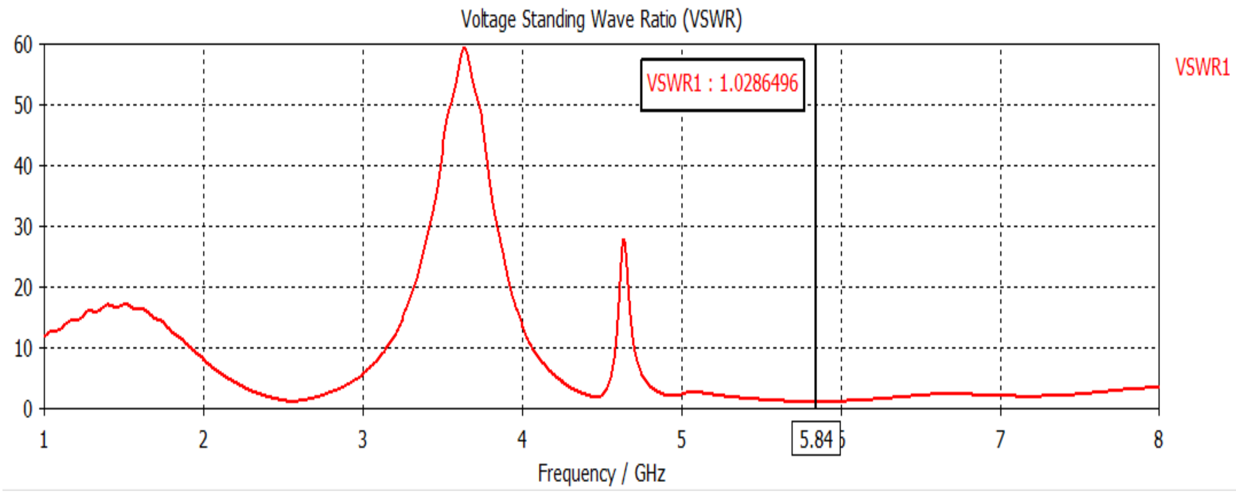
This antenna resonates at 2.55 GHz and 5.84 GHz frequencies which is applicable for WLAN and WiMAX applications and gives an appreciable bandwidth of approximately 307 MHz and 1091 MHz respectively. The bandwidth is calculated by subtracting lower resonating frequency from the upper frequency at -10dB.

3.2.2 Voltage Standing Wave Ratio (VSWR)

This Voltage standing wave ratio (VSWR) parameter is used for matching and tuning of the transmitting antennas. For practical applications the value of VSWR lies between 1 and 2.The voltage standing Wave ratio of the patch antenna in figure 3.5 this plot show that the value of VSWR is less than 2 at resonating frequency 2.55 GHz and 5.84 GHz.



(a)



(b)

Figure 3.3: VSWR plot of proposed antenna plot at 2.55 GHz & 5.84 GHz

3.2.3 Gain

Gain is defined as the ratio of the intensity, in a given direction, to the radiation intensity that would be obtained if the power is accepted by the antenna is radiated isotropically. The simulation results of the gain are given in the Figure below and the gain obtained is 2.21 dB at 2.55 GHz and 2.54 dB at 5.84 GHz

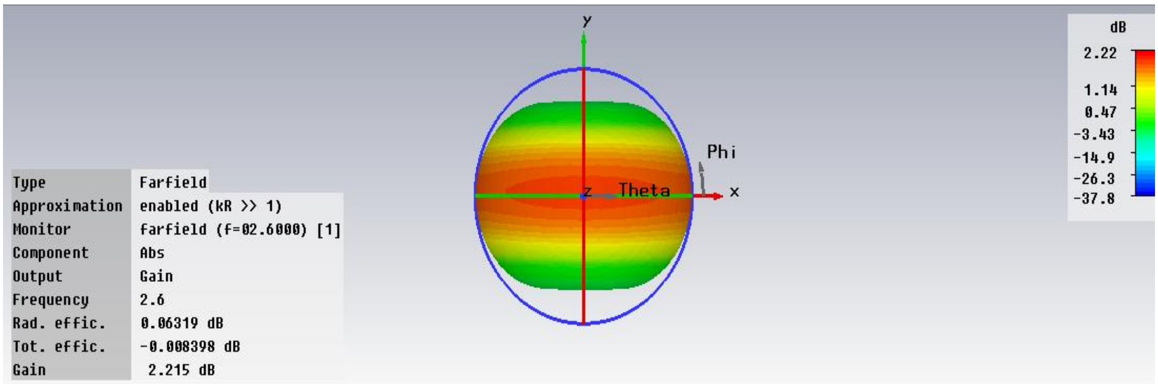


Figure 3.4: Gain at 2.55 GHz

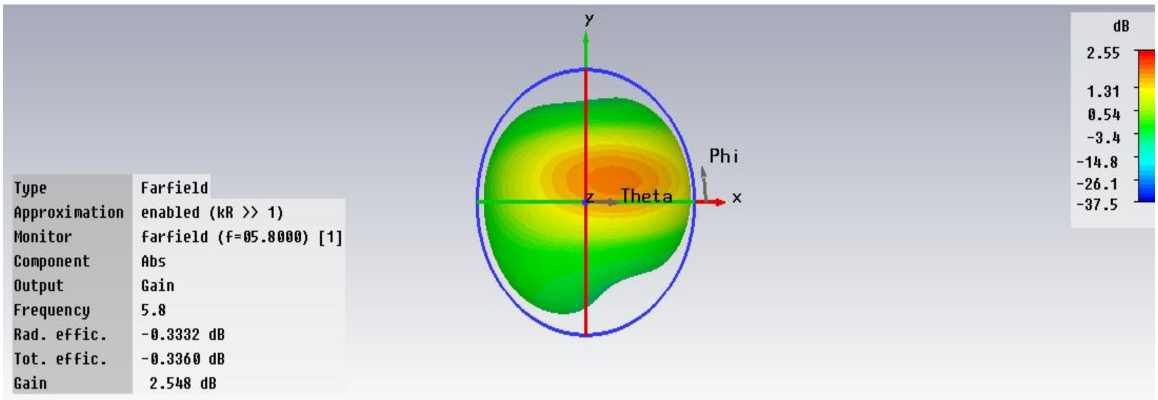


Figure 3.5: Gain at 5.84 GHz

3.2.5 Directivity

Directivity measure the amount of radiated energy to a specific direction, usually the maximal energy. Generally D>1, except in the case of an isotropic antenna for which D=1. An antenna with directivity D>>1 is called directive antenna. The simulated antenna design gives the directivity of 2.15 dBi at 2.55 GHz and 2.88 dBi at 5.84 GHz the simulated results of directivity are given in the Figure below.

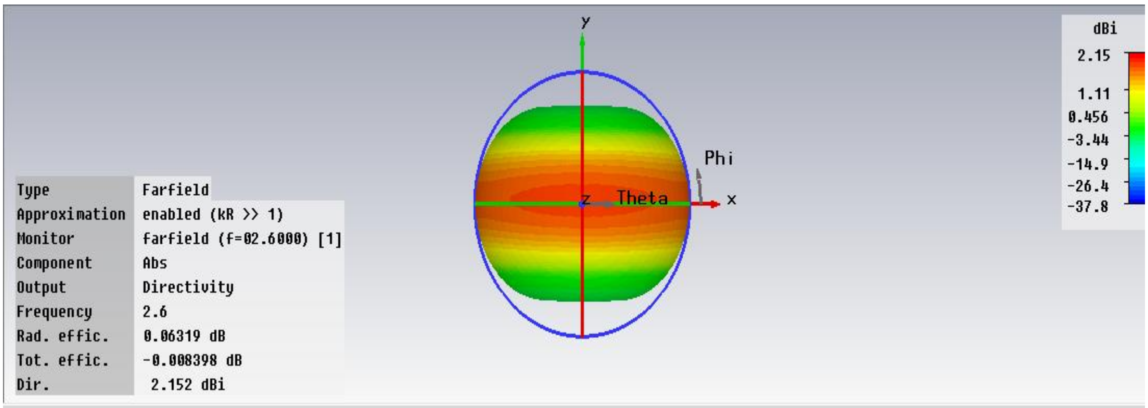


Figure 3.6: Directivity at 2.55 GHz

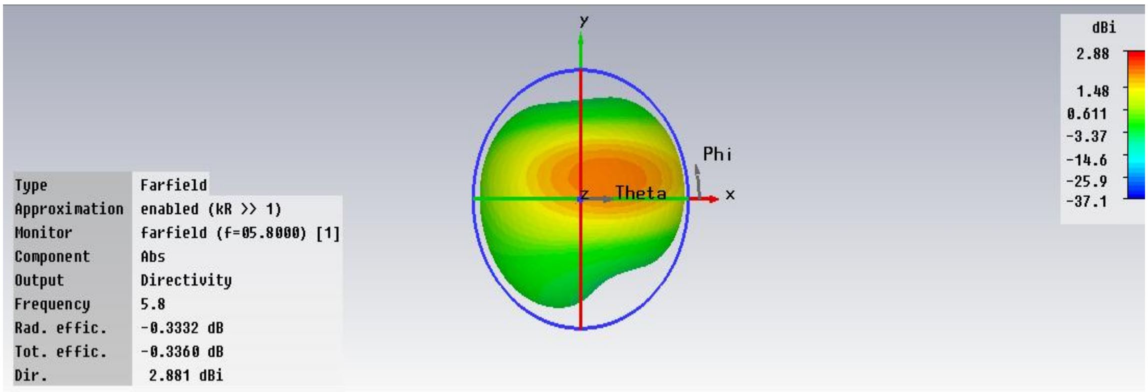
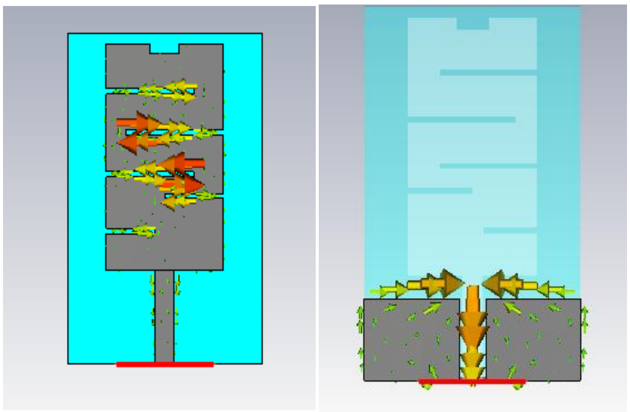


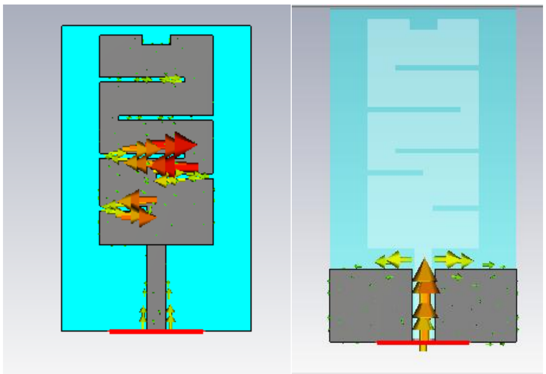
Figure 3.7: Directivity at 5.84 GHz

3.2.6 Current Distribution

Current analysis of antenna have been shown in Fig 3.8, which demonstrate the two resonating modes at 2.55 GHz resonating modes the current is mainly distributed on centre section of radiating element and the slot at ground effect the return loss of antenna and bandwidth at 5.84 GHz resonating mode the current density at lower section of a radiating element is more and on ground side also which gives a larger bandwidth and better return loss.



(a)



(b)

Figure 3.8: Current distribution of simulated antenna at there resonating frequencies (a) 2.55 GHz and (b) 5.84 GHz

The results of the above designed antenna are summarized in the following table.

Parameters	At 2.55 GHz	At 5.84 GHz
Return Loss	-21.88 dB	-35.66 dB
VSWR	1.17	1.02
Bandwidth	307	1091
Gain	2.21	2.54
Directivity	2.15	2.88

Table 3.2: Comparison of the antenna parameters values of Dual band Antenna resonating at 2.55 GHz and 5.84 GHz

3.3 Parametric Study of Antenna

In this section, the effect of the various physical parameters like resonating slot length and gap between the ground and radiating patch etc, by varying one parameter at a time and keeping all other parameters Constant so that one can get an optimized antenna for the desired applications.

3.3.1 Effect of Resonating Slot Length:

The Figure below shows the effect of change in the resonating length 'L_1' on the return loss. By decreasing the value of the patch width from 6 mm to 3 mm, the value of return loss decreases and the resonating frequency shifts towards lefts and there is a small decrease in return loss at the lower band but overall there is a good impedance matching and return loss.

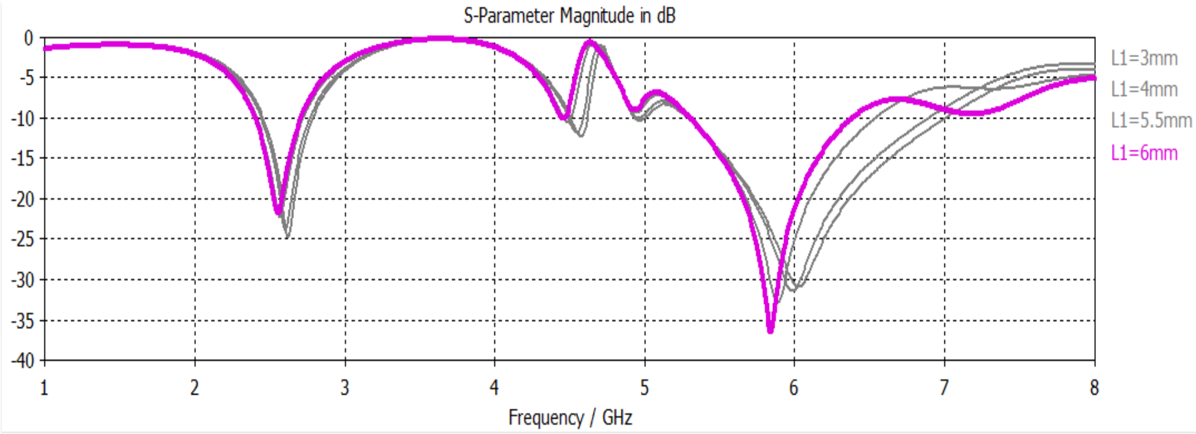


Figure 3.9: Return loss of Antenna with various length of L1 slot

3.3.2 Effect of Gap between Ground and Radiating Patch

The figure Below show that the return loss of Antenna with various dimension of G which impact the return loss and the bandwidth at G=2 mm we get a better impedance matching, return loss and bandwidth so from this we conclude that by adjusting gap G between ground and radiating element we get a good impedance matching.

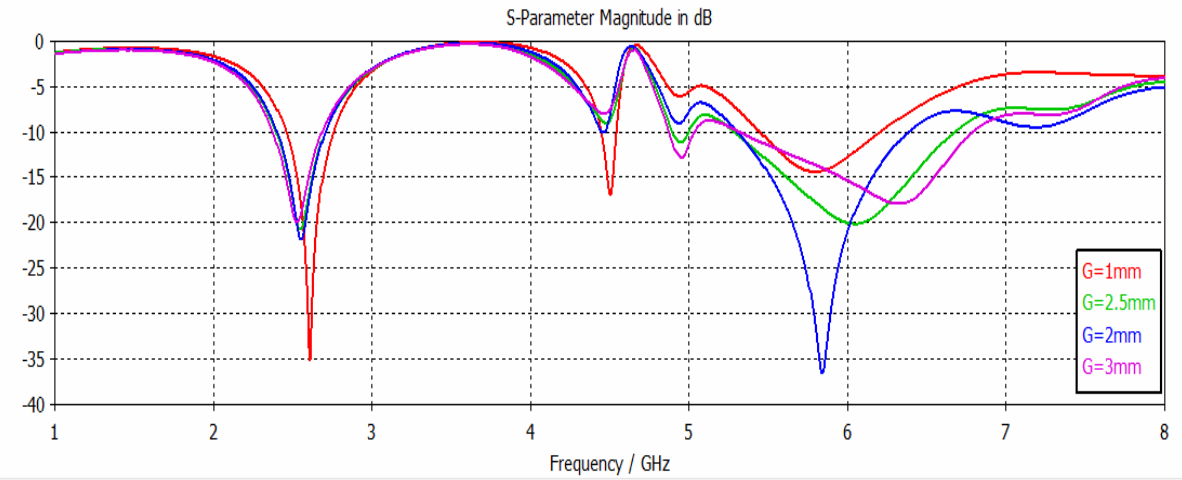


Figure 3.10: Simulated return loss of antenna with various dimension of G

3.4 Fabrication and Measurement

This chapter describes the entire procedure for fabrication of a Dual band CPW fed slotted monopole microstrip patch antenna.

Simulated result of the antenna at 2.5 GHz and 5.8 GHz

The simulated result of the antennas discussed in Chapter 3 has been discussed below:

- Dual band antenna at 2.55 GHz and 5.84 GHz: The dimensions are given below in the Table 3.4

Table 3.4: The Dimension of the designed antenna with Microstrip Feed line

Frequency (f_r)	2.55 GHz, 5.84GHz
Dielectric Constant (ε_r)	4.4
Patch Substrate thickness	1.2 mm
Feed line width	1.65 mm

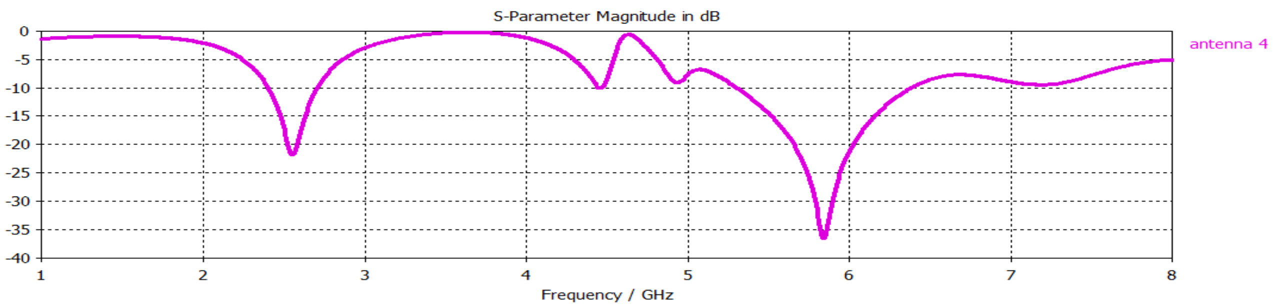
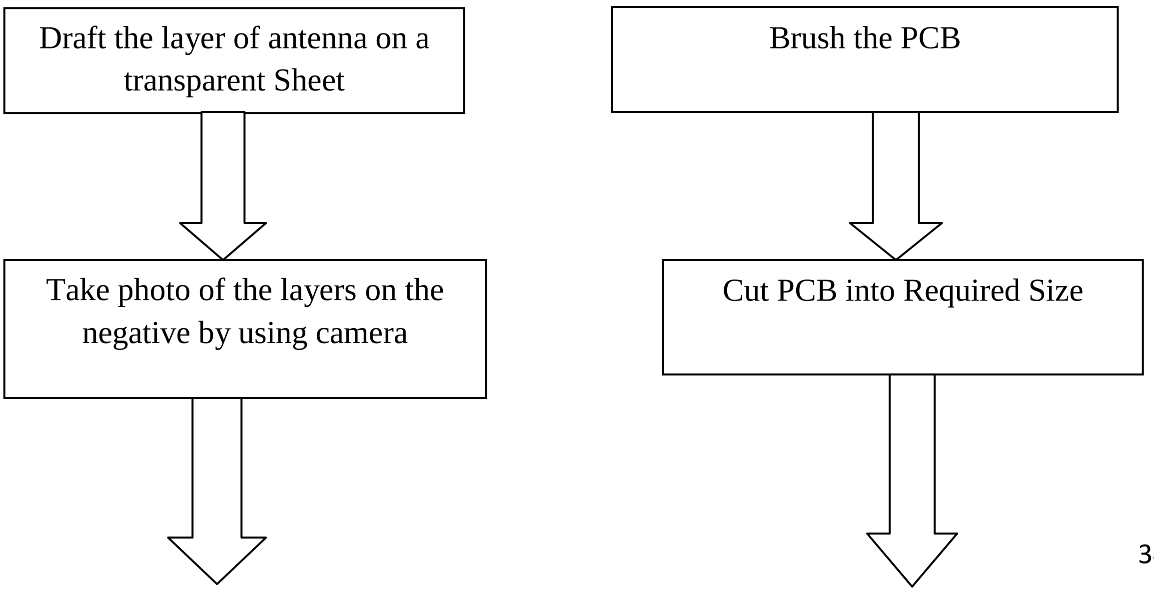


Figure 3.11: return loss S_{11} (in dB) of simulated antenna at 2.55 GHz and 5.84 GHz

3.4.1 Fabrication Process:

There are various step followed when we fabricate an antenna. This can be shown via flow chat:



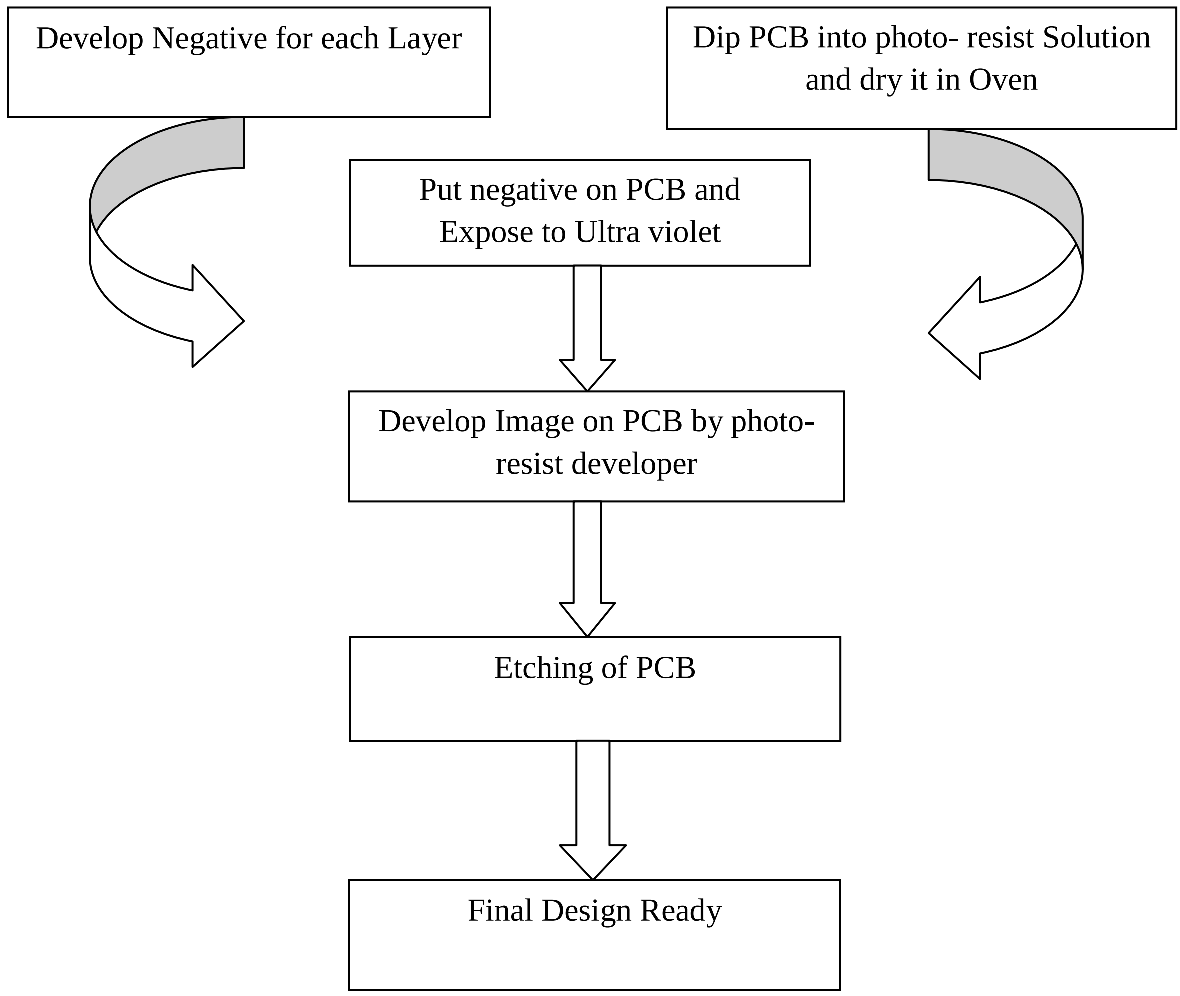


Figure 3.12: Fabricate Flow of PCB Design

3.4.2 Instruments used while fabricating MPA:

The hardware used to design of the antenna includes two processes namely PCB (Printed circuit board) design and testing of the antenna. The various steps for the PCB design are explained as:

- Negative developing: The negative development is done by software. The whole design in designed in this software and then print out of that design is taken.
- The PCB cutter is used to PCB's as per desired size. The actual size of antenna i.e. Substrate size of material, like FR4 ($\varepsilon r = 4.4$) is used here. Figure 6.4 shows the PCB cutter.

Figure 3.13: PCB Cutter

- Operations on PCB: - Now the PCB is dipped once in the photo resist developer placed in yellow light. It dried in an oven for 3-5 minutes. The oven unit is used to dry the final design on antenna, which contain the paint on the layer that protects the copper to clean up. Thus, the oven dries the PCB at 140-150 degree temperature properly. Figure 6.6 shows the picture of the Oven Unit.

Figure 3.14: Oven Unit

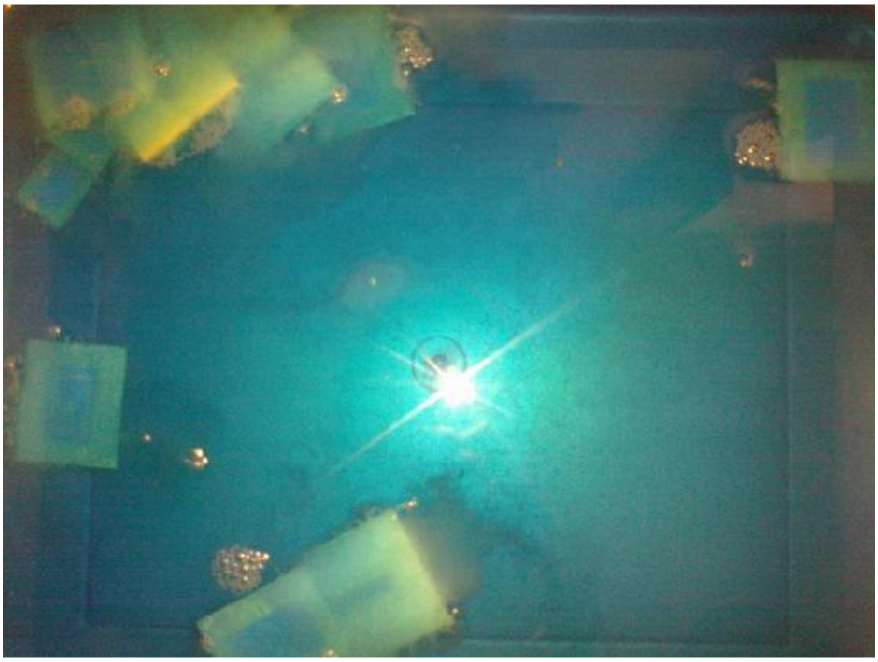
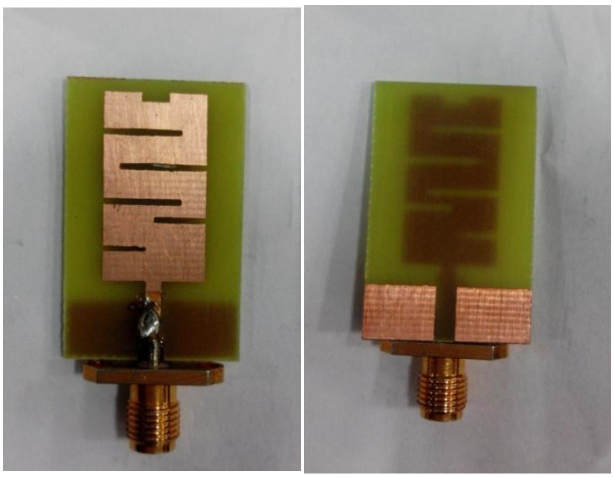


Figure 3.15: Etching Unit

3.4.3 Fabricated Antenna

In Figure give below shows the dual band antenna at 2.55 GHz and 5.84 GHz have a various resonating length on radiating patch to increase the bandwidth and to get the wide dual band covering the frequency band (2.46 GHz-2.80 GHz) to (5.30 GHz-6.39 GHz) and Fabricated Microstrip Patch antenna with coplanar waveguide feed line. The Simulated result of antenna is discussed in chapter.



(a) Top view (b) Back view

Figure 3.16: Fabricated antenna connected with SMA connector

As from above figures, the material used for fabrication antenna is PEC (Copper) of height 0.02 mm with 1.2 mm (Substrate).

3.4.4 Testing of antenna on VNA

A CPW coupled Dual band microstrip patch antenna at 2.55 GHz and 5.84 GHz for WLAN and WiMAX applications was designed using CST 2010 studio (software). But practically, antenna has been tested using VNA model no: E5071C, frequency range is 9 KHz-8.5GHz and is shown below:

Figure 3.17: Instrument used for Testing

The antenna shows results that perfectly matched with the simulated results. The Figures below shows the tested results of designed antenna using network analyser.

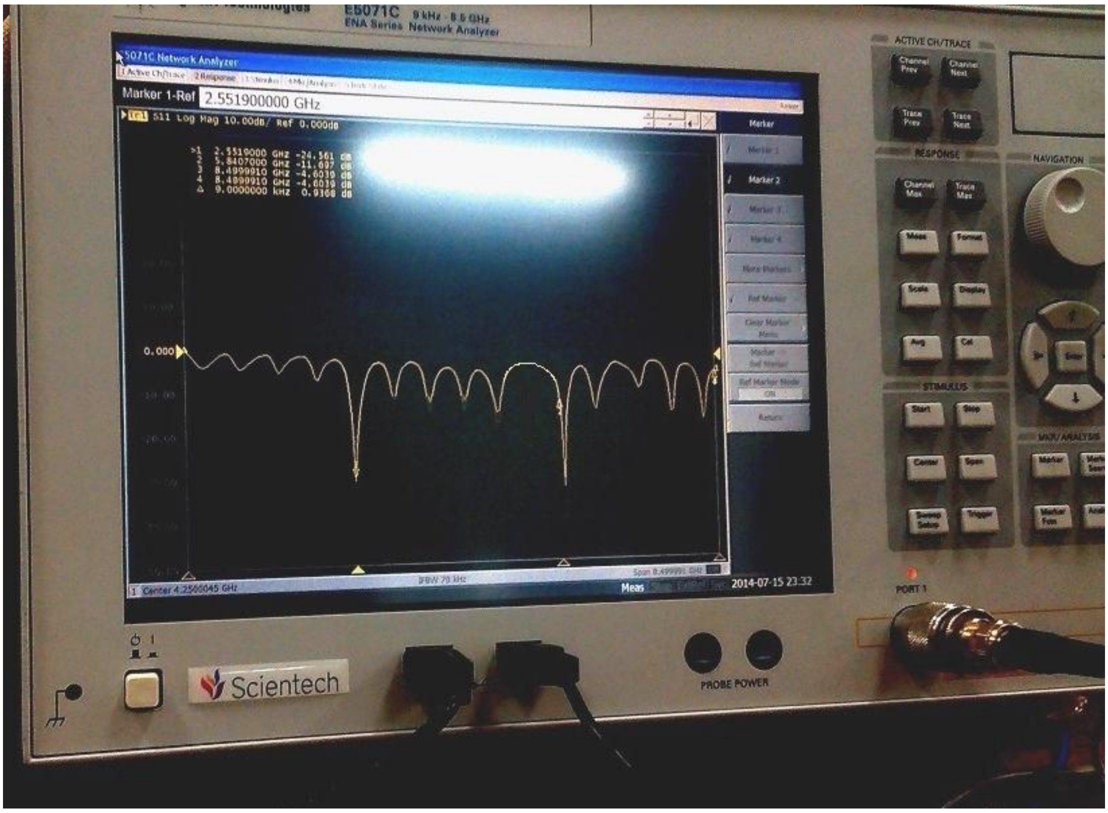


Figure 3.18: Measured result of simulated antenna at Vector Analyser

It was found that result have some variations are given below:

The simulated result cover the bands (2.46 GHz-2.80 GHz) and (5.30 Ghz-6.39 GHZ) but in the fabricated results, lower resonating frequency response is same as simulated results but there is small reduction in return loss and band width on other hand at upper resonate frequency is shift to right and cover frerquency band (5.35 GHz- 6.10 GHz) .The return loss graphs show that the resonant frequencies have shifted in the magnitude from the designed frequency for all the designs. The root cause of the shift is could be due to the FR-4 board, which has that varies from 1.20 to 1.35 In practical world, a material which has varying along a length, width, and height, will affect resonant frequency to shift, during simulation it is assume a constant. The other factors affecting etching accuracy such as chemical used, surface finish and metallization thickness also could be the reason for shifting the resonant frequency.

The comparison of simulated results and fabricated results

Table 3.5: Comparison between simulated and fabricated results

Parameters	Simulated Results	Fabricated Results
Frequencies Covered	(2.46 GHz-2.80 GHz) and (5.30 GHz-6.39 GHz)	(2.46 GHz-2.80 GHz) and (5.35 GHz-6.10 GHz)
Return loss	-21.88 dB and -36.99 dB	-29.01 dB and -30.02 dB
Bandwidth	307 MHz and 1091 MHz	307 MHz and 750 MHz
Applications	WLAN and WiMAX	WLAN and WiMAX

3.5 Conclusion

A dual band antenna with CPW feeding has been suggested. The designed of proposed Antenna is compact and provide a wide bandwidth and better return loss which is suitable for WLAN, WiMAX and Antenna is resonate at (2.55/5.84 GHz) with bandwidth of 307 MHz and 1091 MHz respectively. The directivity of proposed antenna 2.15 dB and 2.88 dB and the gain is 2.21 dB and 2.54 dB. The simulated and tested results are 90% matched; the 10% losses are due to lose soldering connections or due to lose SMA connector connections. After these small variations in the results due to some reasons the results are still acceptable

CHAPTER 4

NOVEL SLOTTED AND STUBBED TRIPLE BAND MICROSTRIP PATCH ANTENNA AND ITS PARAMETRIC STUDY

In this Chapter, the procedure for designing a rectangular microstrip patch antenna is explained. The Design is simulated using Computer Simulated Technology (CST) Microwave studio. Finally the result are obtained from the simulations are demonstrated.

4.1 Design and Simulation of monopole microstrip patch antenna by etching an H-shape and two U-shaped slots on radiation patch and slot in ground plane.

By etching H-shaped and Two-U slot at radiating patch in microstrip antenna and slot in ground plane. The proposed design resonates at 2.01 GHz, 3.59 GHz, and 5.70 GHz and achieves a return loss of -15.44 dB, -22.63 dBi and -23.50 dBi bandwidth of 259 MHz, 889 MHz and 185 MHz.

Table 4.1: Design Specifications of Substrate

Dielectric constant (ε_r)	4.4
Thickness of Substrate	1.6 mm
Tangent loss (δ)	0.0009

Table 4.2: Optimized Parameters

Parameters	L_s	L_g	L_h	L_p	L_1	L_2	L_3	W_f
Values (mm)	41	11	15	3.8	25.5	16.4	9	3
Parameters	W_s	W_1	W_2	W_3	W_4	W_h	L_4	S
Values (mm)	30	8.5	4	1	3	8	3.5	1

4.1.1 Antenna Design:

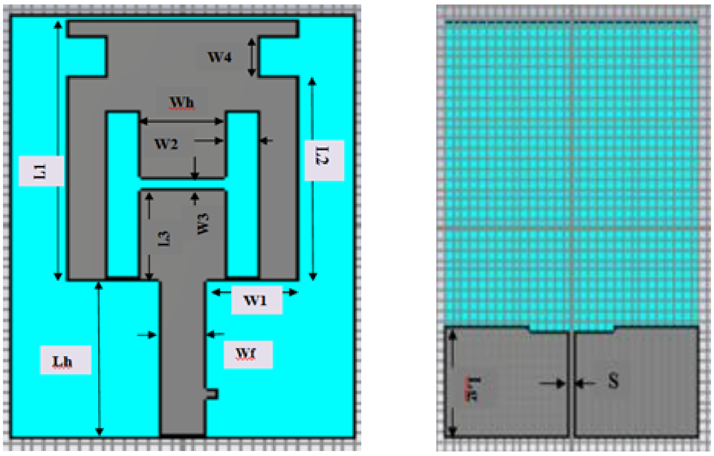


Figure 4.1: Simulated Design (a) Front View (b) Back view

4.2 Simulated Results of Triple band Microstrip patch antenna:

4.2.1 Return Loss and Antenna Bandwidth:

The return loss (RL) is the parameter which indicates the amount of power that is lost to the load and does not return as a reflection. As already known, waves are reflected leading to the formation of standing waves when the transmitter and antenna impedance do not match .The simulated antenna design resonates at 2.01 GHz, 3.59 GHZ and 5.70 GHz and exhibit return loss of -15.44, -22.63 and -23.50 more negative is the return loss, more is the coupling and therefore more will be the directivity and gain of the proposed antenna in particular direction. The bandwidth of the simulated patch antenna is 259 MHz, 889 MHz and 185 MHz at resonant frequency is 2.01 GHz, 3.59 GHz and 5.70 GHz.

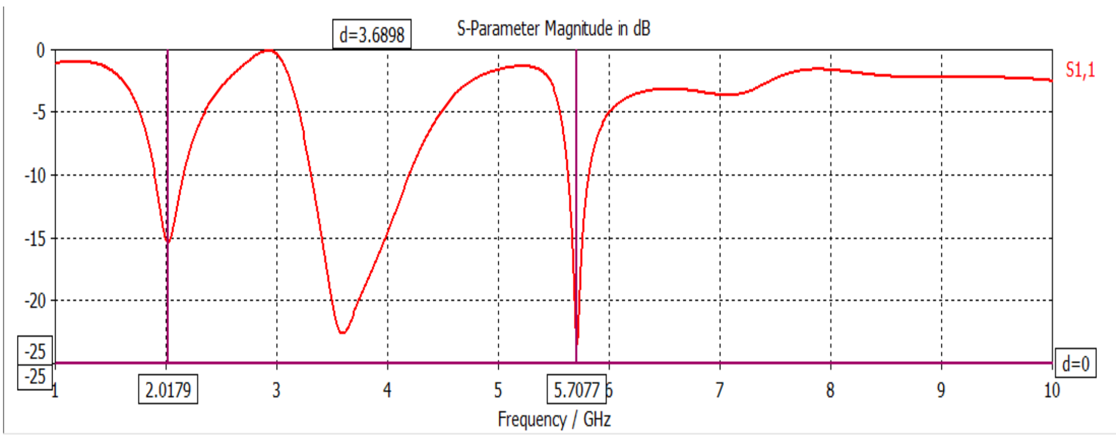
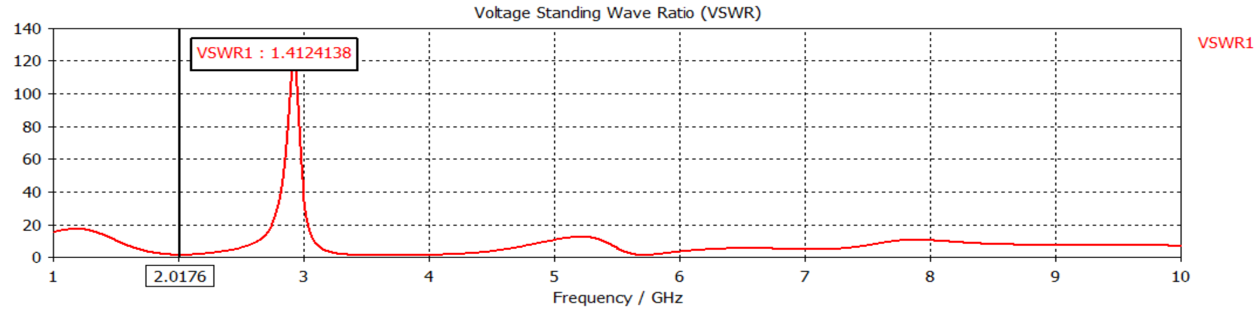


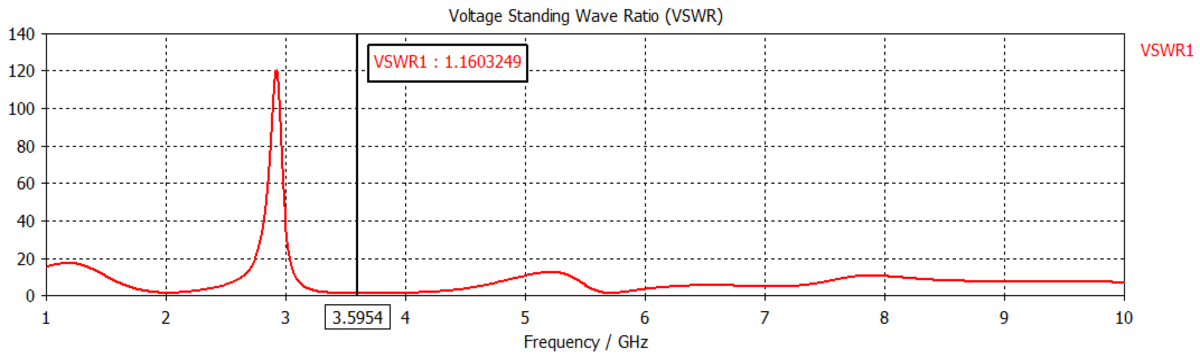
Figure 4.2: Return loss curve of proposed Antenna

4.2.2 VSWR

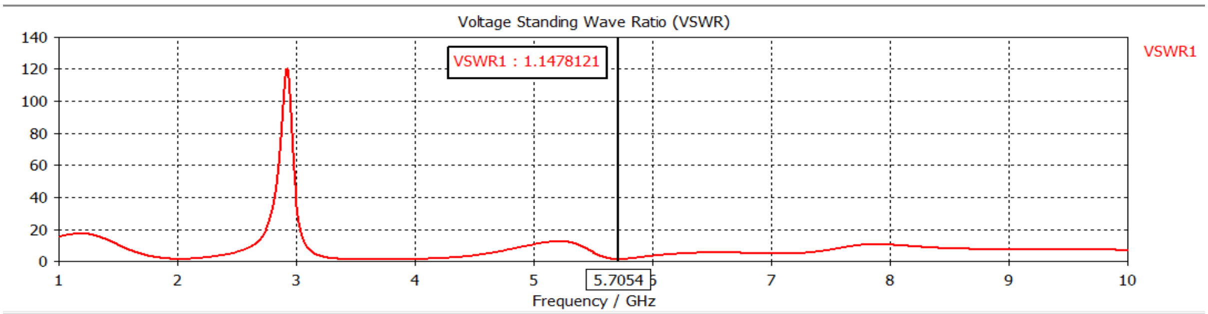
The voltage standing Wave ratio of the patch antenna in figure 4.3 this plot show that the value of VSWR is less than 2 at resonating frequency 2.01 GHz, 3.59GHz and 5.70 GHz.



(a)



(b)



(C)

Figure 4.3: VSWR plot of proposed Antenna plot at (a) 2.01 GHz (b) 3.59 GHz (c) 5.70 GHz

4.2.3 Gain

In this design a reduced ground structure is used which decreases the gain of the antenna but the overall antenna parameters are efficient. The designed antenna gives a gain of 2.291 dB at 2 GHz, 2.684 dB at 3.6 GHz and 4.666 dB at 5.8 GHz. The simulated results of gain at three different frequencies are given below:

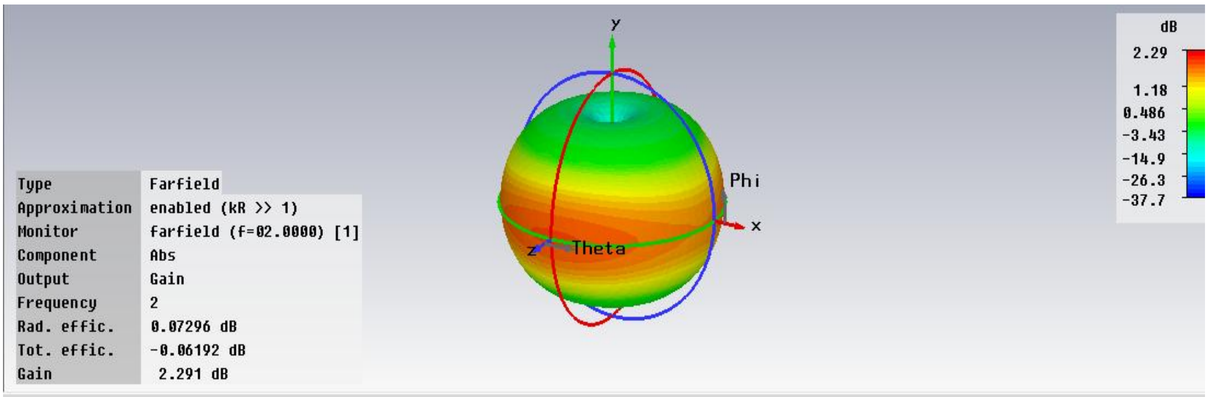


Figure 4.4: Gain of proposed Antenna at 2.01 GHz

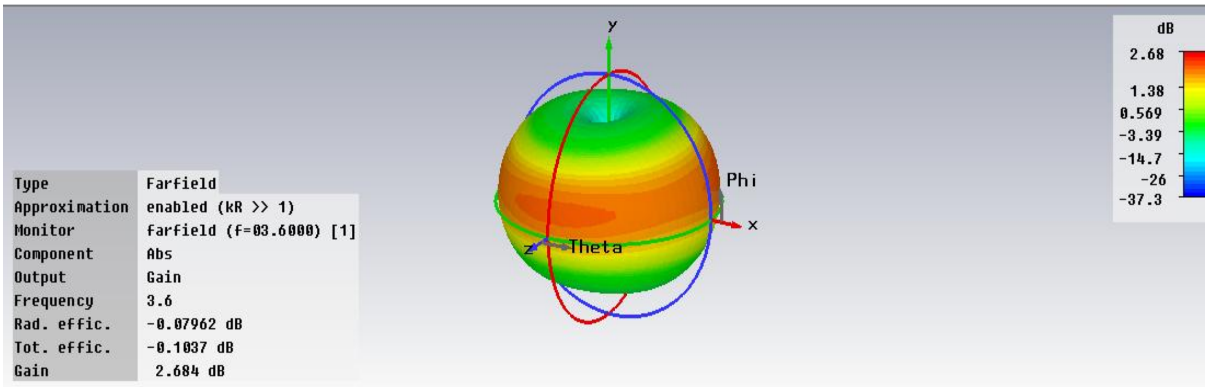


Figure 4.5: Gain of proposed Antenna at 3.59 GHz

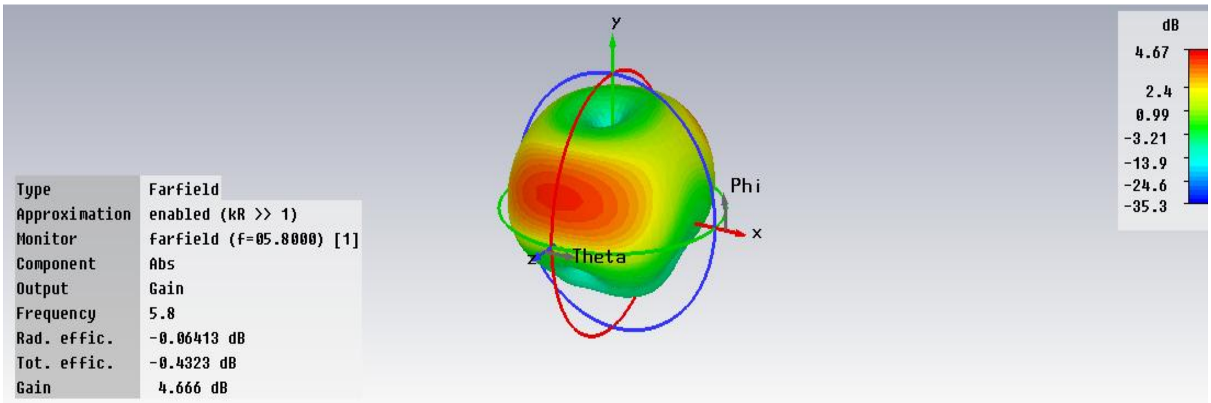


Figure 4.6: Gain of Proposed Antenna at 5.70 GHz

4.2.4 Directivity:

The designed antenna gives a directivity of 2.218 dBi at 2 GHz, 2.764 dBi at 3.7 GHz and 4.134 dBi at 5.6 GHz. The results of directivity at three different frequencies are given below:

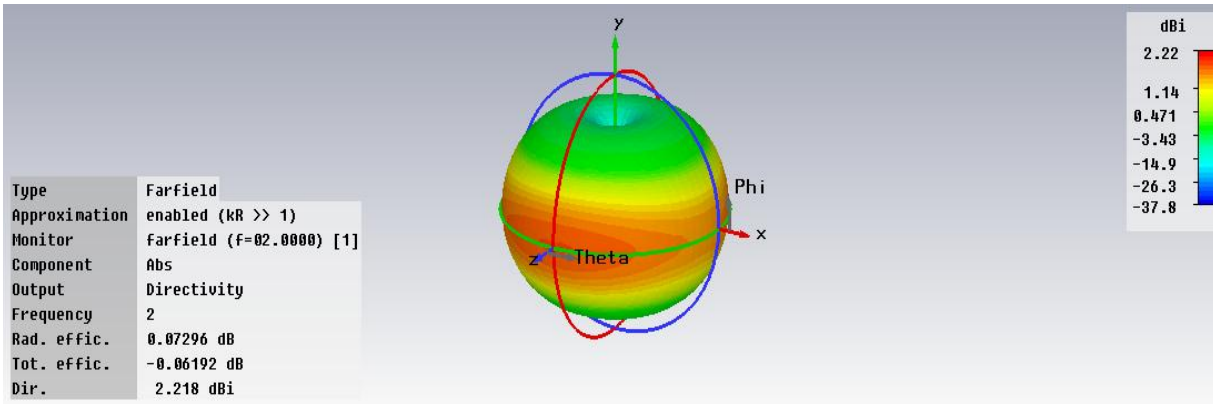


Figure 4.7: Directivity at 2.01 GHz

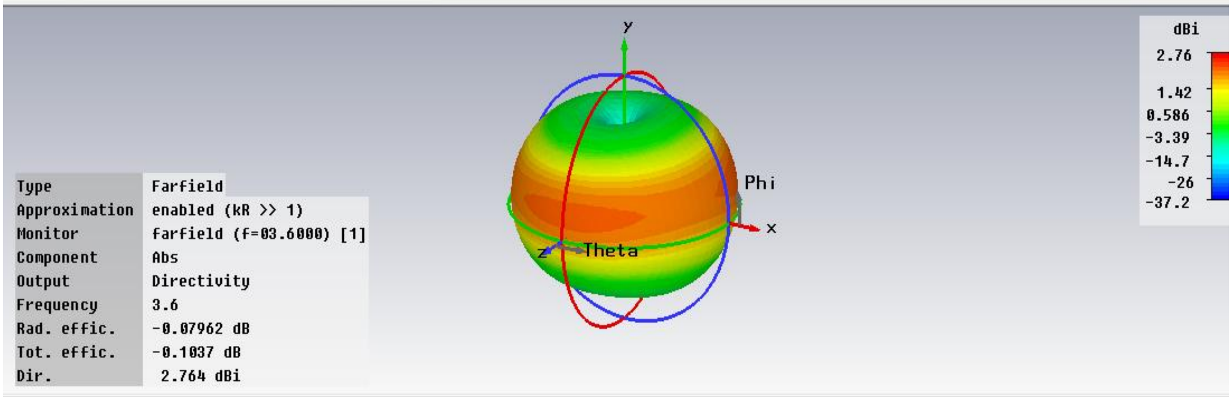


Figure 4.8: Directivity at 3.59 GHz

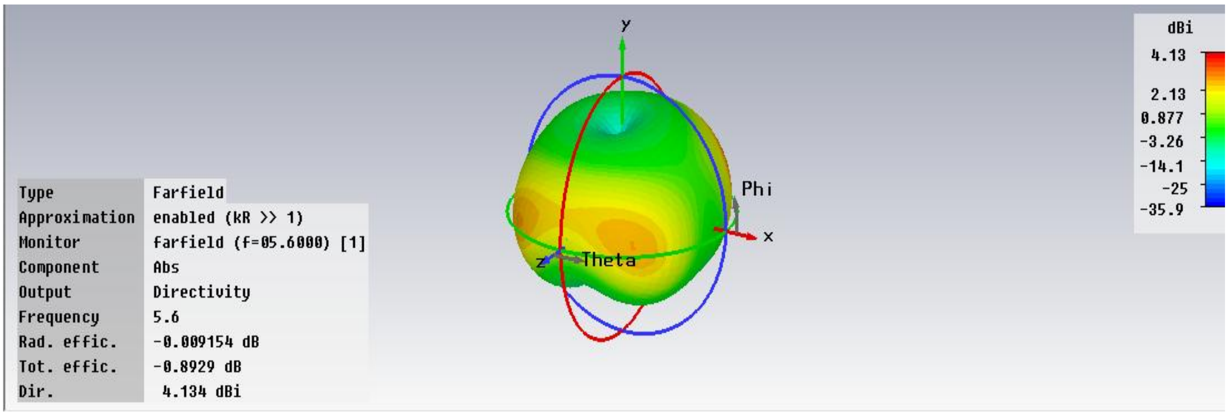
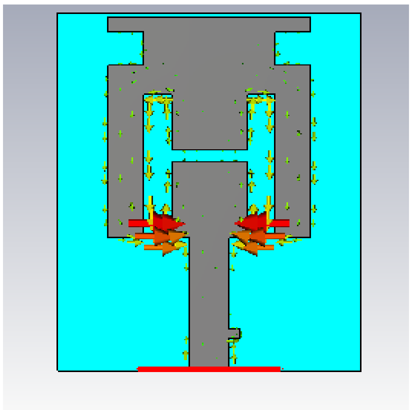


Figure 4.9: Directivity at 5.70 GHz

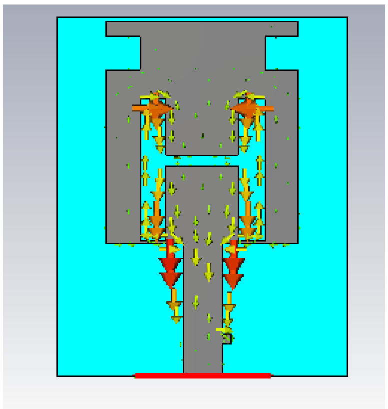
4.2.6 Current Distribution:

In figure given below the current is mainly distributed over the lower edge of two sides of the H-shaped slot at 2.01 GHz. The flowing direction of the current is quite consistent.

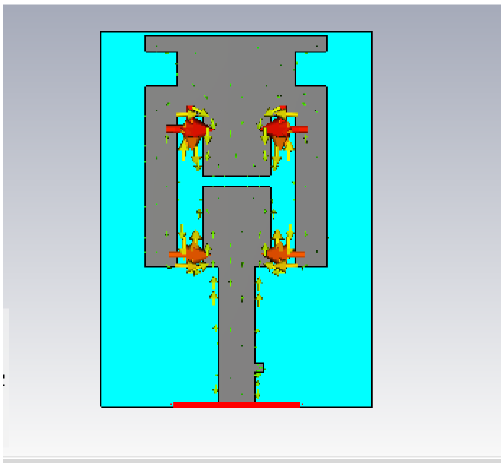
In Fig. 4.11, the current is distributed on the centre section of H-shaped slot two arms at 3.59 GHz.



(a)



(b)



(c)

Figure 4.10: Current distribution of simulated antenna at the resonating frequencies (a) 2.01 GHz (b) 3.59 GHz (c) 5.70 GHz

At 5.70 GHz, the more and stronger induction current distributed around the two arms of the H-shaped slot, which is responsible for the upper resonant frequency.

The comparison of the parameter values at three different resonating frequencies are given in the table below:

Parameters	**At 2.0 GHz**	**At 3.59 GHz**	**At 5.70GHz**
Return Loss	-15.44 dB	-22.63 dB	-23.50 dB
VSWR	1.41	1.16	1.14
Bandwidth	259 MHz	889 MHz	185 MHz
Directivity	2.21 dBi	2.76 dBi	4.13 dBi

Gain	2.29 dBi	2.68 dBi	4.66 dBi

Table 4.3 Comparison of the antenna parameters values of triple band antenna resonating at 2.0 GHz, 3.59 GHz and 5.70 GHz

The table above shows that the antenna is acceptable, for various applications. The return loss is maximum at 5.79 GHz frequency, the gain/directivity is maximum at 5.79 GHz, frequency and bandwidth is maximum at 3.59 GHz frequency. Due to coplanar waveguide feed line the overall bandwidth is increased. The impedance obtained shows that the antenna is matched.

4.3 Conclusion

In triple band slotted and stubbed monopole antenna was designed which resonate at frequency 2.01 GHz, 3.59 GHz and 5.70 GHz and provides a wide triple band having bandwidth of 329MHz covering band at 2.01 GHz, 889 MHz covering band at 3.59 GHz and 185 MHz covering band at 5.70 GHz. The proposed antenna gives a better return loss at resonating frequencies 2.01 GHz, 3.59 GHz and 5.70 GHz respectively. The directivity and gain of the proposed antenna are fair enough to be used for WLAN and WiMAX applications.

CHAPTER 5

TRIDENT SHAPED TRIPLE BAND MONOPOLE MICROSTRIP PATCH ANTENNA FOR WIRELESS APPLICATION

In this chapter, a new printed trident shaped tri-band monopole antenna is presented for the wireless applications. The antenna is constructed by a non-conductor backed trident shaped strip with a microstrip feed line. There are three resonant paths are created for which three resonances are occurring with sufficient large impedance bandwidths. The tri-band performance such as application in WLAN, WiMAX and IMT, can be easily obtained for this type of antenna by fine-tuning the lengths of the three resonant Paths in trident shape strip

5.1 Design of Triple band trident shape Monopole Microstrip patch antenna for Wireless Applications

A printed trident shaped triple-band monopole antenna for wireless application is proposed. The antenna has three different resonant paths forming a trident shaped structure that supports three resonances at around 2.72 GHz, 3.90 GHz and 5.82 GHz, which are reserved for WLAN, WiMAX and IMT applications. In order to match the antenna input impedance to the feed line (50-ohm).

Table 5.1: Design Specification of substrate

Dielectric constant (ε_r)	4.4
Substrate thickness	1.6 mm
Tangent loss (δ)	0.0009

Table 5.2: Optimized parameter trident shaped Microstrip patch antenna

Parameters	M	N	P	S	L	W	L_g	W_f
Values (mm)	3.6	4.25	2.4	1	80	45	45	2

5.1.1 Antenna design

The simulated antenna design using CST 2010 microwave studio is given in the Figure below:

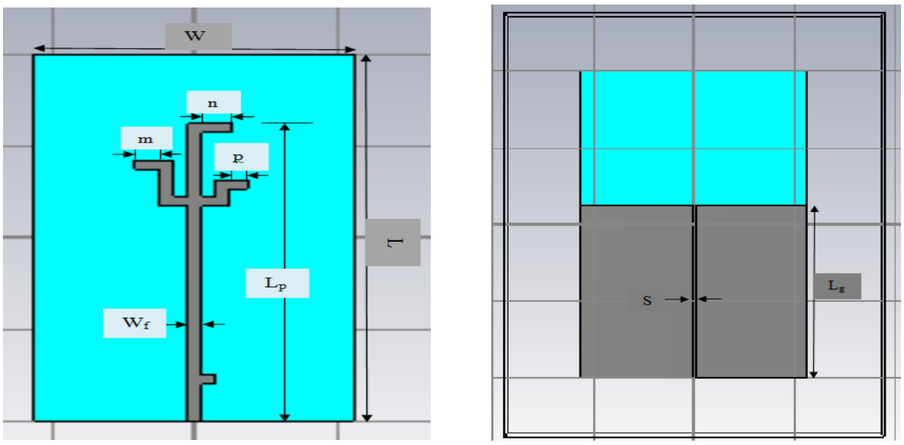


Figure 5.1: Simulated design of Antenna

The Dimension of trident shaped Microstrip Patch Antenna is given below:

5.2 Simulation Results

The software used to model and simulate the Micro strip patch antenna is CST Micro wave Studio version 2010. The simulated results of the proposed antenna are presented in the below figures:

5.2.1 Return loss and Antenna Bandwidth

Figure 5.3 shows the Triple band covering the frequency bands (2.49 GHz- 2.89 GHz), (3.74 GHz-4.06 GHz) and (5.51 GHz-6.20 GHz) having a bandwidth of 404 MHz, 311 MHz and 688 MHz for WiMAX, IMT and WLAN applications.

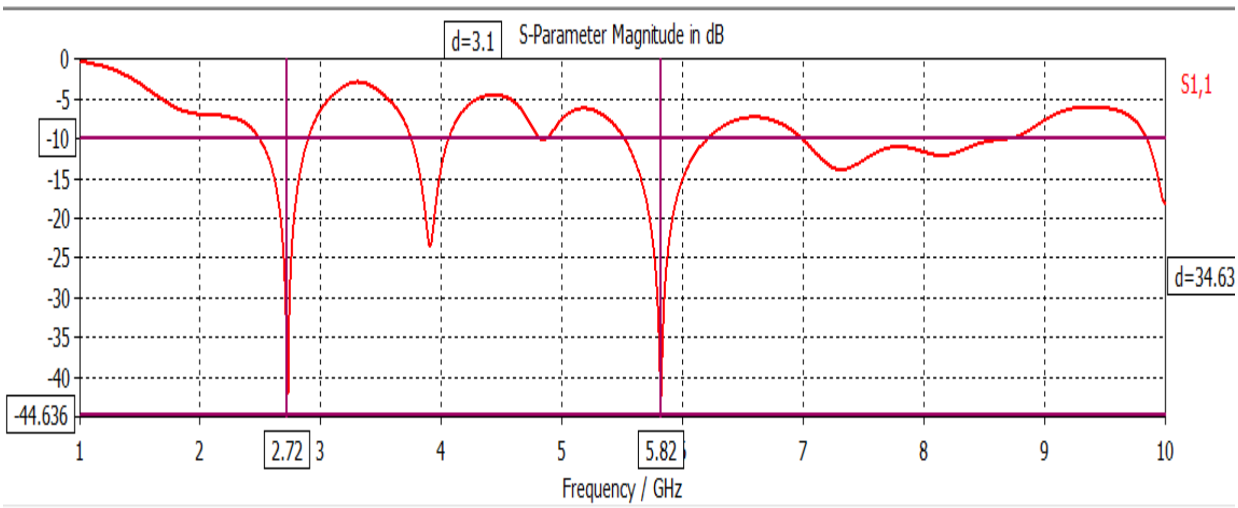
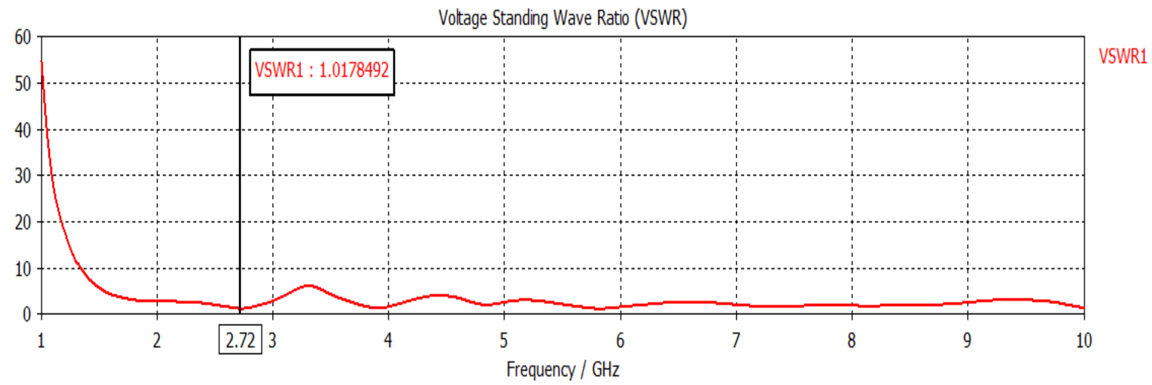


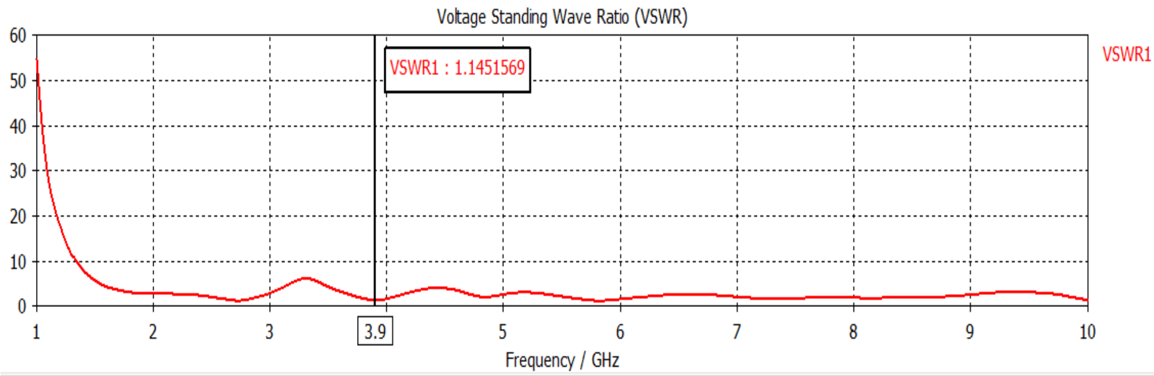
Figure 5.2: Return loss curve of Proposed Antenna

5.2.3 VSWR

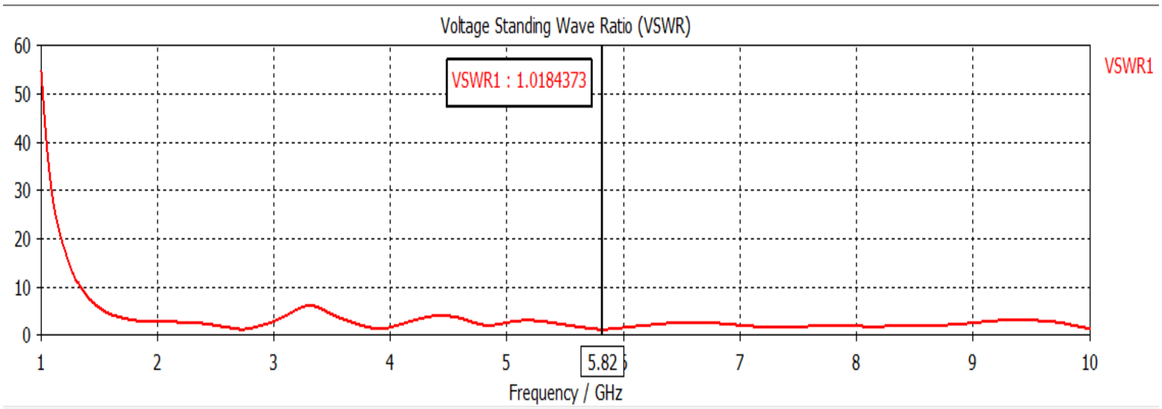
VSWR is another parameter defined for antenna which shows that how well the antenna is matched. The value of VSWR for a good antenna is less than or equal to 2 for practical antennas, the designed antenna gives a VSWR of 1.01 at 2.74 GHz, 1.14 at 3.90 GHz and 1.01 at 5.82 GHz which is below 2 so that value defines that the antenna is perfectly matched.



(a)



(b)

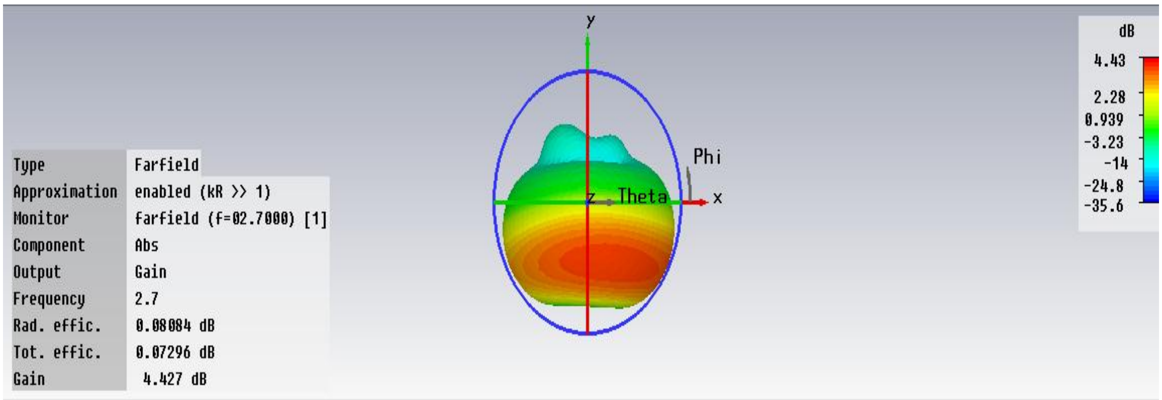


(c)

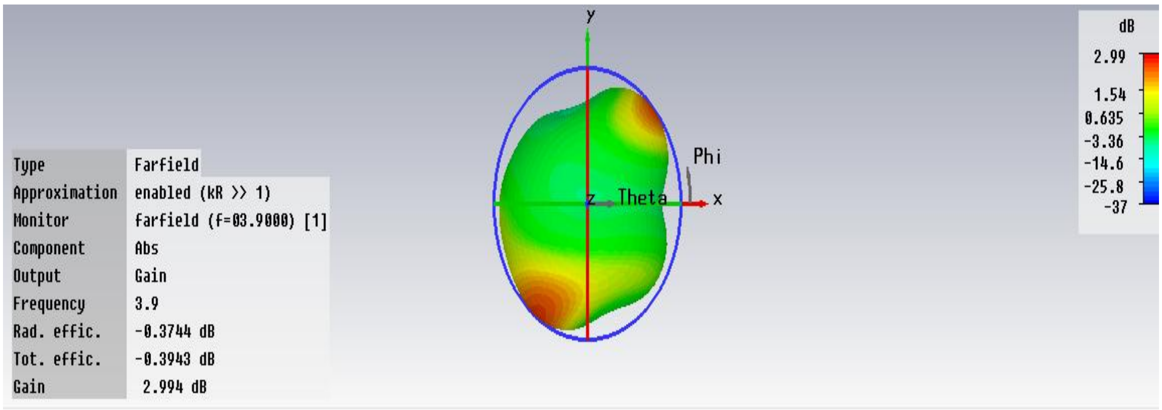
Figure 5.3: VSWR plot of proposed antenna plot at (a) 2.72 GHz, (b) 3.90 GHz and (c) 5.82 GHz

5.2.4 Gain

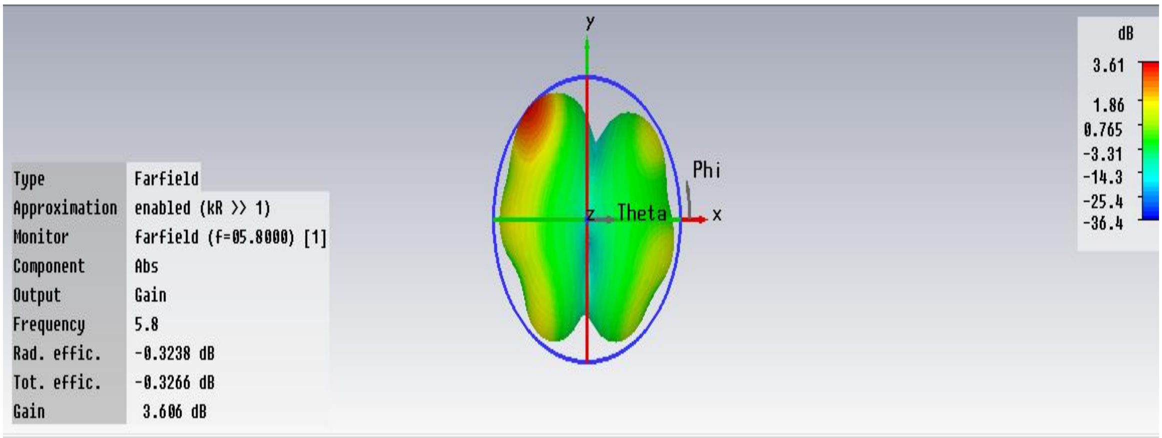
In this design a reduced ground structure is used which decreases the gain of the antenna but the overall antenna parameters are efficient. The designed antenna gives a gain of 4.43 dB at 2.72 GHz, 2.99 dB at 3.90 GHz and 3.61 dB at 5.82 GHz. The simulated results of gain at three different frequencies are given below:



(a)



(b)

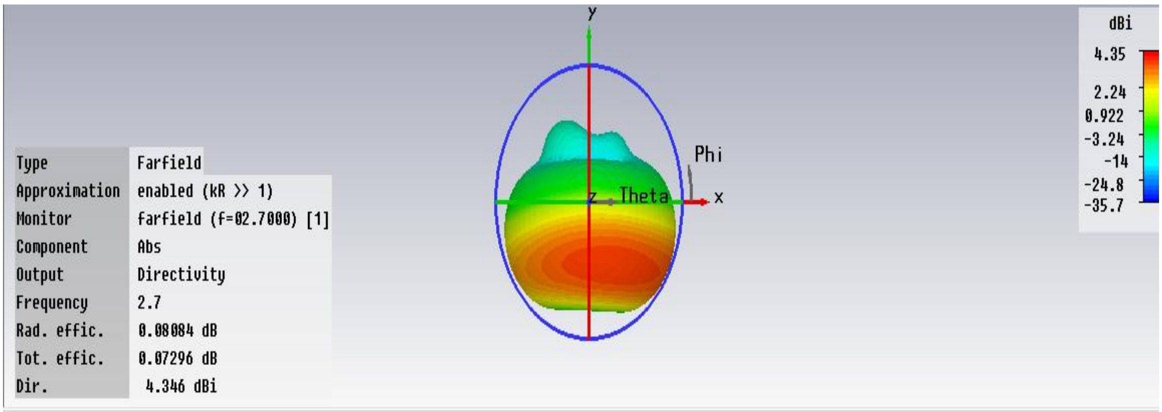


(c)

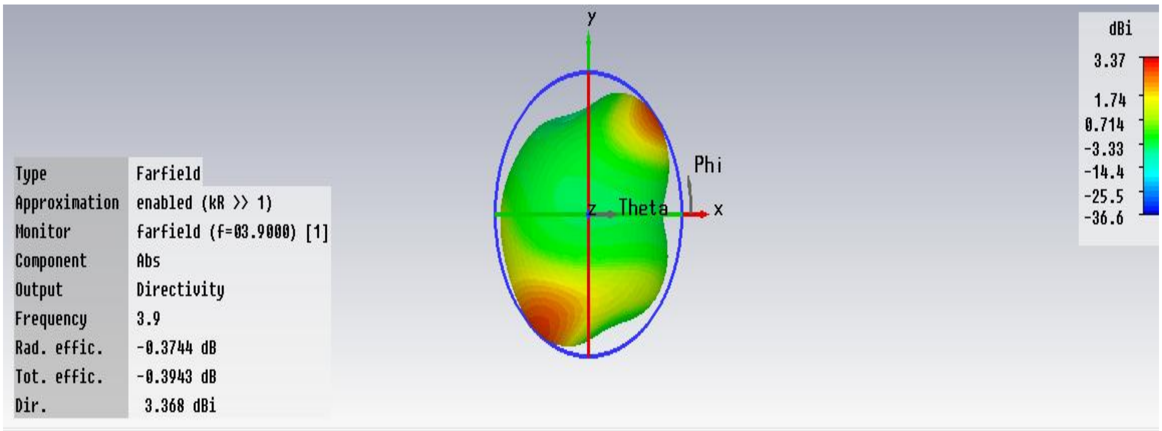
Figure 5.4: Gain of the proposed Antenna at (a) 2.72 GHz (b) 3.90 GHz and (c) 5.82 GHz

5.2.5 Directivity

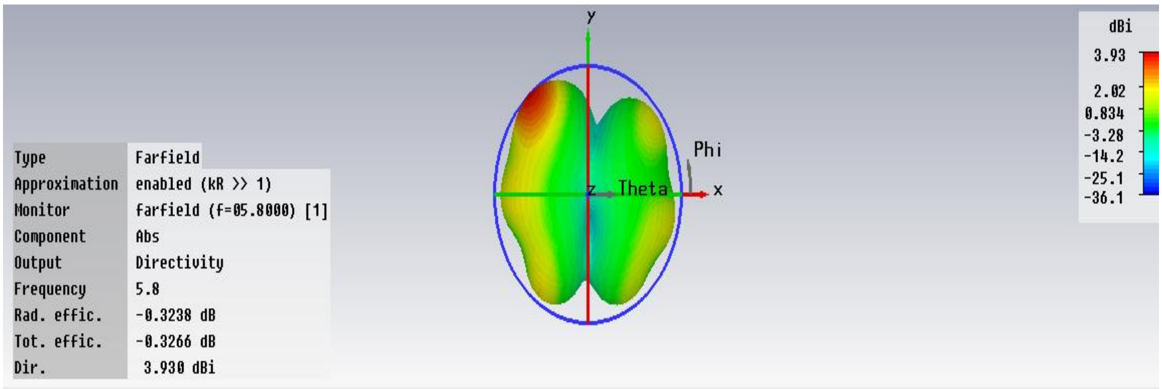
The simulated antenna design gives the directivity of 4.35 dBi at 2.72 GHz, 3.37 dBi at 3.90 GHz and 3.93 dBi at 5.82 GHz the simulated results of directivity are given in the Figure below.



(a)



(b)

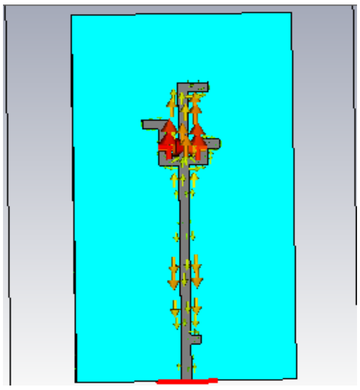


(c)

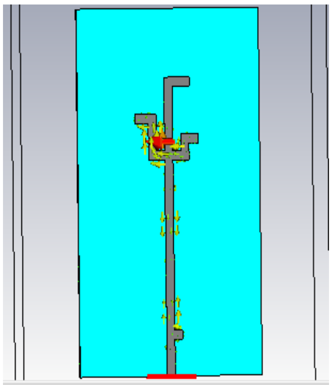
Figure 5.5: Directivity of the proposed Antenna at (a) 2.72 GHz (b) 3.90 GHz and (c) 5.82 GHz

5.2.6 Current Distribution

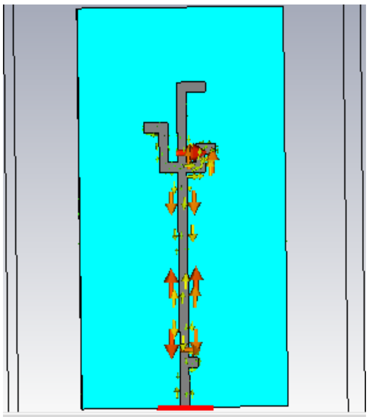
Current analysis of antenna have been shown in Fig 5.7, actually the antenna have a three resonating path ‘m’, ‘n’, ‘p’ which effect the resonating frequency. The three resonating modes at 2.72 GHz resonating modes the current is mainly distributed on three resonating path.



(a)



(b)



(c)

Figure 5.6: The current distribution at there resonating frequencies (a) 2.72 GHz (b) 3.90 GHz (c) 5.82 GHz

at 3.90 GHz resonating mode the current is distributed on ‘m’ resonating path which resonate the middle frequency band at 5.82 GHz resonating mode the current is distributed on ‘m’, ‘p’ and the feed line length is responsible for upper frequency.

The comparison of the parameter values at three different resonating frequencies are given in the table below:

Parameters	At 2.72 GHz	At 3.90 GHz	At 5.82 GHz
Return Loss	-41.38 dB	-23.51 dB	-42.26 dB
VSWR	1.01	1.14	1.01

Bandwidth	404 MHz	311 MHz	688 MHz
Directivity	4.35 dBi	3.37 dBi	3.93 dBi
Gain	4.43 dBi	2.99 dBi	3.61 dBi

Table 5.3: Comparison of antenna parameters values of trident shaped monopole antenna at 2.72 GHz, 3.90 GHz and 5.82 GHz

5.3 Parametric Study of Antenna

In this section, the effect of the various physical parameters likes resonating path length by varying parameter at a time and keeping all other parameters constant so that one can get optimized antenna for the desired applications.

5.3.1 Effect of resonating path "m"

The figure below shows the simulated return loss graph varying the branch resonating path m, when n=4.25 mm and p=2.4 mm. it is clearly visible that there are large variations in the second resonance peak from 3.74 GHz to 4.06 GHz it is clearly visible that there are large variations in the second resonance peak from 3.74 GHz to 4.06 GHz as the m decrease from 3.6 mm to 1.6 mm, where as other two resonance peaks vary a little.

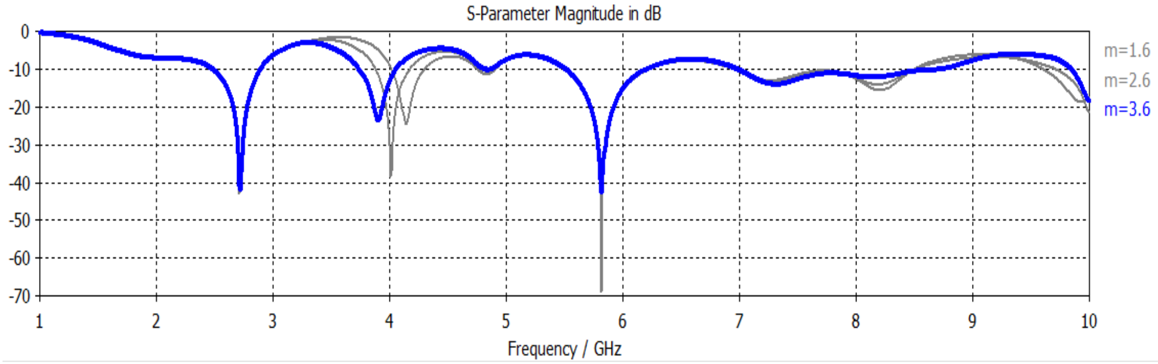


Figure 5.7: Simulated return loss graph varying the branch m of the proposed Antenna (n=4.25 mm and p=2.4 mm).

5.3.2 Effect of resonating Path "n"

In figure below shows the simulated return loss graph varying the resonating path n, when m=3.6 mm and p=2.4 mm. it is clear that there are little variations as compared to the resonance path m in the first resonance peak from 2.49 GHz to 2.89 GHz as n decrease from 4.25 mm to 2.25 mm, where as other two resonance

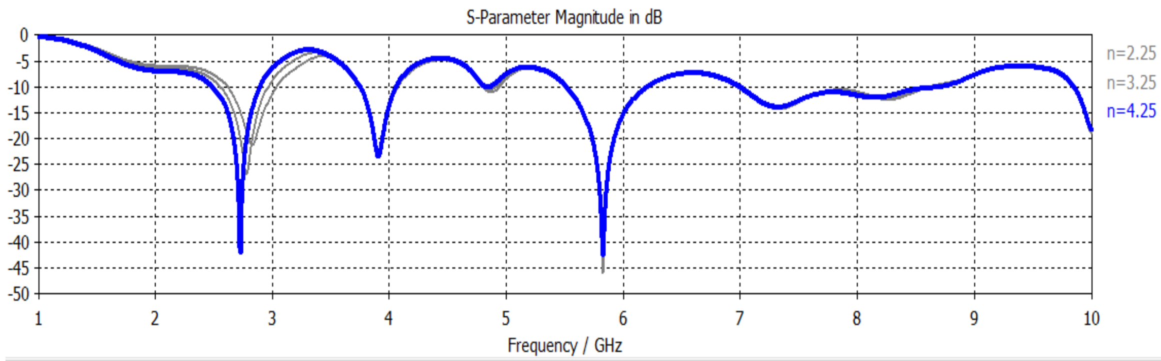


Figure 5.8: Simulated return loss graphs varying the branch n of the proposed Antenna (m=3.6 mm and p=2.4 mm)

5.3.3 Effect of resonating path "p"

Figure below shows the simulated return loss graph varying the branch p of the resonating p, when m=3.6 mm and n=4.25 mm. it is clearly visible that there are also large variations in the third resonance peak from 5.51 GHz to 6.20 GHz as the p decrease from 3.4 mm to 1.4 mm. In this case resonant path m also varies large from 3.74 GHz to 4.06 GHz and the resonance path n varies a little in comparison to other two resonant paths.

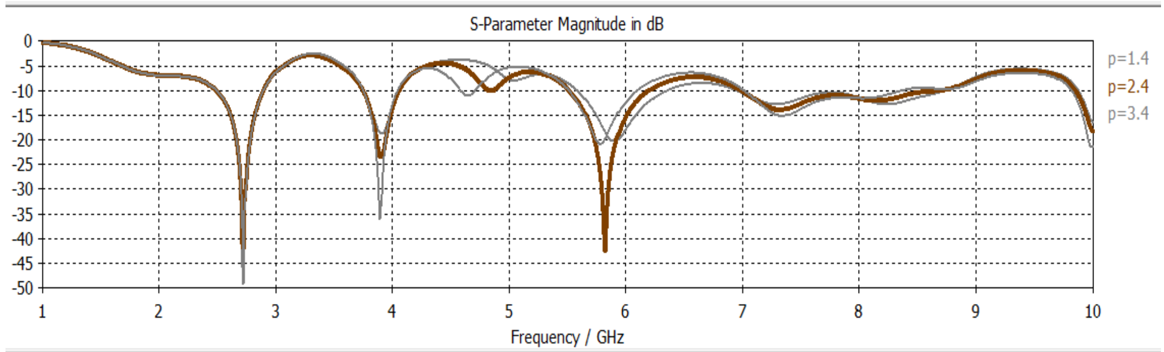


Figure 5.9: Simulated return loss graphs varying the branch p of the proposed Antenna (m=3.6 mm and n=4.25 mm)

5.4 Conclusion

A trident shaped design triple band monopole antenna for wireless operation has been presented. Satisfactory tri-band operation for IMT, WLAN and WiMAX can be easily achieved by the trident shaped configuration, which provides three resonant paths of different lengths for the excitation of the three resonant frequencies. The proposed antenna gives a return loss of -32.81dB, -19.81 dB and -34.89dB at resonant frequencies 2.74 GHz, 3.96 GHz and 6.03 GHz provide a bandwidth of 375 MHz, 333 MHz and 768 MHz. Hence the proposed antenna may be a suitable candidate for the tri-band operation in wireless applications.

CHAPTER 6

CONCLUSION AND FUTURE SCOPE

In this thesis report three configuration of slotted Microstrip Patch Antenna using Microstrip Feed Line and CPW technique is given for WLAN, WiMAX and IMT applications. The first is the typical design of dual band CPW fed slotted monopole antenna for WLAN/WiMAX, the second is Triple Band slotted and stubbed Microstrip patch antenna with H shaped and Two U shaped slots on radiating patch and Third design is Trident shaped Triple Band microstrip Patch Antenna have a Trident shaped resonating path slot on patch.

The various antenna parameters like return loss, VSWR, directivity, gain, bandwidth and operating frequency are studied for antenna designing. The effect of physical parameters on the antenna parameters are also studied in this thesis report.

Initially, the work starts with the designing of the Dual band monopole coplanar microstrip patch antenna operating at 2.55 GHz and 5.84 GHz for WLAN and WiMAX applications. The designed Dual band Antennas give efficient results. The results gives return loss of -21.88 dB and -35.66 dB and band width of 307 MHz and 1091 MHz respectively.

It is also concluded that physical parameters like resonate length of slot, Gap between ground and radiating patch and slot in ground effects the results of the antenna. It can be observed that varying these parameters in the right manner gives optimized results for a desired resonant frequency operation of MSA which is shown in above chapter 3.

Table 7.1: Parameter variation and their effects

Parameters varied	Different values of varied Parameters	Effect of the parameters Varied
Resonating length L1	L1=3.0 mm L1= 4.0 mm L1= 5.5 mm L1=6.0 mm	The slot “L1” impact on return loss of antenna and it also remove the unwanted resonance at upper band in Figure 3.9, the various length of slot at L1=6 mm the frequency is move to

		lower side at upper band and have a better return loss and there is small decrease in return loss at the lower band but overall there is good impedance matching return loss and remove the unwanted resonance.
Gap between ground and radiating Patch G	G= 1.0 mm G= 2.0 mm G= 2.5 mm G= 3.0 mm	In the Figure 3.10 show the return loss of Antenna with various dimension of G which impact the return loss and the bandwidth at G=2 mm we get a better impedance matching, return loss and bandwidth so from this we conclude that by adjusting gap G between ground and radiating element we get a good impedance matching.

A compact triple-band slotted and stubbed microstrip patch antenna for WLAN/WiMAX applications is presented. The antenna is simulated using (CST MWS V10.0). Compared to many antennas proposed earlier, this antenna is designed based on a rather simple structure and suitable for all frequency bands of WLAN and WiMAX applications simultaneously. The proposed antenna can be considered to achieve multi bands just through etching H slot and two U slots on the radiating patch and etching a slot at centre of ground plane. The measured results show that the obtained impedance bandwidths are 259 MHz, 889 MHz and 185 MHz respectively, good enough for WLAN and WiMAX applications. The proposed antenna is also provide a better return loss of -15.44 dB, -22 dB and -23.50 dB at resonate frequencies 2.01 GHz, 3.59 GHZ and 5.70 GHz. In addition, the proposed antenna has good radiation characteristics, gains and directivity in the three operating bands, so it can emerge as an excellent candidate for multiband generation of wireless.

In another design in which triple band trident shaped monopole microstrip patch antenna in which there is three resonating path which obtained a three operating frequencies at 2.74 GHz, 3.96 GHz and 6.03 GHz which is suitable for WLAN, WiMAX and IMT applications. The gain of antenna is 4.47 dBi, 2.93 dBi and 3.63 dBi. The directivity of antenna is 4.42 dBi, 3.32dBi and 3.94 dBi. The directivity and gain of antenna is fair enough for wireless applications.

6.2 Future scope

The designed antennas in this thesis report are used in various applications like WLAN, IMT (International Mobile Telecommunications) and WiMAX.

The work on microstrip antenna design using microstrip and CPW feed line can be extended to:

- Using different structure configuration, the use of different dielectric substrate material as well as combination of different substrate in one structure
- Using different slots on the patch and the ground, the use of different shape of patch with larger radiating area.
- Using impedance matching network to enhance the impedance bandwidth.

Various techniques can also be used in future to design optimized antennas which are as Follows:

- **Split-Ring Resonator Structure (SRS):** A single cell SRR has a pair of enclosed loops with splits in them at opposite ends. A magnetic flux penetrating the metal rings will induce rotating currents in the rings, which produce their own flux to enhance or oppose the incident field. The small gaps between the rings produces large capacitance values which lower the resonating frequency.
- **Electromagnetic Band Gap Structure (EBG):** Electromagnetic Band Gap (EBG) substrates for patch antennas significantly reduce the effect of surface waves as a function of frequency and are able to provide relatively broadband frequency performance.
- **Metamaterials:** A metamaterial is a metallic or semiconductor substance whose properties depend on its inter-atomic structure rather than on the composition of

the atoms themselves. Certain metamaterials bend visible light rays in the opposite sense from traditional refractive media. Some metamaterials also exhibit such behaviour at infrared (IR) wavelengths. Possible applications of transparent metamaterials with negative indices of refraction include red and IR lasers, optical communications systems, spectrometry, monitoring systems to detect trace gases in the atmosphere, medical diagnostic equipment and optical cloaking devices. In metamaterials both εr and μr are negative.

- **Other Feeding Techniques:** The other feeding techniques of microstrip patch antenna like coaxial feeding, aperture coupling and proximity coupling can also be used in future to design the same microstrip patch antennas.

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