DESIGN, FABRICATION AND PERFORMANCE EVALUATION OF DUAL AND TRIPLE BAND MICROSTRIP PATCH ANTENNAS WITH MICROSTRIP FEEDING FOR WIRELESS APPLICATIONS

A Dissertation submitted in partial fulfilment of the requirements for the award of Degree of

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CERTIFICATE

I hereby declare that the thesis report entitled **"Design, Fabrication And Performance Evaluation Of Dual And Triple Band Microstrip Patch Antennas For Wireless Applications"** is an authentic record of my study carried out as requirement for the award of degree of M.E. (Wireless Communication Engineering) at Thapar University, Patiala, under the supervision of **Mrs. Amanpreet Kaur**, Assistant Professor, Electronics and Communication Engineering Department.

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

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ABBREVIATIONS

MPA	Microstrip Patch Antenna
RMPA	Rectangular Microstrip Patch Antenna
WLAN	Wireless Local Area Network
BW	Band Width
CST	Computer Simulation Technology
DGS	Defected Ground Structure
GPRS	General Packet Radio Service
GSM	Global System for Mobile
HIPERLAN	High Performance Local Area Network
MPA	Microstrip Patch Antenna
OFDM	Orthogonal frequency-division multiplexing
RF	Radio Frequency
RL	Return Loss
UHF	Ultra High Frequency
UWB	Ultra Wideband
VHF	Very High Frequency
VSWR	Voltage Standing Wave Ratio
Wi-MAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network

CHAPTER 1

INTRODUCTION

1.1 OVERVIEW OF WIRELESS COMMUNICATIONS

In the last few decades, the rapidly increasing demand of high data rate communication has made the wireless systems the fastest growing sector of communication industry. As the name suggests, wireless communication refers to the transmission of data without using wires, cables or any other type of conducting materials. Initially, the light portion of EM spectrum was utilized in optical devices but with the advancement in technology, the communication systems are also utilizing the electromagnetic spectrum outside the visible region. The wireless technology has evolved from analog First generation communication systems and is about to reach an advance high-speed fourth generation [1].

First Generation (1G) technology: In 1964-1974, the Bell Labs developed an analog system named HCMTS, which used frequency modulation and bandwidth of 30 Hz with signaling rate of only 10 kbps. Later, its name was changed to AMPS (Advanced Mobile Phone Service) and it was deployed in 1984. 1G communication systems were based on circuit switching [2].

Second Generation (2G) technology: The digital mobile cellular systems known as GSM (Global System for Mobile) came into evolution in 1983 in Europe. The digital TDMA based GSM system was deployed in Germany in 1991. The AMPS system could not support the fast growing number of users. Thus, CDMA system was developed which supports times more users than AMPS at that time. In 2000, GPRS (General Packet Radio Service) came as an enhancement of GSM system which supports data rate upto 14.4 to 64 kbps. The next enhancement to GPRS was EDGE (Enhanced Data rates for GSM Evolution) whose data rate was upto 500kbps [2].

Third Generation (3G) technology: The current generation of mobile communication systems is 3G which uses packet switching for data services and circuit switching for voice services. It offers data rate upto 2 Mbps and supports services such as video calling, mobile internet, mobile TV, telemedicine etc. [2].

Fourth generation (4G) technology: 4G technology promises very high downloading speed and many additional features such as IP telephony, ultra broadband internet access, gaming services, etc. 4G technology may include Flash OFDM, Wi-MAX (802.16e) and HC-SDMA [2].

1.2 SIGNIFICANCE OF ANTENNAS IN WIRELESS COMMUNICATION

Antenna plays a very important role in the performance and consistency of any wireless communication system. An antenna is defined as a structure which is associated with the transition region between free space and guiding medium and transmits and receives the electromagnetic waves. It acts as a transducer which transforms the electric signals into radio waves at the transmitting end and converts the radio waves back into electric current at receiving end. The antenna carries a pulsating or alternating current which generates an EM field around the wire which varies in the same manner as the current does. If another conducting wire is placed near it, the electromagnetic field lines will induce weaker electric current in that wire also. Antennas find their applications in radios, television, RADAR, cell phones, wireless LAN, spacecraft communication and many other applications. Antennas can be classified according to different frequency types: Radio antennas are used for amplitude modulation and frequency modulation broadcasting whereas television antennas could be used for UHF, VHF or both. Antennas can also vary in terms of range i.e., short, medium or long range. Antennas may also be classified according to installation location; indoor, outdoor or attic [3].

1.3 TYPES OF ANTENNAS

Antennas can be categorized according to various parameters such as geometrical shape, size, directivity, radiation pattern, frequency, wavelength and applications. The different types of antennas are discussed here:

Wire antennas can take the shape of a straight wire, loop or helix and is used in automobiles, ships, aircrafts, spacecrafts and buildings. Aperture antennas can be easily flush-mounted on the surface of spacecrafts and aircrafts as these are coated with dielectric material to protect them from hazardous environmental conditions. A small and less bulky antenna is a Microstrip Antenna. Microstrip antennas consist of metallic patch and ground plane. These two are separated by a dielectric substrate. The patch can be of any geometrical shape but rectangular and circular patches are used mostly. Another type is array antennas which are used as radiating elements for desired radiation characteristics in particular directions. Reflector antennas are built with large dimensions to achieve high gain and long distance transmission. Lens antennas are classified according to their geometrical shapes and material from which they are constructed. By varying their shapes and the constructing material, their characteristics and applications can be varied [4].

1.4 MICROSTRIP ANTENNA

Microstrip antenna is one of the fastest emerging segments in the telecommunication industry and a promising technology to be used in the future telecommunications. Microstrip antennas are very advantageous in many practical applications as compared to the conventional antennas. Microstrip antenna consists of two parallel conductors- a radiating patch and a ground plane separated by a dielectric substrate [5]. A microstrip antenna is shown in Figure 1.1.

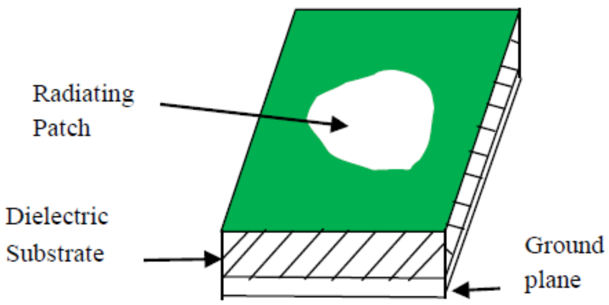

Figure 1.1: Microstrip antenna [5]

Microstrip antennas can be differentiated by various physical parameters and can be designed by using different geometrical shapes and dimensions. The microstrip antennas are basically divided into four types:

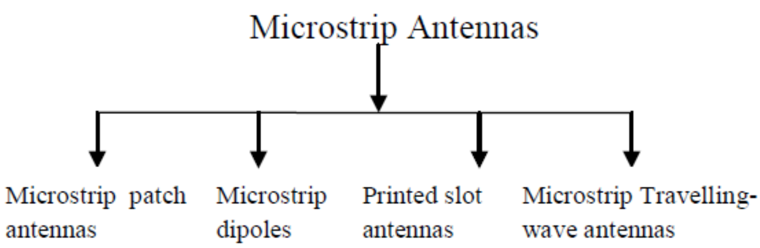

Figure 1.2: Microstrip Antenna types [5]

1.4.1 Microstrip Patch Antennas

Microstrip patch antenna consists of two parallel conductors – a thin metallic patch and the ground plane, which are separated by dielectric substrate [6]. The length (L), thickness (t) and height (h) of this patch is restricted by:

$$\lambda_0/3 < L < \lambda_0/2 \quad (1)$$

$$t << \lambda_0 \quad (2)$$

$$0.003\lambda_0 \leq h \leq 0.05\lambda_0 \quad (3)$$

The patch can take any geometry i.e. rectangular, circular, elliptical, triangular or dipole but rectangular patch is used as it is easy to analyze. This patch when excited in fundamental mode gives pattern maximum and maximum directivity normal to the patch i.e. broadside. The value of dielectric constant for the substrate lies in range of $2.2 \leq \epsilon_r \leq 12$. Thick substrates having low value of dielectric constant are preferred for good antenna performance in terms of efficiency, bandwidth, and radiation pattern but at the cost of element size. For microwave circuitry, thin dielectric substrates having higher value of dielectric constant are used due to tightly bound fields of radiation but the efficiency and bandwidth are relatively lesser [7].

The 50Ω microstrip line is used for feeding. A feedline is connected to the antenna by direct or indirect contact to excite it to radiate. Microstrip feedline is used as it is easy to fabricate and can be viewed as an extension of the patch. Microstrip antennas cover a broad frequency spectrum from 100 MHz to 100 GHz, thus possess several advantages as compared to conventional antennas such as low profile, simple and inexpensive to design and manufacture, flexible in terms of configuration, polarization, pattern, resonant frequency and impedance when a particular shape and mode are selected. The advantages of Microstrip Antenna are discussed in table 1.1. These are used in various government and commercial applications like mobile radio and wireless applications. For the upcoming wireless applications, smaller antenna size is required to meet the small size requirements of mobile units. The compact antennas are also designed for broadband, dual frequency; dual polarized and gain enhanced operations. These antennas are made robust to be used on the surface of aircrafts, satellites, cars, missiles, spacecrafts and mobile units [8].

A simple rectangular patch antenna is shown in figure 3.

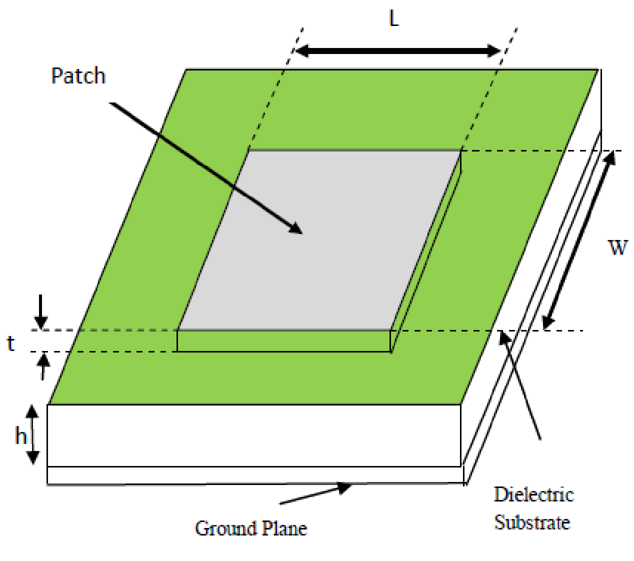

Figure 1.3: Rectangular Patch Antenna [6]

1.4.2 Advantages and Disadvantages

Sr. No	Advantages	Disadvantages
1.	Low weight	Low efficiency
2.	Low profile	Low gain
3.	Thin profile	Large ohmic loss in the feed structure of arrays
4.	Required no cavity backing	Low power handling capacity
5.	Linear and circular polarization	Excitation of surface waves
6.	Capable of dual and triple frequency operation	Polarization purity is difficult to achieve
7.	Feed lines and matching networks can be fabricated	Complex feed structures require high performance arrays

Table 1.1: Advantages and Disadvantages of Microstrip Antennas

1.4.3 Applications

Microstrip antennas are becoming popular in all the fields and areas. The Microstrip patch antennas are well known for their performance and their robust design, fabrication and their extent usage [8]. Microstrip patch antenna has several applications. Some of these applications are discussed as below:

Mobile and satellite communication application: Mobile communication requires small, low-cost, low profile antennas. Microstrip patch antenna meets all requirements and various types of microstrip antennas have been designed for use in mobile communication systems. In case of satellite communication circularly polarized radiation patterns are required and can be realized using either square or circular patch with one or two feed points [9].

Global Positioning System applications: Nowadays microstrip patch antennas with substrate having high permittivity sintered material are used for global positioning system. These antennas are circularly polarized, very compact and quite expensive due to its positioning. It is expected that millions of GPS receivers will be used by the general population for land vehicles, aircraft and maritime vessels to find their position accurately.

Radio Frequency Identification (RFID): RFID uses Microstrip Antennas in different areas like mobile communication, logistics, manufacturing, transportation and health care. RFID system generally uses frequencies between 30 Hz and 5.8 GHz depending on its applications. Basically RFID system is a tag or transponder and a transceiver or reader.

Worldwide Interoperability for Microwave Access (WiMAX): The IEEE 802.16 standard is known as WiMAX. It can reach upto 30 mile radius theoretically and data rate 70 Mbps. MPA generates three resonant modes at 2.7, 3.3 and 5.3 GHz and can, therefore, be used in WiMAX compliant communication equipment.

Radar Applications: Radar can be used for detecting moving targets such as people and vehicles. It demands a low profile, light weight antenna subsystem, the microstrip antennas are an ideal choice. The fabrication technology based on photolithography enables the bulk production of microstrip antenna with repeatable performance at a lower cost in a lesser time frame as compared to the conventional antennas [10].

Rectenna Application: Rectenna is a rectifying antenna, a special type of antenna that is used to directly convert microwave energy into DC power. Rectenna is a combination of four subsystems i.e. Antenna, ore rectification filter, rectifier, post rectification filter. in rectenna application, it is necessary to design antennas with very high directive characteristics to meet the demands of long-distance links. Since the aim is to use the rectenna to transfer DC power through wireless links for a long distance, this can only be accomplished by increasing the electrical size of the antenna.

Telemedicine Application: In telemedicine application antenna is operating at 2.45 GHz. Wearable Microstrip antenna is suitable for Wireless Body Area Network (WBAN). The proposed antenna achieved a higher gain and front to back ratio compared to the other antennas, in addition to the semi directional radiation pattern which is preferred over the omni-directional pattern to overcome unnecessary radiation to the user's body and satisfies the requirement for on-body and off-body applications. An antenna having gain of 6.7 dB and an F/B ratio of 11.7 dB and resonates at 2.45GHz is suitable for telemedicine applications.

Medicinal applications of patch: It is found that in the treatment of malignant tumors the microwave energy is said to be the most effective way of inducing hyperthermia. The design of the particular radiator which is to be used for this purpose should posses light weight, easy in handling and to be rugged. Only the patch radiator fulfils these requirements. The initial designs for the Microstrip radiator for inducing hyperthermia was based on the printed dipoles and annular rings which were designed on S-band. And later on the design was based on the circular Microstrip disk at L-band. There is a simple operation that goes on with the instrument; two coupled Microstrip lines are separated with a flexible separation which is used to measure the temperature inside the human body. A flexible patch applicator can be seen in the figure below which operates at 430 MHz [10].

1.5 ANTENNA PARAMETERS

Various parameters are used to analyze the efficiency of an antenna and are discussed as following:

1.5.1 Return Loss

Return loss gives the measure of power lost to the load and that does not return as reflection. When the impedance of transmitter and antenna do not match, some portion of the transmitted waves reflects back which leads to standing waves. Hence, Return loss indicates the matching between transmitter and antenna and is given by:

$$RL = -20\log_{10}|\Gamma| \quad (4)$$

where Γ is the reflection coefficient. Typical value of RL should be -9.5 dB or 11% power reflection for practical applications [3].

1.5.2 Smith Chart

Smith Chart was invented by Philip H. Smith to solve the problems of transmission lines and matching circuits. It is plotted on a complex two dimensional reflection coefficient plane. The scaling is done mostly in normalized impedance, normalized admittance or both and the charts are called Z, Y and YZ Smith Charts respectively. Normalization is done to use Smith Chart for solving problems taking any value of characteristic impedance or system impedance, but the most commonly used value is 50 ohms [3]. In Smith Chart, the upper portion is inductive and lower part is capacitive and the centre circles are constant resistance circles.

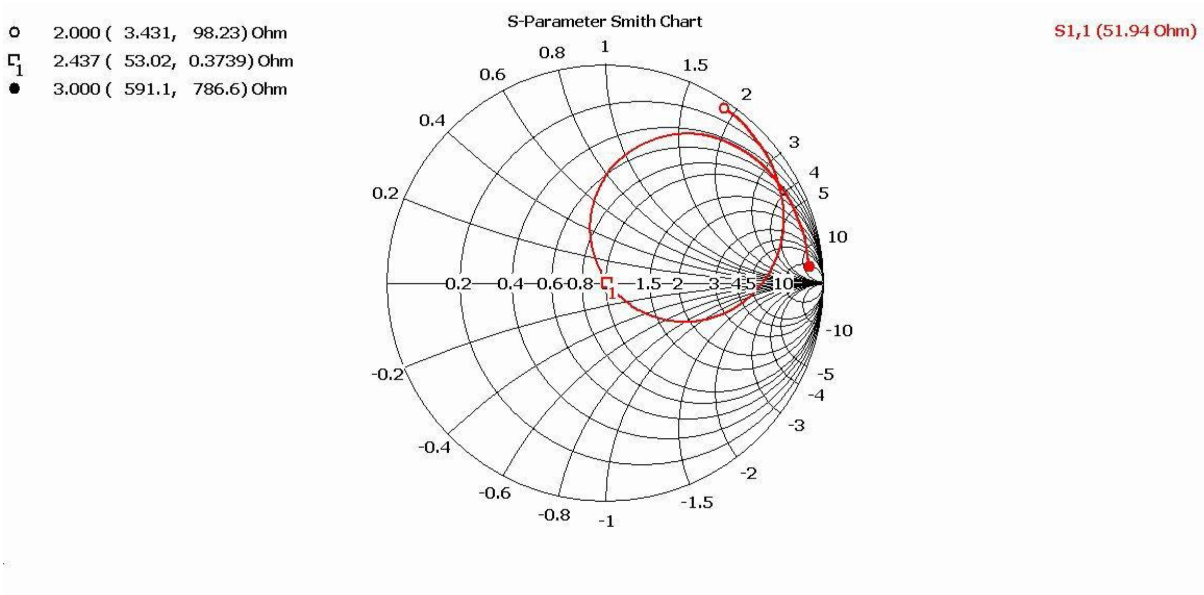

Figure 1.4 Smith Chart [2]

1.5.3 Voltage Standing Wave Ratio (VSWR)

VSWR is the most important parameter considered during the installation and tuning of transmitting antennas. When an antenna connects the transmitter to the feed line, their impedance needs to match exactly so that the maximum energy transfer takes place. When the impedances of antenna and feed line do not match, some portion of electrical energy is not transferred from feed line to the antenna. This portion of energy which is not transferred to antenna reflects back to the transmitter. These reflected waves interact with the forward waves and results into standing wave patterns. An antenna tuner is used to match the impedance of the feed line to that of the antenna [3]. This tuner can be installed in between the transmitter and feed line or between feed line and the antenna. In both the cases, the transmitter can operate at low VSWR. The value of VSWR must lie in range of 1-2.

1.5.4 Directivity

Directivity of an antenna is defined as the ratio of radiation intensity of antenna in a given direction to the radiation intensity of that antenna averaged over all directions and it is dimensionless [3]. It can be represented mathematically as:

$$D = \frac{U}{U_0} = \frac{4\pi U}{P_{rad}} \tag{5}$$

U = radiation intensity (W/unit solid angle)

U_0 = radiation intensity of isotropic source (W/unit solid angle)

P_{rad} = total radiated power (W)

1.5.5 Gain

Gain of an antenna gives the measure of the efficiency of the antenna and its directional capabilities. Gain is defined as the ratio of radiation intensity in a particular direction to the radiation intensity obtained if power is radiated isotropically by that antenna [4].

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

$$Gain = 4\pi U(\theta, \varphi)/P_{in} \quad (6)$$

1.5.6 Radiation Pattern

Radiation pattern of an antenna is defined as the mathematical or graphical representation of the antenna properties in terms of space coordinates. The radiation pattern graphically depicts the relative field strength of the transmitting or receiving antenna. This pattern is taken at only one frequency, one polarization and plane cut and are mostly presented with a dB strength scale in polar or rectilinear form [4].

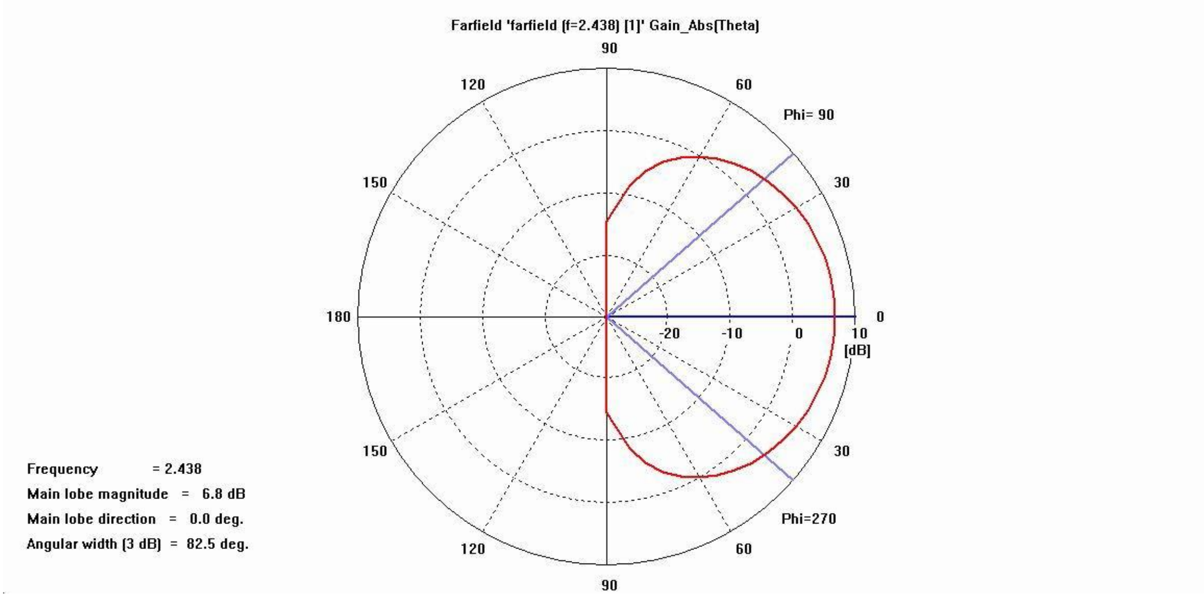

Figure 1.5 Radiation Pattern

1.6 MODELS FOR ANALYSIS OF MICROSTRIP ANTENNAS

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). The transmission line model is the simplest of all and it gives good physical insight but it is less accurate. The cavity model is more accurate and gives good physical insight but is complex in nature.

1.6.1 Transmission Line Model

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

(A) Fringing Effects

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 Figure 1.6 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 [11].

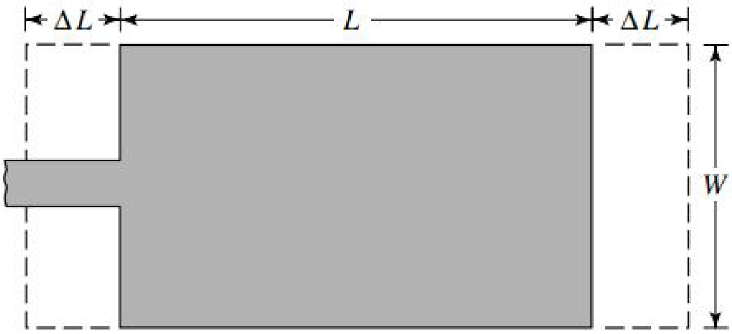

Fig. 1.6 Physical and effective length of MSA [3]

For a line with air above the substrate, the effective dielectric constant has values in the range of $1 \ll \varepsilon_{reff} \ll \varepsilon_r$. For most applications, where the dielectric constant of the substrate is much greater than unity ($\varepsilon_r \gg 1$), 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.

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 [12].

The effective dielectric value of the substrate is given by:

$$W/h > 1$$

$$\epsilon_{reff} = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2}\left[1+12\frac{h}{W}\right]^{-1/2} \tag{7}$$

(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 1.6 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) [13]. A very popular and practical approximate relation for the normalized extension of the length is

$$\frac{\Delta L}{h} = 0.412\frac{(\epsilon_{reff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\epsilon_{reff}-0.258)\left(\frac{W}{h}+0.8\right)} \tag{8}$$

Since the length of the patch has been extended by ΔL on each side, the effective length of the patch is now ($L = \lambda/2$ for dominant TM_{010} mode with no fringing)

$$L_{eff} = L + 2\Delta L \tag{11}$$

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

$$(f_r)_{010} = \frac{1}{2L\sqrt{\epsilon_r}\sqrt{\mu_0\epsilon_0}} - \frac{v_0}{2L\sqrt{\epsilon_r}} \tag{12}$$

where v_0 is the speed of the light in free space [13].

(C) Design

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

Dielectric constant of the substrate (ϵ_r): The dielectric constant of substrate (ϵ_r) 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 [14].

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 but for a higher bandwidth greater heights are preferred so optimized value is chosen. After the proper selection of above three parameters, the next step is to calculate the radiating patch width and length mathematically.

Step 1: Calculation of Width (W)

For an efficient radiator, practical width that leads to good radiation efficiencies is [14].

$$W = \frac{1}{2f_r\sqrt{\mu_0\epsilon_0}}\sqrt{\frac{2}{\epsilon_r + 1}} \quad (13)$$

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

The effective dielectric constant is given by:

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-1/2} \quad (14)$$

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

The effective length is given by:

$$L_{eff} = \frac{c}{2f_0\sqrt{\epsilon_{reff}}} \quad (15)$$

Step 4: Calculation of Length Extension (L)

Before calculation of "L", ΔL will be calculated by

$$\frac{\Delta L}{h} = 0.412\frac{(\epsilon_{reff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\epsilon_{reff} - 0.258)\left(\frac{W}{h} + 0.8\right)} \quad (16)$$

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

Thus, the actual length of radiating patch is obtained by

$$L = L_{eff} - 2\Delta L \quad (17)$$

Step 6: Calculation of Ground Dimensions (L_g, W_g)

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 [15] 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 [16]. Hence, for this design, the ground plane dimensions would be given as:

$$L_g = 6h + L \quad (18)$$

$$W_g = 6h + W \quad (19)$$

The work covered in the thesis includes designing, simulating and analyzing Microstrip Patch Antennas at different frequency bands for various applications and also improving the bandwidth of the designed antenna using Defected Ground Structure DGS. Moreover, the antennas are optimized for improved bandwidth. Then, the fabrication and testing of the antennas at 5.5, 6.3 and 6.8 GHz is done for WiMAX and STM level I applications on a VNA.

1.7 OUTLINES OF THE THESIS

The thesis is composed of 7 chapters and organized as follow:

Chapter 1:- Concentrates on the brief overview of the microstrip patch antenna, Role of antenna and history for wireless communication and an introduction to Microstrip Antennas and their analysis.

Chapter 2:- Provides an insight into literature review related to the microstrip patch antenna with microstrip line feeding techniques and also with defected ground structures to improve the bandwidth of antenna. Also, the objectives are defined for the thesis work carried out.

Chapter 3:- Microstrip Antennas with microstrip line feed operating at 5.5, 6.3 and 6.8 GHz is designed and simulated for STM link I applications. Parametric analysis is done to obtain the desired gain, directivity, Return loss, current distribution etc.

Chapter 4:- Provides the design and development of a Microstrip Patch Antenna using Defected Ground Structure (DGS). The parameters like return loss, smith chart, radiation pattern and VSWR etc. are plotted and studied for antenna operating at 4.9 and 7.6 GHz.

Chapter 5:- Results of Microstrip Patch Antenna for triple band with reduced ground structure and DGS are discussed through plots of gain, directivity, return loss, different fields etc.

Chapter 6:- Presents the fabrication process of a microstrip patch antenna using microstrip line feed. Testing of antenna is done using VNA & measured and stimulated results are compared.

Chapter 7:- Concludes the work carried out in this thesis with the future scope and future prospective of the Microstrip Patch Antenna.

1.8 CONCLUSION

The advantages of microstrip antennas given in table 1.1 make them the best choice for various applications as discussed in the chapter. Moreover, the role of antennas in different wireless application is also discussed. For these wireless applications, it is desired to design an antenna which covers multiple frequency bands so that the requirement of multiple antennas for different applications is covered by a single antenna. Also the designed antenna should be low profile, simple and inexpensive and should show the desired performance measures as explained above in the chapter.

CHAPTER- 2
LITERATURE SURVEY

2.1 INTRODUCTION

The concept of microstrip antenna was first proposed by Deschamps in 1953. A patent was issued in France in 1955 in the names of Gutton and Baissinor. After the 1970s research publications started to flow with the appearance of the first design equation. Since then different authors started investigation on microstrip patch antennas like James hall, David M. Pozar and there are also some contributed a lot [17]. Throughout the years, authors have dedicated their investigations to create new designs or variations to the original antenna that, to some extent; produce either wider bandwidth or multiple frequency operation in a single element.

2.1.1 Progress of the Microstrip Feedline Antenna and their utilization in dual band applications

In 1991, Hugh K. Smith et al. presented a dual-feed microstrip patch antenna. This new radiator had broad-band match and unidirectional azimuth pattern, desirable characteristics for use in broad-band end fire arrays. Design, construction, and experimental results realized in gain, input impedance, and far-field patterns are given for a log-periodic array of dual-feed patches. An array with only 10 elements has been demonstrated to operate at nearly constant gain over a 2:l frequency band with voltage standing-wave ratio (VSWR) less than 2:l [18].

In 1995, David Sinchez-Hemindez et al. made concerning research on frequency agility of microstrip patch antennas. The analysis and design of a novel dual-band circularly polarized microstrip patch antenna using a spur-line band- stop filter and a perturbation segment technique is presented. This dual frequency operation can be obtained without increasing either the size or the thickness of the patch while other features are not degraded [19].

In 1998, N. Fayyaz et al. introduced and implemented a novel design for increasing the bandwidth of a rectangular patch antenna. The design concept involved terminating a suitable point of the patch with appropriately designed stub. This stub simultaneously acts as a short circuit and impedance thereby creating two close resonances. This new design is very useful since it improves the bandwidth of a tradition rectangular patch antenna by three times [20].

In 2003, Y. L Kuo et al. proposed an antenna that was designed for dual band operation "Printed Double T-Monopole antenna for 2.4/5.2 GHz Dual-band WLAN Operations. It is a microstrip-fed double-T monopole antenna, comprises two stacked T-shaped monopoles of different sizes, which generate two resonant modes for desired dual band operations, and covers 2.4 and 5.2 GHz bands at 50ohm impedance for WLAN operations [21].

In 2007, F.Y. Zulkilfi et al. presented a dual band microstrip patch antenna for solution standard wireless local area network (WLAN). Dual band characteristic is produced by combining the 2.4 GHz band and the 5 GHz band by using slot U. Wideband characteristics is achieved at frequency 5 GHz by using slot S. This design can completely cover the IEEE standard (802.11 b/g and 802.11 a) for WLAN [22].

In 2009, Mohammed Al-Husseini presented a low-cost ultra-wide band microstrip antenna for wireless communications used for 3G/WLAN/WiMAX and UWB applications. The ground plane is partial and comprises a rectangular part and a trapezoidal part. The patch is a half ellipse, where the cut is made along the minor axis. Several slots are incorporated into the patch [23].

In 2010, Kuang Fuqiang presented a triple band antenna named "A triple-band Microstrip Antenna for WLAN Applications". The proposed antenna is made up of two one-quarter wavelength resonating components, fed by a 50ohmic microstrip line. The lower and higher resonant frequencies can be easily tuned by adjusting a few parameters of the presented antenna [24].

2.1.2 Progress in the Field of increasing BW using DGS:

In 1998, J. P. Geng et al. applied electromagnetic band gap (EBG) in the field of antenna to improve the performance of antenna, such as suppression of surface wave propagation, increasing the gain of antenna and improving the radiation pattern by inserting the EBG structure into the substrate. DGS is realized by etching the ground plane of microstrip antenna, this disturbs the shield current distribution in the ground plane which influences the input impedance and current flow of the antenna [25].

In 2003, Y.J.Sung et al. gave a method to reduce the higher order harmonics with the help of Defected Ground Structure. A H-shaped defect on the ground plane helped to reduce the harmonics. Then its comparison with a conventional antenna is made and it was found that radiated power was drastically reduced which is based on the stop band characteristics of defected ground structure cell [26].

In 2006, Himanshu Singh et al. designed a novel structure called Defected Ground Structure & Defected Microstrip Structure, which is widely used in several applications such as reducing the size of patch antennas without degrading the performance of the antenna as better efficiency, better bandwidth etc. DGS/DMS has other application is suppression of harmonics without introducing a big attenuation in the fundamental frequency [27].

In 2010, C. Vazquez et al. studied the effect of DGS, to the different antenna parameter enhancement. Defected ground structures (DGS) have been developed to improve characteristics of many microwave devices. Although the DGS has advantages in the area of the microwave filter design, microwave oscillators, microwave couplers to increase the coupling, microwave amplifiers, etc., it is also used in the microstrip antenna design for different applications such as antenna size reduction, cross polarization reduction, mutual coupling reduction in antenna arrays, harmonic suppression etc., The DGS is motivated by a study of Photonic / Electromagnetic Band gap structures. The etching of one or more PBG element creates defect in the ground plane and used for the same purpose. The DGS is easy to be an equivalent L-C resonator circuit. The value of the inductance and capacitance depends on the area and size of the defect. By varying the various dimensions of the defect, the desired resonance frequency can be achieved [28].

In 2010, J. Liu et al. developed a miniaturized proximity coupled antenna with DGS for switchable polarization application. A new DGS is proposed, and compared with the conventional cross and dumbbell shaped ones; the proposed DGS has better SWF and higher unloaded Q-factor. The back to back geometries have been reported by the various researchers but here a new coupling method i.e. proximity coupling with the defected ground structure is used for the consideration of the increased bandwidth. The application of DGS is given for size reduction of microstrip antennas. A dumbbell shaped DGS is used in the common ground plane of a back to back combined single feed proximity coupled microstrip antenna [28].

In 2011, Mouloud Challal et al. studied the effect of inserting a rectangular shape defected ground structure (DGS) into the ground plane of the conventional rectangular microstrip patch antenna (CRMPA).The performances of the CRMPA are characterized by varying the dimensions of the rectangular slot (RS-DGS) and also by locating the RS-DGS at specific position [29].

In 2011, Ashwini K. Arya et al. implemented the Defected Ground Structures (DGS) by etching slots of different shapes in the ground planes. They have been employed to improve the performance in multiple applications such as filters, couplers or dividers, as well as to reduce the mutual coupling between elements of antenna arrays [30].

In 2011, Wen-Chung Liu et al. presented a triple frequency Microstrip Fed Monopole Antenna Using Defected Ground Structure. Defected ground structure (DGS) is used in this antenna, which has a rectangular patch with dual inverted L-shaped strips and is fed by a cross-shaped strip-line, operates over the frequency ranges, 2.14–2.52 GHz, 2.82–3.74 GHz, and 5.15–6.02 GHz suitable for WLAN 2.4/5.2/5.8 GHz and WiMAX 3.5/5.5 GHz applications [31].

In 2011, Halappa R. Gajera et al. proposed their design of rectangular microstrip patch antenna (RMPA). The glass epoxy substrate with height 1.6mm and the dielectric constant is 4.4 is used. The half circular slot etched on the patch at the top right as DMS, two circular slots etched on the ground plane as DGS. The DGS helps in shifting the resonant frequency to desired frequency. DGS was used to improve the bandwidth and reduce the size of patch to make antenna, thereby achieving the gain of 4.65dBi [32].

In 2012, Rajeshwar Lal Dua et al. proposed the rectangular patch antenna designed with swastik structure DGS in the year 2012. Here, the radiating patch area is smaller as compared to the conventional antenna without DGS. So, this antenna design with DGS not only improve the parameters of the antenna without DGS but also can provide a smaller size of radiating patches, which will cause an overall reduction in antenna size [33].

In 2012, Rajeshwar Lal Dua et al. presented a 2.45 GHz Microstrip Patch Antenna with Defected Ground Structure for Bluetooth. The proposed antenna has been simulated at 2.45 GHz frequency. This compact antenna fed by Quarter Transformer feeding. This type of feeding is mostly used for impedance matching purposes. The antenna is simulated by the software CST MS 2010 [34].

2.1.3 Development of Microstrip patch antenna in field of Wi-MAX, WLAN and Wireless applications

In 1998, N. Fayyaz et al. investigated and implemented a novel design for a dual band rectangular patch antenna is. In this implementation, the patch is a quarter wavelengths in length, with one edge shorted and another edge connected to a strip of transmission line. This new design is very useful in PCS where two distinct frequency ranges exist for transmitting and receiving. The design method is based on using reactive loading to create an additional resonant frequency [35].

In 2001, Mari Komulainen et al. proposed a dual frequency microstrip patch antenna operating at 2.45 GHz and 5.2 GHz ISM (Industrial, Scientific and Medical) band. IEEE 802.11b WLAN (Wireless Local Area Network) and Bluetooth standards utilize the 2.45 GHz band and 5.2 GHz is specified as an operating frequency in HIPERLAN (High Performance Radio Local Area Network) standard. Antenna design was based on the previously developed dual frequency microstrip patch antenna. Adjustment for the desired frequencies 2.45 GHz and 5.2 GHz was achieved by using two different multiplying factors and setting the gaps between the two patches so that the return loss would be under -10 dB. The bandwidth was over 100 MHz for both of these frequencies. FR4 was chosen as a substrate material in order to have cost savings [36].

In 2004, Qihong Zhong et al. proposed and demonstrated a novel dual-frequency microstrip patch antenna for WLAN applications. By embedding two pairs of arc shaped slots with a narrow slot protruding at each side, dual-band operation with its operating mode centered at about frequency 2.4 GHz and 5.2 GHz has been obtained. The proposed antenna has good gain and its impedance bandwidths defined by VSWR ≤ 2 can meet the requirements of dual ISM bands [37].

In 2009, Boutheina Tlili et al. presented and simulated a small compact Microstrip patch antenna with C-shaped slot using Advanced Design Systems by. It is developed to operate in the WiMax frequency range of 2.5-2.69 GHz. The antenna presents a size reduction of about 37% when compared to a conventional patch antenna. The return loss is -19.1 dB and the antenna presents a broad radiation pattern [38].

In 2010, Li Xiaoang et al. presented and discussed a novel multi-slotted microstrip patch antenna with high gain. The design adopts contemporary techniques such as probe feeding and multi-slotted patch. These techniques can contribute to the enhanced performance of the antenna. The design also employs a novel shape patch. By integrating these techniques the proposed design offers low profile, high gain and compact antenna element. The maximum gain at the resonant frequency of 2.45GHz is 11.35dBi. The lowest return loss can be -34.49 dB at 2.45GHz. The proposed design has a simple structure and a compact dimension of 87mm*51mm. The proposed design is suitable for particular wireless communication application such as WiFi and WLAN [39].

In 2010, B. Tlili et al. proposed that Microstrip Patch Antenna is a very good candidate for integrations in applications such as wireless communication systems, mobile phones and laptops. A double C-slot microstrip antenna is designed and simulated for the WiMAX frequency range of 2.5-2.69 GHz. This antenna presents an extension to the single C slot antenna presented at LAPC 2009. The proposed antenna has a gain of 6.46 dBi and presents a size reduction of 37% when compared to a conventional square microstrip patch antenna. Extensive simulation results using Advanced Design Systems by Agilent (uses the MOM method) is presented [40].

2.2 RESEARCH GAPS

- The use of parasitic elements, stacked patches, using thick substrates of low permittivity etc have proved to improve the bandwidth of the antenna [41]. However, the broad banding design in microstrip antenna results in high volume in spite of its efficient results. The work regarding the reduction of the profile can be done.
- A novel structure called DGS & Defected microstrip structure is used to reduce the size of patch antennas without degrading the performance of antenna [29]. Different shapes of DGS can be worked upon to improve the efficiency of antennas.
- The use of different shaped patch antenna geometry has brought good performance in the VSWR and in response at low dielectric constant. Work can be done to analyze the CPW feeding with microstrip line feed to improve the results [42].
- Different shaped slots on ground can help in achieving multiband applications [22]. As different parameters of the slots are varied to get single, dual and quad band antennas.
- With the defected ground structure having different shapes can be used to reduce the higher order modes obtained also increase the bandwidth and increase the gain [31].
- The effects of dielectric position on top layer, changing the positions of patches horizontally, length and position of the DGS and the length of the top patch can provide high coupling and can also be varied to obtain the increased gain and bandwidth for different applications [43].

2.3 OBJECTIVE OF THE THESIS

Based on the above research gaps, the following objectives are designed for the work covered in thesis:

- To design, simulate and analyze a Triple band Microstrip Patch Antenna for STM (Synchronous Transport Module level I) and WIMAX (Worldwide Interoperability for Microwave Access) applications at 6.3 and 6.8 GHz frequency bands using microstrip line feed.

- To improve the bandwidth of the designed antenna using Defected Ground Structure DGS.
- To design, simulate and analyze a Dual band Microstrip Patch Antenna operating at 4.9 and 7.6 GHz frequency bands using Defected Ground Structure for applications.
- To design, simulate and analyze a Dual band Microstrip Patch Antenna using DGS for WLAN and WIMAX (Worldwide Interoperability for Microwave Access) applications at 4.3 and 5.9 GHz frequency bands.
- To optimize the antennas for improved bandwidth.
- To fabricate and test the antennas at 5.5, 6.3 and 6.8 GHz for WiMAX and STM level I applications on a VNA.

2.4 CONCLUSION

A survey of literature related to the proposed antenna design is presented. The papers referred are mainly for wireless application employing various techniques like simple patch antennas, Microstrip Patch Antennas using slots in patch, Microstrip Patch Antennas using Defected Ground Structure (DGS) for size reduction and improved bandwidth. Also, the research gaps in the existing work and the work covered in thesis report is discussed.

CHAPTER- 3
DESIGN AND SIMULATION OF TRIPLE BAND MSA FOR STM LINK I AND WiMAX APPLICATIONS

3.1 INTRODUCTION

In this chapter, a rectangular microstrip patch antenna using Microstrip feeding technique has been discussed and the results are simulated using CST MWS 2010. The results are analyzed in terms of Return loss, Bandwidth, Gain, Directivity and Current distribution. Tri-band has been achieved in this design. The first band has resonant frequency 5.5 GHz and bandwidth is 66 MHz with return loss -12.95. This frequency range is used for Wi-MAX applications. The resonant frequency of second band is 6.3 GHz and bandwidth is 190 MHz with return loss -30.56. The third band has resonant frequency 6.8 GHz and bandwidth is 102 MHz with return loss -16.72. This second and third band is suitable for wireless application of STM link 1 (Synchronous Transport Module level 1). The dimensions of ground, substrate and patch of proposed design are calculated using the equations (13) to (19) discussed in section 1.8.1 in chapter 1.

3.1.1 DESIGN OF RECTANGULAR MICROSTRIP PATCH ANTENNA

The rectangular patch antenna is approximately a one-half wavelength long section of rectangular Microstrip transmission line. When air is the antenna substrate, the length of the rectangular Microstrip antenna is approximately one-half of a free-space wavelength. The length of the antenna decreases as the relative dielectric constant of the substrate increases. The resonant length of the antenna is slightly shorter because of the extended electric "fringing fields" which increases the electrical length of the antenna slightly [10]. A single element of rectangular patch antenna can be designed for 5.5, 6.3 and 6.8 GHz resonant frequency using transmission line model.

3.2 DESIGN OF MICROSTRIP ANTENNA FOR TRIPLE BAND

The geometry of proposed antenna with Microstrip line feeding is used in Wi-MAX and STM (Synchronous Transport Module level -1) applications shown in figure 3.1. The advantages of Microstrip antenna are their low cost fabrication and its input impedance is easily controllable [15]. The major disadvantage of this feeding technique is that it has narrow bandwidth. The main dimensions of design based on Transmission line model are given in Table 3.1.

Substrate material	FR4
Substrate height	1.60 mm
Substrate size	30x40 mm
Dielectric constant	4.4
Width of Ground (W_g)	30 mm
Length of Ground (L_g)	40 mm
Length of Patch 1 (L)	13 mm
Width of Patch 1 (W)	23.44 mm
Length of Patch 2 (L_1)	7 mm
Length of Patch 2 (L_2)	12 mm
Width of Patch 2 (W_2)	18.66 mm

Table 3.1 Dimensions of the designed antenna with microstrip line feed

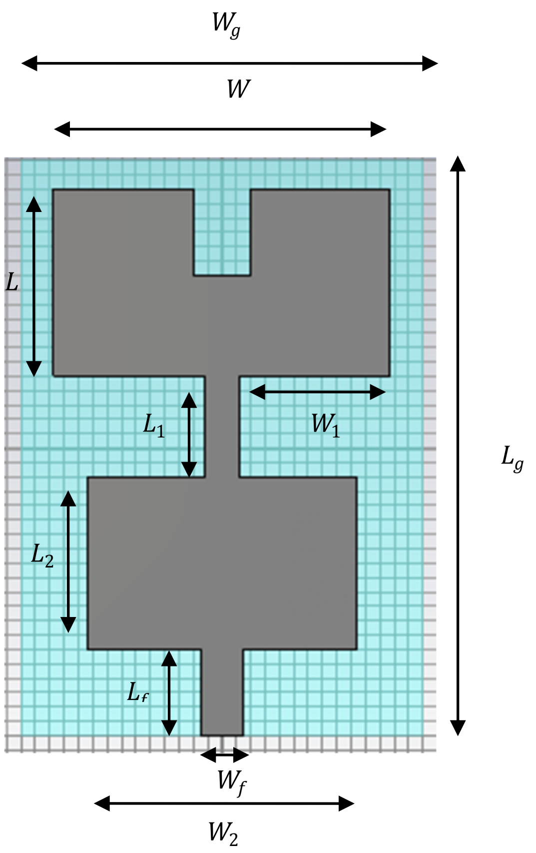

Figure 3.1 Front view of the proposed antenna

Here, L and W is the length and width of the patch respectively. L_g and W_g are length and width of the ground plane and L_f and W_f are length and width of the feed line respectively.

Simulation is done using CST MWS 2010 for Microstrip line feeding and following results are obtained and are discussed below:

3.2.1 Return Loss and BW:

The Return Loss should be more negative for best power coupling, as per discussed antenna parameters for better performance and wideband requirement [18]. That is, return loss is the negative of the reflection coefficient expressed in decibels. Thus we measure return loss at -10dB. Tri-band has been achieved in this design. The first band has resonant frequency 5.5 GHz and bandwidth is 66 MHz with return loss -12.95. This frequency range is used for Wi-MAX applications. The resonant frequency of second band is 6.3 GHz and bandwidth is 190 MHz with return loss -30.56. The third band has resonant frequency 6.8 GHz and bandwidth is 102 MHz with return loss -16.72. This second and third band is suitable for wireless application of STM link 1 (Synchronous Transport Module level 1).

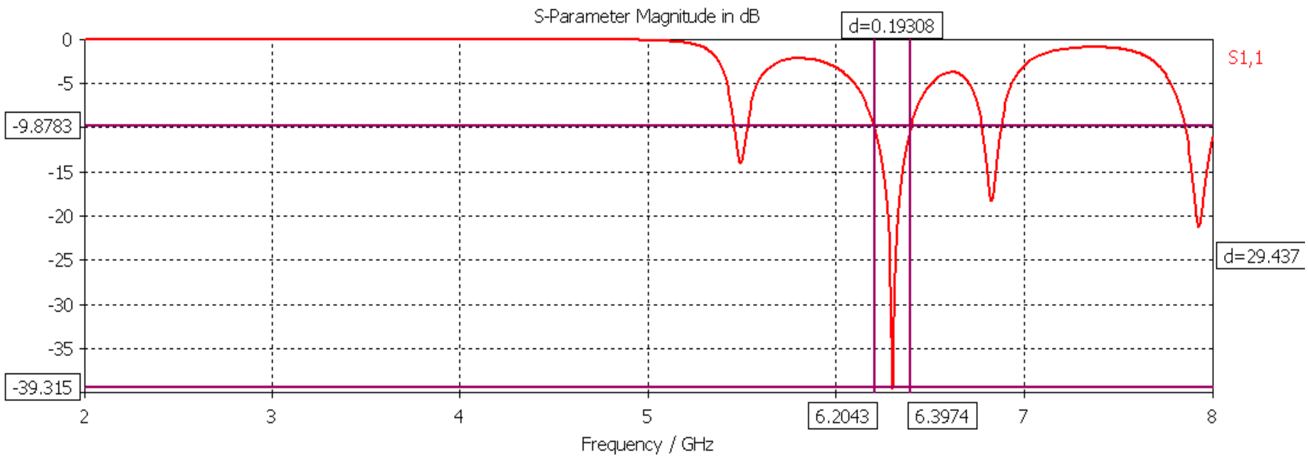

Figure 3.2: **Simulated Return Loss [S11] at 5.5, 6.3 and 6.8 GHz**

3.2.2 Smith Chart:

Figure 3.3 shows the Smith Chart results at 50ohm impedance. The smith chart represents that how antenna impedance varies with frequency. For proper matching, the locus must be large enough that it passes through the center of the smith chart. Figure 3.3 shows three circles in the Smith Chart corresponding to three resonant frequencies i.e. 5.3 GHz, 6.3 GHz and 6.8 GHz.

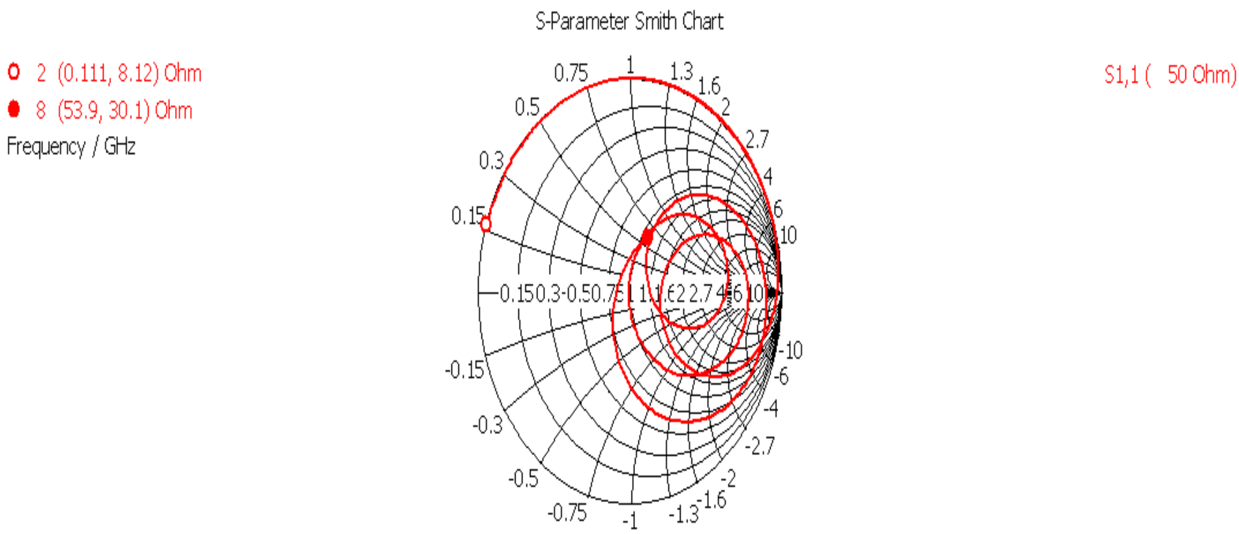

Figure 3.3: Smith Chart [S11] at 5.3, 6.3 and 6.8 GHz

3.2.3Gain:

Figure 3.4 shows the Gain plot for the proposed antenna with 9.291 dB gain at 6.2GHz frequency. The gain of the antenna in a particular direction is more as compared to isotropic antenna radiating in all directions which is very useful for Wi-MAX and STM (Synchronous transport module level 1) applications for providing a better performance. The 2D view and polar plot for Gain are given in Fig. 3.5 (a) and (b) respectively. As seen from figure 3.5, the main lobe magnitude is 9.3 dB and with angular width 62 degrees

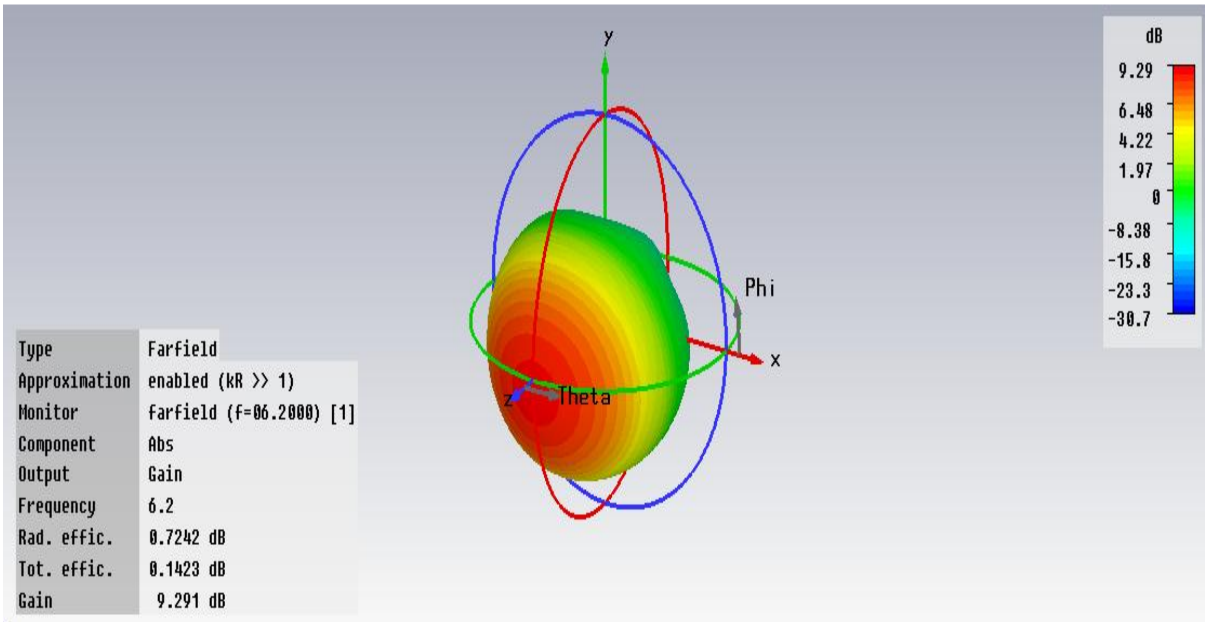

Figure 3.4: 3D Gain Plot at 6.3 GHz

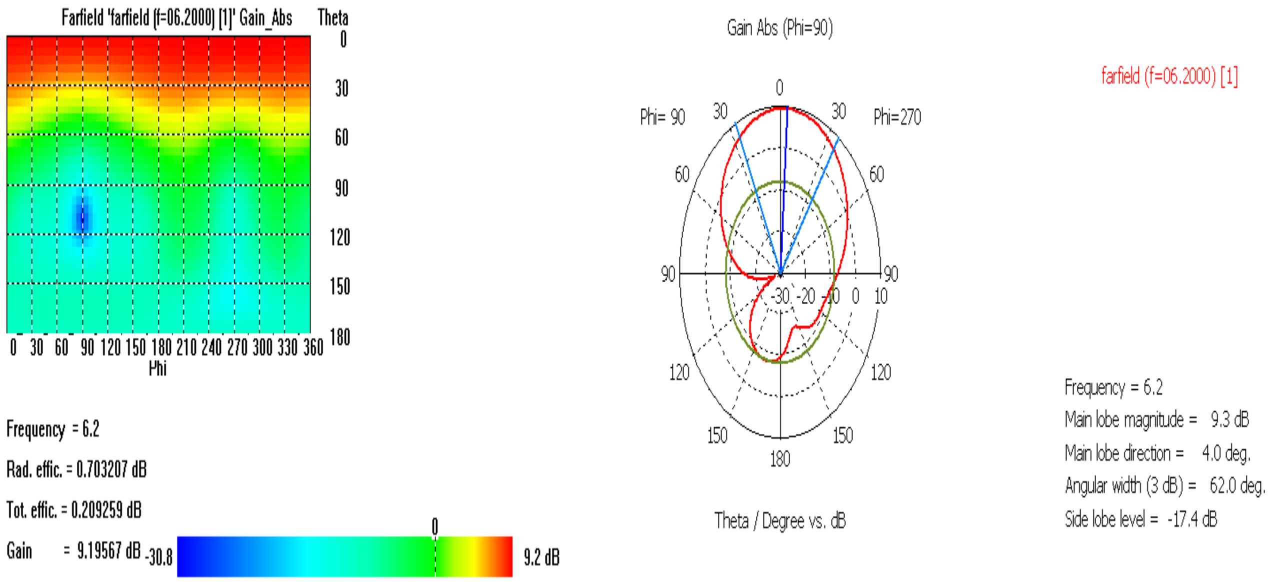

Figure 3.5: (a) 2D Gain Plot at 6.3 GHz (b) Polar plot of Gain at 6.3 GHz

3.2.3 Directivity:

The Directivity plot as shown in figure 3.6 represents amount of radiation intensity i.e. is equal to 8.567 dBi. The antenna radiates more in a particular direction as shown in polar plot, as compared to the isotropic antenna which radiates equally in all directions, by an amount of 8.567 dBi.

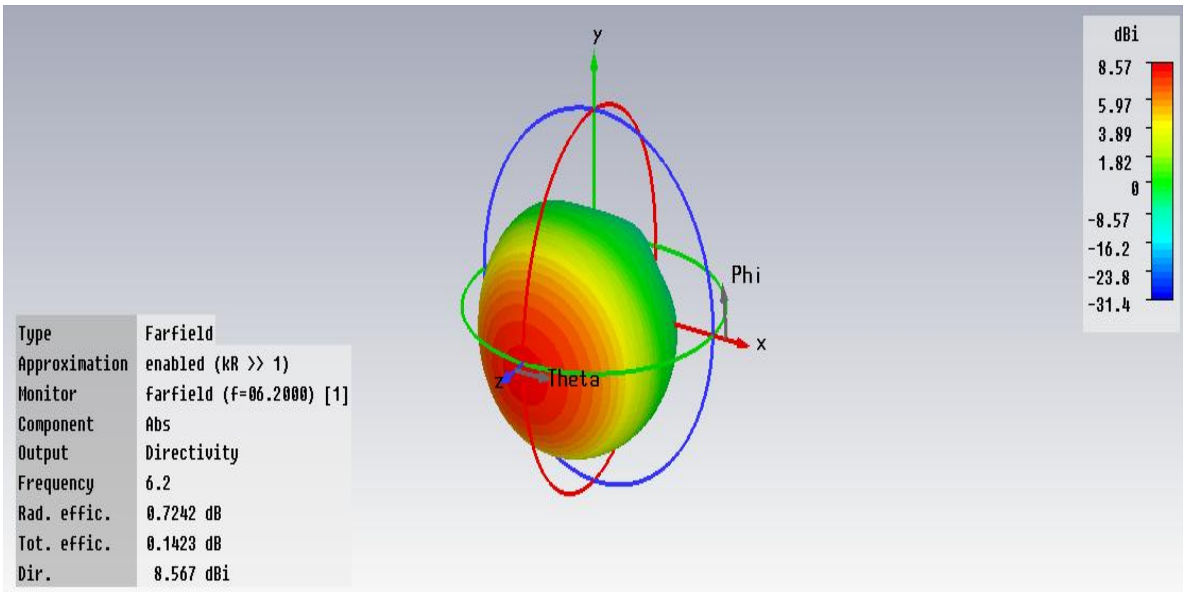

Figure 3.6: **3D Directivity Plot at 6.2 GHz**

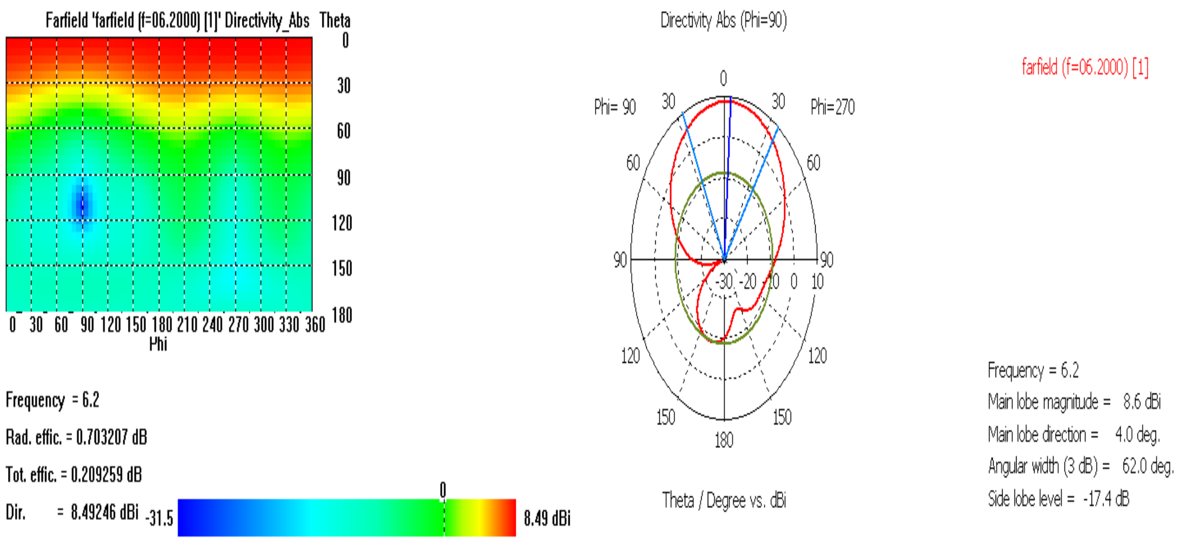

Figure 3.7: **(a) 2D Directivity Plot at 6.2 GHz (b) Radiation Pattern at 6.2 GHz**

3.2.4 VSWR:

The VSWR (voltage standing wave ratio) plot for the design antenna (Microstrip feed) at 5.5, 6.3 and 6.8 GHz are shown in Figure 3.8 (a), (b) and (c) respectively. The value of VSWR is 1.53 at 5.4 GHz, 1.061 at resonating frequency 6.3 GHz and 1.3 at 6.8 GHz. A VSWR of 1:1 means that there is no power being reflected back to the source. At a VSWR of 2.0, approximately 10% of the power is reflected back to the source. Not only does a high VSWR mean that power is being wasted, the reflected power can cause problems such as heating cables or causing amplifiers to fold-back.

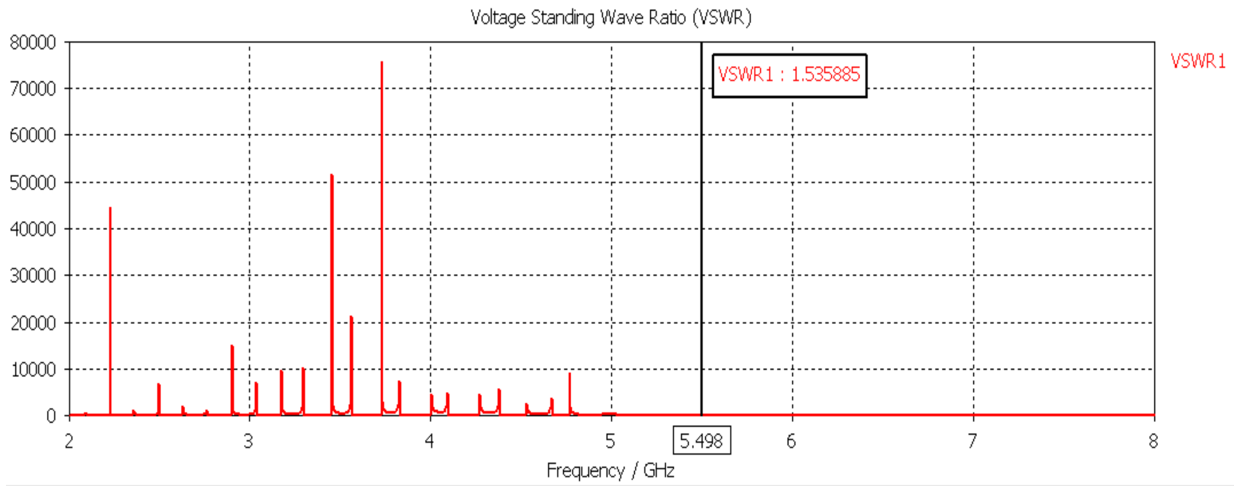

Fig. 3.8(a): VSWR plot at 5.4 GHz

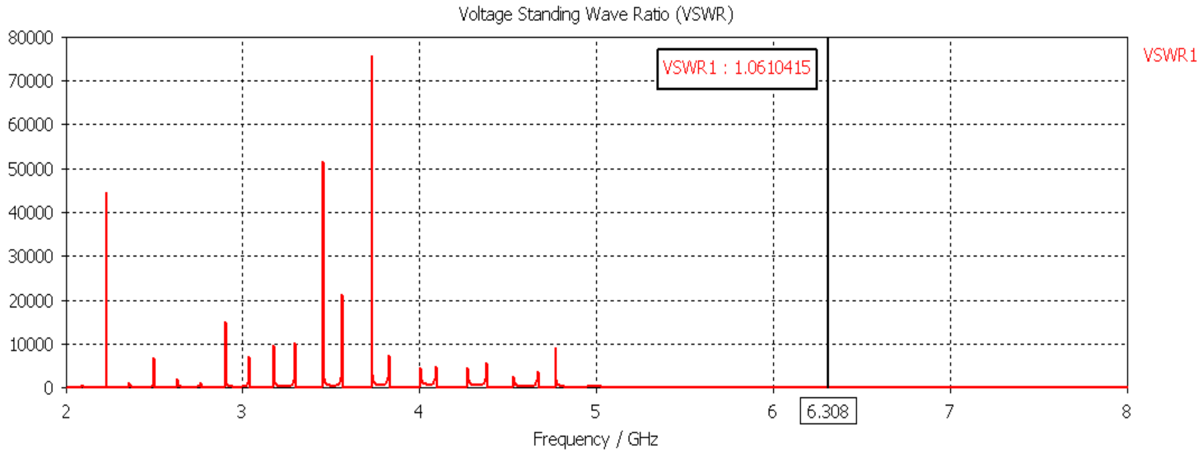

Fig. 3.8(b): VSWR plot at 6.3 GHz

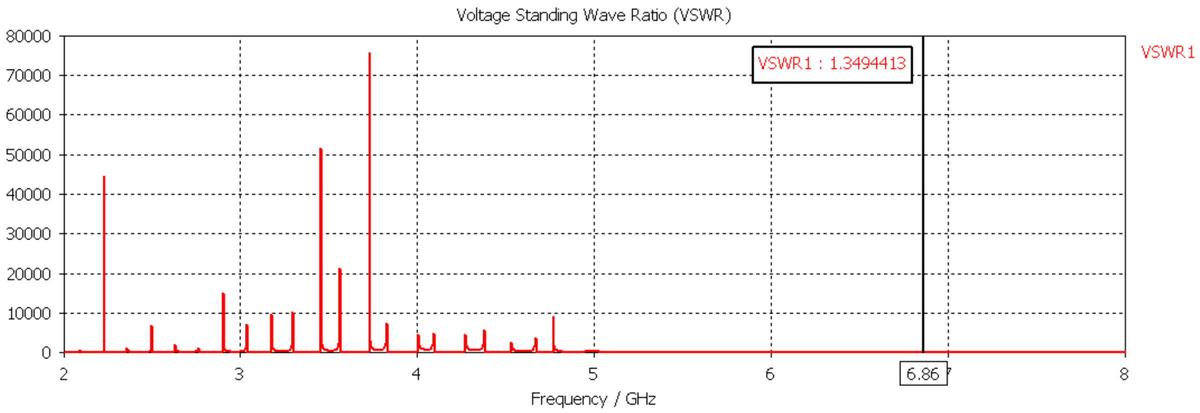

Fig. 3.8(c): VSWR plot at 6.8 GHz

3.2.5 Current Distribution

The current should be maximum at the centre of the patch and minimum at the edges, which has been obtained in this design. The current distribution of the proposed design is shown in Fig. 3.9. The current distribution basically represents the current intensity around the periphery of different parts of antenna.

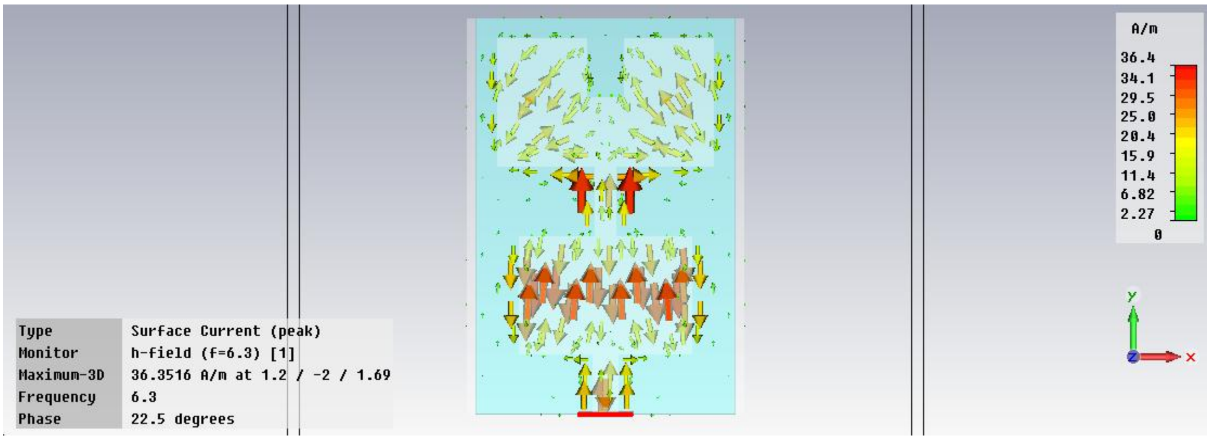

Figure 3.9 Current Distribution

As seen from Figure 3.9, the main current distribution represented by red arrows is dense at the lower patch of the proposed antenna as compared to the upper patch.

3.3 ANTENNA OPTIMIZATION

In this section, the effect of the various physical parameters like patch length, patch Width, antenna and feed substrates, feed line dimensions etc are studied, 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 varying Stub Length

Feed line should be chosen in such a way so that there is a good impedance match between the generator impedance and the input impedance of the patch element. For maximum coupling, it should be placed perpendicular to the slot. [16] As from the figure 3.10, it can be seen that as a feed length is increased, the return loss is decreased from -5.5dB to -42dB till 2.3mm and then again increased to -16dB. So for proper matching, the stub length chosen is 2.3mm with return loss of -42dB and Stub length equal to 2.85mm is considered to be optimum for the design of this antenna.

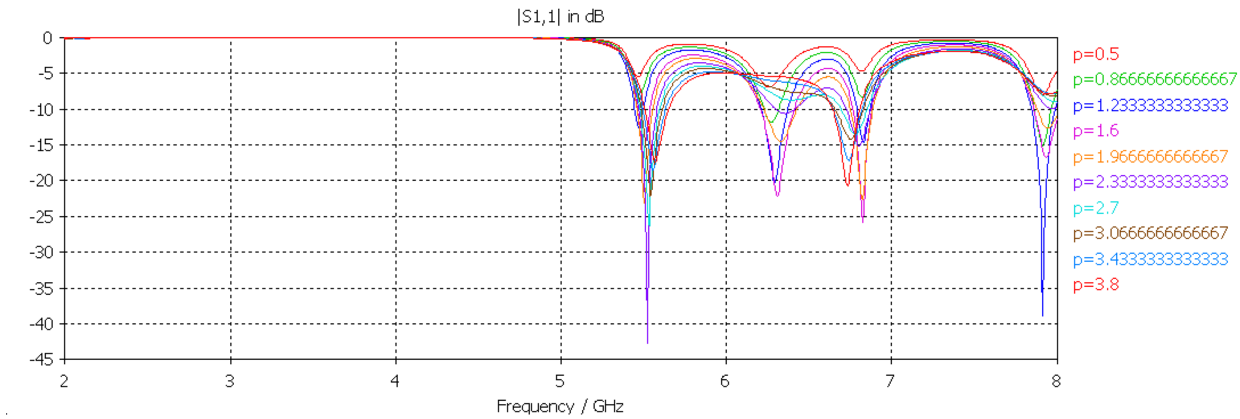

Fig. 3.10 Variations in S11 with stub length

3.3.2 Effect of varying Patch Length

On increasing the length of patch antenna, the resonant frequency moves towards the lower band and on decreasing the patch length the resonant frequency moves towards upper band. Maximum coupling will be obtained when patch is at the centre. The length of lower patch is varied and the return loss decreases as the length of patch is increased upto 9.5 mm and then starts increasing. Thus, the length is taken 9.5 to obtain return loss of -41.5 dB.

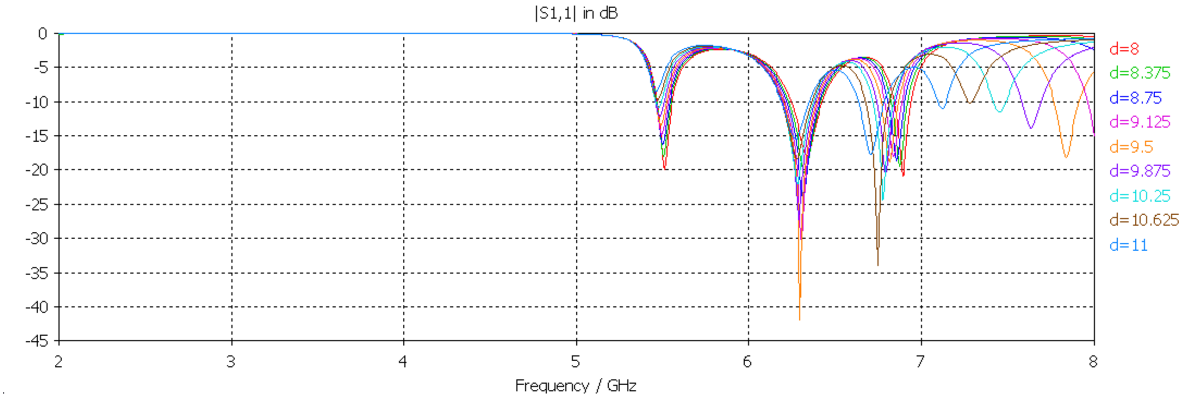

Fig. 3.11 Variations in S11 with length of patch

3.4 CONCLUSION

A simple microstrip patch antenna with microstrip feeding technique has been successfully designed according to design specifications mentioned in Table 3.1, simulated and analyzed. The performance of the antenna meets the desired requirements in terms of return loss and VSWR at the desired operating frequency. The first band has resonant frequency 5.5 GHz and bandwidth is 66 MHz with return loss -12.95. This frequency range is used for Wi-MAX applications. The resonant frequency of second band is 6.3 GHz and bandwidth is 190 MHz with return loss -30.56. The third band has resonant frequency 6.8 GHz and bandwidth is 102 MHz with return loss -16.72. This second and third band is suitable for wireless application of STM link 1 (Synchronous Transport Module level 1).

CHAPTER- 4

DUAL BAND MICROSTRIP PATCH ANTENNA USING DEFECTED GROUNG STRUCTURE (DGS) FOR STM-1 AND CELLULAR MOBILE APPLICATIONS

In this chapter, a microstrip patch antenna with Defected Ground Structure (DGS) and its effect has been discussed. The dual band is achieved in this design and the antenna operates at 4.9 and 7.6GHz. The defected ground structure (DGS) reduces the antenna size and mutual coupling between two antennas. Moreover, it reduces the harmonics of the antenna. The design is simulated on CST Microwave Studio 2010 Software. Finally, the results obtained from the simulation are demonstrated.

4.1. DEFECTED GROUND STRUCTURE

A Defected Ground Structure (DGS) is an etched lattice shape, which locates on the ground plane. Defected ground structure (DGS) is realized by etching defects in the backside metallic ground plane under a microstrip line. A basic and widely used DGS cell is composed of two wide defected areas and a narrow connecting slot such as H shape narrow at middle or U shape with narrow at bottom [44]. The name for this technique simply means that a “defect” has been placed in the ground plane, which is typically considered to be an approximation of an infinite, perfectly-conducting current sink. DGS allows the designer to place a notch (zero in the transfer function) almost anywhere.

DGS is an etched periodic or non-periodic cascaded configuration defect in ground of a planar transmission line (e.g., microstrip, coplanar and conductor backed coplanar wave guide) which disturbs the shield current distribution in the ground plane cause of the defect in the ground. This disturbance will change characteristics of a transmission line such as line capacitance and inductance [45]. In a word, any defect etched in the ground plane of the microstrip can give rise to increasing effective capacitance and inductance.

4.2. DUAL BAND ANTENNA CONCEPT

In principle, multi-band planar antennas should operate with similar features, both in terms of radiation and impedance matching, at two or more separate frequencies. It is known, a simple rectangular Microstrip patch can be regarded as a cavity with magnetic walls on the radiating edges. The first three modes with the same polarization can be indicated by TM10, TM20 and TM30. TM10 is the mode typically used in practical applications; TM20 and TM30 are associated with a frequency approximately twice and triple of that of the mode. This provides the possibility to operate at multiple frequencies.

In this dual-frequency design, the two operating frequencies are associated with the TM10 and TM30 modes of the un-slotted rectangular patch. In addition, this two operating frequencies have the same polarization planes and broadside radiation patterns, with a frequency ratio within the range of 1.6-2.0 for the inset feed case. The above approach characterizes a first category of dual-frequency patch antennas, which will be identified as 1) orthogonal mode dual-frequency patch antenna [46]. This category can be extended to any kind of patch shape that offers two cross-polarized resonant modes. Most of the other dual-frequency patch antennas found in the literature can be subdivided into 2) multi-patch dual frequency antennas, and 3) reactively-loaded dual-frequency patch antennas.

4.3 ANTENNA DESIGN

The dimensions of patch, substrate and ground are calculated using the equations (13) to (19) mentioned in section 1.8.1 of chapter 1.

Dielectric Material	FR4
Dielectric Constant	4.4
Length of Patch (L)	14 mm
Width of Patch (W)	19 mm
Thickness of substrate	1.06 mm
Length of Ground (L_g)	28.6 mm
Width of Ground (W_g)	23.6 mm
Length of Slot 1 in Ground (L_1)	1.5 mm
Width of Slot 1 in Ground (W_1)	13.35 mm
Length of Slot 2 in Ground (L_2)	9.75 mm
Width of Slot 1 in Ground (W_2)	3.6 mm
Length of feed (L_f)	7.3 mm
Width of Feed (W_f)	2 mm

Table 4.1 Dimensions of the designed antenna with microstrip line feed

The front view and back view of the proposed design is given in Fig. 4.1 and 4.2 respectively.

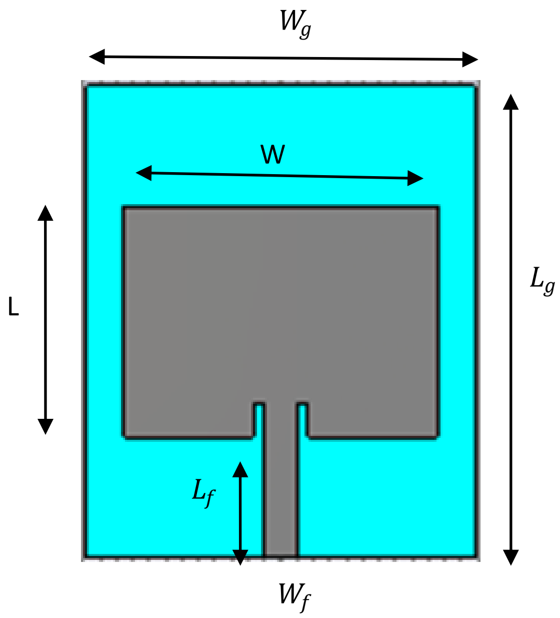

Fig. 4.1 Front View of proposed antenna

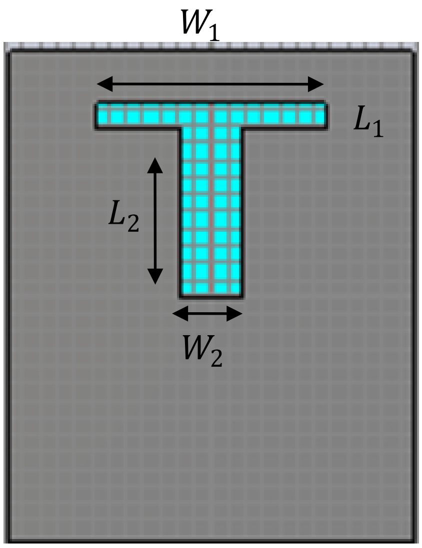

Fig. 4.2 Back View of Proposed Antenna

The designed antenna is simulated using CST MSW 2010 and following results are obtained as follows:

4.3.1. Return loss and BW:

The designed antenna resonates at 4.9 GHz and 7.6 GHz frequencies respectively. The return loss for 4.9 GHz is -12.75 dB and the return loss for 7.6 GHz is -13.01 dB which covers the minimum required value of return loss of -10 dB. The Bandwidth covered under first and second band is 175MHz and 159. 8 MHz respectively. The plot for Return Loss is shown in Fig. 4.3.

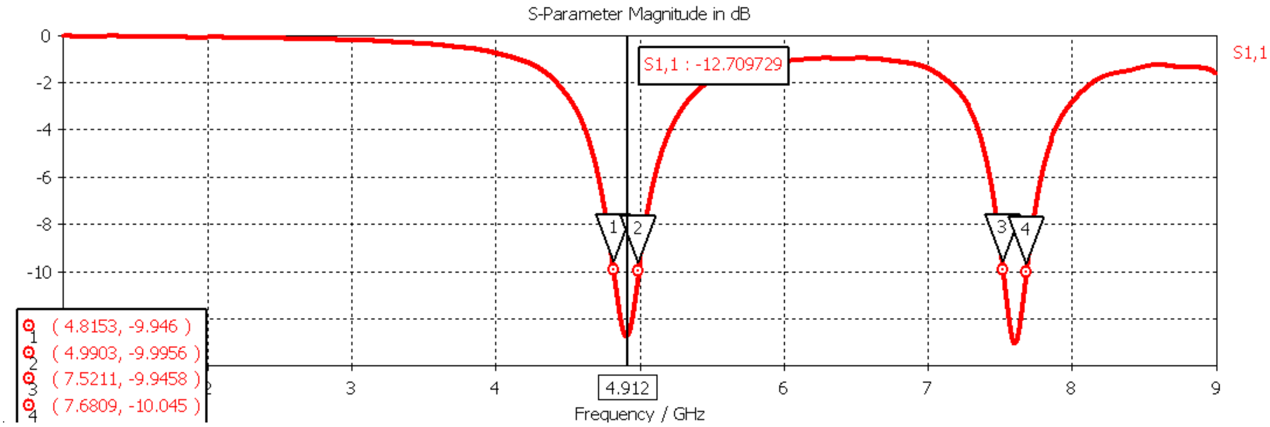

Fig. 4.3 Return Loss [S11] at 4.9GHZ and 7.6 GHz

4.3.2. Smith Chart:

The Smith Chart plot represents that how the antenna impedance varies with frequency. The value of impedance should lie near 50 ohms in order to perfectly match the port with the antenna. The two circles represent the two resonant frequencies i.e. 4.9 GHz and 7.6 GHz.

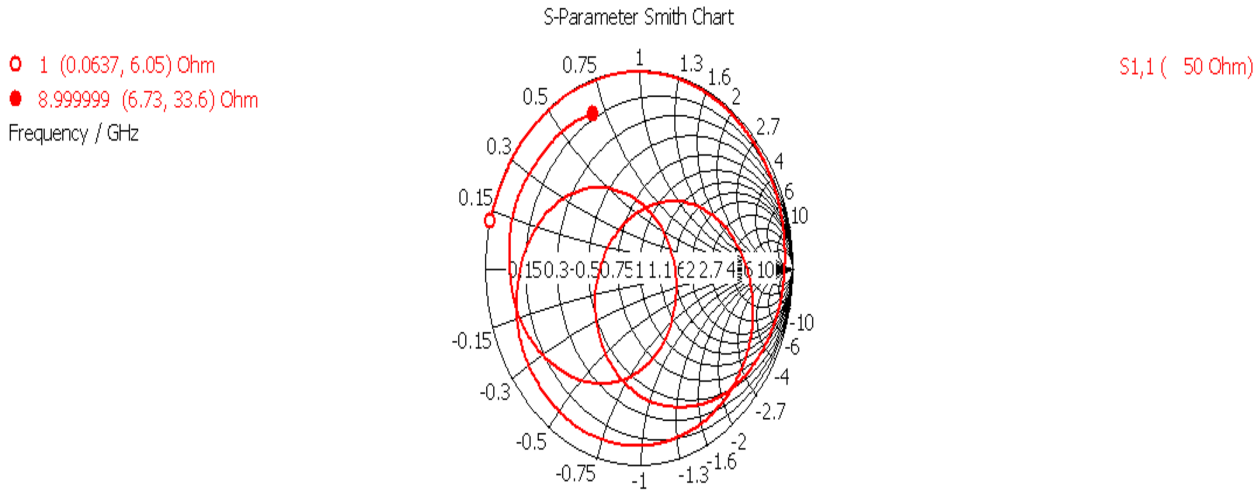

Fig. 4.4 Smith Chart

4.3.3. Gain:

Figure 4.5 shows the 3-D gain plot for the proposed antenna with 4.069 dB gain at 4.9 GHz frequency. The gain of the antenna in a particular direction is more as compared to isotropic antenna radiating in all directions for providing a better performance. The 2D plot and the polar plot or radiation pattern for Gain are also shown in Fig. 4.6 and 4.7. As seen from figure 4.7, main lobe magnitude is 4.1 dB and angular width is 89.9 degrees.

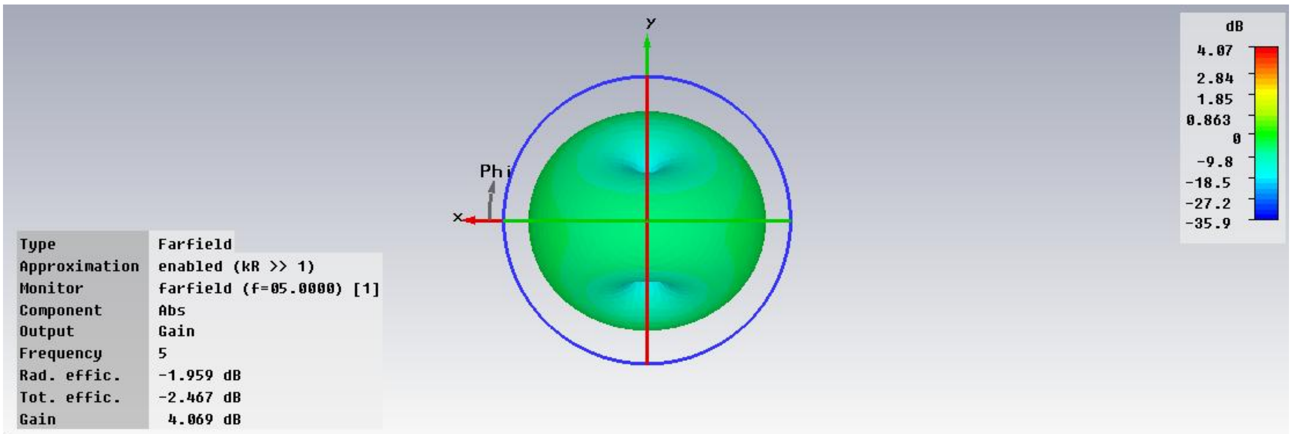

Fig. 4.5. Gain (3-D view) at 4.9 GHz

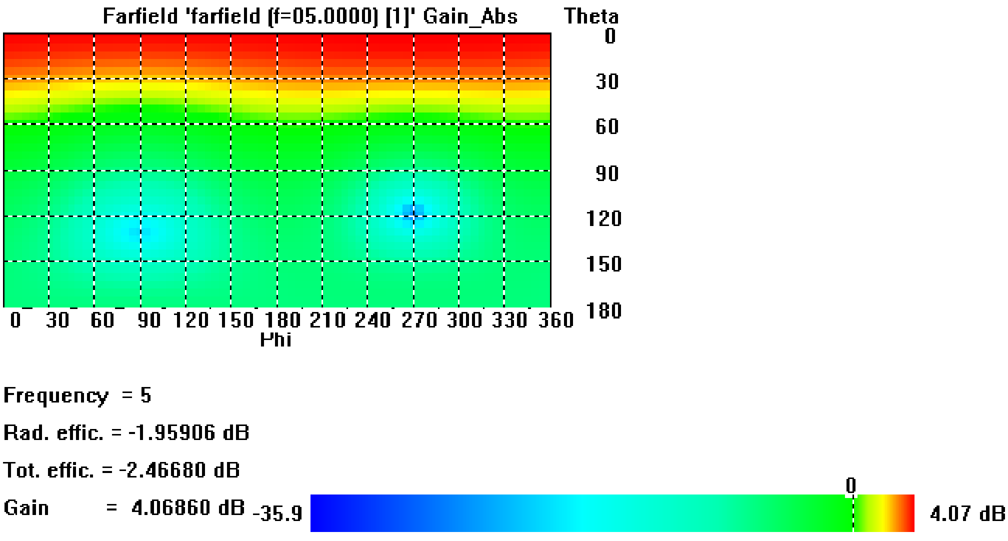

Fig. 4.6. Gain (2-D view) at 4.9 GHz

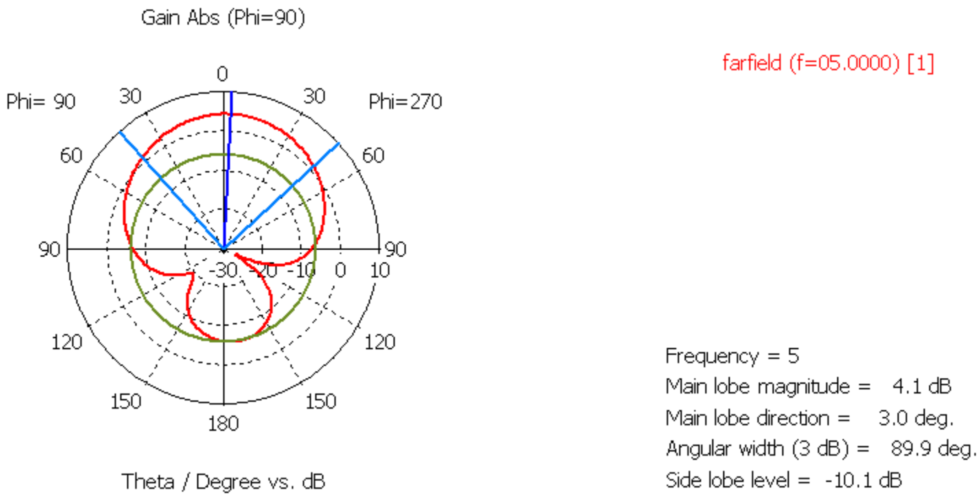

Fig. 4.7. Radiation Pattern of Gain at 4.9 GHz

4.3.4 Directivity:

The Directivity plot as shown in figure 4.8 represents amount of radiation intensity i.e. is equal to 6.028 dBi. The antenna radiates more in a particular direction as shown in polar plot, as compared to the isotropic antenna which radiates equally in all directions, by an amount of 6.028 dBi. The 2D plot and radiation pattern for directivity is given in Fig. 4.9 (a) and (b).

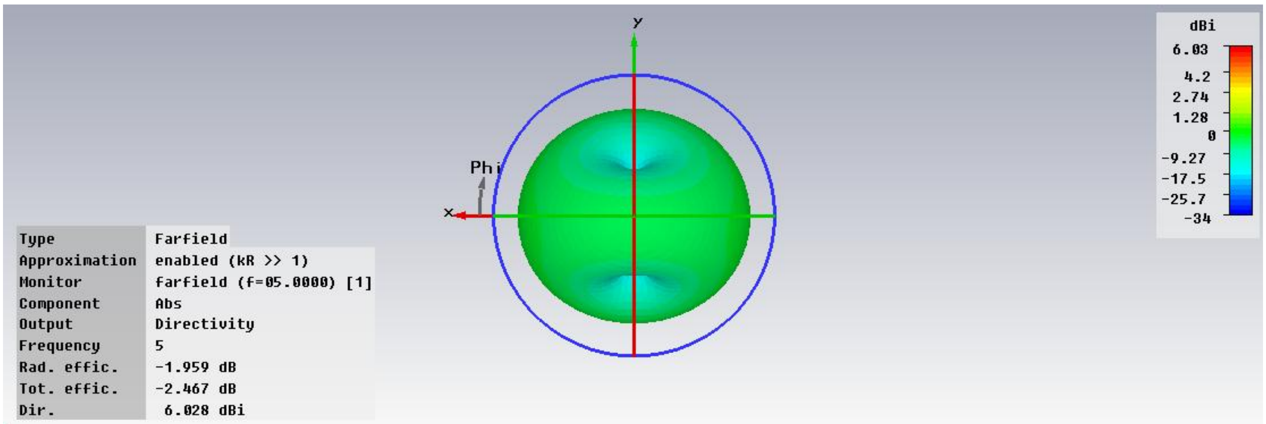

Fig. 4.8. Directivity (3-D view) at 4.9 GHz

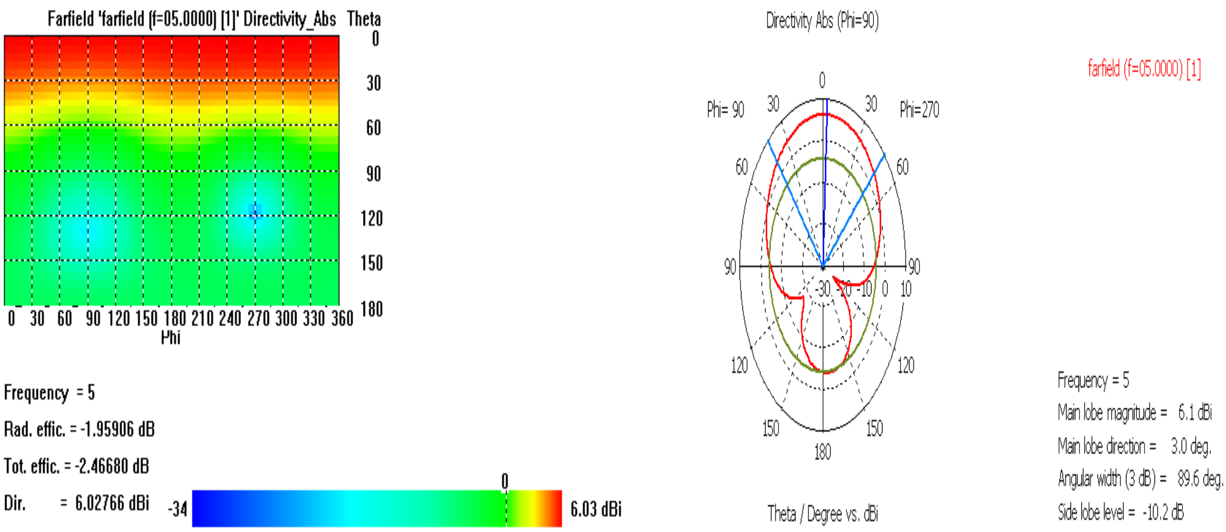

Fig. 4.9. (a) Directivity (2-D view) at 4.9 GHz (b) Radiation Pattern at 4.9 GHz

4.3.5. VSWR:

The VSWR (voltage standing wave ratio) plot for the design antenna (Microstrip feed) is shown in figure 4.10. The value of VSWR is 1.5833 at resonating frequency 4.9 GHz. A VSWR of 1:1 means that there is no power being reflected back to the source. At a VSWR of 2.0, approximately 10% of the power is reflected back to the source. Not only does a high

VSWR mean that power is being wasted, the reflected power can cause problems such as heating cables or causing amplifiers to fold-back. Here VSWR lies in range of 1-2 which is required for the satisfactory performance.

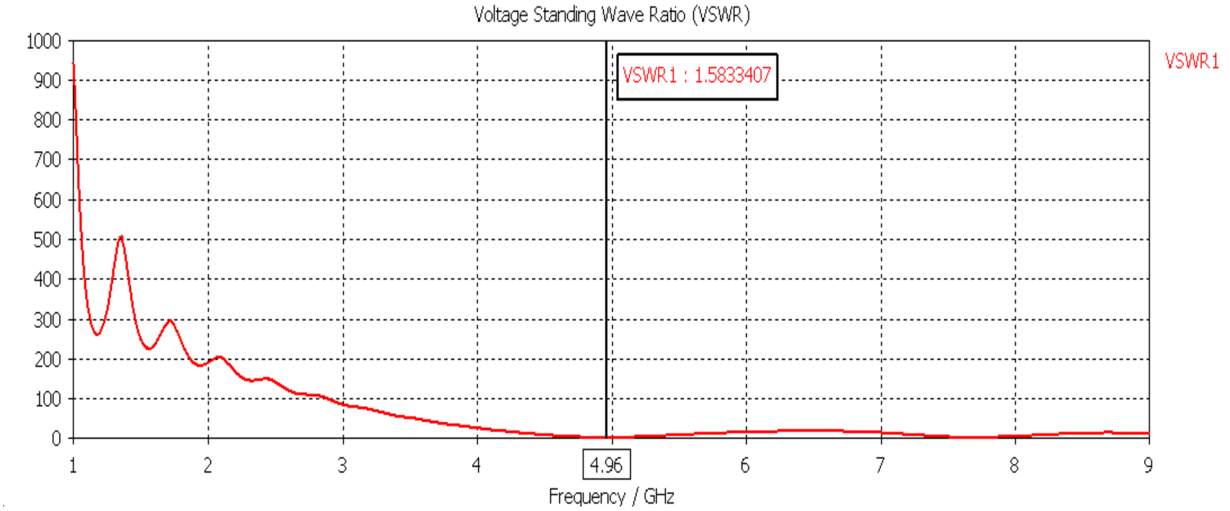

Fig. 4.10.(a) VSWR at 4.9 GHz

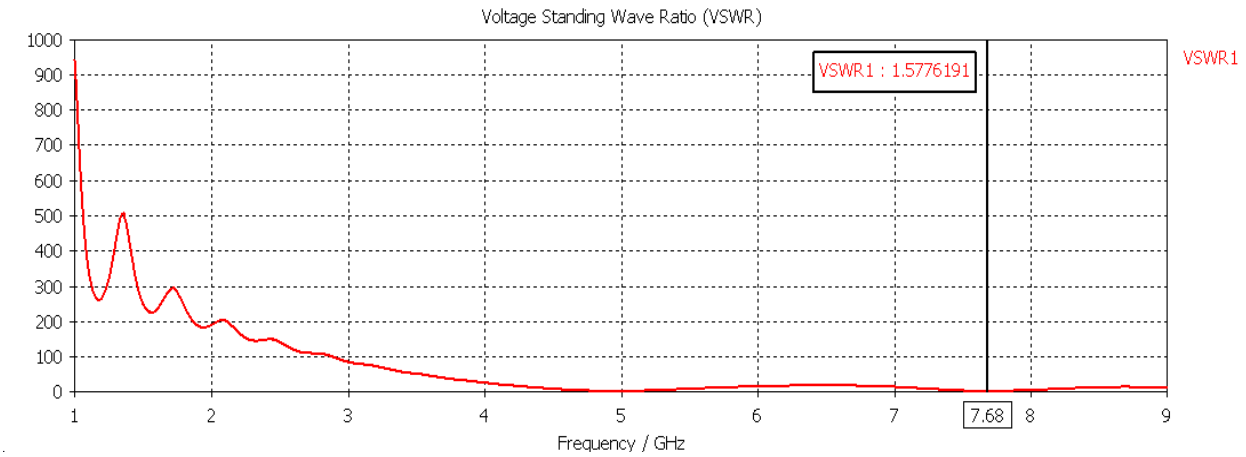

Fig. 4.10.(b). VSWR at 7.6 GHz

4.3.6. Current Distribution

The current should be maximum at the centre of the patch and minimum at the edges, which has been obtained in this design. The current distribution of the proposed design is shown in Fig. 4.11. The current distribution basically represents the current intensity. As seen from Figure 4.11, the current intensity shown by red arrows is maximum towards the periphery of the antenna.

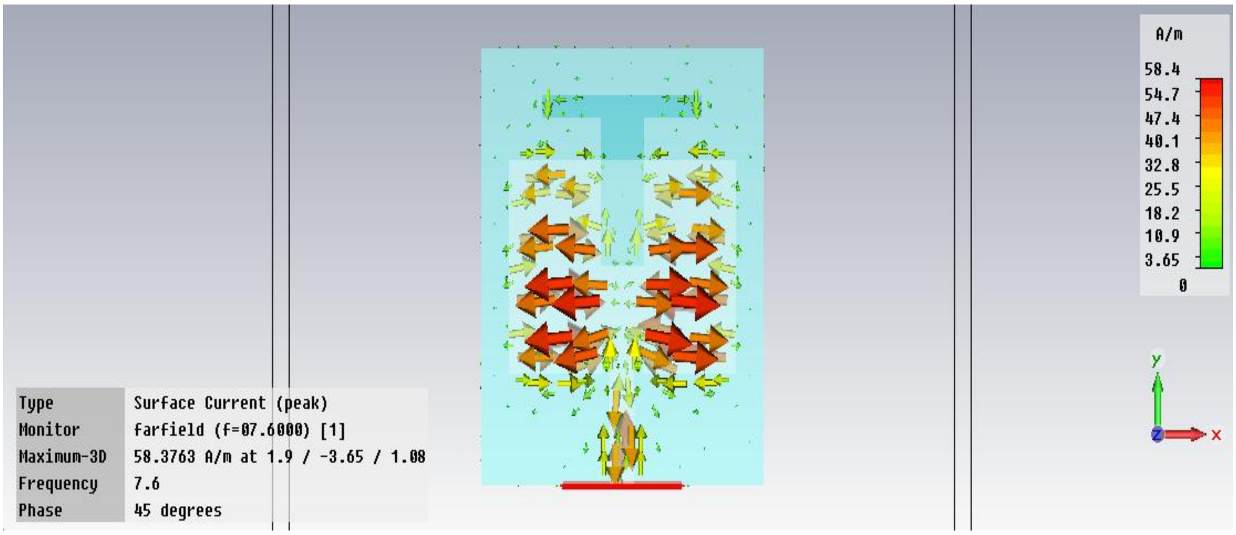

Figure 4.11 Current Distribution

4.4. ANTENNA OPTIMIZATION

The parametric study of proposed antenna is done using CST2010 microwave studio. The effect of changing different slots, slot of ground and study is also done on feed is given below:

4.4.1 Effect of varying Slot Width

The slot length shows the coupling level of the antenna and it also shows the level of back radiation. Therefore, slot should be cut in a proper way so that impedance matching should be maximum. The effect of varying slot length on return loss is as shown below in Fig. 4.12 that the maximum return loss i.e. around -24 dB is obtained at 2.8 mm. Hence this value of width of feed line is considered for the design.

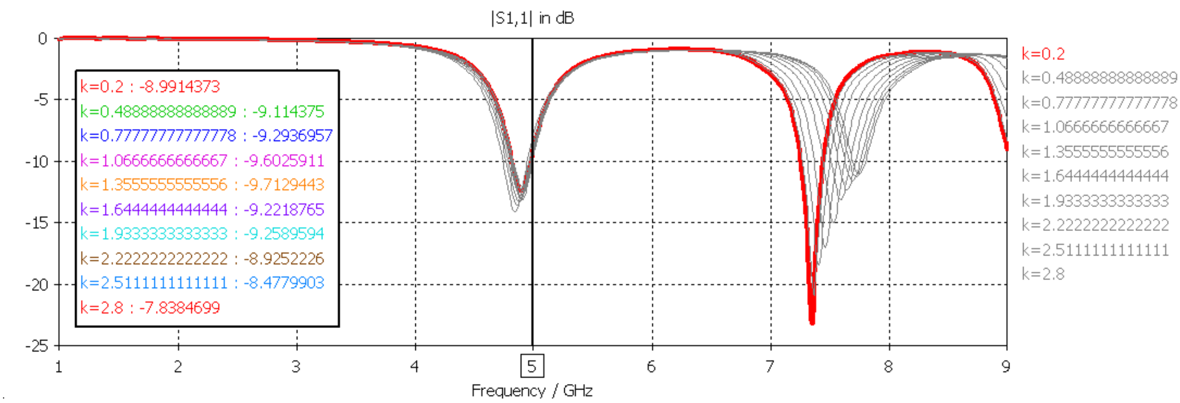

Fig. 4.12 Variations in S11 with slot length in ground plane

4.4.2 Effect of change in feed length (FL):

Feed line should be chosen in such a way so that there is a good impedance match between the generator impedance and the input impedance of the patch element. For maximum coupling, it should be placed perpendicular to the slot [16]. In Figure 4.13, it can be seen that as a feed length is increased, the return loss is decreased from -5.2 dB to -42 dB till 2.7 mm and then again increased to -25 dB. So, for proper matching, stub length equal to 2.3mm is considered for design of this antenna.

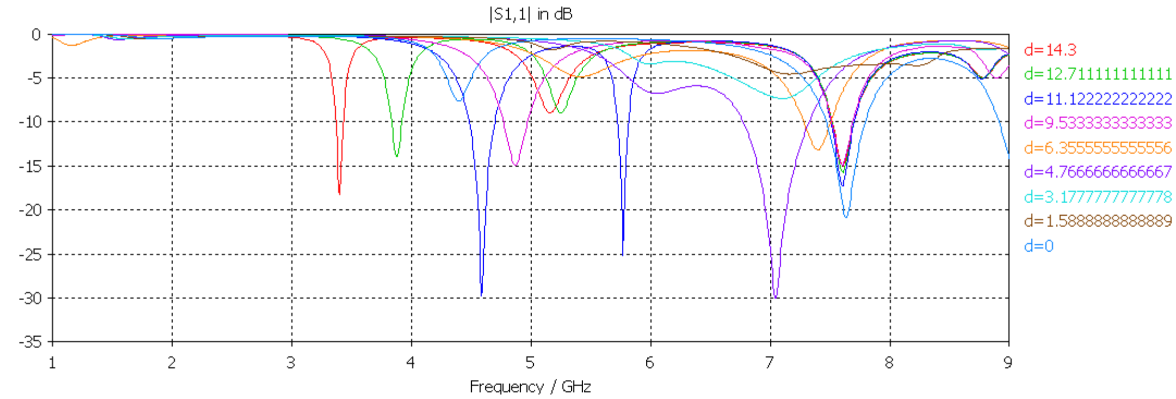

Fig. 4.13 Variations in S_{11} with stub length

4.5 CONCLUSION

A dual band microstrip patch antenna with Defected Ground Structure (DGS) and Microstrip feeding technique has been successfully designed according to design specifications mentioned in Table 4.1, simulated and analyzed. The first band has resonant frequency 4.9 GHz and bandwidth is 175 MHz with return loss -12.75 dB. The resonant frequency of second band is 7.6 GHz and bandwidth is 159.8 MHz with return loss -13.01 dB. The performance of the antenna meets the desired requirements in terms of return loss and VSWR at the desired operating frequency. Hence, this antenna can be used for STM-1 (synchronous transport module level-1) and cellular mobile applications.

CHAPTER 5

A DUAL BAND MICROSTRIP PATCH ANTENNA WITH DEFECTED GROUND STRUCTURE FOR WLAN AND WIMAX APPLICATIONS

5.1 INTRODUCTION

In this chapter, a dual band microstrip antenna using Defected Ground structure is designed and simulated. A dual frequency band is achieved through this design at resonant frequencies 4.3 GHz and 5.9 GHz. The defected ground structure (DGS) reduces the antenna size and mutual coupling between two antennas. Moreover, it reduces the harmonics of the antenna.
The design is simulated on CST Microwave Studio 2010 Software. Finally, the results obtained from the simulation in terms of Return Loss, Gain, Directivity, Smith Chart, VSWR and Current distribution are demonstrated and analyzed.

5.2 ANTENNA DESIGN

The dimensions of ground, patch and substrate of the proposed design are calculated using the equations (13) to (19) mentioned in section 1.8.1 in Chapter 1 and are presented in Table 5.1. The front and back view of the proposed antenna is shown in Fig. 5.1 and 5.2 respectively.

Dielectric Material	FR4
Dielectric Constant	4.4
Length of Patch (L)	19.5 mm
Width of Patch (W)	28 mm
Thickness of substrate	1.57 mm
Length of Ground (L_g)	28.92 mm
Width of Ground (W_g)	30.36 mm
Length of Slot 1 in Ground (L_1)	1 mm
Width of Slot 1 in Ground (W_1)	8 mm
Length of Slot 2 in Ground (L_2)	12 mm
Width of Slot 1 in Ground (W_2)	1 mm
Length of feed (L_f)	4.71 mm
Width of Feed (W_f)	0.4 mm

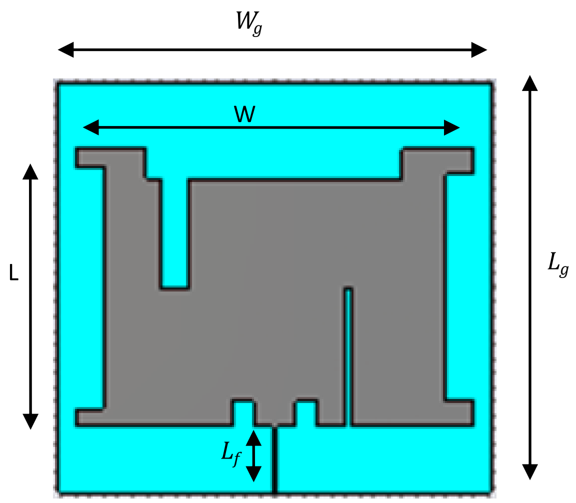

Figure 5.1 Front View of designed antenna at 4.9 and 5.6 GHz

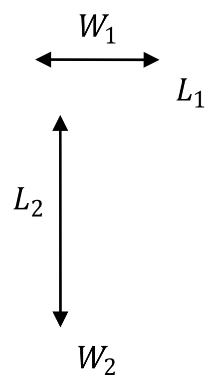

Figure 5.2 Back View of designed antenna at 4.9 and 5.6 GHz

5.2.1. Return loss and BW:

The designed antenna resonates at 4.31 GHz and 5.96 GHz frequencies respectively. The return loss for 4.31 GHz is -20.6 dB and the return loss for 5.96 GHz is -14.46 dB which covers the minimum required value of return loss of -10 dB. These frequency bands find their application in WiMAX and WLAN respectively. The bandwidth covered by first and second band is 56 and 30 MHz respectively. The plot for Return Loss of the proposed design is shown in Fig. 5.2.

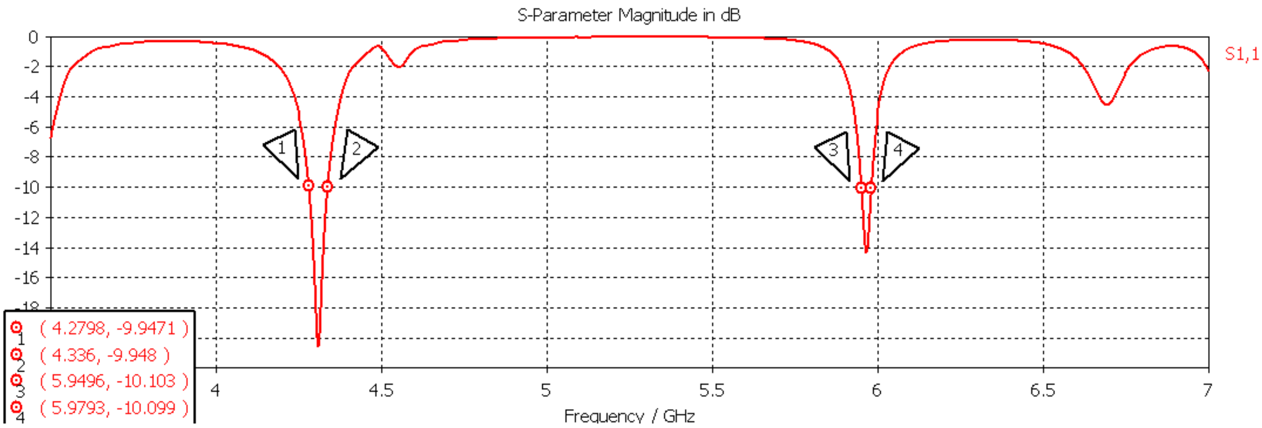

Figure 5.3 Return Loss

5.2.2. Smith Chart:

The Smith Chart plot represents that how the antenna impedance varies with frequency and is shown in Fig. 5.4. The value of impedance should lie near 50 ohms in order to perfectly match the port with the antenna. The circles in the Smith chart represent the resonant frequencies at 4.3 and 5.9 GHz.

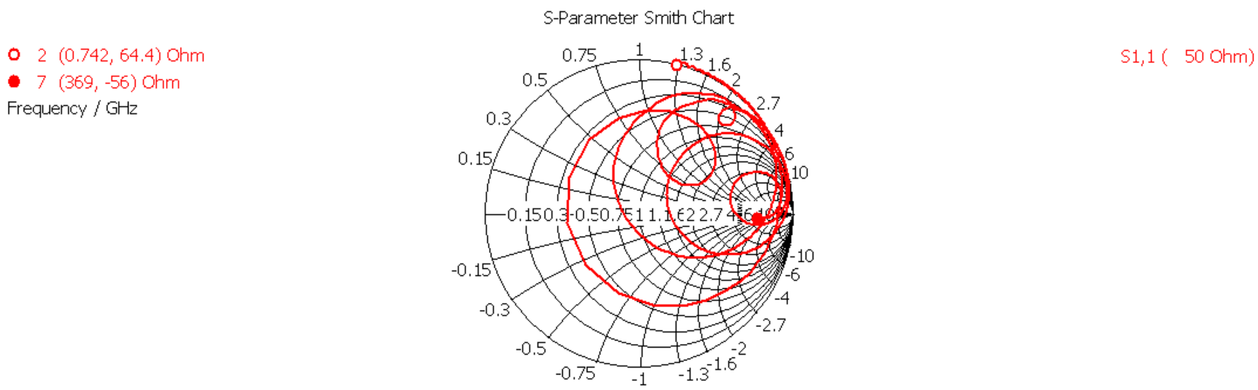

Figure 5.4 Smith Chart

5.2.3. Gain:

Figure 5.5 shows the 3-D gain plot for the proposed antenna with 5.73 dB Gain at 4.3 GHz frequency. The gain of the antenna in a particular direction is more as compared to isotropic antenna radiating in all directions for providing a better performance. The 2D plot and the polar plot or radiation pattern for Gain are also shown in Fig. 5.6 and 5.7. As seen from figure 5.7, the main lobe magnitude is 5.7 dB and angular width is 209.1 degrees.

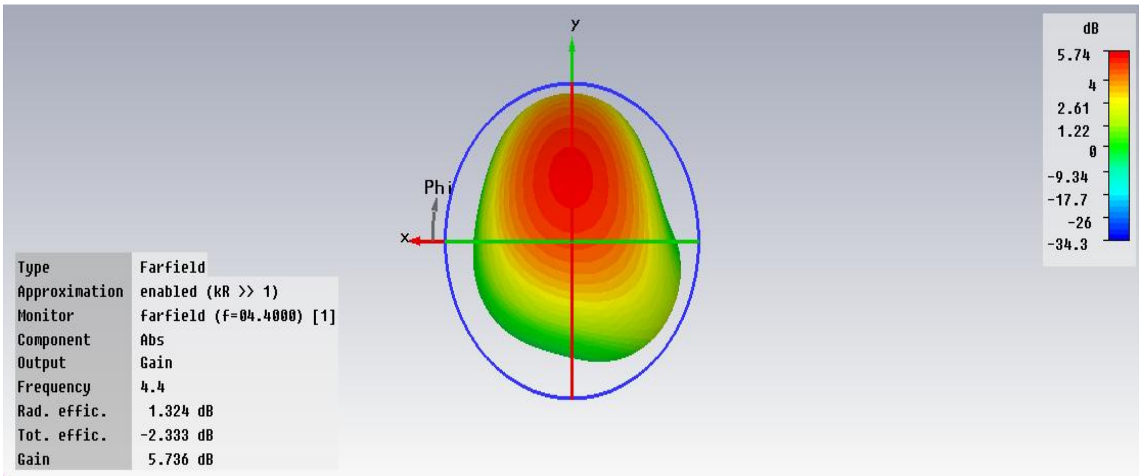

Fig. 5.5. Gain (3-D view) at 4.3 GHz

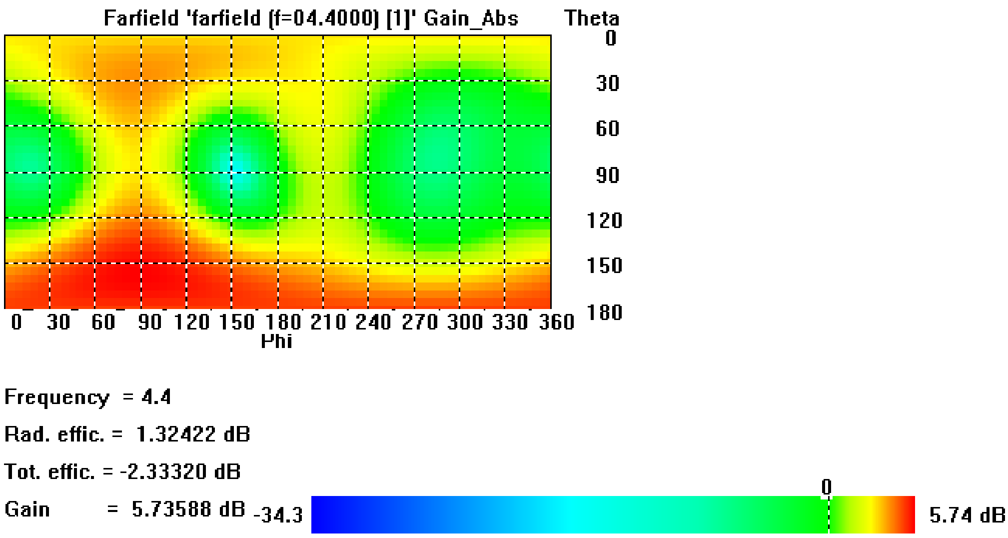

Fig. 5.6. Gain (2-D view) at 4.3 GHz

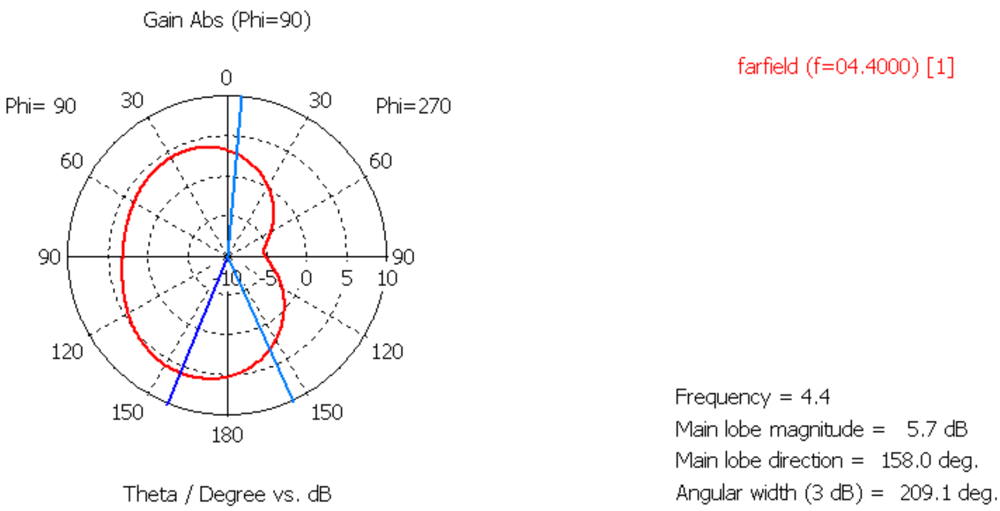

Fig. 5.7. Radiation Pattern of Gain at 4.3 GHz

5.2.4 Directivity:

The Directivity plot as shown in figure 5.8 represents amount of radiation intensity i.e. is equal to 4.412 dBi. The antenna radiates more in a particular direction as shown in polar plot, as compared to the isotropic antenna which radiates equally in all directions, by an amount of 4.412 dBi. The 2D plot for Directivity is given in Fig. 5.9.

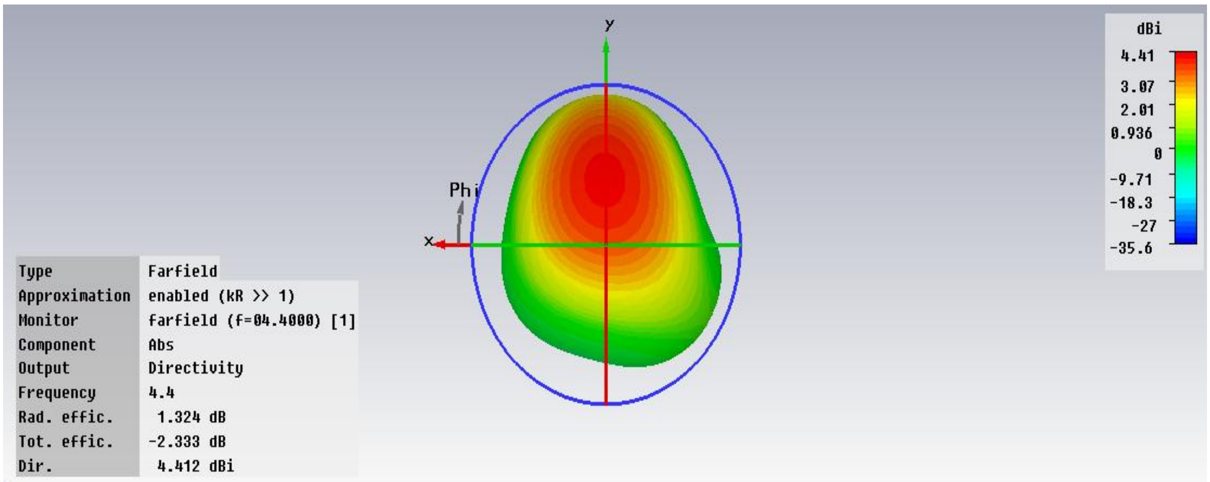

Fig. 5.8. Directivity (3-D view) at 4.3 GHz

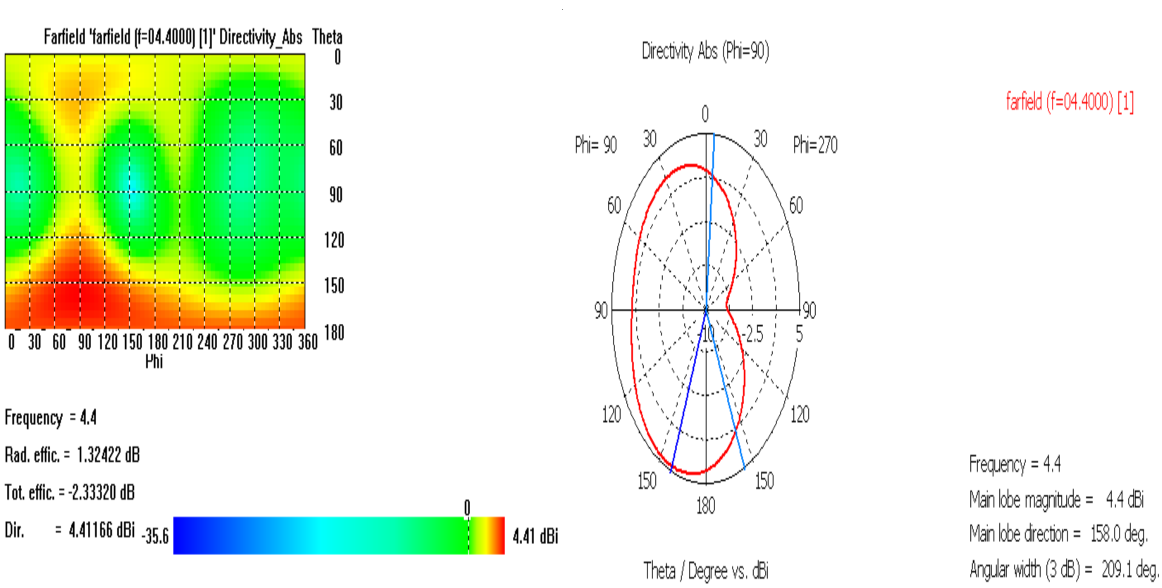

Fig. 5.9. (a) Directivity (2-D view) at 4.3 GHz (b) Polar Plot of Directivity at 4.3 GHz

5.2.5. VSWR:

The VSWR (voltage standing wave ratio) plot for the design antenna (Microstrip feed) at 4.3 and 5.9 GHz is shown in figure 5.10 (a) and (b). The value of VSWR is 1.2 and 1.49 at resonating frequency 4.3 and 5.9 GHz. At a VSWR of 2.0, approximately 10% of the power is reflected back to the source. Here VSWR lies in range of 1-2 which is required for the satisfactory performance.

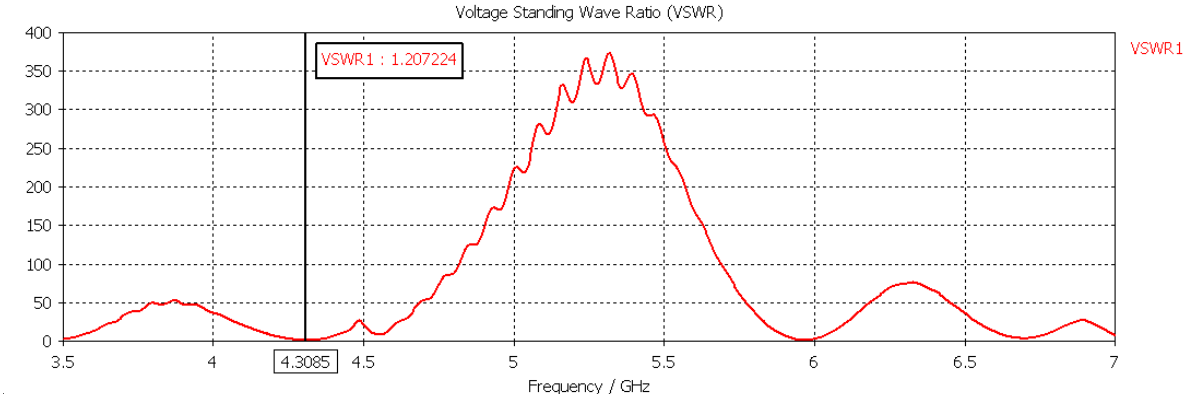

Fig. 5.10(a). VSWR at 4.3 GHz

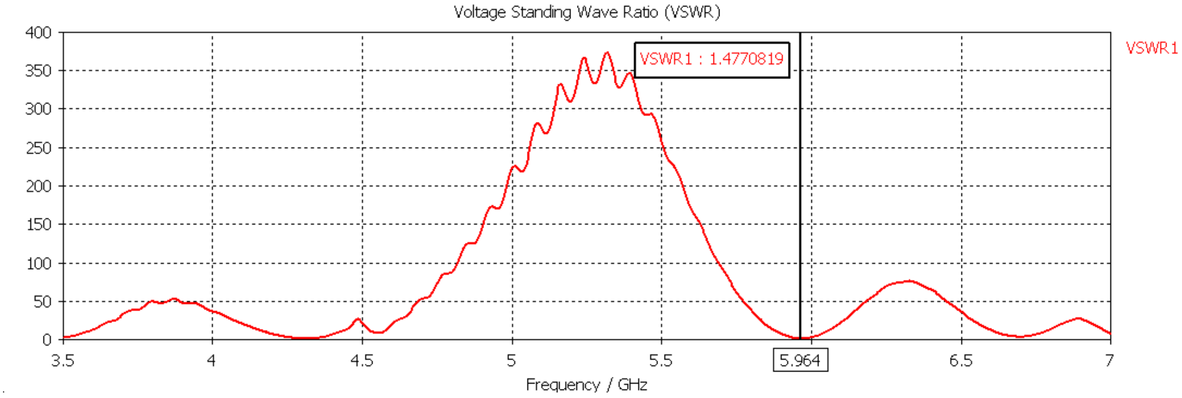

Fig. 5.10 (b). VSWR at 5.9 GHz

5.2.6. Current Distribution

The current should be maximum at the centre of the patch and minimum at the edges, which has been obtained in this design. The current distribution of the proposed design is shown in Fig. 5.11. The current distribution basically represents the current intensity.

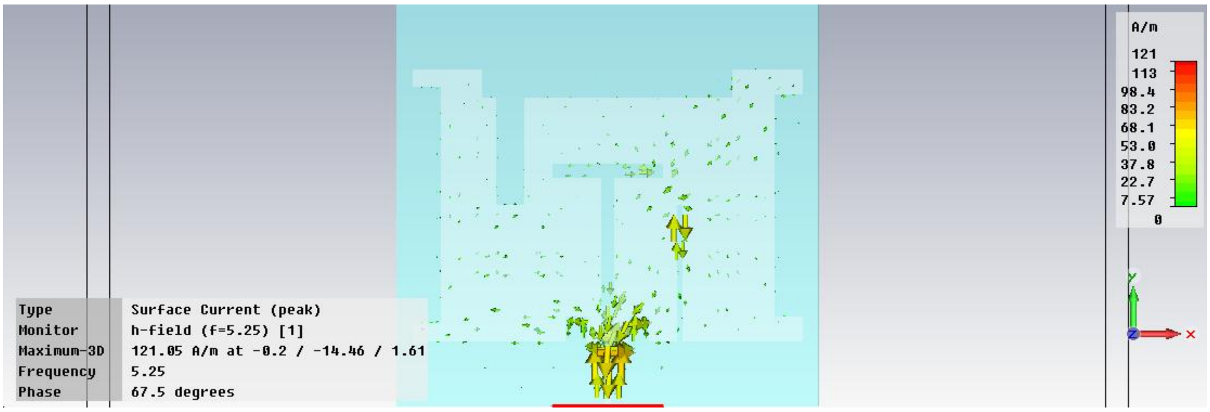

Figure 5.11 Current Distribution

5.3 ANTENNA OPTIMIZATION

In this section, the effect of the various physical parameters like patch length, patch Width, antenna and feed substrates, feed line dimensions etc are studied, 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.

5.3.1 Effect of change in feed length (FL) and width (FW):

Feed line should be chosen in such a way so that there is a good impedance match between the generator impedance and the input impedance of the patch element. For maximum coupling, it should be placed perpendicular to the slot [16]. In Figure 5.12, it can be seen that as a feed length is increased, the return loss is decreased from -5.2 dB to -34 dB till 0.46 mm and then again increased to -25 dB. So, for proper matching, stub length equal to 0.4mm is considered for design of this antenna.

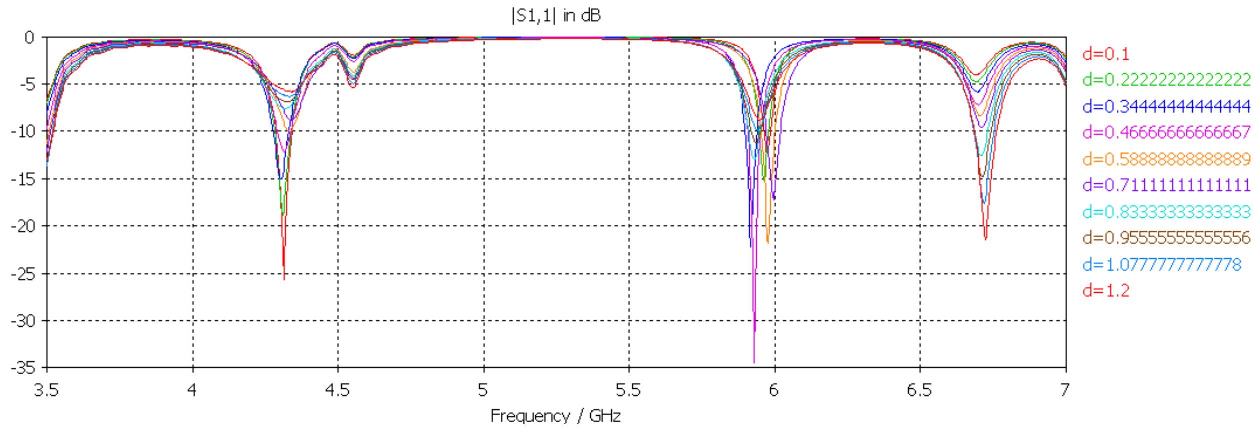

Fig. 5.12 Variations in S_{11} with stub length

5.4 CONCLUSION

A dual band microstrip patch antenna with Defected Ground Structure (DGS) and microstrip feeding technique has been successfully designed according to design specifications mentioned in Table 5.1, simulated on CST Microwave Studio 2010 Software and analyzed. A dual frequency band is achieved through this design at resonant frequencies 4.3 GHz and 5.9 GHz. The return loss for 4.31 GHz is -20.6 dB and the return loss for 5.96 GHz is -14.46 dB which covers the minimum required value of return loss of -10 dB. These frequency bands find their application in Wi-MAX and WLAN respectively. The bandwidth covered by first and second band is 56 and 30 MHz respectively. The defected ground structure (DGS) reduces the antenna size and mutual coupling between two antennas. Moreover, it reduces the harmonics of the antenna. Finally, the results obtained from the simulation in terms of Return Loss, Gain, Directivity, Smith Chart, VSWR and Current distribution are demonstrated. The performance of the antenna meets the desired requirements in terms of all the parameters at the desired operating frequency.

CHAPTER 6

FABRICATION AND TESTING OF TRIPLE BAND ANTENNA AT 5.5, 6.3 AND 6.8 FOR WiMAX AND STM APPLICATIONS

6.1 FABRICATION PROCEDURE

This chapter describes the entire procedure for fabrication of a triple band microstrip patch antenna presented and simulated in chapter 3. The flow chart makes the whole fabrication easily understandable.

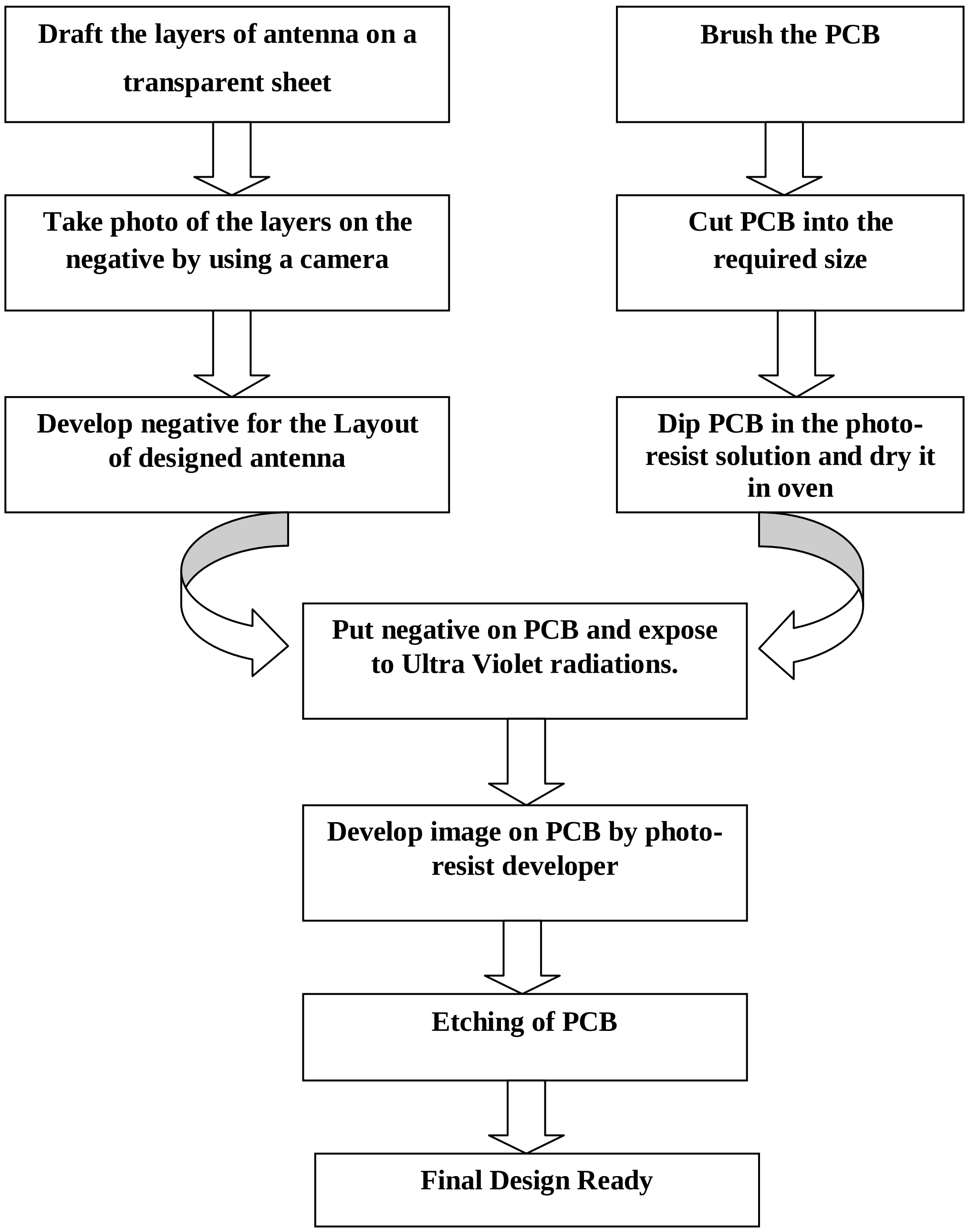

Fig. 6.1 Flow chart of Antenna fabrication process

6.2 FABRICATED ANTENNA DESIGN

The negative of the designed antenna and fabricated design of the microstrip patch antenna is given in the Figure 6.2 and 6.3 respectively.

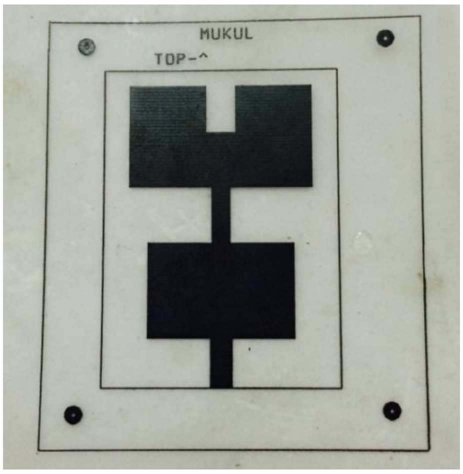

Fig. 6.2 Top view of the designed antenna in negative

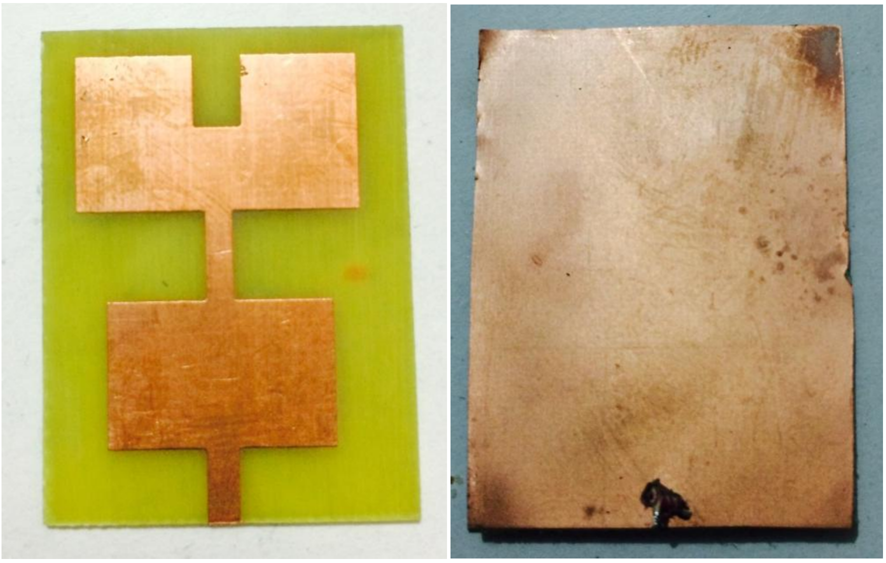

Fig. 6.3 (a) Top view of the fabricated antenna (b) Back view

6.3 SIMULATED RESULTS OF THE DESIGNED ANTENNA

This triple band that is fabricated is designed, simulated and discussed in Chapter 3 of this report. Tri-band was achieved in this design during simulation. The first band has resonant frequency 5.5 GHz and bandwidth is 66 MHz with Return loss -12.95. The resonant frequency of second band is 6.3 GHz and bandwidth is 190 MHz with return loss -30.56. The third band has resonant frequency 6.8 GHz and bandwidth is 102 MHz with return loss -16.72. The simulated results of designed antenna are shown in Fig. 6.4.

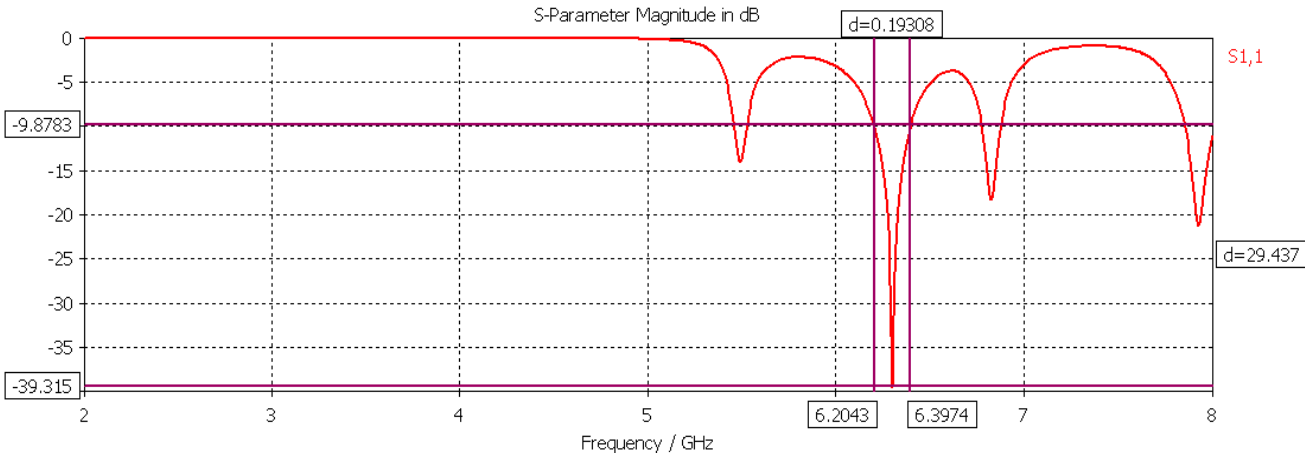

Figure 6.4: **Simulated Return Loss [S11] at 5.5, 6.3 and 6.8 GHz**

6.4 RESULTS OF TESTING ON VNA:

A triple band microstrip patch antenna at resonant frequencies 5.5, 6.3 and 6.8 GHz is designed using CST2010 studio (software). But practically, antenna has been tested using VNA (9 KHz-8.5GHz) shown in Fig. 6.5.

Fig. 6.5 Instrument used for testing

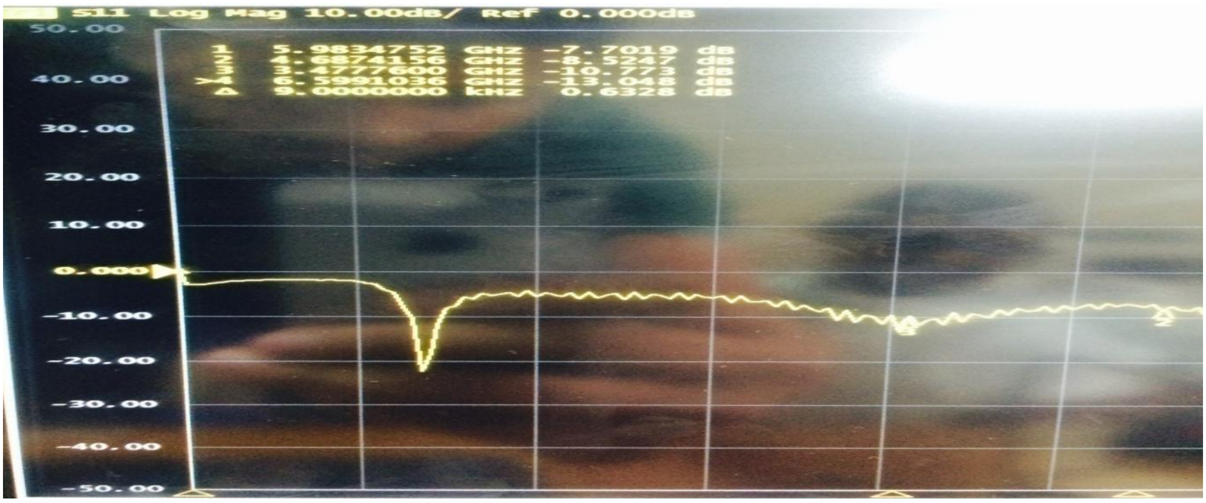

Figure 6.6: **Measured Return Loss [S11] of the fabricated antenna**

By testing results using VNA, it is clear from the snapshot that the antenna resonates at 5.9 GHz frequency as shown in Fig. 6.6. The return loss graphs show that the resonant frequencies have shifted in the magnitude from the designed frequency for triple band antenna and reduce the BW. The root cause of the shift is could be due to the FR-4 board. 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 variation on the return loss, resonant frequency and bandwidth, form the simulation software constraint.

In simulation, the design is ideal and no air gap exists between the patch and the ground plane. Practically, with the use of adhesive to glue the ground plane to the substrate causes the variation and is more visible as the adhesive will affect the effective dielectric constant value and contribute some height to the gap also. One major reason of reduced BW is the connector used to give supply; the available connector is small as compared to port applied for giving supply the antenna.

6.5 COMPARISON OF SIMULATED AND FABRICATED RESULTS

The comparison between simulated and tested results is given below as for triple band antenna referring to the figures 6.4 and 6.6:

Parameters	**Simulated Results**	**Fabricated Results**
Frequencies Covered in wide Triple band antenna	5.5 to 6.8 GHz	4.6 to 6.59 GHz
Return Loss of wide Triple Band antenna	-30.56 dB (at 6.3 GHz)	-21.5(at 6.5 GHz)
Applications covered by Triple Band antenna	Covers a large range of frequencies that supports Wi-MAX and many wireless applications of STM link 1 (Synchronous Transport Module level 1).	Covers the range of frequencies that supports applications of WLAN at 5.2GHZ and also used in military applications covering the bands from 4.6 GHz to 5GHz.

Table 6.1 Comparison between Simulated results and fabricated results

6.6 CONCLUSION

The fabrication and the testing of the triple band antenna are done and it is observed that there occur some shifts in the results of simulated and fabricated antenna. The losses are due to lose soldering connections, due to presence of air or due to lose SMA connector connections. After these small variations in the results due to some reasons, the results are still acceptable.

CHAPTER 7
CONCLUSION AND FUTURE SCOPE

7.1 CONCLUSION

In this report, three configurations of microstrip patch antenna are designed and the physical parameters examined in this study include the substrates and their dielectric constants, feed line and ground plane coupling slot. The antenna parameters like operating frequency, input impedance, VSWR, Bandwidth, Return loss, directivity and gain are analyzed for each antenna performance. Also, the effect of varying the physical parameters is studied in order to optimize the antenna for a specific performance.

- Initially, a triple band Microstrip Patch Antenna with Microstrip feeding technique is successfully designed, simulated and analyzed. The first band has resonant frequency 5.5 GHz and bandwidth is 66 MHz with return loss -12.95. This frequency range is used for Wi-MAX applications. The resonant frequency of second band is 6.3 GHz and bandwidth is 190 MHz with return loss -30.56. The third band has resonant frequency 6.8 GHz and bandwidth is 102 MHz with return loss -16.72. The performance of the antenna meets the desired requirements in terms of return loss and VSWR at the desired operating frequency. This design has been fabricated and the simulated and measured results are compared. The second and third band is suitable for wireless application of STM link 1 (Synchronous Transport Module level 1) with Gain 9.291 dBi.
- Secondly, a dual band Microstrip Patch Antenna with Defected Ground Structure (DGS) and Microstrip feeding technique is discussed. The first band has resonant frequency 4.9 GHz and bandwidth is 175 MHz with return loss -12.75 dB. The resonant frequency of second band is 7.6 GHz and bandwidth is 159.8 MHz with return loss -13.01 dB. Then, the different parameters are varied to observe the optimized results for desired operating frequency.
- Finally, a dual band Microstrip Patch Antenna with Defected Ground Structure (DGS) and microstrip feeding technique having application in Wi-MAX and WLAN has been successfully designed, simulated on CST Microwave Studio 2010 Software and analyzed. A dual frequency band is achieved through this design at resonant frequencies 4.3 GHz and 5.9 GHz. The return loss for 4.31 GHz is -20.6 dB and the return loss for 5.96 GHz is -14.46 dB which covers the minimum required value of

return loss of -10 dB. The bandwidth covered by first and second band is 56 and 30 MHz respectively. Parametric analysis is also done to get the improved performance.

- Then the Triple band antenna designed in Chapter 3 is fabricated and the results are compared with the simulated results. There is variation in the results but it is acceptable.

The results of different parameters of all the designed antennas are summarized in the table 7.1.

Designs	**Resonant frequency (GHz)**	**Return Loss (dB)**	**Bandwidth (MHz)**	**Gain (dBi)**	**Directivity (dBi)**	**VSWR**	**Feeding Techniques**	**DGS**
Design 1	5.5	-12.95	66	8.78	8.027	1.49	Microstrip feeding	Not Used
	6.3	-30.56	190	9.291	8.567	1.06		
	6.8	-16.72	102	6.17	5.557	1.27		
Design 2	4.9	-12.75	175	4.069	6.028	1.58	In-set feeding	Used
	7.6	-13.01	159.8	1.27	4.47	1.57		
Design 3	4.3	-20.6	56	5.73	4.41	1.2	Microstrip feeding	Used
	5.9	-14.46	30	7.112	6.071	1.47		

Table 7.1: Parametric values of all the antenna designs

Based on the results shown in the table 7.1, the best results are obtained when the antenna is designed using DGS (Defected Ground Structure). The values of all the parameters of the proposed antennas meet the desired requirements in terms of return loss, Gain, Directivity and VSWR at the desired operating frequencies.

7.2 FUTURE SCOPE

The designed antennas in this thesis report are used in various applications like WLAN, Wi-MAX, microwave applications, USB dongles, satellite communications, STM link 1 etc.

The work on microstrip antenna design can be extended to:

- **Cognitive Radios:** The Microstrip antennas can be easily integrated into cognitive radio; when the antenna is operating in the UWB mode, it can sense the whole spectrum to find the spectrum holes and then from sensing information it will decide to switch to work in one of the available predefined bands (e.g., Band I or II). Usually sensing places severe requirements on sensitivity, linearity, and dynamic range of the cognitive radio RF front end. This is because the RF signal presented at the antenna of a cognitive radio includes signals from close or separated transmitters and from transmitters operating at different power levels.

- **Different geometries and perturbations:** Various geometries and perturbations can be used to introduce multiple resonances as well as input impedance matching. A novel design of broad band stacked patch antenna has been proposed very recently by Ooi *et al.* [45] where they have used stacked patch with shaped slots and used probe compensation by metallic washer on the probe. They have obtained 44.9 % impedance bandwidth. Another new technique of impedance matching by capacitive loading of inverted microstrip has been recently proposed.
- **Genetic Algorithm (GA) based optimization:** Optimization of patch geometry is an ideal technique to have single or more optimized figures of merit like, impedance bandwidth. The optimized shape however is too much irregular and unconventional and as such this can only be fabricated using the pattern produced in true scale by the GA code.
- **Photonic Band Gap (PBG):** Photonic Band Gap (PBG) structures can be used as printed antenna substrates. The PBG structure is basically a periodic metallic pattern printed on dielectric substrate for microwave and millimeter wave applications and this provides a stop band of electromagnetic waves propagating through it. The frequency range of the stop band depends on the pattern geometry and its dimensions. If the antenna operating frequency falls within this stop band, it is attenuated during propagating through the substrate. Thus the generation and propagation of surface wave is stopped.
- **Frequency Selective Surfaces (FSS):** Frequency Selective Surfaces (FSS) can be used as multilayered substrate or ground Plane. The FSS is also created by printing periodic patterns on microwave substrates to simulate equivalent Land C to an electromagnetic wave and thus its basic characteristic is to scatter or reflect certain frequencies of electromagnetic waves incident on it.

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[1]. Mukul Bhardwaj, Amanpreet Kaur, “A Tri-band Microstrip Patch Antenna for Wireless Applications at 5.5, 6.3 and 6.8 GHz”, International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, vol. 3, issue 6, pp. 9834-9841, 2014.

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