STACKED MICROSTRIP PATCH ANTENNA WITH DEFECTED GROUND STRUCTURES FOR WLAN AND WIMAX APPLICATIONS

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Submitted By

Yoshita Gupta

Roll No. 801261031

Under guidance of

Mrs. Amanpreet Kaur

Assistant Professor, ECED

T.U., Patiala

Department of Electronics and Communication Engineering

THAPAR UNIVERSITY, PATIALA

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CERTIFICATE

I hereby declare that the work which is being presented in the thesis entitled, **"STACKED MICROSTRIP PATCH ANTENNA WITH DEFECTED GROUND STRUCTURES FOR WLAN AND WIMAX APPLICATIONS"** in partial fulfilment of the requirement for the award of degree of M.E in Electronics and Communication 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 Mrs. Amanpreet Kaur, Assistant Professor, ECED.

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

Yoshita Gupta

Date: 27/6/2014

(YOSHITA GUPTA)

ROLL NO: 801261031

It is certified that the above statement made by the student is correct to the best of my knowledge and belief.

Amanpreet Kaur

(Mrs. Amanpreet Kaur)

Assistant Professor

ECED, Thapar University

Countersigned By:-

Dr. Sanjay Sharma

Professor & Head

ECED, Thapar University

Patiala, 147004

Dr. S.K. Mahopatra

Dean of Academic Affairs

Thapar University

Patiala, 147004

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(Yoshita Gupta)

Yoshita Gupta

ABSTRACT

During the last few years wireless technology has gained so much importance and has been rapidly and widely developed in the modern world. For further development in future the aim of the communication devices is to provide speech, image and data communications anywhere and anytime all over the world. This shows that for communication purpose in future the antennas must be able to cover all the possible frequency bands. For this it should meet the requirements of wideband or multi-band. With the increase in number of frequency bands the design of antennas become more difficult. For miniaturisation in wireless technology the size of the antenna should be so small that it can be easily placed in the system. For the transmission and reception of more information there is requirement of large bandwidth. Therefore researchers are working to improve the bandwidth of the antenna. The presented work includes the simulation of aperture coupled microstrip patch antenna using transmission line model. The effect of various antenna parameters is studied such as length (L), width (W) and effective dielectric constant of the material. The effect of using stacked antennas is also studied. The substrates with lower dielectric constant are preferred over substrates having high dielectric constant because the lower dielectric constant substrates give more bandwidth which is the main necessity. The patch is placed on the substrate layer and has different shapes like rectangular and circular etc. but rectangular shape is generally preferred. The antenna length is nearly half of the wavelength in dielectric and it gives the resonant frequency of the antenna. For the designing procedure, the selection of the length and width of the patch and the dimensions of feedline are the major parameters. Therefore, in the following thesis the design of simple aperture coupled microstrip antenna operating at 5.8 GHz having bandwidth 340 MHz for WLAN application is discussed and simulated using CST (Computer Simulation Technology) Microwave Studio 2010. The parametric study of antenna is done and the physical parameters are examined such as stub length and slot in the ground plane. Also comparison of a stacked patch aperture coupled microstrip antenna and single layered aperture coupled microstrip antenna resonating at 5.8GHz providing 80% bandwidth enhancement is discussed. A dual band aperture coupled microstrp stacked patch antenna with DGS covering the WLAN and WiMAX bands is simulated and then fabricated in this thesis. Various parameters like return loss, Gain, Directivity, VSWR, Bandwidth, input impedance and

operating frequency are discussed. The dual band antenna is fabricated and it has been tested using VNA. The results of testing are compared with results of fabricated antenna. In future tests can be carried out to implement the designed antenna in practical scenario.

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ABBREVIATIONS

CST	Computer Simulation Technology
CDMA	Code Division Multiple Access
FDMA	Frequency Division Multiple Access
GSM	Global System for Mobile Communications
IMT	International Mobile Telecommunications
LOS	Line of Sight
LTE	Long Term Evolution
MPA	Microstrip Patch Antenna
NLOS	Non Line of Sight
OFDM	Orthogonal frequency Division Multiplexing
RMPA	Rectangular Microstrip Patch Antenna
TDMA	Time Division multiple Access
VNA	Vector Network Analyser
WIMAX	Worldwide Interoperability Microwave Access
WLAN	Wireless Local Area Network

CHAPTER 1

1. INTRODUCTION

1.1 Overview of Wireless Communication

Communication is basically the transfer of information from one system to another through some channel which may be wired or wireless. Nowadays for long distance communication, electromagnetic spectrum is used. The electromagnetic spectrum is a natural resource and this resource is fully utilised by antenna systems. In the communication industry, wireless communication is growing very rapidly. From the last few years cellular systems have grown exponentially and there are billions of users all over the world. The cellular systems have become a major business tool in the world and an important part of our daily life in almost all the leading countries [1]. Cellular systems employ wireless communication. Wireless communication is that in which there is no direct connection between two or more points and still there is transfer of information between them. The name "Wireless" is basically used for referring a radio transmitter and receiver. The term wireless refers to that type of operation in which the wires are not used and whole system will be without wires [2].

1.2 Wireless Communication System

Wireless technology is near about reaching the Fourth generation (4G). It has covered many evolutionary paths and has improved performance and efficiency in mobile environment. With every generation the wireless technology has improved its performance. In the first generation (1G) has fulfilled the target of basic mobile voice and in the second generation the coverage and capacity has been introduced. After these generations, third generation (3G) came into existence which improves the data speed in the broadband which will be further improved in Fourth generation (4G) [2].

1.2.1 First Generation

The First Generation of wireless technology was introduced in 1980. This generation used analog telecommunications standard which were used to transmit voice signals. Analog signals are basically radio signals sent in a wave like form. In this generation frequency division multiple access technology (FDMA) was used and all the users shared the given frequency spectrum within the system [2]. In First generation, the analog wireless network is used which is narrowband and we can have voice calls and can send text messages. All the above services are provided with the help of circuit switching.

1.2.2 Second Generation

The 2G is enhanced version of 1G and it overcomes some limitations of 1G technology. The basic difference is that the first generation use analog signals and second generation use digital signals. In digital modulation voice is converted into digital code and then into analog signals again. In 2G, CDMA or TDMA multiple access technique is used [2]. In this technique each user is given unique code but they use same frequency band at the same time. The first generation has some limitations such as limited capacity, harmful radiations and security protection was also not good. But second generation overcome all these problems. The data transmission rate is 64,000 bits per second in 2G. In both generations voice optimised systems are used and both have limited bandwidth, due to this high speed data services are not possible in both the generations.

1.2.3 Third Generation

Later in the 20th century, third generation of mobile technology came into existence. It was developed to overcome the limitations of 2G. In third generation wideband wireless network is used which increases the clarity of voice and gives the perfection of real conversation. The technology used for sending data is packet switching [2]. The information transfer rate is 2 Mbps per second. Later development of 3G often denoted as 3.5G and 3.75G provides broadband access up to several Mbps for modems used in laptops and smart phones. The operating frequency range of 3G is 2100 MHz and bandwidth is 15-20 MHz. Applications of 3G wireless technology are mobile internet access, multimedia messaging service (MMS), video calling, voice telephony, mobile TV, gaming and fixed wireless internet access.

1.2.4 Fourth Generation

4G is the wireless telecommunication technology which is succeeding the 3G wireless technology. 4G promises a high downloading speed. It is expected to have a data transmission rate of 20,000,000 bit/sec. This is possible with the help of various techniques such as Orthogonal Frequency Division Multiplexing (OFDM), self-adaptive modulation, multiple carriers and so on. The technology used for sending data is packet switching. The capacity of fourth generation wireless technology is much more times greater than 3G technologies and therefore data transmission rate is high as compared to 3G. Two popular candidates of 4G are WIMAX (Worldwide interoperability for Microwave Access) and LTE (Long Term Evolution). WLAN is also very promising technology and provides various data services to the mobile users. In WLAN multiplexing technique used is OFDM. Table below shows the emerging wireless technology and their standards available.

Table 1.1 Different wireless communication applications and their BW

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
		4700-4900	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 WLAN Standards (Wireless Local Area Networks)

Using this wireless distribution method, two or more devices are linked in WLAN. The wireless distribution method is either OFDM radio or spread spectrum. It usually provides a connection to the wider internet through an access point (AP) [3]. Due to this users can move around inside the local coverage area and still they will be connected to the network. In WLAN people can use their laptops and computers anywhere within the local area network such as within a building, office and educational institutes same as people can use their cordless phones anywhere in the home. WLAN has gained so much importance because use of laptops and computers are increasing day by day and WLAN system is also very easy to install. IEEE 802.11 standard is the most widely used standard in WLANs and in market it is called as Wi-Fi. The maximum network bandwidth of this standard is 2 Mbps which is very slow for most of the applications. There are four subsets of Ethernet based protocol standards which were considered in order to improve this standard [4].

Table 1.2 Different WLAN Standards

Parameters	**802.11 a**	**802.11 b**	**802.11 g**	**802.11 n**
Frequency	5-6 GHz	2.4 GHz	2.4 GHz	2.4/5 GHz
Data rate	54 Mbps	11 Mbps	54 Mbps	248 Mbps
Range	120 m	140 m	140 m	250 m
Type	LAN	LAN	LAN	LAN

1.4 WIMAX Standards (Worldwide Interoperability for Microwave Access)

WIMAX (Worldwide Interoperability for Microwave Access) is a wireless communication standard. This standard has a data transmission rate of 30 to 40 Mbps. For fixed stations WIMAX provide data rate upto 1Gbit/s. With variety of devices WIMAX gives broadband connectivity in almost all the cities as well as countries. It also provides data and telecommunication services and a source of internet connectivity which is a part of business plan.

Working of WiMAX: Non-line of sight is just like WiFi service, in which a small antenna of laptop or computer is connected to the tower. In this mode, lower frequency range from 2 GHz to 11 GHz is used by WiMAX. There is no effect of physical obstructions on lower wavelength transmissions. They can better diffract or bend around obstacles.

There is LOS service, in which a fixed antenna points at the WiMAX tower directly from the top of the roof or pole. LOS connection is stronger and stable so we can send a lot of data with lesser errors. LOS transmissions use higher frequencies because at higher frequencies, the interference is less and bandwidth is more.

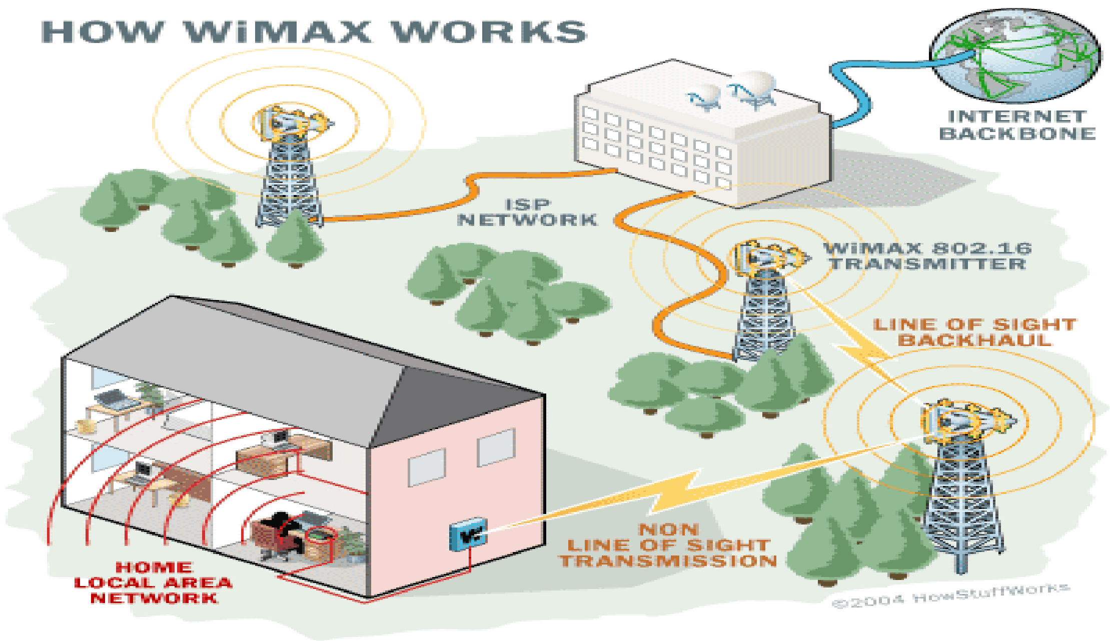


Fig. 1.1 Working of WiMAX

Table 1.3 Different WIMAX Standards

Parameters	802.16	802.16 a	802.16 e
Spectrum	10-66 GHz	2-11 GHz	2-6 GHz

Channel bandwidth	20,25 and 28 MHz	1.5 to 20 MHz	1.5 to 20 MHz with UL sub channels
Data rate	32-134 Mbps(28 MHz)	75 Mbps(20 MHz)	15 Mbps(5 MHz)
Channel conditions	LOS	Non-LOS	Non-LOS
Typical cell radius	2-5 Km	7-10 Km max 50 Km	2-5 Km
Application	Fixed	Fixed and Portable	Mobility

1.5 Antennas in Different Wireless Communication Systems

An antenna is a type of transducer which converts electrical energy into radio waves (electromagnetic energy) and vice versa. An antenna is used with a radio transmitter or radio receiver. During transmission, transmitter supplies a current which is oscillating at radio frequency towards the terminals of antenna and the radiation of energy from the current in the form of electromagnetic waves is done by antenna. During reception, the antenna seizes some power of the electromagnetic wave and produces small amount of voltage at its terminals, which is further applied to the receiver for amplification.

1.5.1 Role of Antennas

According to the IEEE standard, "Antenna is considered as the means of transmission and reception of radio waves". Antennas are needed for every transmitter and receiver whether in either hidden form or protected as in radio and laptops which are equipped with Wi-Fi or in some other common systems. An antenna is also defined as the transformational structure between the guiding space and free space [5]. At the speed of light, radio waves can convey signals through air or space which are basically the electromagnetic waves. The main use of radio transmitters and radio receivers is to carry signals or data towards the systems which includes Wi-Fi, remote controlled instruments and point to point transmission links. All systems would require an antenna that is non bulky and occupies less space. One such antenna is Microstrip Patch Antenna.

1.6 Introduction to Microstrip Patch Antennas

Nowadays, in mobile communication systems, the requirement of small sized antenna for miniaturisation purpose of mobile units has been increased. Hence, reduced size and enhanced bandwidth are the major considerations in microstrip antennas for practical applications. Therefore, study regarding small size and enhanced bandwidth of microstrip antenna has been greatly increased. In the past few years, great progress in the design of small sized microstrip antenna with dual and circular polarisation, dual frequency, broadband and gain enhanced performance has been reported [5]. The proposal of microstrip antenna was launched in 1950's but it gained importance in 1970's and was used in various applications at that time. After 1970 large number of authors explained the radiations coming from the ground plane with the dielectric substrate for different designs of antenna. Howell [6] and Munson [7] developed the first antenna which was practical antenna. Munson showed that the microstrip antenna was a practical antenna to be used in various antenna system problems by using it in missiles and rockets as a flush mounted low profile antenna. For this antenna mathematical model was developed and its applications were enhanced in many other fields. Microstrip antenna consists of a conducting patch on upper side of dielectric substrate and a ground plane on the lower side of dielectric substrate. The material of patch is copper or gold and the patch can have any shape such as rectangular and circular etc. On the dielectric substrate the feedline and the patch are photo etched. The length of the patch is usually between $0.3333\ \lambda_0 < L < 0.5\ \lambda_0$, where λ_0 is the wavelength in free-space. The thin patch is selected where t is the thickness of the patch. The h is the height of the dielectric substrate and is usually between $0.003\ \lambda_0 \leq h \leq 0.05\ \lambda_0$. The dielectric constant (ϵ_r) of the substrate has range typically between $2.2 \leq \epsilon_r \leq 12$.

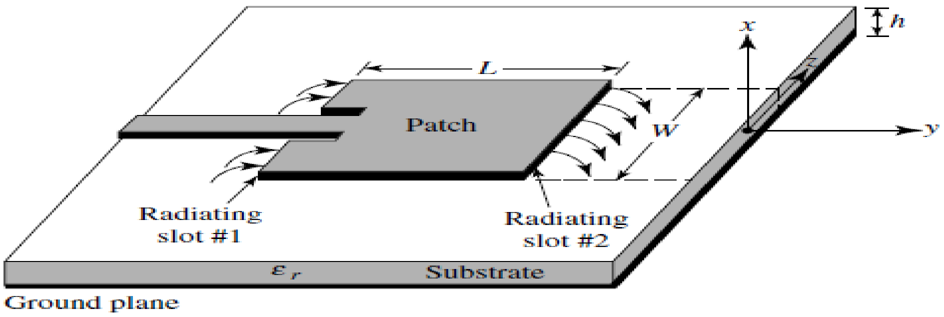


Fig 1.2 Structure of Micro-Strip Patch Antenna [5]

1.7 Advantages and Disadvantages of Microstrip Antenna

As compared to conventional antennas, microstrip antennas have various advantages and many applications which covers the frequency range of ~100 MHz to ~100 GHz. Some advantages of microstrip antennas are given below:

- Low volume, thin profile configurations and light weight.
- Fabrication cost is less and therefore can be produced in large quantities.
- Circular as well as linear polarisation is supported.
- Matching networks and feed lines can also be fabricated with the antenna simultaneously.
- Dual frequency and triple frequency antennas can be made easily.
- Integration with microwave integrated circuits is easy.

On the other hand microstrip antennas have some drawbacks also which are discussed below

- Microstrip antennas have narrow bandwidth which is the biggest drawback.
- Low gain and low efficiency.
- It is difficult to achieve polarisation purity.
- Surface waves get excited.
- For high performance arrays complex feed structures are required.

1.8 Mathematical Model of Microstrip Patch Antenna

Mathematical model help us to find the various dimensions of the antenna according to resonant frequency of separation and the mathematical model of microstrip patch antenna is as discussed below:

1.8.1 Transmission Line Model

Transmission line model is used to describe the mathematics behind working of MSA. This has an advantage of being simple but lacks versatility in some cases.

1.8.2 Effect of Fringing

According to transmission line model, along the length and width, the dimensions of patch are finite and therefore at the edges of the patch the fields undergo fringing. The quantity of fringing is basically the function of the height of the substrate and the patch dimensions. For E-plane fringing are basically the function of the substrate's dielectric constant ϵ_r and the length of the patch to the height of the substrate ratio. Since L/h>1, fringing is reduced for microstrip antennas; as it influences antenna's resonant frequency and it should be considered.

Waves are moving in both substrate and air. Due to this the dielectric constant is not considered but effective dielectric constant of material is considered for fringing effects and wave propagation. The effective dielectric constant is calculated by the formula which is as given below in equation (1.1). [1]

$$\frac{W}{h} > 1$$

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

1.8.3 Effective Length, Resonant Frequency, and Effective Width

Due to fringing effects, the patch of the antenna looks electrically greater than the physical dimensions of the patch. A practical and very popular relation for extension of length is

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

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

The resonant frequency of microstrip patch antenna is as given below

$$(frc)_{010} = \frac{1}{2L_{eff}\sqrt{\epsilon_{reff}}\sqrt{\mu_0 \epsilon_0}} \qquad (1.3)$$

The values of length and width of the patch is given by

$$W = \frac{1}{2f_r\sqrt{\mu_0 \epsilon_0}}\sqrt{\frac{2}{\epsilon_r + 1}} = \frac{\upsilon_0}{2f_r}\sqrt{\frac{2}{\epsilon_r + 1}} \qquad (1.4)$$

$$L = \frac{1}{2f_r\sqrt{\epsilon_{reff}}\sqrt{\mu_0 \epsilon_0}} - 2\Delta L \qquad (1.5)$$

This model is related to only those ground planes which are infinite. For practical considerations, it is necessary that there should be a finite ground plane. It is found that for both infinite and finite ground planes same results can be obtained if the dimensions of the ground is greater than the patch dimensions by nearly six times the thickness of the substrate all around periphery[8]same. Therefore, the length and width of ground is given

$$L_g = 6h+L \tag{1.6}$$

$$W_g = 6h+W \tag{1.7}$$

Where

h= thickness of the substrate

L = Length of the patch

W= Width of the patch

L_{eff} = Effective length

C= speed of light which is $3X10^8$ m/sec

$\in_r$= relative permittivity

$\in_{reff}$= effective permittivity

L_g= Length of ground

W_g= Width of ground

1.9 Various Feeding Techniques of Microstrip Antennas

There are various techniques of feeding microstrip antennas. These techniques are classified into two categories one is contacting and the other is non-contacting. In the first technique, the RF power is fed to the patch directly using a joining element like microstrip line. In the second technique, electromagnetic coupling is done between the radiating patch and microstrip line to transfer the power [9]. There are four feeding techniques which are used. Out of them two are contacting, one is called microstrip feed line and other is called coaxial probe and other two are non-contacting called proximity coupling and aperture coupling. In the thesis below Aperture Coupled technique is followed for antenna design because it has less spurious feed radiations and large bandwidth.

Table 1.4 Reason of choosing aperture coupled feeding technique

Characteristics	Microstrip Feed line	Coaxial Feed	Aperture Coupled Feed	Proximity Coupled Feed

Spurious feed radiation	More	More	Less	More
Reliability	Better	Poor due to Soldering	Good	Good
Impedance Matching	Easy	Easy	Easy	Easy
Bandwidth	2-5 %	2-5 %	13 %	21 %

Due to good reliability, ease in impedance matching and more spurious radiation, aperture coupled technique is used. This technique has better bandwidth in comparison to Microstrip line and Coaxial coupled feeding techniques [10]. Higher Bandwidth is achieved in Aperture Coupled Feeding technique.

1.10 Methods of increasing Bandwidth of Antenna

There are two methods of increasing the bandwidth of antenna. One is stacking and other is Defected Ground Structures.

1.10.1 Stacked Microstrip patch antennas

The aperture coupled technique leads to the excitation of the surface waves. The solution to this problem is to take size of patch large enough due to which surface waves will not be any more excited. But these methods again suffer from the problem of narrow bandwidth. Stacking is the method through which these problems of narrow bandwidth can be solved. In stacking one patch is mounted on high dielectric constant substrate and another patch on low dielectric constant substrate [11]. In the layer alignment another substrate and patch is placed on the lower substrate and patch and both these layers should be properly placed otherwise layer alignment problem may arise. Layer alignment problem is very common in aperture coupled feeding technique and stacking because in both cases more than one layer is used.

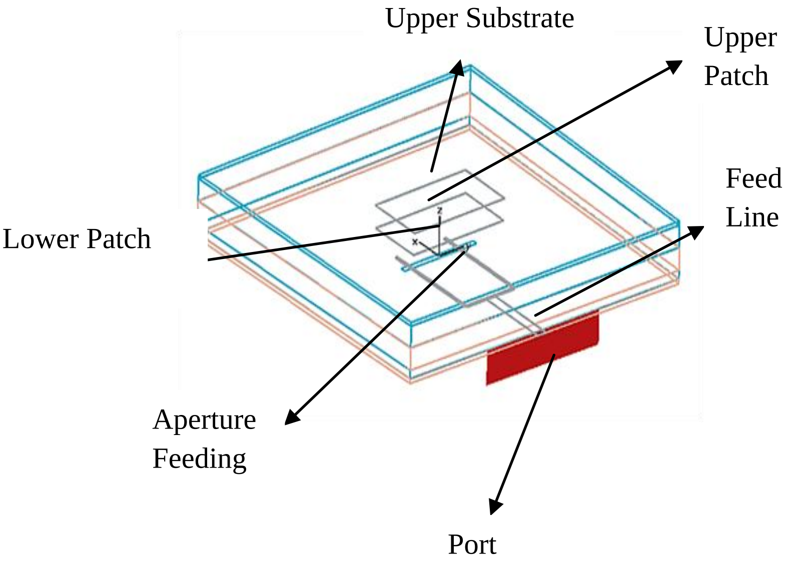


Fig. 1.3 Microstrip Stacked Patch Antenna

In stacked patch antennas, coupling aperture is generally used but resonant aperture can also be used sometimes which nearly doubles the bandwidth. In this case, aperture is used in the form of a resonator directly instead to use it for coupling of patches. If the spacing will be less between two different patches in stacked antenna, there will be mutual coupling between the two patches and due to mutual coupling there will be disturbance in the resonance of both patches which results in dual band antenna and if there will be accurate spacing between both the patches then the antenna can be obtained which is broadband and has large bandwidth. On varying the length of top patch the lower frequency band will be affected and the upper band will be affected on variations in the length of bottom patch [12].

1.10.2 Mathematical Model of Stacked Patch Antenna

Microstrip stacked patch antenna has same model as the transmission line model. The only difference is that the value of epsilon is taken as the net value because two substrates are considered. The net value of epsilon is as shown below

$$\epsilon_r' = \frac{2\,\epsilon_{reff} - 1 + A}{1 + A} \qquad (1.8)$$

Where

$$A = [1 + \frac{12h_{12}}{W}]^{-1/2}$$

1.10.3 Defected Ground Structures

Because of various advantages, microstrip patch antennas become more suitable for large number of applications in communication systems and telemetry. Microstrip antennas have numerous advantages like small size, less weight, low cost, low profile and easy to integrate on same substrate with microwave integrated. But microstrip antennas have biggest drawback of narrow bandwidth, low efficiency, low gain and power handling capacity is also low. Defective ground structures and Electromagnetic Band Gap structures also known as photonic band gap structures are two generic structures which are used for high performance and compact microwave devices. These are very attractive structures as they reject the unwanted frequency and reduce the circuit size. Defected ground structures have been developed recently and they are achieved by engraving a simple defect of any shape in the ground plane. Due to this the current distribution is of disturbed in the ground plane which results in managed excitation and propagation of radio waves across the substrate layer and the characteristics of transmission line is changed. i.e. inductance and capacitance. The defect can be changed according to desired performance from simple shape to complex shape. In microstrip antennas defective ground structures have various advantages in the field transmission lines, couplers, dividers, power amplifiers, oscillators and combiners [5]. For particular frequency, the antenna designed using transmission line model has large size and therefore not compatible for large number of applications. So there is necessity of reducing antenna size. It is considered as a unique technique of etching a simple shape defect in the ground plane which reduces the antenna size [13].

The DGS is examined as an equivalent circuit which consists of inductance and capacitance. The value of both L and C depends on the size and area of the defect which is to be cut in the ground plane. On varying the dimensions of defect the desired resonant frequency can be achieved. The formula for L and C are as given below:

$$C = \frac{f_c}{2Z_0} \cdot \frac{1}{2\pi(f_0^2 - f_c^2)} \qquad (1.9)$$

$$L = \frac{1}{4\pi^2 f_0^2 C} \qquad (1.10)$$

Different methods have been adopted already for reduction in size of antenna and those methods are using the substrate which has high dielectric constant, edge shorted patch along with shorting plates, at the acceptable position use of shorting pin etc. DGS is also considered harmonic reduction [14], cross polarisation reduction [15], and mutual coupling reduction [16].

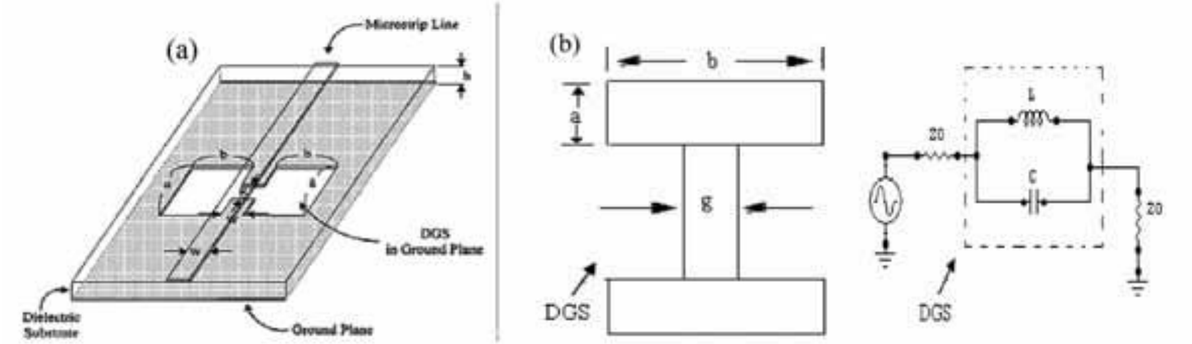


Fig. 1.4 DGS (a) Microstrip Line with Dumbbell Shaped DGS (b) DGS unit cell and its L-C equivalent

1.11 Thesis Overview

The main objective of the thesis is to design, fabricate and test the aperture coupled microstrip stacked patch antenna using aperture coupled feeding technique for WLAN and WiMAX applications. Stacking is done to improve bandwidth with same occupied surface area. The other job is to use defected ground structures to improve the gain and reduce the size of the antenna. For the design of microstrip patch antenna operating at specific resonating frequency the dimensions of substrate, patch and height should be accurate. Therefore, it is necessary to use simulation programs to test the antenna performance before fabrication. For simulation procedure of patch antennas CST microwave Studio 2010 is used and after simulation one of the antenna is fabricated and tested using VNA.

1.12 Thesis Outline

The thesis has been divided into eight chapters

In **Chapter 1,** the basics of microstrip patch antenna, antenna with defected ground structure, stacking of antennas has been discussed. Mathematical model has also been explained.

In **Chapter 2,** Literature survey based on aperture coupled antenna, stacked aperture coupled antenna and effect of DGS has been discussed. In literature survey brief idea of researchers work for bandwidth and gain enhancement has taken, Research gaps and objectives defined.

In **Chapter 3**, Design and simulation of single band aperture coupled microstrip antenna and its parametric analysis is shown to optimize it at WLAN bands of operation.

In **Chapter 4**, Design and simulation of dual band aperture coupled microstrip antenna operating at WLAN and WiMAX bands is shown.

In **Chapter 5**, Stacking of Aperture Coupled antenna is done. The results and analysis of both the antennas are compared.

In **Chapter 6**, Design and simulation of dual band aperture coupled microstrip stacked patch antenna operating at 2.4 GHz and 5.2 GHz is done to get enhanced Bandwidth at both bands.

In **Chapter 7**, Design, simulation and fabrication of dual band aperture coupled microstrip stacked patch antenna with defected ground structures operating at 2.4 and 5.2 GHz is shown to get further get better results.

In **Chapter 8**, Fabrication using PCB fabrication process and Testing of Antenna using VNA and then simulated and measured results are compared.

In **Chapter 9**, Conclusion and Future Scope is discussed.

CHAPTER 2

2. LITERATURE REVIEW

2.1 APERTURE COUPLED MICROSTRIP ANTENNA

Allen Buck was the student who fabricated and tested the first aperture coupled microstrip antenna in the Antenna lab of University of Massachusetts on August 1, 1984. The coupling aperture was circular in shape and Duroid substrates were used in this antenna which operated at 2 GHz [17]. It was observed that this antenna was working properly- impedance matching and radiation patterns were good. The required aperture was sufficiently small so that there exists much smaller back radiations from the coupling aperture as compared to the forward radiation level [18].

In 1996, Shigeru Egashira et al gave an approach to improve the gain and the bandwidth of the microstrip antenna, basically an antenna has been designed which has two parasitic elements. One element improves the gain and other improves the bandwidth [19].

In 1997, S.C. Maci et al recommended dual-frequency microstrip patch antennas which provided replacement to large-bandwidth antennas. A dual frequency structure can be obtained if two operating frequencies are independent of each other and this will help to avoid the need of separate antennas. Dual frequency multi patch antennas, Dual-frequency patch antennas which are reactively loaded, Dual-frequency orthogonal antennas are discussed [20].

In 1998, Naftali Herscovici et al recommended an antenna where a single-layer patch is a narrow band element and is printed on a dielectric substrate. For better efficiency and low cost the substrate taken should not be very thick. Additional resonators of different combinations and different configurations are used in order to improve the bandwidth of microstrip elements which are generally slots and parasitic elements etc. The widest bandwidth of microstrip antenna element is nearly 40–50%. The patch is supported by a pin which is non-conductive and is etched on the ground plane. The feeding is done through three-dimensional transition which is connecting the patch of antenna and a perpendicular connector. This element has a typical bandwidth of 90% [13].

In 1999, Y. Horri et al discussed the single band microstrip antenna which has photonic band gap structure (PBG) in the ground plane and also discussed the effect of photonic band gap structure to suppress the resonance of the antenna at the harmonic frequencies. The experimental study shows that at harmonic frequencies the radiation patterns are drastically diminished when PBG structure is used. At the third harmonic frequency the radiation forward to the photonic band gap antenna is repressed at more than 15 dB [21].

In 2001, S.C. Gao et al proposed a dual-polarised microstrip patch antenna which is capable to achieve a high isolation, low backward radiation levels, wide bandwidth and low cross-polarisation levels. The coupling aperture used is H-shaped. It uses stacked aperture coupled microstrip square patches which is easy to integrate with active devices and gives wide bandwidth. In this paper return loss has bandwidth of 20.9% and over this bandwidth the isolation is better than 36 dB. Front-to-back ratio and cross-polarisation levels are also good [22].

In 2003, Y.J Sung et al presented a paper in which defected ground structure is used in microstrip patch antenna which will suppress the higher order harmonics. An H-shaped defect is cut in the ground plane which has one or more unit lattices and produced bandstop characteristics. The radiated power in the defected ground structure antenna has been highly decreased at harmonic frequencies as compared to microstrip antenna without DGS [17].

In 2007, M.K. Mandal et al proposed a paper in which a compact filter which is low pas (LPF) with high selectivity and wide stop band is considered on the feedline of microstrip patch antenna. Suppressions of harmonics is an important element for microstrip antennas which are radiating harmonic frequencies. The stop band of 15 dB low pass filter exists over 10 GHz. The operating frequency falls in the pass band of low pass filter of the fundamental antenna [23].

In 2008, Himanshu Singh et al presented a novel paper called microstrip antenna using Defected Microstrip Structure & Defected Ground Structure which reduces the size of patch antennas and do not degrade the performance characteristics as bandwidth and efficiency etc. It has also another application of suppressing the harmonics without establishment of huge attenuation in the fundamental frequency [24].

In 2008, Ashwani Arya et al proposed an antenna in which there is improvement in efficiency and reduction in size. Mutual coupling reduction and cross polarisation reduction etc. are also some of the advantages of using Defected ground structure. DGS is considered as an identical LC resonator circuit. The size and area of the defect determines the value of capacitance and inductance. The efficiency of microstrip patch antenna is increased by 10% using a cavity backed structure, where patch is surrounded by the electric walls [25].

In 2009, J.P. Geng et al presented a paper in which a series of microstrip patch antenna with DGS for multiband applications have been discussed. These antennas have wide radiation beam and are much smaller in size and are suitable in different conditions for WLAN applications. The defected ground structure which is made in the ground plane of the Microstrip patch antenna is used to achieve small size, gain enhancement and useful multiband [26].

In 2011, Omid Hoseini et al presented a paper in which a microstrip slot antenna using E-shaped aperture is considered. In this paper various parameters of antenna are discussed. It is shown that the antenna can be made for dual band characteristic, high gain and quad band characteristic by making variations in the dimensions of stub length and E-shaped slot [27].

In 2011, Mouloud Challal et al showed the effect of introducing a defected ground structure of rectangular shape in the ground plane of simple microstrip patch antenna. On varying the dimensions of defected ground structure in the ground plane and also on locating the defect at proper position the performances of conventional rectangular microstrip antenna are characterised [28].

In 2011, Ali Dheyab et al proposed a method of using dielectric substrate of different value to enhance the bandwidth. Generally Microstrip antennas have some drawbacks like low gain, low efficiency, narrow bandwidth and more surface wave losses. In this paper the biggest drawback has been removed by increasing the bandwidth of microstrip antenna. The microstrip antenna when operating at 2.4 GHz and substrate thickness 4mm is considered the bandwidth comes out to be 155.1 MHz and when the substrate thickness of 6mm is used the bandwidth comes out to be 200 MHz . Therefore it is shown that on increasing the thickness of substrate the bandwidth also increases [29].

In the year 2011, Halappa R et al presented the paper in which they discussed their design of rectangular microstrip antenna. They considered the substrate of dielectric constant 4.4 and height 1.6mm and the name of this substrate is glass epoxy substrate. At the top right of patch the half circular shape slot is etched as DMS and in the ground plane two circular slots are etched as DGS. The Defected ground structure shifts the resonant frequency to required frequency. In this paper defected ground structure was considered to reduce the size and to improve the bandwidth of microstrip patch antenna. In this case the gain achieved is 4.65 dBi [30].

In 2012, Gurdeep Singh et al proposed an antenna in which two techniques called microstrip line feed technique and coaxial feed technique are combined. The antenna discussed in this paper offers high gain, low profile, small size and narrow bandwidth. When both feeding techniques are compared it is shown that better impedance matching technique is coaxial feeding [31].

In the year 2012, Rajeshwar Lal Dua et al proposed the rectangular microstrip patch antenna in which defect taken is swastika in shape. In this design patch area is much smaller in comparison to the simple microstrip antenna without defective ground structure. So, this type of antenna design using defected ground structure not only helps to improve the antenna parameters but it also helps to reduce the size of radiating patches which further reduces the overall size of the antenna [32].

In 2012, Sudipta Das et al presented a paper in which multi resonant frequency antenna using defected ground structure has been discussed. This paper showed that the size of antenna is reduced upto 57% with enhanced frequency ratio and multi-frequency operation on introducing the slots at patch edges [33].

In the year 2012, Pavan Kumar Sharma et al proposed an antenna which is operating in S and X-bands and have three resonating frequencies. Basically microstrip antennas and arrays are easy to manufacture and have small size. The proposed antenna has two resonant frequencies in X-band and third resonant frequencies in the S-band. The X-band is used in missile application, long-range tracking radar, weather detection and satellite communications. The S-band has application at 4.98GHz frequency WiFi of 13.5Mbps with a bandwidth of 10MHz with the QPSK modulation technique [34].

2.2 Stacked Patch Aperture Coupled Microstrip Antennas

In 2006, Y. Lu et al presented a stacked patch antenna which is wideband and aperture-coupled circularly polarised. In this paper three-stub hybrid coupler, aperture coupled feed and one stacked patch are used in combination. Due to this both the 3 dB axial ratio bandwidth and the impedance bandwidth have been improved. This design has axial ratio bandwidth of nearly 40.3% and -10 dB return loss bandwidth of nearly 37% which is operating in X band. The maximum gain of this design is 8.4dBi. Since this antenna has simple structure and good performance therefore it is used in many applications [35].

In 2008, N. Ghassemi et al presented a paper in which they discussed that by using two stacked patches the gain bandwidth of the antenna can be improved and the thickness of the structure can be reduced. To achieve this, the mathematical study is done on effects of length of the top patch, changing the patch position in horizontal direction, position of dielectric in top layer, length of slot and position of slot [36].

In 2009, Anil B. Nandgaonkar et al proposed a paper for broadband WLAN application systems using a broadband patch antenna which is parasitically coupled. It was analysed that widened bandwidth and antenna performance can be improved further with the help of substrates having low insertion losses. For this stacked multi-resonators which are microstrip antennas of electromagnetically coupled type are used [37].

In 2011, Rajesh Kumar et al presented a paper which showed that the dual band can also be achieved using air gap in the microstrip patch antenna. On taking variations in air gap between the aperture coupled patch and single patch microstrip antenna the dual band can be achieved. The main advantage of using air gap is that it improves the bandwidth of antenna and at both resonant frequencies input impedance is matched easily [38].

In 2012, N. Ramli et al presented a Frequency Reconfigurable Micostrip Stacked Patch Antenna in which aperture coupling feeding technique and stacked technology has been used. This design can accommodate both S/X band separately using the same antenna. In order to achieve the frequency reconfigurability, two patches are activated consecutively at different substrates by changing the mode of switch at feedline. There are two small apertures in the ground through which feedline and both the patches are coupled electromagnetically. In this paper the configuration of switch and effect of aperture slots at ON or OFF state are discussed. The antenna is changed in terms of gain, resonant frequency and radiation pattern by changing the position of switch at feedline. This design operates at two frequencies using different states of switch. During ON state the antenna operates at S-band and has return loss of -30.1 dB and during OFF state operates at X-band with return loss of -34.01 dB [39].

In 2013, N. Ramli et al presented a frequency reconfigurable microstrip patch antenna which can be applied to LTE (2.6 GHz) or WIMAX (3.5 GHz) applications. This design is made by the combination of aperture coupled feeding technique and microstrip stacked patch technique. It has three substrate layers. To enhance the gain and to reduce the spurious radiations from the feed line air gap of 3 mm thickness is taken between the bottom patch substrate and ground. The study was made on the effect of switch configuration which is either in ON or OFF state. The antenna is changed in terms of gain, resonant frequency and radiation pattern by changing the position of switch at feedline. When the switch is in ON state, both the aperture slots and radiating patches are activated and the resonant frequency is 2.6 GHz with return loss of -25.58 dB. When switch is in OFF state the aperture slot 1 is activated and the resonant frequency is 3.5 GHz with return loss of -45.37 dB. The microstrip stacked patch antenna provides the benefit of producing high gain which is more than 6 dBi in the ON and OFF states respectively [40].

2.3 Research Gaps

- The bandwidth of antenna can be improved by the use of stacked patches, parasitic elements and thick substrates which have low permittivity etc [24]. But in spite of good efficiency the broad banding in design of microstrip patch antenna will increase the volume. The work can be further done to reduce the volume of the antenna.
- The size of patch antennas can be reduced without the degradation in performance of antennas using a novel structure called Defected Microstrip Structure and Defected Ground Structure. Gain/Bandwidth can also be increased using DGS. Not much work is available in literature regarding this.
- At low dielectric constant good performance of VSWR and return loss can be achieved by using different shaped patch. Further work can be done to examine the antenna by considering the slot shape same as the patch shape.
- On varying the thickness of antenna the results are improved in terms of return loss [28], we can also use dielectric substrates of different permittivities. Since in aperture coupling technique the upper substrate of low permittivity and lower substrate of high permittivity is used for proper functioning of antenna. The work can be done to provide improved and distinctive results because in the whole antenna body there is asymmetric variations in dielectric constant.
- Multiband applications can be achieved using different shapes of slots in the ground plane called defected ground structures. To obtain single band, dual band and quad band antennas different variables of the slots are varied.
- In microstrip patch antennas air gap has very important role. Multiple bands are obtained by the variations in air gap. In case of stacking also air gap can be used and this will help to improve the bandwidth of the antenna.

- There are two proposed different slot configurations called longitudinal slot configuration and transverse slot configuration. The transverse slot configuration is simpler than longitudinal slot configuration and impedance matching is not required. The longitudinal slot antenna has wider bandwidth as compared to another slot antenna [33]. In the first configuration DGS is used to improve the gain and bandwidth.
- The performance characteristics of microstrip patch antenna heavily depend on the slot dimensions. On increasing the length and width of the slot the VSWR and return loss of the microstrip patch antenna increases but the gain decreases [41].
- In spite of the fact that dual band microstrip antenna exhibits good performance characteristics but its size is not compact and gain is also very less i.e. 4.262 dB at 5.5 GHz band and 4.668 dB at 6.4 GHz of the wireless communication [42]
- The harmonics and size of the antenna [43] are reduced upto third order and almost 90% compared to [21] respectively. If we compare it with [23], the order of reduction reaches 40%.But the peak gain of the antenna at first harmonic decreases [43]. So work can be done to improve gain with harmonics reduced by 40%.

2.4 Thesis Objective

Based upon the research gaps mentioned above, following objectives had been designed to carry out the thesis work:

- To Design and simulate a single band microstrip antenna with aperture coupled technique operating at 5.8 GHz and its parametric analysis.
- To Design and simulate a dual band aperture coupled microstrip antenna with U-slot in the ground and patch.
- To do Stacking to improve the Bandwidth of Single band Aperture Coupled Microstrip Antenna.
- To Design and simulate a dual band stacked aperture coupled microstrip antenna operating at 2.4 and 5.2 GHz.
- Use of DGS to further improve the Bandwidth and reduction in size.
- Fabrication and testing of the antennas.
- Publish research papers based on work done.

CHAPTER3

3.SINGLE BAND APERTURE COUPLED MICROSTRIP ANTENNA OPERATING AT 5.8 GHZ

In this chapter design of single band microstrip antenna based on aperture coupling technique operating at 5.8 GHz has been discussed and the dimensions of antenna are calculated using transmission line model. This antenna has applications in WLAN and WiMAX bands. The effect of various parameters such as slot length and stub length are also discussed. The design is simulated using CST (Computer Simulation Technology) 2010 Microwave Studio software.

3.1 Basics of Aperture Coupled Microstrip Antenna

The patch antenna is nearly half-wavelength of Microstrip Transmission line. When air is taken as the substrate, the length of antenna is nearly one-half of free space wavelengths. As the dielectric constant of the substrate increases the length and bandwidth of the Microstrip antenna decreases. The electrical length of the antenna is more because of the effect of fringing fields due to which the resonant length of the microstrip antenna is small [3].

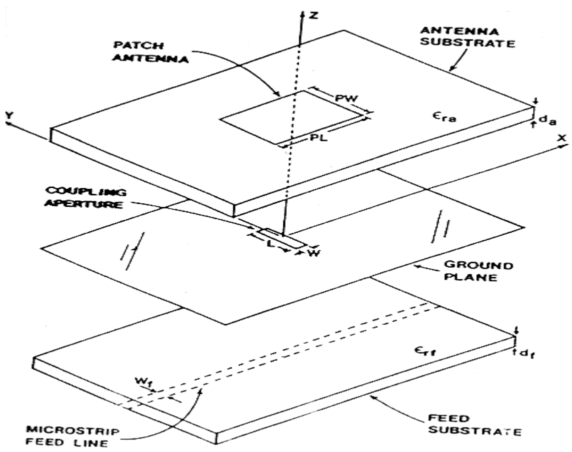


Fig 3.1 Aperture Coupled Microstrip Antenna

3.2 Design and Simulation of Single Band Microstrip Patch Antenna with Aperture Coupled feeding

The single band aperture coupled microstrip patch antenna operating at 5.8 GHz is designed and simulated in this chapter. Various parameters of the antenna are as shown below:

3.2.1 Antenna Design

The design of the antenna is done using transmission line model [5]. The dimensions of ground, substrate and patch of the design operating at 5.8 GHz frequency are calculated using the equations which are discussed in Chapter 1 (equations (1.4), (1.5), (1.6), (1.7)).

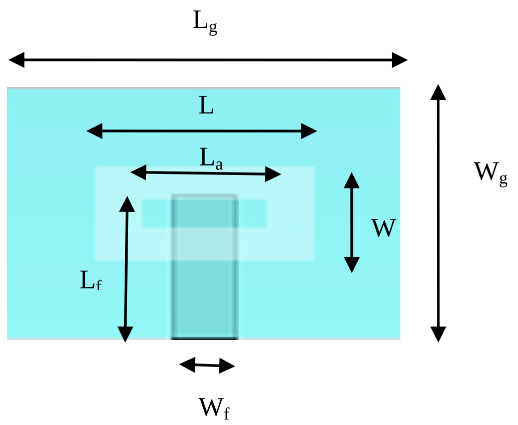


Fig. 3.2 Front view of antenna with dimensions

Table 3.1 Design Specifications of Single Band

Dielectric constant of the material	4.4
Thickness of substrate	1.57 mm
Length of patch (L)	7.7 mm
Width of patch (W)	17 mm
Width of aperture (W_a)	8 mm
Length of stub (L_s)	1.5 mm
Width of feed line (W_f)	4 mm

3.2.2 Impedance Bandwidth in terms of Return Loss

Return loss is basically the difference between the forward power and the reflected power and is generally measured in dB. The small value of return loss shows that maximum power has been transferred means the value of return loss should be as greater as possible in negative. e.g. -30 dB return loss is better than -20 dB return loss. The bandwidth of this design is 346.5 MHz at 5.8 GHz shown in Fig. 3.3 which is very good and this antenna can be used for WLAN and WiMAX applications. More return loss shows that impedance matching is good and therefore the directivity and gain will also be good.

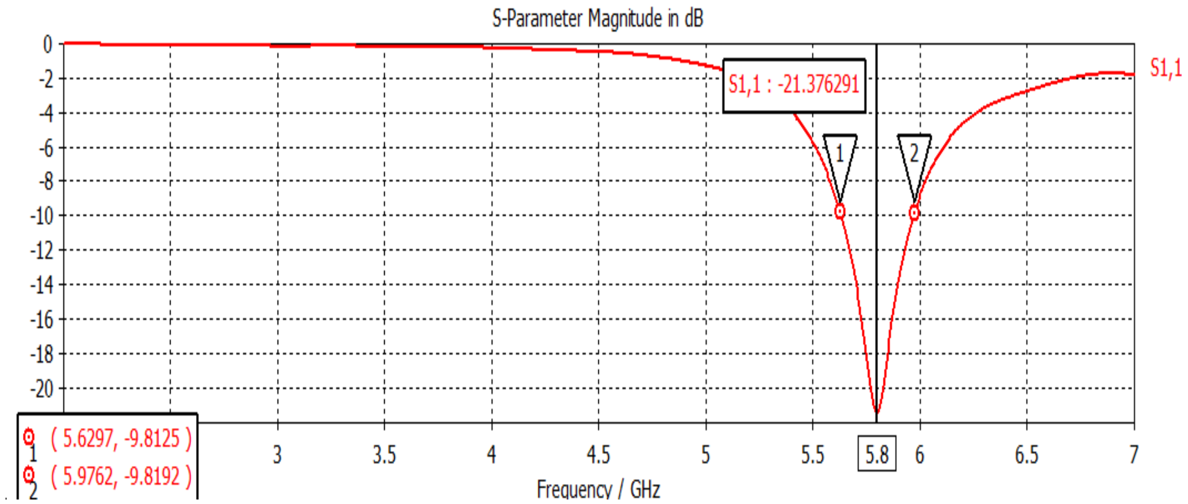


Fig. 3.3 Return loss S_{11} (in dB)

3.2.3 Smith Chart

The following plot of Smith Chart shows the variation of impedance with frequency and this Fig. 3.4 of smith chart gives 50 ohm impedance which is accurate because when we fabricate the antenna then to check it on VNA it should be 50 ohm. The length of slot controls the locus of the Smith Chart and as the length of the aperture increases the locus also increases. In Smith chart the upper part is inductive and lower part is capacitive and centre circles are constant resistance circles. The impedance is complex.

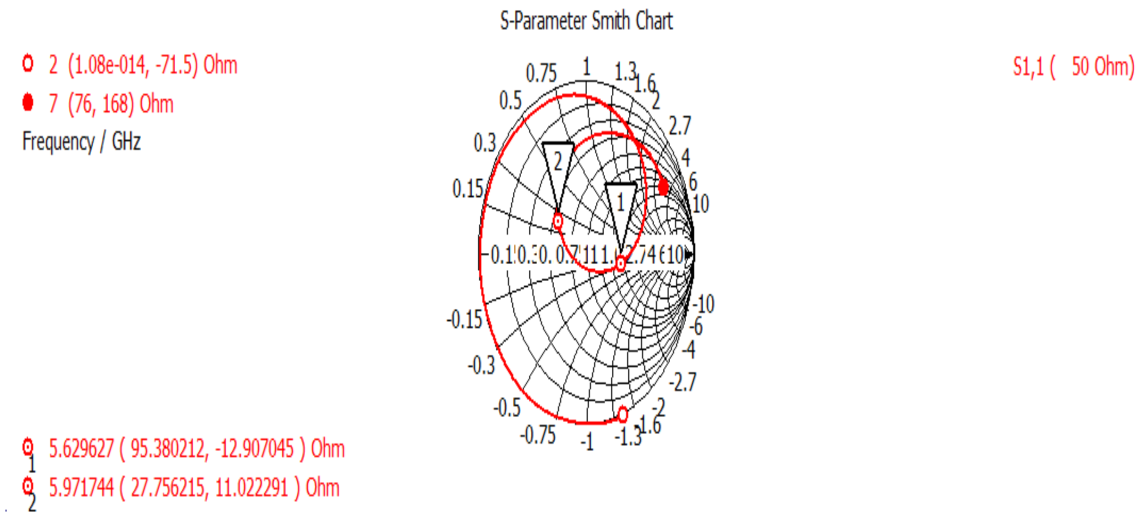


Fig. 3.4 Smith Chart at 5.8 GHz

3.2.4 VSWR

When both the transmitter and the antenna are connected through feedline, the impedance matching of both the transmitter and the antenna should be proper so that the maximum transfer of energy takes place. If matching between the two is not proper then waves will come back and are called reflected waves. The interaction of these reflected waves with the forward waves forms standing waves. Ideally the value of VSWR should be in between 1 and 2 and in this case it is 1.192 which is satisfying the criteria.

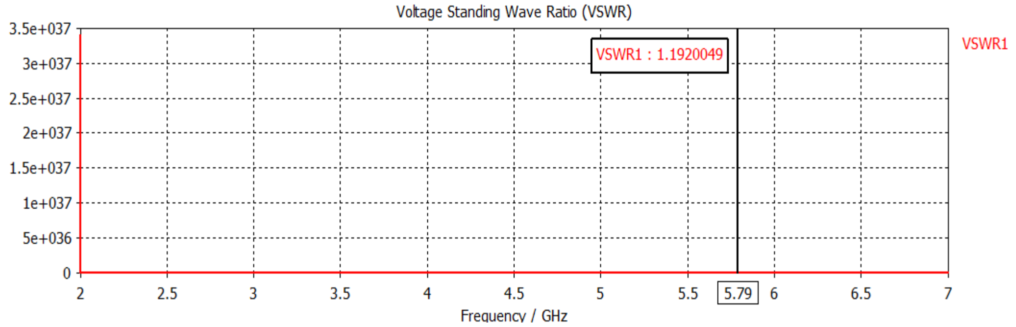


Fig. 3.5 VSWR

3.2.5 Directivity

The 3D plot of directivity is as shown in Fig. 3.6 which is representing the amount of radiation intensity and in this case it is equal to 5.307 dBi. The value of directivity should be greater than 5 dBi and it is satisfying in this case. This antenna is directional and operating in one particular direction comparing to the antenna which radiates equally in all the directions like isotropic antenna. This value of directivity has application in Wlan and WiMAX bands.

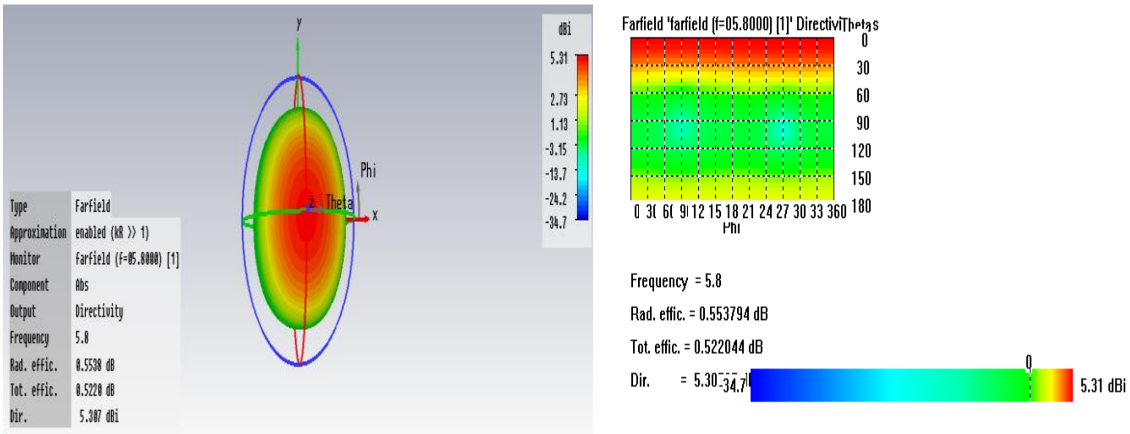


Fig. 3.6 Directivity (3D and 2D view) at 5.8 GHz

3.2.6 Gain

The plot of gain shown in Fig. 3.7 has value 5.861 dBi which is good because it is greater than 5 dBi. For WLAN and WiMAX applications the gain of the antenna should be more in a particular direction in comparison with isotropic antenna which equally radiates in all the directions. The polar plot of gain is also shown in Fig. 3.8. The gain has value 5.861dBi at 5.8 GHz, the radiation pattern is omnidirectional and has main lobe which is directed at an angle of 358 degree. The angular beam width is at an angle 86.9 degree. The value of the main lobe as shown in Fig. 3.8 is 5.9dB.

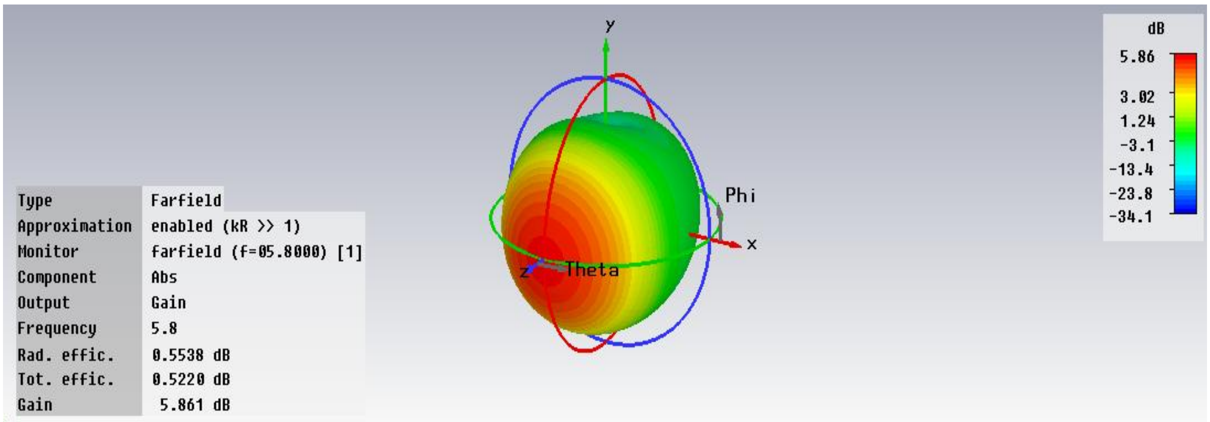


Fig. 3.7 Gain (3D view) at 5.8 GHz

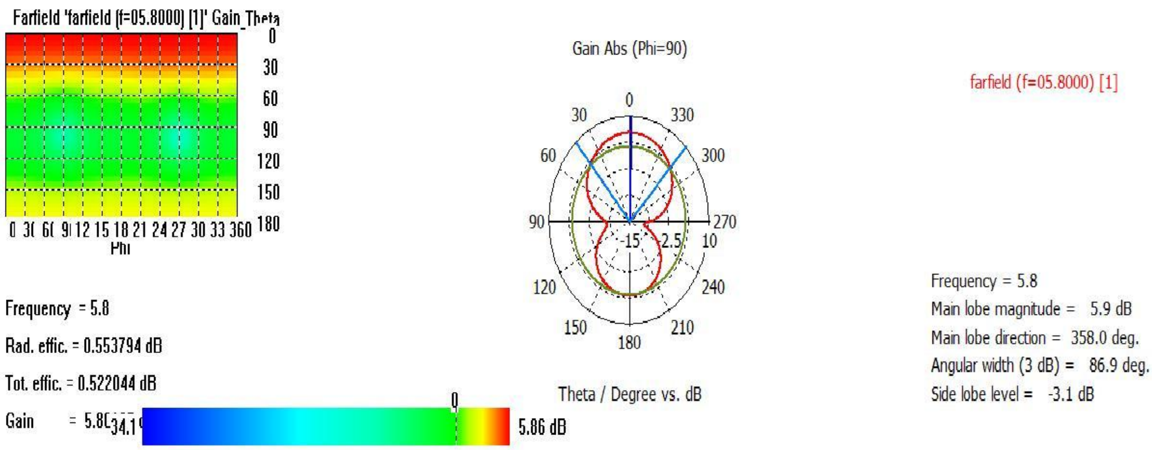


Fig. 3.8 Gain (polar plot and 2D view) at 5.8 GHz

3.2.7 Current Distribution

The current should be maximum at the centre of the patch and minimum at edges which are as obtained in this case. As can be seen the frequency of 5.8 GHz peak surface current is shown. The current is maximum at the centre of the patch and at the edges of the rectangular slot as shown in Fig. 3.9 by the red arrows. Basically the current intensity is shown by the current distribution.

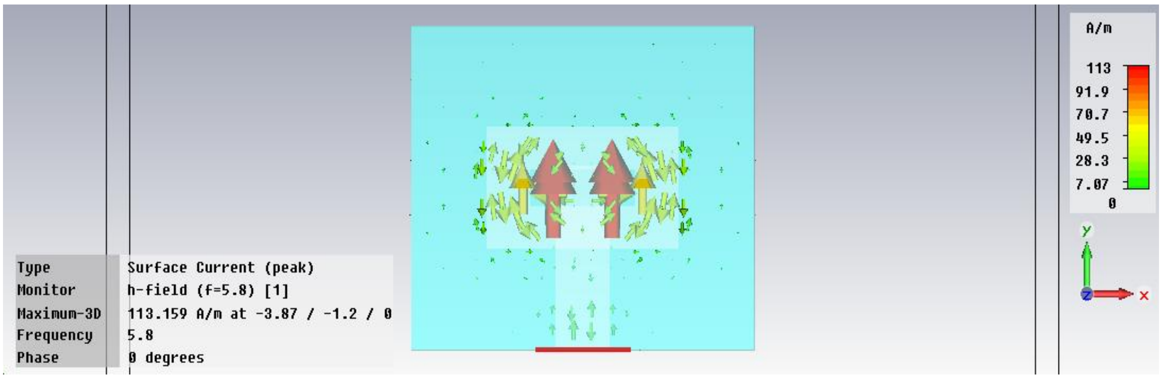


Fig. 3.9 Surface Current of the Antenna at 5.8 GHz

3.3 Parametric analysis of the antenna

The parametric analysis of the antenna is as shown in the figures below. In parametric analysis different values are given to a particular parameter and results are noted. The value which is good is considered.

3.3.1 Effect of varying the Slot Length

The amount of coupling depends on the length of the slot. Resonant and non-resonant are the two types of slot which depends on slot length. If the length of the slot is nearly half of the antenna's wavelength then it is called resonant slot and if the length of slot is smaller then it is called non-resonant aperture. There is decrease in input resistance and coupling between patch and feed with decrease in slot length [10]. When the length of the slot is increased from 2mm to 4mm then the value of return loss increases and therefore 4mm is chosen as shown in Fig. 3.10.

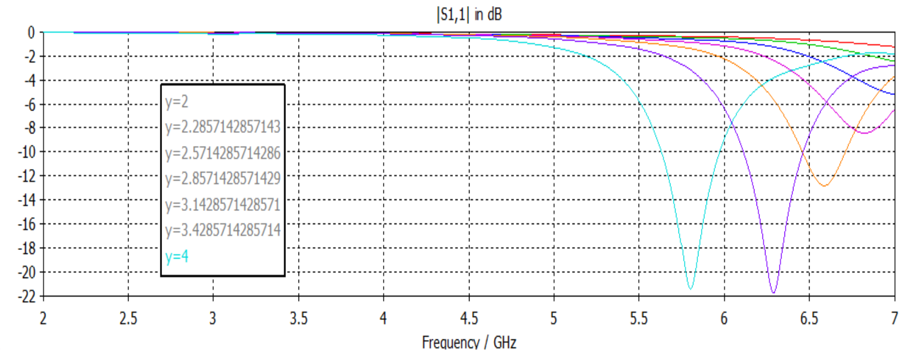


Fig. 3.10 Variations in S_{11} with slot length

3.3.2 Effect of varying slot length on Smith Chart

From Fig. 3.11 it is seen that the slot length controls the size of the impedance locus of the Smith Chart also. The size of the impedance locus increases with increase in slot length. So the impedance locus must be large enough to pass through the middle of the smith chart which shows the proper matching. Therefore, the length of slot should be chosen properly and in this case the optimised value is chosen to be 4mm.

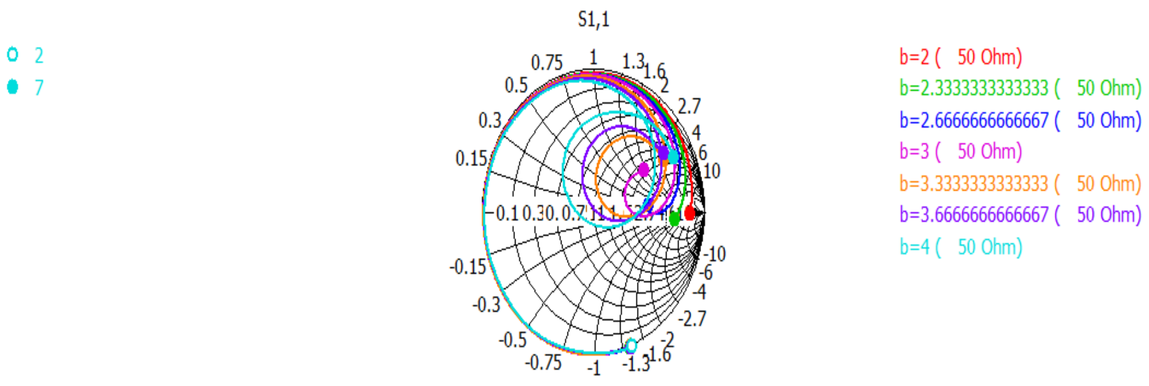


Fig. 3.11 Variations in Smith Chart with slot length

3.3.3 Effect of varying slot length on Z_{11}

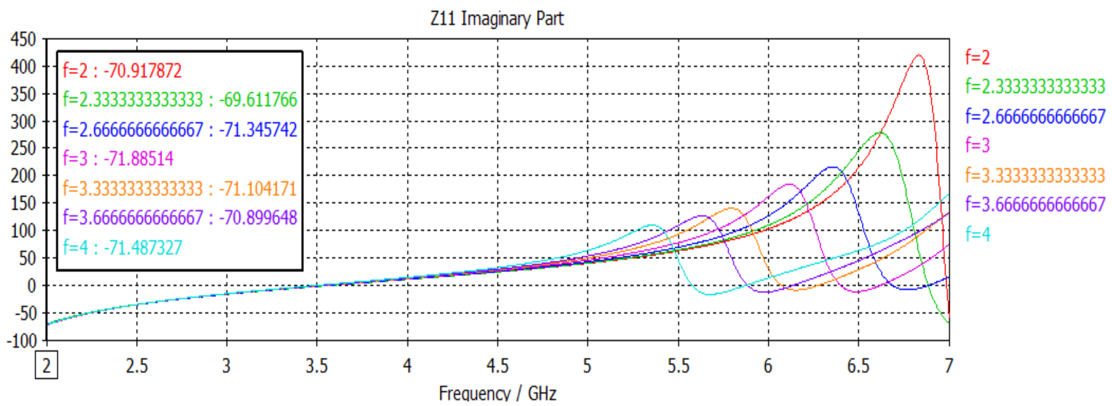


Fig. 3.12 Variations of Imaginary Z_{11} with respect to slot length

3.3.4 Effect of varying the Stub Length

The length of the feedline also affects the coupling level of the antenna. For maximum coupling the feedline must be placed perpendicular to the direction of the slot [10]. As shown in Fig. 3.13 as the length of feed increases the return loss also increases upto some extent and then start decreasing. Therefore the value of stub length taken is 1.5mm with return loss -21.376. This shows the proper matching of the antenna.

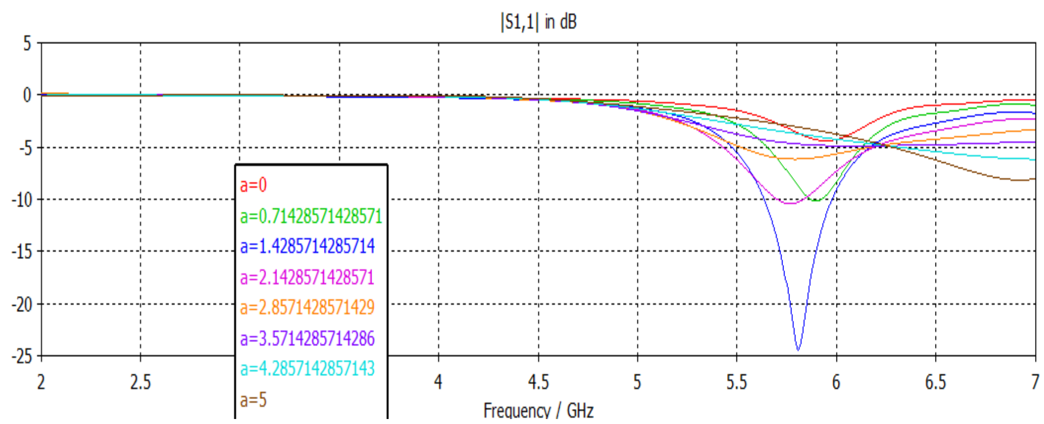


Fig. 3.13 Variations in S_{11} with stub length

Conclusion

The design of single band microstrip antenna based on aperture coupling technique operating at 5.8 GHz has been discussed in this chapter. The various dimensions of the antenna are calculated using transmission line model [5]. The Bandwidth comes out to be 346.5 MHz which is good and also VSWR is less than 2. The entire parameters show good performance of the above design. The various parametric analysis of the antenna is done and the best results are selected for this design. This antenna has applications in WLAN and WiMAX bands. The design is simulated using CST (Computer Simulation Technology) 2010 Microwave Studio software.

CHAPTER 4

4.DUAL BAND MICROSTRIP PATCH ANTENNA USING APERTURE FEEDING WITH U-SLOT IN GROUND AND PATCH

In this chapter dual band aperture coupled microstrip antenna using U-slot in patch and ground is designed and simulated. The resonating frequency is 3.62 GHz and 5.77 GHz. These two resonating frequencies has applications in WiMAX and WLAN bands respectively.

4.1 Design of dual band aperture coupled Microstrip Antenna with U-slot

In this design U-slot is cut in the patch and ground and dual band is obtained. Various parameters of the antenna are as shown below:

4.1.1 Antenna Design

The design of the antenna is as shown below. U-slot is cut in the ground plane as well as on the patch. The antenna is resonating at two frequencies 3.62 GHz and 5.77 GHz. The stub is also used in this antenna. Stub is used for the matching purpose. The higher return loss shows that the impedance matching is good. The values of length and width of patch are calculated using Transmission line model as discussed in Chapter 1.

(a)Perspective view **(b)Front view** **(c)Back view**

Fig. 4.1 Different views of Antenna

Table 4.1 Antenna Dimensions

Dielectric constant of the material	4.4
Width of ground	40mm
Length of ground	32mm

Width of patch	22mm
Length of patch	18mm
Thickness of the substrate	1.57mm

4.1.2 Return Loss and Bandwidth

Fig. 4.2 has return loss (S_{11}) -40 dB and -14 dB for the designed antenna operating at 3.62 GHz and 5.772 GHz. The coupling will be more if the return loss will be more negative and this shows that the matching is good. The gain and directivity of the antenna will be more in a particular direction and this is what needed for WLAN and WiMAX. This antenna has bandwidth of 74.5 MHz at 3.62 GHz and 111 MHz at 5.772 GHz.

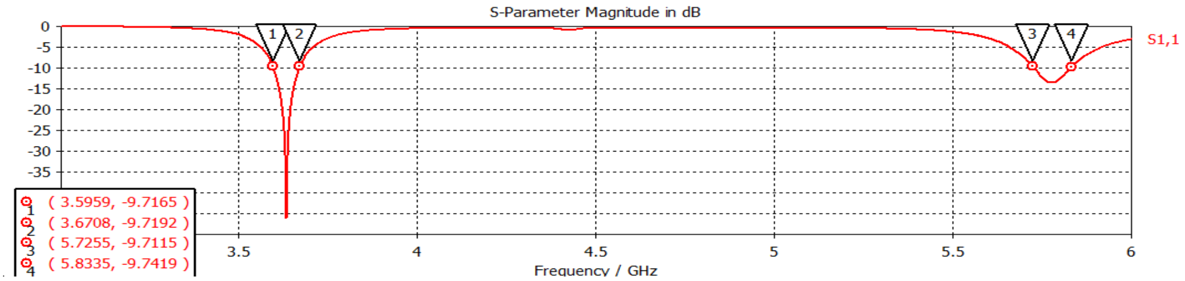


Fig. 4.2 Return Loss S11 (in dB)

4.1.3 Smith Chart

The Smith Chart shown below has two circles. These two circles are obtained because it is a dual band antenna. In Smith chart the upper part is inductive and lower part is capacitive and centre circles are constant resistance circles. The impedance is complex in case of Smith Chart. The lower circle (1, 2) belongs to lower frequency band and upper circle (3, 4) belongs to 5.8 GHz band.

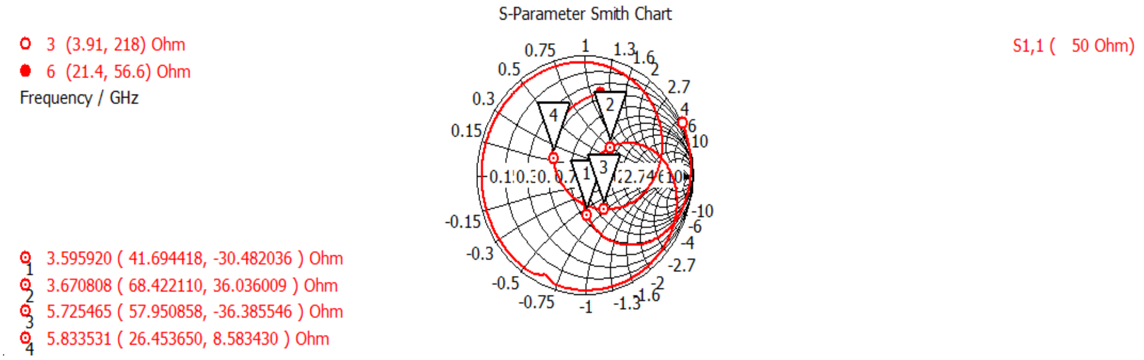


Fig. 4.3 Smith Chart

4.1.4 Directivity

The 2D and 3D plot of directivity is as shown in Fig. 4.4 which is representing the amount of radiation intensity and in this case it is equal to 6.035 dBi for 3.62 GHz. The value of directivity should be greater than 5 dBi and it is satisfying in this case. This antenna is directional and operating in one particular direction in comparison to the antenna which radiates equally in all the directions like isotropic antenna. This value of directivity has application in WiMAX and WLAN bands.

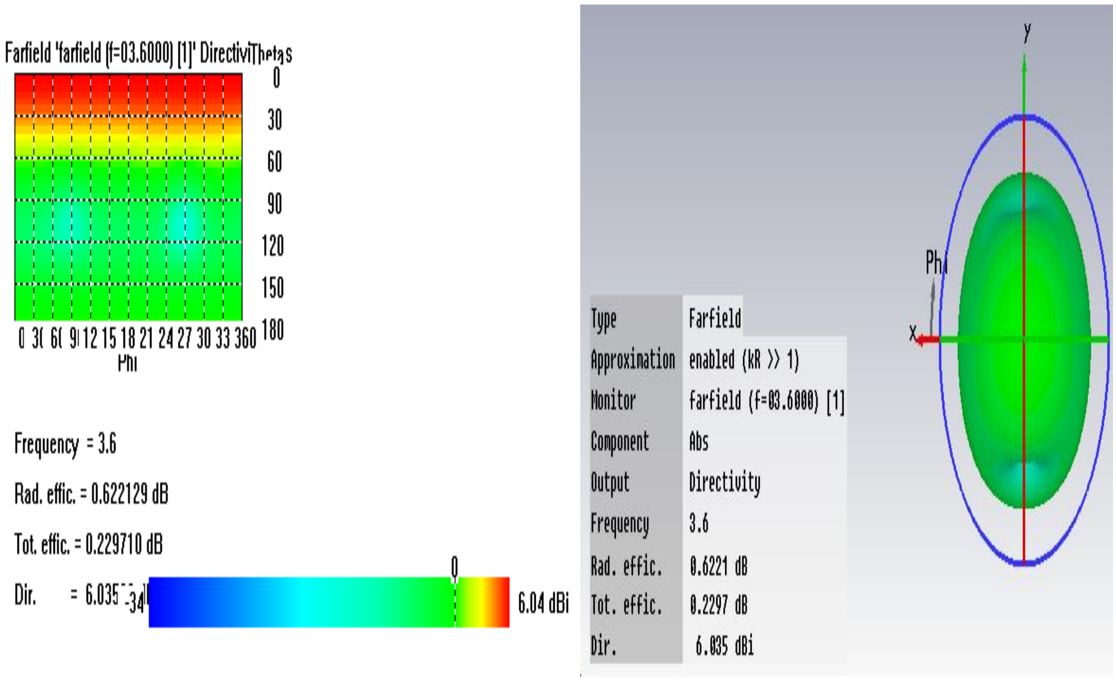


Fig 4.4 Directivity (2D and 3D view) at 3.6 GHz

4.1.5 Gain

The radiation pattern of gain at 3.62 GHz is shown in Fig. 4.5. The radiation pattern shown below is omnidirectional and the main lobe is directed at 359 degree angle. The angular beam width obtained is 89.9 degree and the main lobe magnitude is 6.7 dB.

In Fig. 4.6 the 3D view of gain at 5.772 GHz is discussed. In this design the gain comes out to be 6.388 dBi. The gain obtained in this design is more than the isotropic antenna which radiates in all directions equally. This antenna is more directional therefore it has applications in WLAN and WiMAX applications.

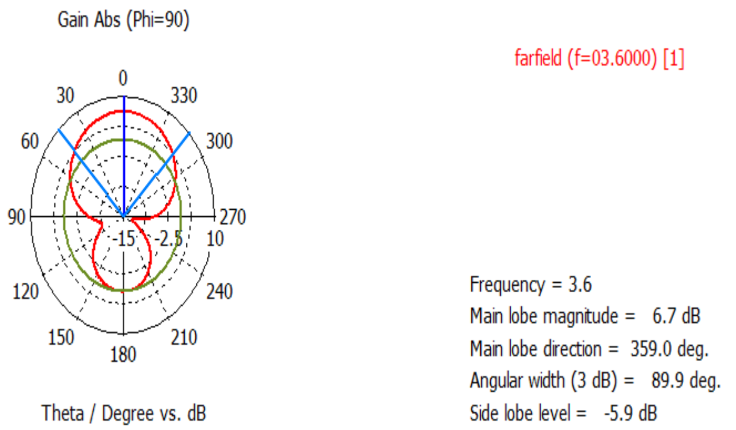


Fig. 4.5 Radiation pattern of Gain at 3.6 GHz

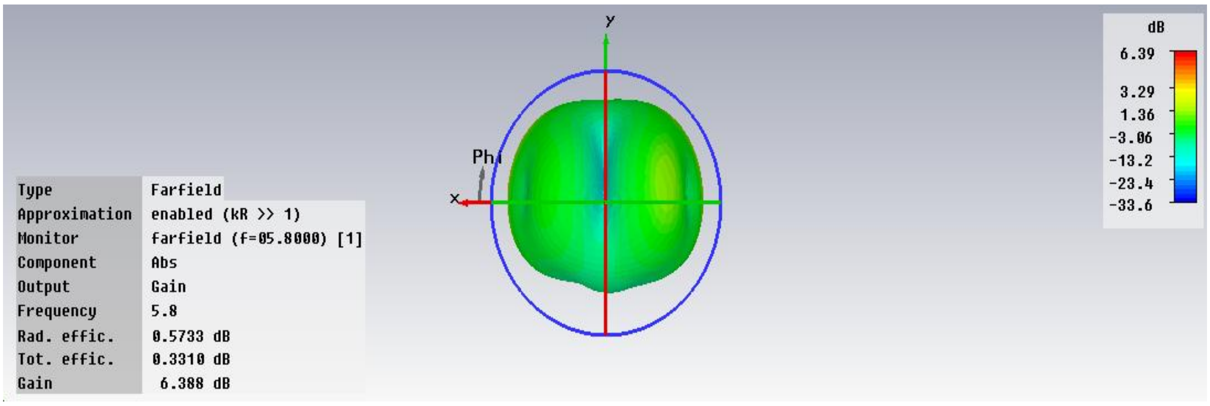


Fig. 4.6 Gain (3D view) at 5.8 GHz

4.1.6 Surface Current

The surface current at both the resonating frequencies are shown. The current is maximum at the centre of the patch and at the edges of the rectangular slot as shown in Fig. 4.7 and 4.8 by the red arrows. Basically the current intensity is shown by the current distribution. The current should be maximum at the centre of the patch and minimum at edges which are as obtained in this case. The lower resonant frequency is due to the slot which has been cut in the ground and upper resonant frequency is due to patch.

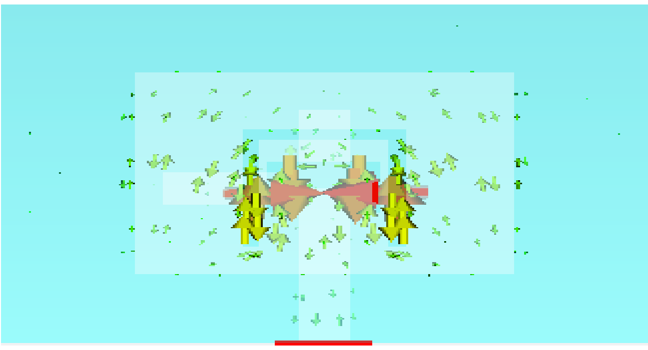


Fig. 4.7 Current Distribution at 3.6 GHz

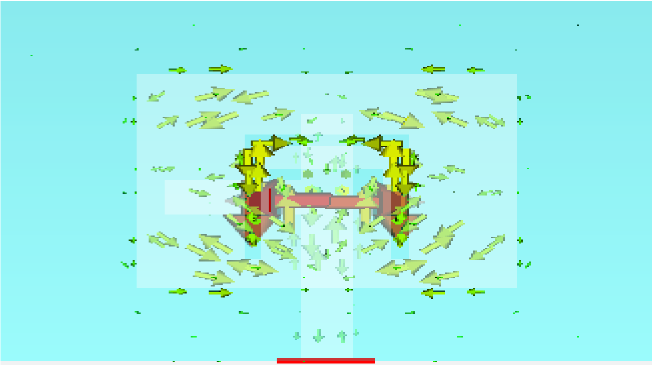


Fig. 4.8 Current Distribution at 5.8 GHz

Conclusion

In this above design U-slot is cut in the ground as well as on the patch. The dimensions of the slot, ground, patch etc. are calculated using transmission line model as discussed in chapter (using equations (1.1), (1.4), (1.7), (1.8)). The antenna is resonating at 3.62 GHz and 5.772 GHz. The bandwidth, VSWR and other parameters shows good results. Due to U-slot which is cut in the patch, the dual band is obtained. The Smith chart has also two circles showing that it is a dual band antenna. This antenna has applications in WiMAX and WLAN bands respectively.

CHAPTER 5

5. MIROSTRIP STACKED PATCH APERTURE COUPLED ANTENNA AT 5.8 GHZ

In this chapter performance to improve Bandwidth and comparison of single band aperture coupled microstrip antenna and stacked patch aperture coupled microstrip antenna operating at 5.8 GHz has been discussed and the dimensions of antenna are calculated using transmission line model as discussed in chapter 1 from equations 1.1 to 1.8 [5]. This antenna has applications in WLAN and WiMAX applications. In stacking, the multilayer structure is considered. In this design the upper layer and upper patch are of same dimensions as lower substrate and lower patch. There is improvement in bandwidth of nearly 80%. Therefore stacking is preferred over single layered microstrip antenna. The comparison of different parameters of both the antennas is discussed in the last of the chapter. The design is simulated using CST (Computer Simulation Technology) 2010 Microwave Studio software.

5.1 Antenna Design

The design of the antenna is as shown below. The dimensions of ground, substrate and patch of the design operating at 5.8 GHz frequency are calculated using transmission line model [5]

Front View

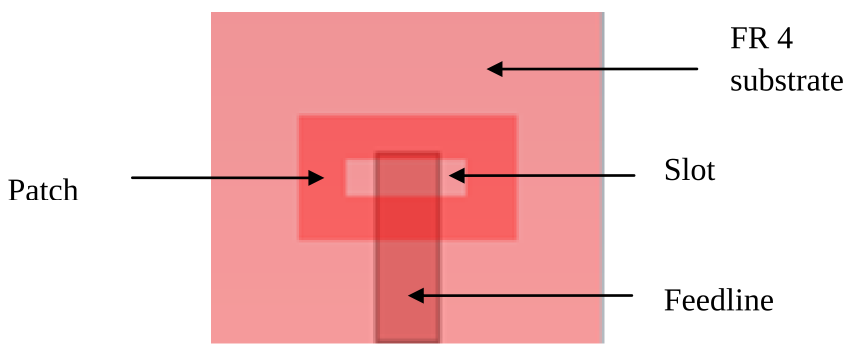


Fig. 5.1 Front view of Antenna

Perspective and Back view

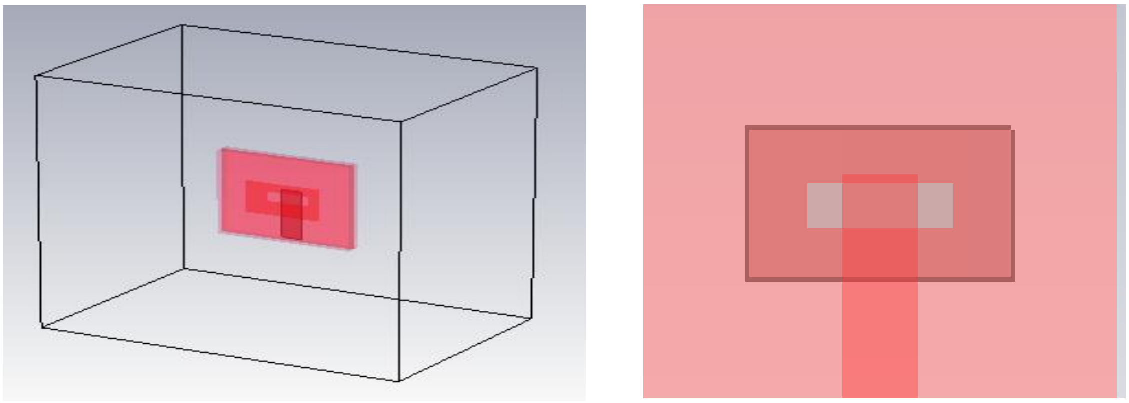


Fig. 5.2 Perspective view and back view of Antenna

5.2 Return loss and Bandwidth

Fig. 5.3 shows the return loss (S_{11}) for the designed antenna which is -29.39 dB. The resonating frequency of the designed antenna is 5.8 GHz. The coupling will be more if the return loss will be more negative and this shows that the matching is good. The gain and directivity of the antenna will be more in a particular direction. The antenna has bandwidth of 293 MHz. The formula for calculating return loss is - $20\ log_{10}\,\rho$. This antenna has applications in WiMAX and WLAN bands.

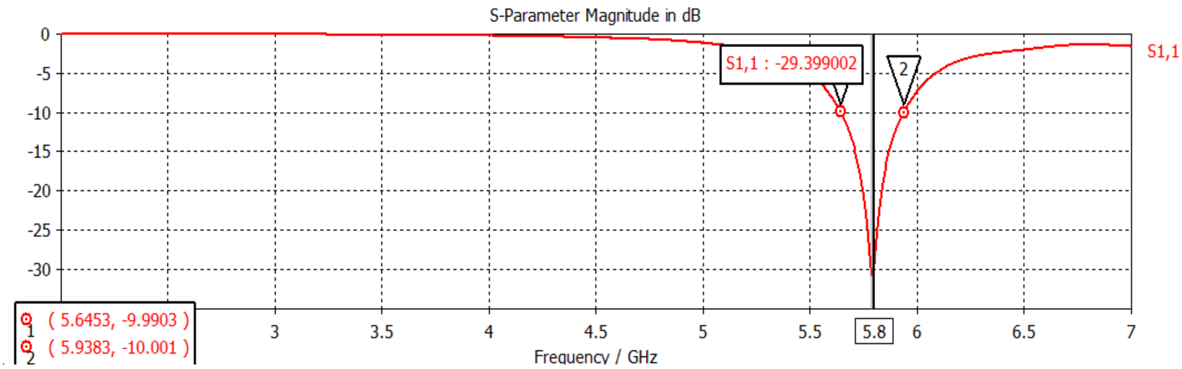


Fig. 5.3 Return loss S_{11} (in dB) at 5.8 GHz

5.3 Smith Chart

In Fig. 5.4 the Smith Chart is shown. The Smith Chart shows the variation of antenna impedance with frequency. The length of the aperture controls the locus of the Smith Chart and as the length increases the impedance locus also increases. In Smith chart the upper part is inductive and lower part is capacitive and centre circles are constant resistance circles. The impedance is complex. The locus should be large enough so that it can pass through the centre of the Smith Chart and this shows the proper impedance matching.

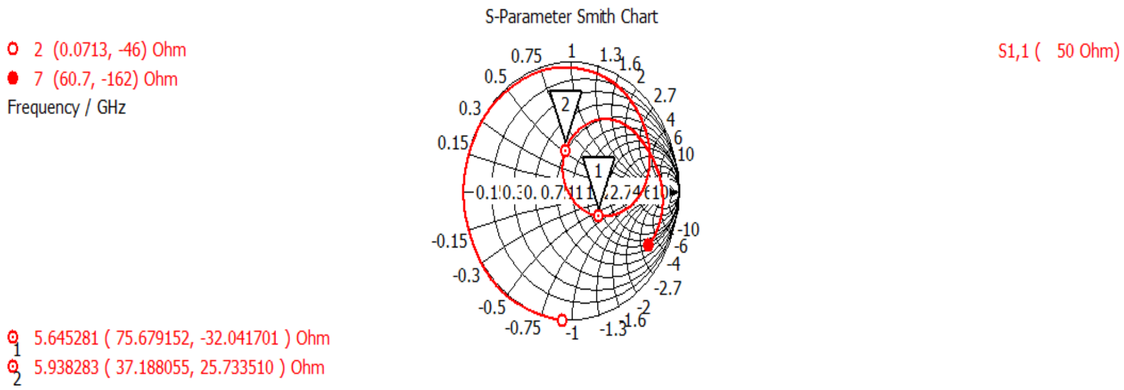


Fig. 5.4 Smith chart at 5.8 Ghz

5.4 VSWR

When both the transmitter and the antenna are connected through the feedline, the impedance matching of both the transmitter and the antenna should be proper so that the maximum transfer of energy takes place. The waves due to mismatch come back and are called reflected waves. The standing waves are formed due to interaction between the reflected waves and the forward waves. Ideally the value of VSWR should be in between 1 and 2 and in this case it is 1.07 which is satisfying the criteria. Ideal matching is not possible and therefore the mismatch is in the ratio of 1:1.07 which is very less.

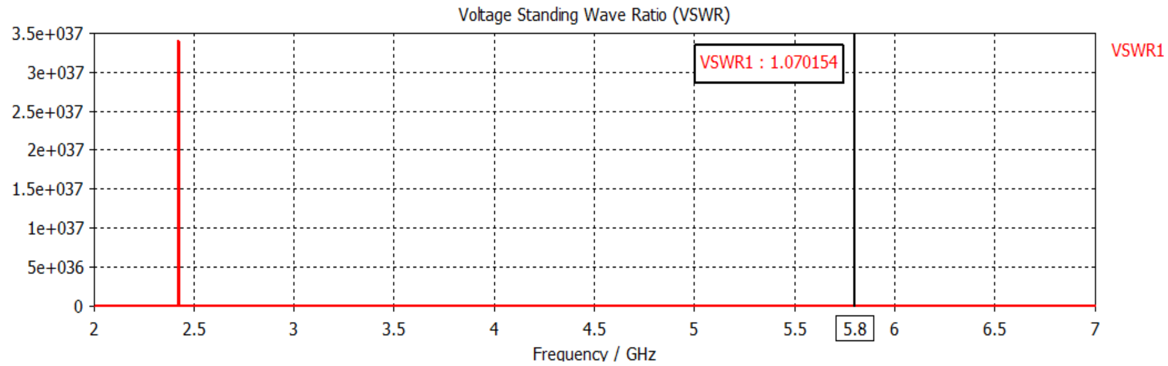


Fig. 5.5 VSWR

5.5 Directivity

In the Fig. 5.6 and 5.7 the 3D view and 2D view of directivity are shown. The value of directivity comes out to be 5.576 dBi which is good because generally the value of directivity should be greater than 5 dBi. The simulated antenna radiates more in one direction which is the direction of the main lobe in comparison to the isotropic antenna radiating in all the directions equally and it is nearly 100 times greater.

The 2D view shows the directivity at every value of theta and phi.

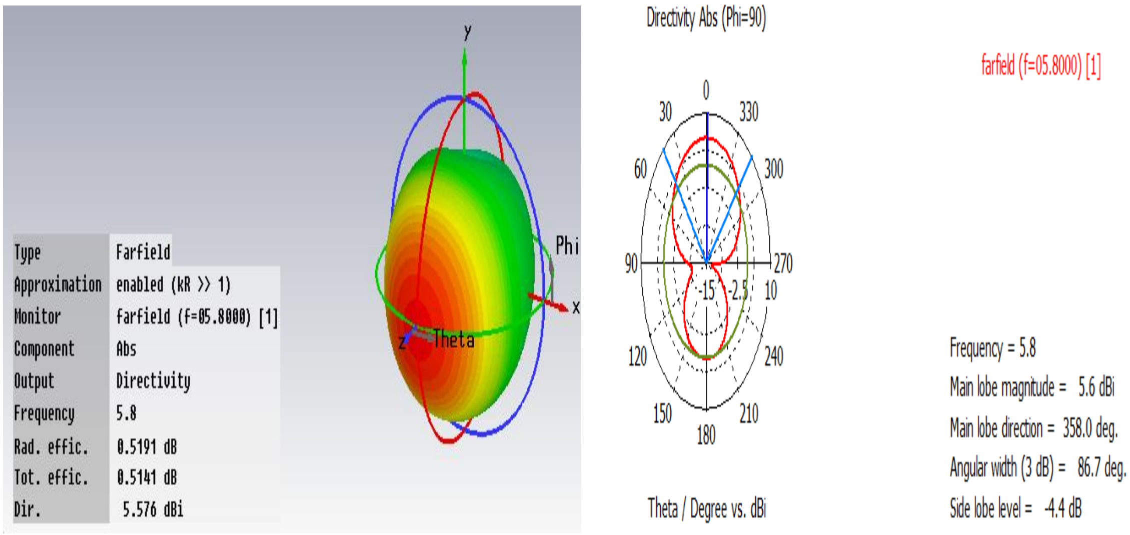


Fig. 5.6 Directivity (3D view) at 5.8 GHz

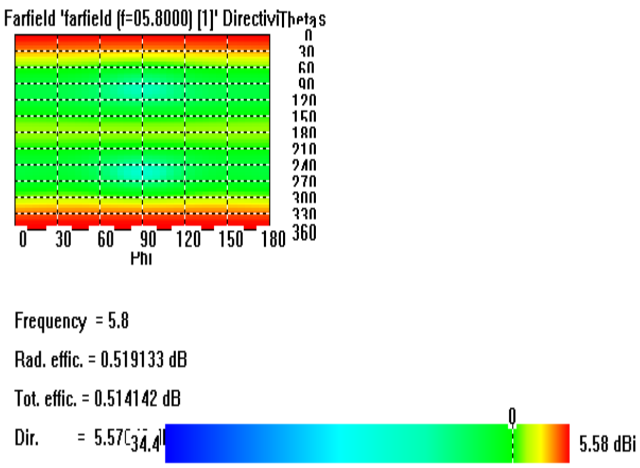


Fig. 5.7 2D view of Directivity

5.6 Gain

In Fig. 5.8 and 5.9 the 3D view and radiation pattern of gain are discussed. The gain of designed antenna comes out to be 6.096 dBi. The gain obtained in this design is more than the isotropic antenna which radiates in all directions equally. This shows that the proposed antenna has more gain therefore it will be more directional. The bandwidth of this antenna is good and finds its application in WLAN and WiMAX.

The polar plot shown in Fig. 5.9 has gain 6.096 dBi and operating frequency is 5.8 GHz. The radiation pattern in the polar plot is omnidirectional and the main lobe is directed at 358 degree angle. The angular beam width obtained is 86.7 degree and the main lobe magnitude is 6.1 dB.

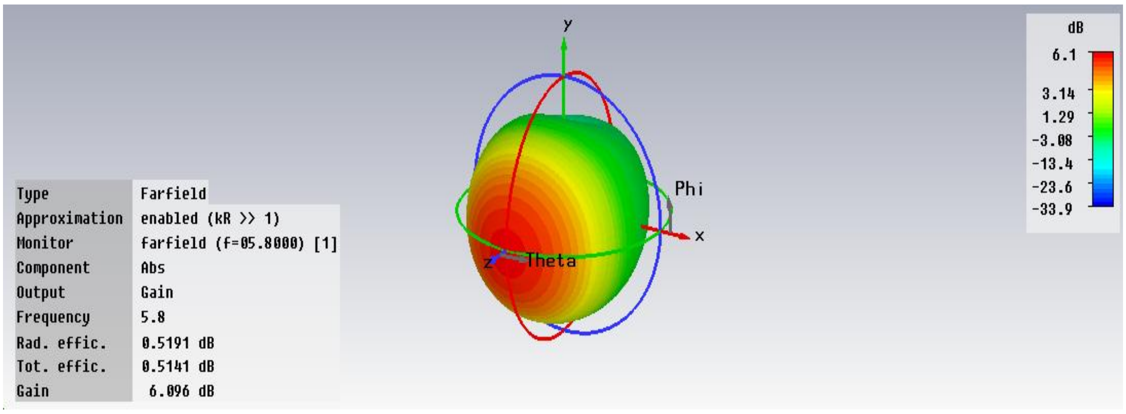


Fig. 5.8 Gain (3D view) at 5.8 GHz

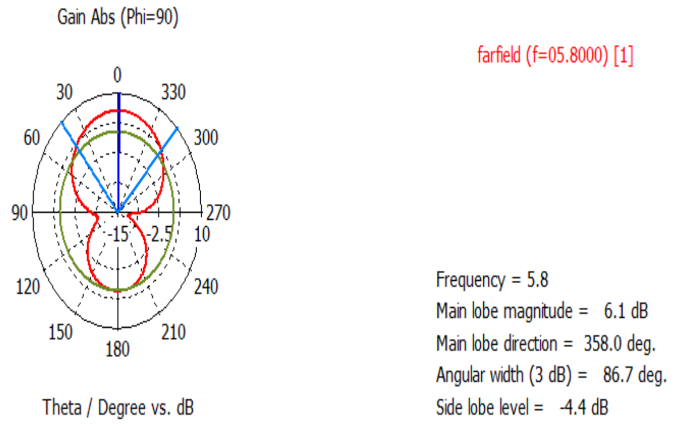


Fig. 5.9 Radiation pattern of gain at 5.8 GHz

5.7 Stacked Microstrip Patch Antenna

As discussed earlier stacked antennas lead to an improved performance so simple aperture coupled microstrip antenna and stacked patch aperture coupled microstrip antenna are compared. In stacking the layer is placed over the top layer and this increases the bandwidth of the antenna. In our design the substrate and the patch of same dielectric constant and same dimensions are placed over the top layer and the bandwidth is increased upto 80% as compared to unstacked one.

5.7.1 Stacked Antenna Design at 5.8 GHz

Bottom View

The bottom view and front view of the antenna are as shown in Fig. 5.10 and 5.11 respectively. The values of ground, patch, aperture and substrates are calculated using Transmission line model as discussed in chapter 1 (equations (4), (5), (6), (7)) [5].

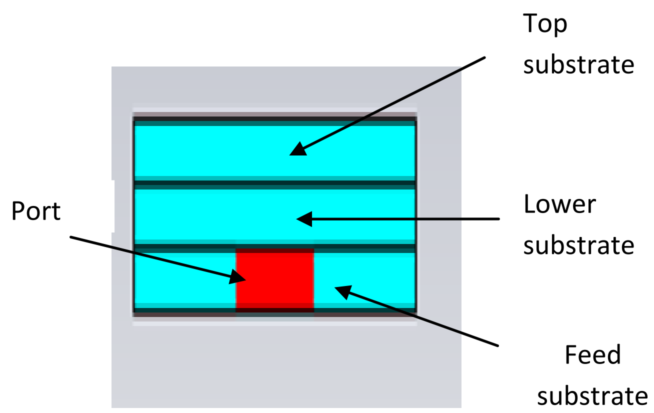


Fig. 5.10 Bottom view of Stacked Patch Antenna

Front view

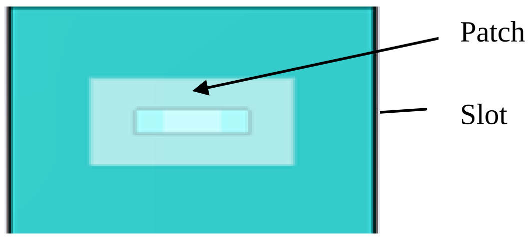


Fig. 5.11 Front view of Stacked Patch Antenna

Table 5.1 Antenna Dimensions

Dielectric constant of the substrate	4.4
Thickness of substrate	1.57 mm
Length of patch	8 mm
Width of patch	14 mm
Length of ground	21.192 mm
Width of ground	25.12 mm
Length of stub	6.5 mm
Width of Feed	4 mm
Length of aperture	2.4 mm
Width of aperture	7.74 mm

5.7.2 Return loss and Bandwidth

Fig. 5.12 shows the return loss (S_{11}) for the designed antenna which is -50 dB and is more as compared to the single layer microstrip antenna. The bandwidth of single layer microstrip antenna is 293 MHz and the bandwidth of stacked antenna comes out to be 539 MHz which is 80% greater than the single layered antenna. Therefore stacking is preferred over simple antenna. This Antenna exhibits applications for WiMAX and WLAN bands.

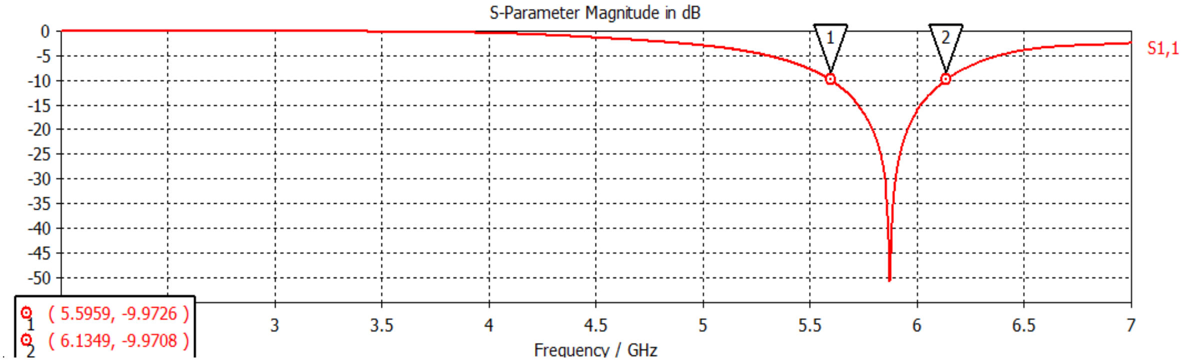


Fig. 5.12 Return loss S_{11} (in dB) of Stacked Antenna

5.7.3 Smith Chart

The following plot of Smith Chart shows the variation of impedance with frequency and this Fig. 5.13 of Smith Chart gives 50 ohm impedance which is accurate. The length of slot controls the locus of the Smith Chart and as the length of the aperture increases the size of the impedance locus also increases. The resonant frequency of the antenna is 5.8 GHz.

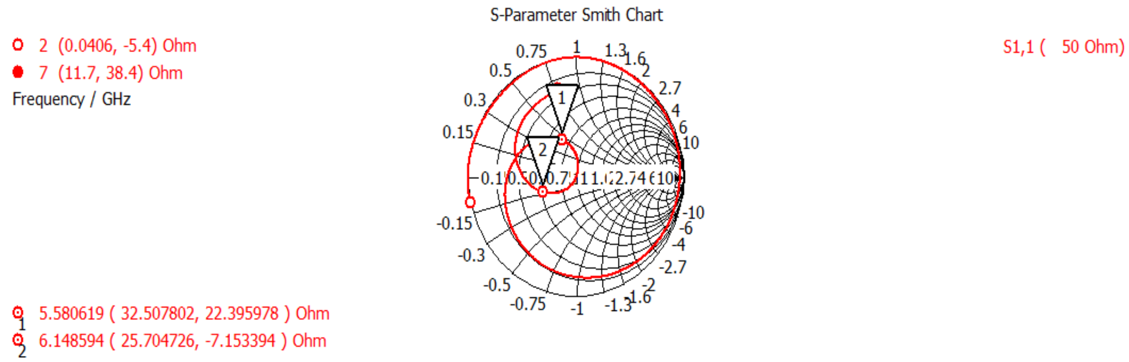


Fig. 5.13 Smith Chart of Stacked Antenna at 5.8 GHz

5.7.4 Directivity of Designed Antenna

In the Fig. 5.13 3D view and radiation pattern of directivity are shown. The value of directivity comes out to be 6.209 dBi which is good because generally the value of directivity should be greater than 5 dBi. The simulated antenna radiates more in one direction which is the direction of the main lobe in comparison to the isotropic antenna radiating in all the directions equally and it is nearly 100 times greater.

In the polar plot of directivity it is observed that at 5.8 GHz the directivity is 5.553 dBi and omnidirectional radiation pattern is obtained which has main lobe directed at 3 degree angle and the value of angular beam width of 101.3 degree.

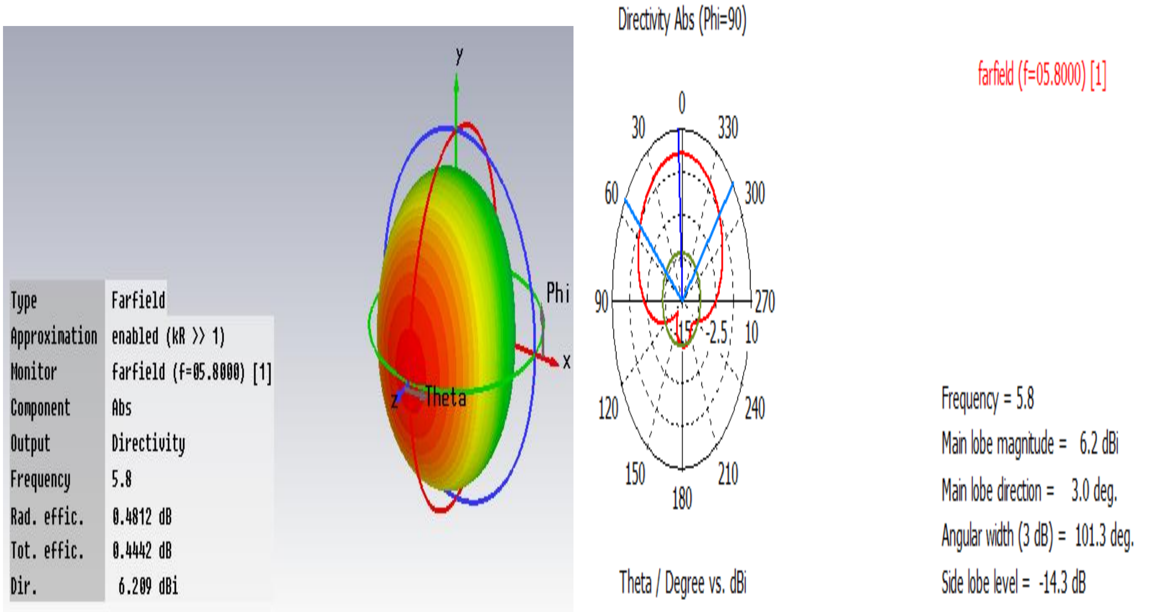


Fig. 5.14 Directivity (3D view) and polar plot of Stacked Antenna

5.7.5 Gain of Designed Antenna

In Fig. 5.15 the 3D view and radiation pattern of gain are discussed. In this design the gain comes out to be 6.7 dB which is more than single layered antenna. The gain obtained in this design is more than the isotropic antenna which radiates in all directions equally. This shows that the proposed antenna has more gain therefore it will be more directional. The bandwidth of this antenna is good and its application is in WLAN and WiMAX.

The polar plot shown in fig. 5.15 has gain 6.7 dBi and operating frequency is 5.8 GHz. The radiation pattern in the polar plot is omnidirectional and the main lobe is directed at 3 degree angle. The angular beam width obtained is 101.3 degree which is greater than single layered antenna and the main lobe magnitude is 6.7 dB which is greater than single layered antenna. Therefore stacking is preferred over simple microstrip patch antenna.

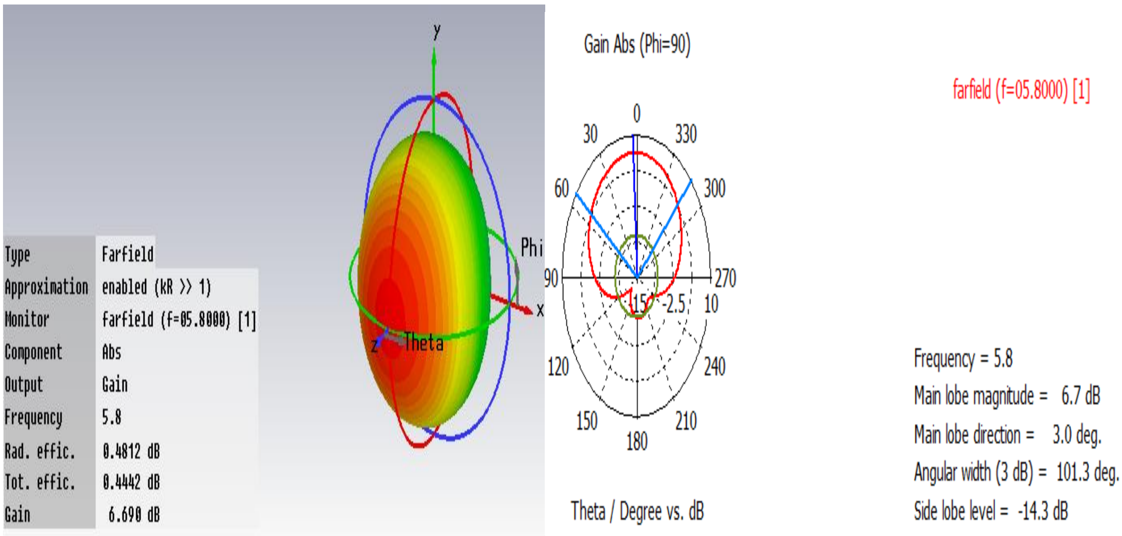


Fig. 5.15 Gain (3D view and polar plot) of Stacked Antenna

5.7.6 VSWR of the Stacked patch Antenna

When both the transmitter and the antenna are connected through the feedline, the impedance matching of both the transmitter and the antenna should be proper so that the maximum transfer of energy takes place. The waves due to mismatch come back and are called reflected waves. The standing waves are formed due to interaction between the reflected waves and the forward waves. Ideally the value of VSWR should be in between 1 and 2 and in this case it is 1.01 which is satisfying the criteria. Ideal matching is not possible and therefore the mismatch is in the ratio of 1:1.01 which is very less and also it is less than single layered antenna which shows that matching in case of stacking is better.

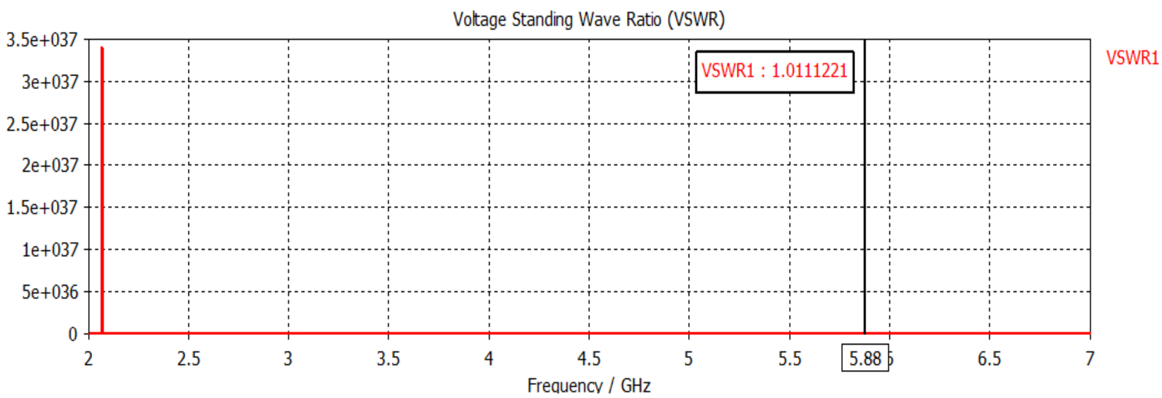


Fig. 5.16 VSWR of Stacked patch Antenna

5.7.7 Surface current of Stacked Antenna

At the frequency of 5.8 GHz peak surface current is shown. The current is maximum at the centre of the patch and at the edges of the rectangular slot as shown in Fig. 5.17 by the red arrows. This corresponds to 5.8 GHz band because dimensions of patch are calculated for 5.8GHz resonant frequency.

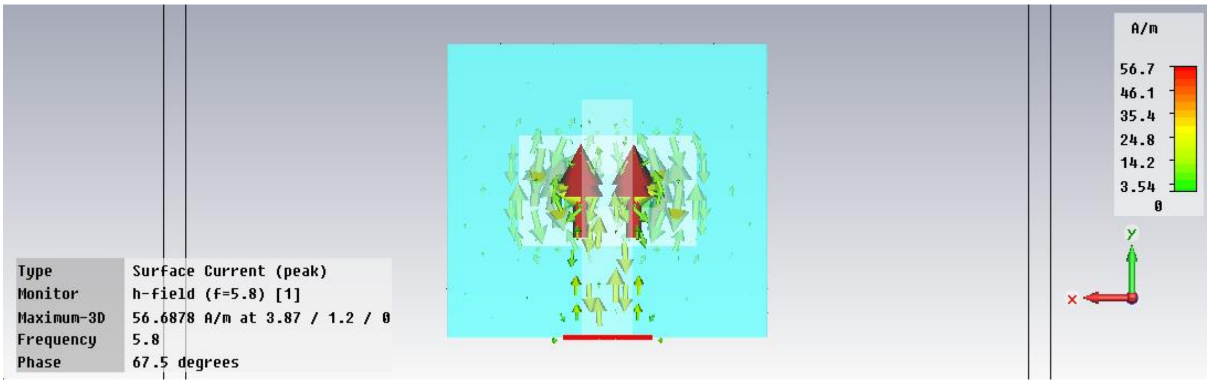


Fig. 5.17 Surface Current at 5.8 GHz

On the basis of above discussion, following comparison is made:-

Table 5.2 Comparison between simple and stacked aperture coupled microstrip antenna

Parameters	Single layer	Stacked antenna
Operating frequency	5.8 GHz	5.88 GHz
Return Loss	29.399 dB	45.45 dB
Bandwidth	290 MHz	530 MHz
Gain	6.096 dBi	6.690 dBi
Directivity	5.576 dBi	5.553 dBi
VSWR	1.07	1.01

5.8 Conclusion

The above design shows that the stacked antenna is better as compared to the single layer MSA antenna because it gives 80% more bandwidth. Stacking is basically used to improve the bandwidth of the antenna. If the two layers of stacked antenna are disturbing the mutual coupling of each other then dual band will be obtained and if there is proper spacing between the two layers then broadband antenna will be achieved.

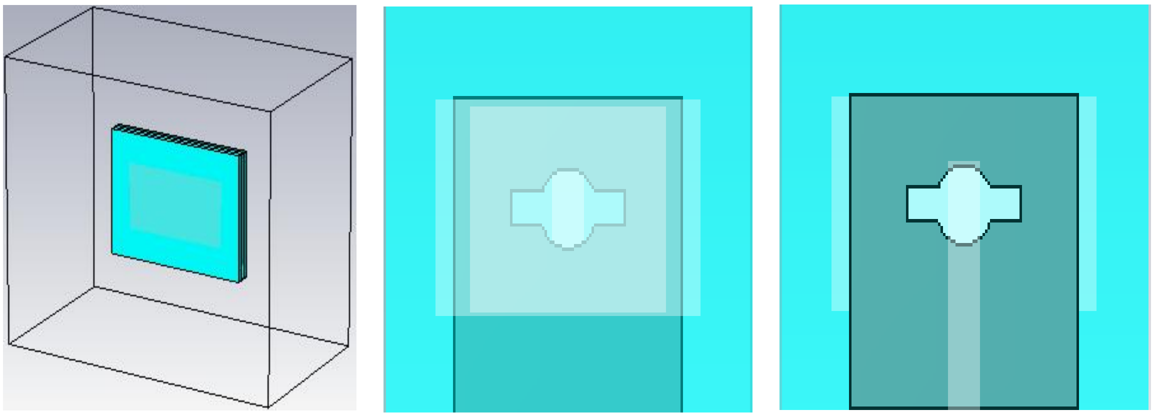
CHAPTER 6

6. DUAL BAND APERTURE COUPLED MICROSTRIP STACKED PATCH ANTENNA AT 2.4 GHZ AND 5.2 GHZ

In this chapter dual band aperture coupled microstrip stacked patch antenna has been discussed. Stacking is done to further improve the Bandwidth of dual band antenna. The antenna is operating at two resonant frequencies 2.4 GHz and 5.2 GHz. This is the range of WLAN band. The antenna is simulated using CST (Computer Simulation Technology) 2010 Microwave Studio.

6.1 Antenna Design

In this design stacking is used. Stacking is the method in which a substrate and a patch is placed on the layer allready having the substrate and the patch. Both the substrates may or may not have the same dielectric constant. Stacking helps to improve the bandwidth of the antenna. If the spacing is proper between the two layers then the broadband antenna is achieved and if spacing is not proper the dual band will be achieved.



(a)Perspective view **(b)Front view** **(c)Back view**

Fig. 6.1 Different views of Designed Antenna

The antenna is designed using the equations discussed in Chapter 1. The dimensions of ground, patch, aperture and feedline are calculated using these equations.

Table 6.1 Antenna Dimensions

Dielectric constant of the material	4.4
Length of lower patch	19.5mm
Width of lower patch	25.35mm

Length of upper patch	20.46mm
Width of upper patch	34.46mm
Length of substrate	38.88mm
Width of substrate	47.88mm
Length of aperture	3.2mm
Width of aperture	15mm
Width of feedline	4mm
Width of ground	29.88mm
Length if stub	4.14mm

6.2 Return Loss and Bandwidth

Fig. 6.2 has return loss (S_{11}) -29 dB and -24 dB respectively for the designed antenna operating at 2.4 GHz and 5.2 GHz. The coupling will be more if the return loss will be more negative and this shows that the matching is good. The gain and directivity of the antenna will be more in a particular direction and this is what needed for WLAN and WiMAX. This antenna has bandwidth of 72 MHz at 2.4 GHz and 165 MHz at 5.2 GHz.

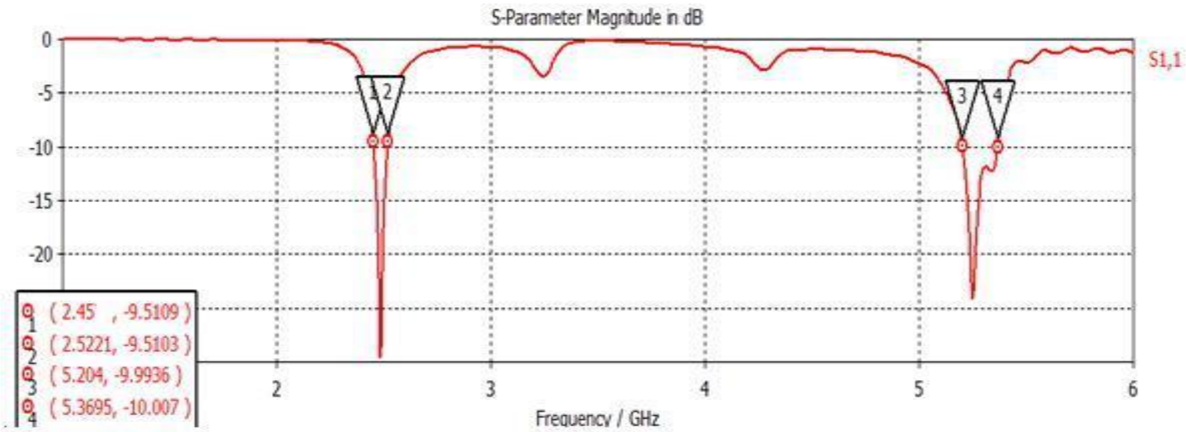


Fig. 6.2 Return Loss S_{11} (in dB)

6.3 Smith Chart

In Fig. 6.3 the Smith Chart is shown. The Smith Chart shows the variation of antenna impedance with frequency. The length of the aperture controls the locus of the Smith

Chart and as the length increases the impedance locus also increases. In Smith chart the upper part is inductive and lower part is capacitive and centre circles are constant resistance circles. The impedance is complex. The locus should be large enough so that it can pass through the centre of the Smith Chart and this shows the proper impedance matching. The upper circle corresponds to lower resonant frequency and lower circle corresponds to upper resonant frequency 5.2 GHz.

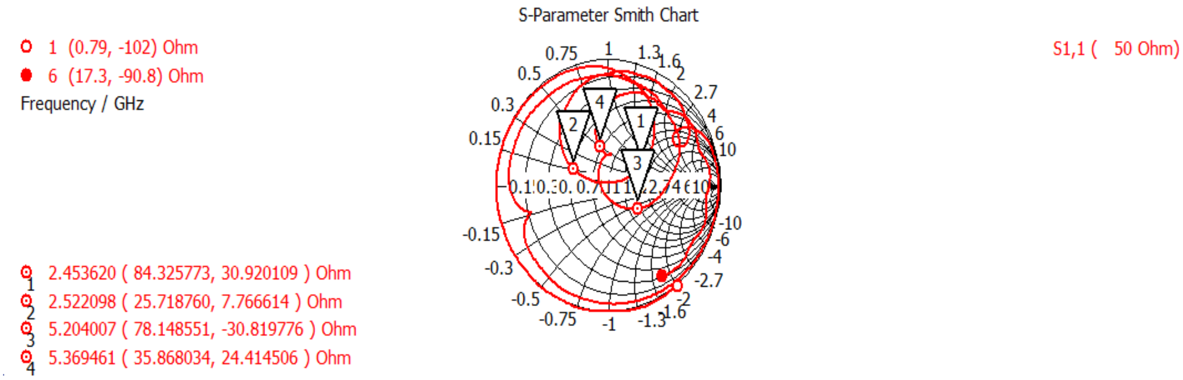


Fig. 6.3 Smith Chart of the Antenna

6.4 Directivity

The 3D plot of directivity is as shown in fig. 6.4 and 6.5 which is representing the amount of radiation intensity and in this case it is equal to 3.8 dBi and 4.2 dBi for 2.4 GHz and 5.2 GHz respectively. The value of directivity should be approximately 5 dBi and it is near about in this case. This antenna is directional and operating in one particular direction in comparison to the antenna which radiates equally in all the directions like isotropic antenna. This value of directivity has application in WiMAX and WLAN bands.

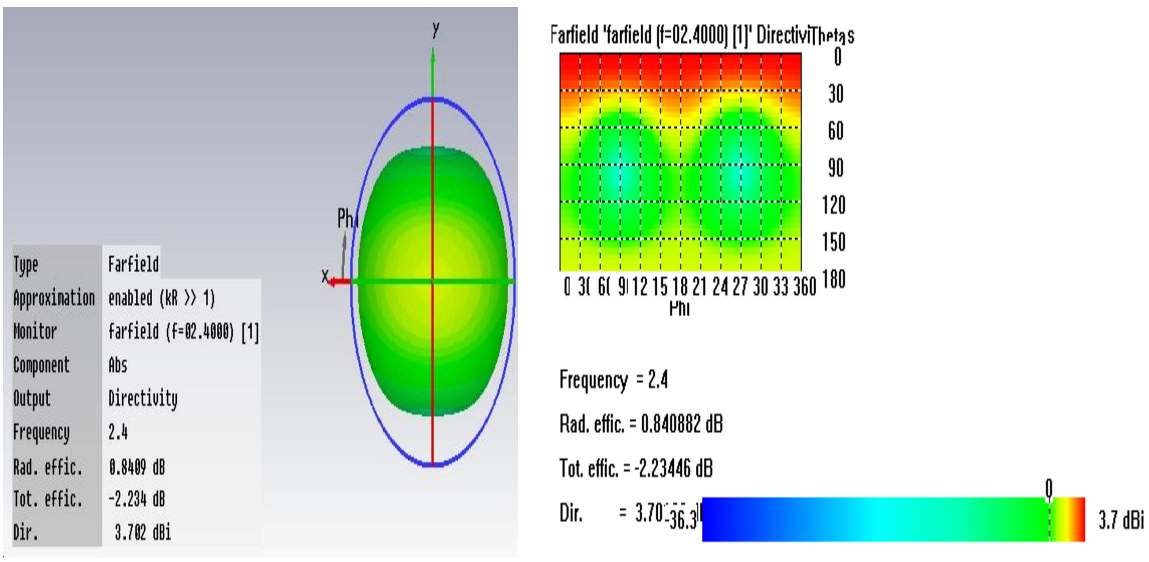


Fig. 6.4 Directivity (3D view and 2D view) at 2.4 GHz

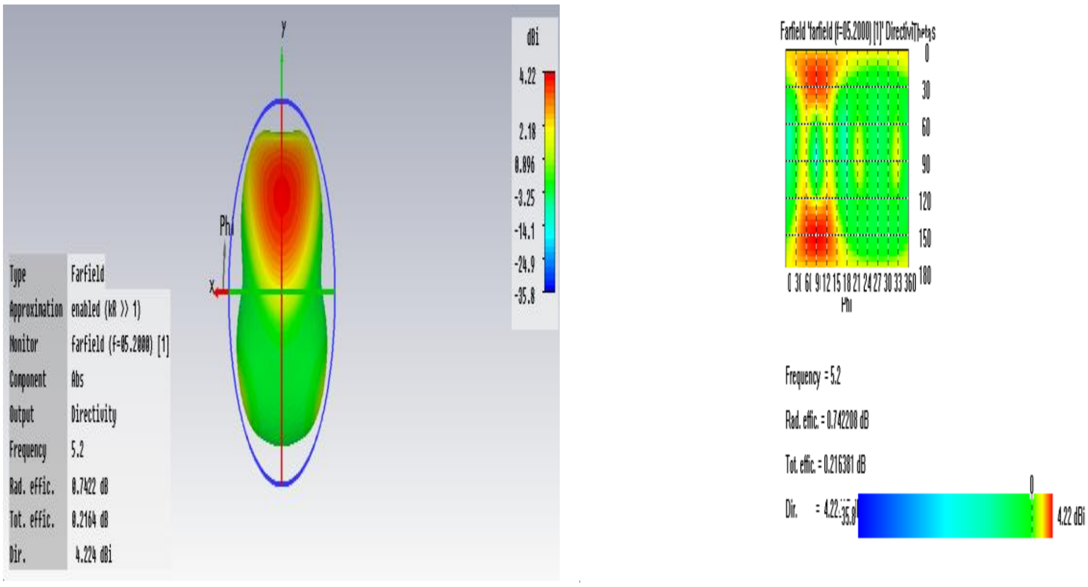


Fig. 6.5 Directivity (3D view and 2D view) at 5.2 GHz

6.5 Gain

In fig.6.6 and 6.7 the 2D and 3D view of gain at 2.4 GHz and 5.2 GHz is shown. In this design the gain comes out to be 4.6 dBi and 5 dBi respectively. This shows that the proposed antenna has 4.6 dBi gain therefore it will be more directional. This antenna is more directional therefore it has applications in WLAN and WiMAX applications.

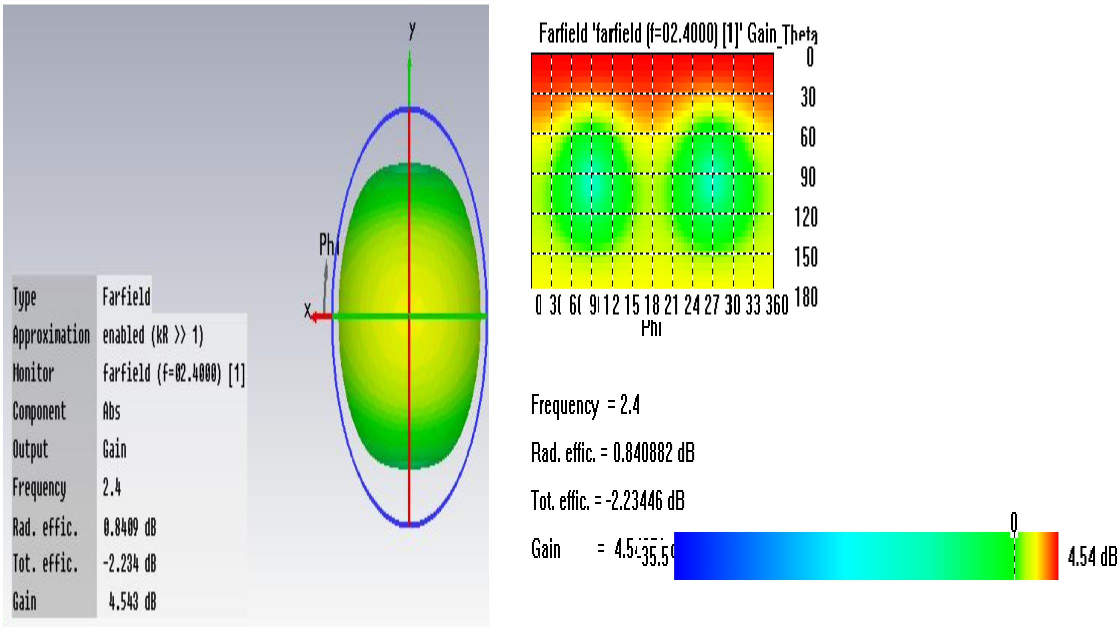


Fig. 6.6 Gain (3D view and 2D view) at 2.4 GHz

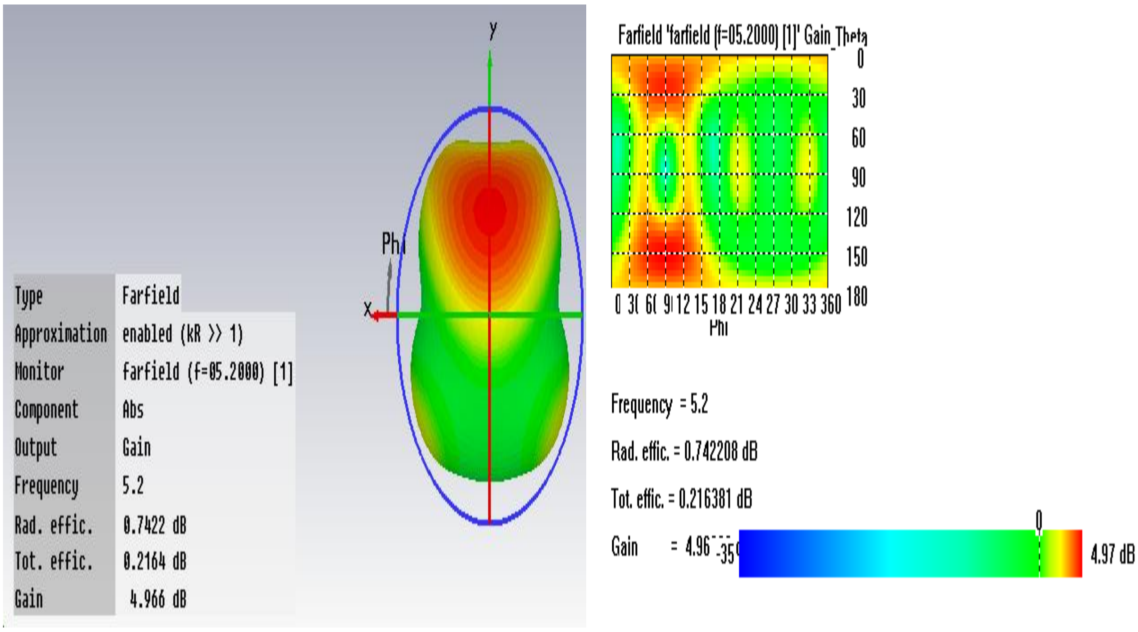


Fig. 6.7 Gain (3D view and 2D view) at 5.2 GHz

6.6 Surface Current at 2.4 GHz and 5.2 GHz

The surface current at both the resonating frequencies are shown. The current is maximum at the centre of the patch and at the edges of the rectangular slot as shown in Fig. 6.8 and 6.9 by the red arrows.

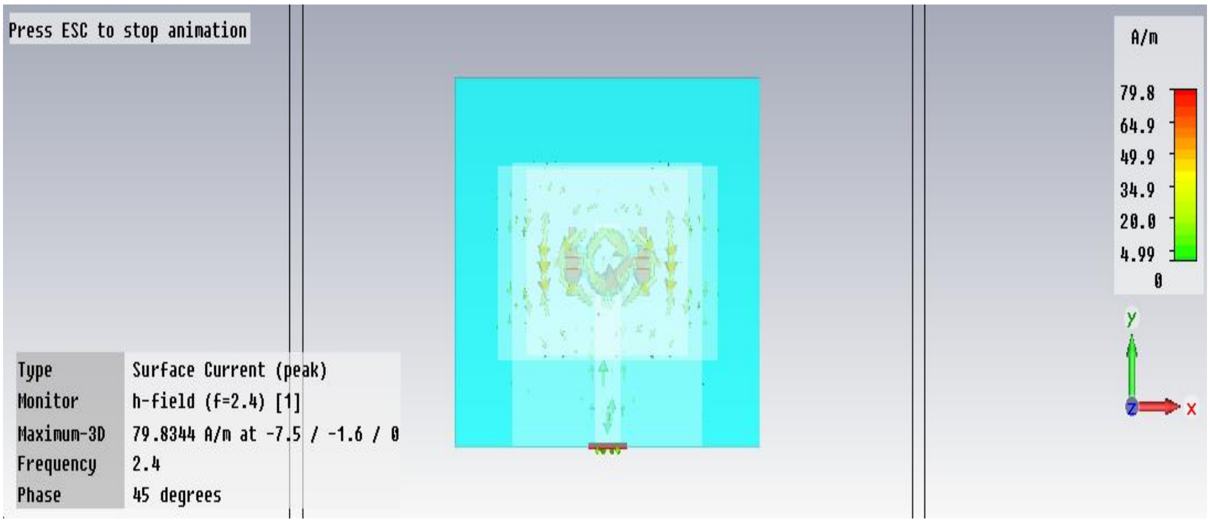


Fig. 6.8 Surface Current at 2.4 GHz

The current distribution is shown below for 5.2 GHz. The current is maximum at the centre of the patch and at the edges of the slot. The upper frequency band is due to the lower patch and the lower resonant frequency is due to the upper patch. In stacking the lower frequency band is responsible for resonating frequencies and current and the upper frequency band is responsible for improvement in Bandwidth.

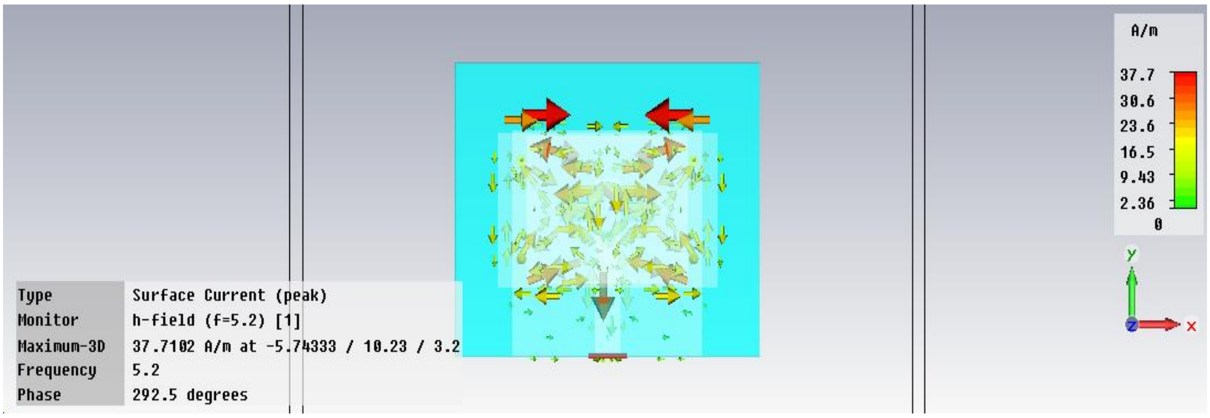


Fig. 6.9 Surface Current at 5.2 GHz

Conclusion

In this design dual band is obtained because stacking is used and stacking also improves the bandwidth. If the spacing between two substrates is large enough then antenna is obtained with large bandwidth and if there is no spacing between the two layers then dual band antenna is obtained because they will disturb the mutual coupling of each other. Two resonant frequencies are obtained 2.4 GHz and 5.2 GHz. In this design the ground has also been reduced as it helps to reduce the harmonics. Various parameters of antenna have shown good performance characteristics.

CHAPTER 7

7. DUAL BAND APERTURE COUPLED MICROSTRIP STACKED PATCH ANTENNA WITH DEFECTED GROUND STRUCTURES FOR WLAN AND WIMAX APPLICATIONS

In this chapter Aperture coupled microstrip stacked patch antenna with defected ground structures has been discussed. The dual band is achieved in this design using stacking and the antenna operates at 2.4 GHz and 5.8 GHz. At 5.8 GHz the wide band is obtained which is covering both the WLAN and WiMAX bands. The defected ground structure reduces the antenna size and mutual coupling of the two antennas and also reduces the harmonics of the antenna.

7.1 Antenna Design

In this design the stacking is used which will give dual band and also improve the bandwidth of the antenna. Stacking is the method in which a substrate of same or different dielectric constant and dimensions are used and is placed above the lower layer which has substrate and patch. The patch can also have same or different dimensions. In this case the substrate has same dimensions and dielectric constant but the patch has different dimensions. The upper patch has dimensions greater than the lower patch and the upper patch will give lower frequency band and lower patch will give upper frequency band. If the spacing between the two substrates is proper then the broadband is achieved and if there is no spacing between the substrates then both the antennas will disturb the mutual coupling of each other which will result in dual band.

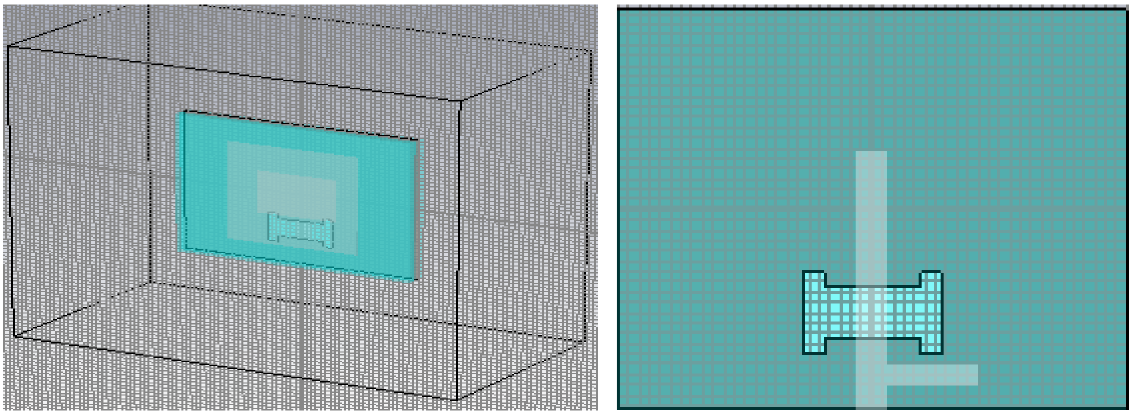


Fig. 7.1 Perspective view and back view of Antenna

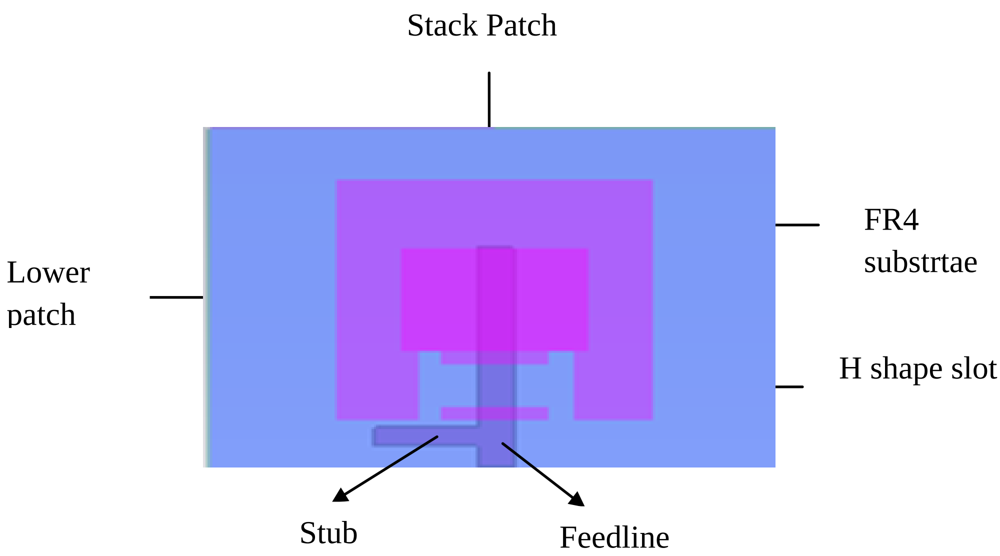


Fig. 7.2 Front view of the Antenna

Table 7.1 Antenna Dimensions

The dimensions of the antenna are as follows and are calculated using equations 1.1 to 1.8.

Dielectric constant of the material	4.4
Thickness of substrate	1.57 mm
Length of lower patch	11.772 mm
Width of lower patch	15.7 mm
Length of upper patch	27.46 mm
Width of upper patch	26.46 mm
Length of ground	38.88 mm
Width of ground	47.88 mm
Length of middle aperture	5 mm
Width of middle aperture	9 mm
Length of arms	8 mm

Width of left arms	2 mm
Length of stub	2 mm
Width of stub	8.5 mm
Width of feedline	3 mm

7.2 Return Loss and Bandwidth

Fig. 7.3 shows the return loss (S_{11}) for the designed antenna operating at 2.4 GHz and 5.8 GHz and comes out to be -17.5 dB and -18 dB respectively. The coupling will be more if the return loss will be more negative and this shows that the matching is good. The gain and directivity of the antenna will be more in a particular direction. The antenna has bandwidth of 55 MHz at 2.4 GHz and 600 MHz (5210-5810) at 5.8 GHz. The formula for calculating return loss is - $20\, log_{10}\, \rho$. This antenna is useful in WLAN and WiMAX applications.

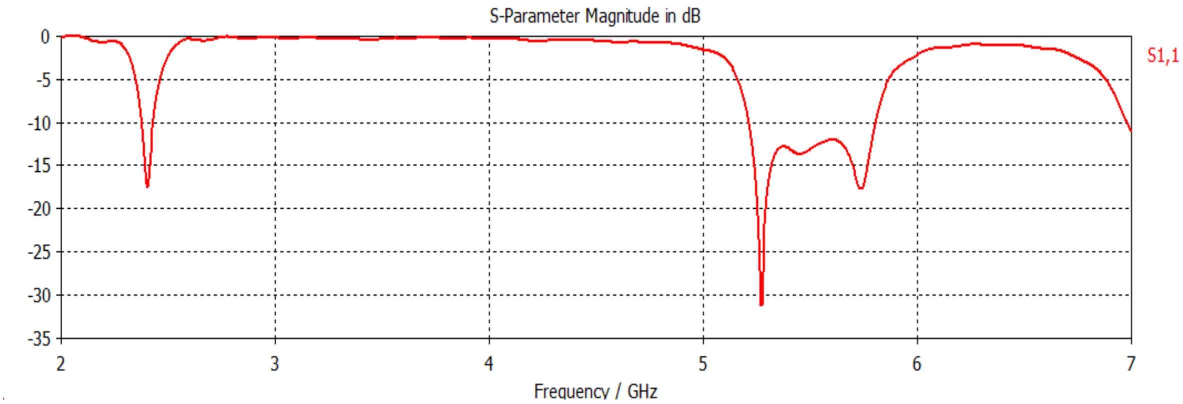


Fig. 7.3 Return loss S_{11} (in dB)

7.3 Smith Chart

In Fig. 7.4 the Smith Chart is shown. The Smith Chart shows the variation in antenna impedance with frequency. The length of the aperture has control on the size of the locus and as the length of the aperture increases the impedance locus also increases. The Smith Chart has two circles which show that dual band has been achieved in this design. The impedance is always complex in Smith Chart. In Smith chart the upper part is inductive and lower part is capacitive and centre circles are constant resistance circles. The locus should be large enough so that it can pass through the centre of the Smith Chart and this shows the proper impedance matching.

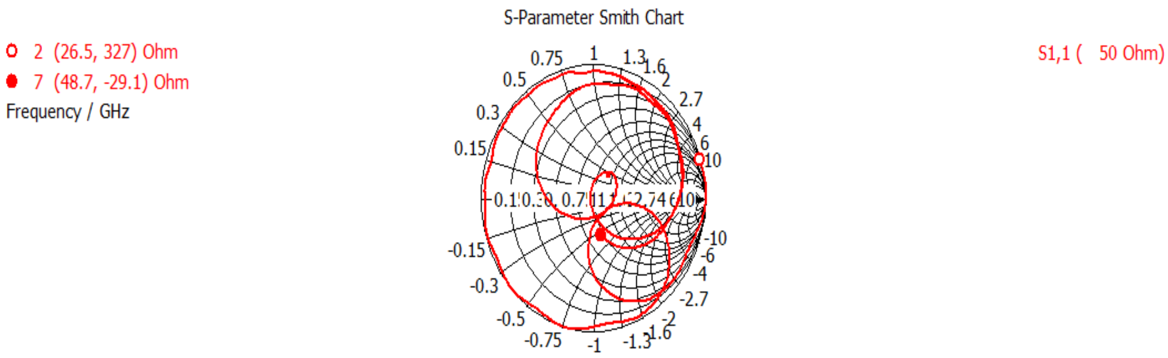


Fig. 7.4 Smith Chart

7.4 VSWR at 2.4 GHz

When both the transmitter and the antenna are connected through the feedline, the impedance matching of both the transmitter and the antenna should be proper so that the maximum transfer of energy takes place. The waves due to mismatch come back and are called reflected waves. The standing waves are formed due to interaction between the reflected waves and the forward waves. Ideally the value of VSWR should be in between 1 and 2 and in this case it is 1.327 which is satisfying the criteria.

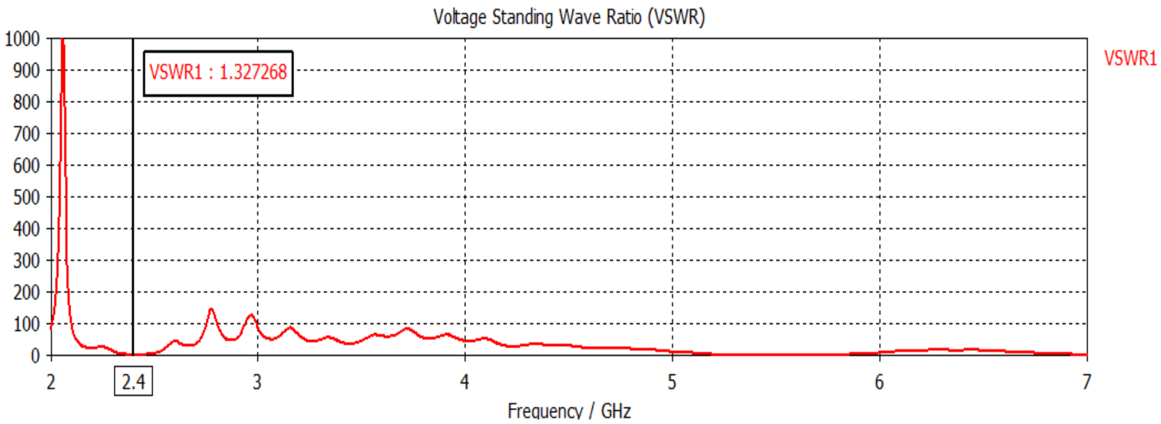


Fig. 7.5 VSWR at 2.4 GHz

7.5 Directivity at 2.4 GHz

Fig. 7.6 and 7.7 shows the 3D view and radiation pattern of the directivity of an antenna. The value of directivity comes out to be 5.587 dBi which is satisfactory because generally the value of directivity should be greater than 5 dBi. In the polar plot of directivity it is observed that at 2.4 GHz the directivity is 5.587 dBi and omnidirectional radiation pattern is obtained which has main lobe directed at 0 degree angle and the value of angular beam width of 100.5 degree. The main lobe has magnitude equal to 5.6dBi.

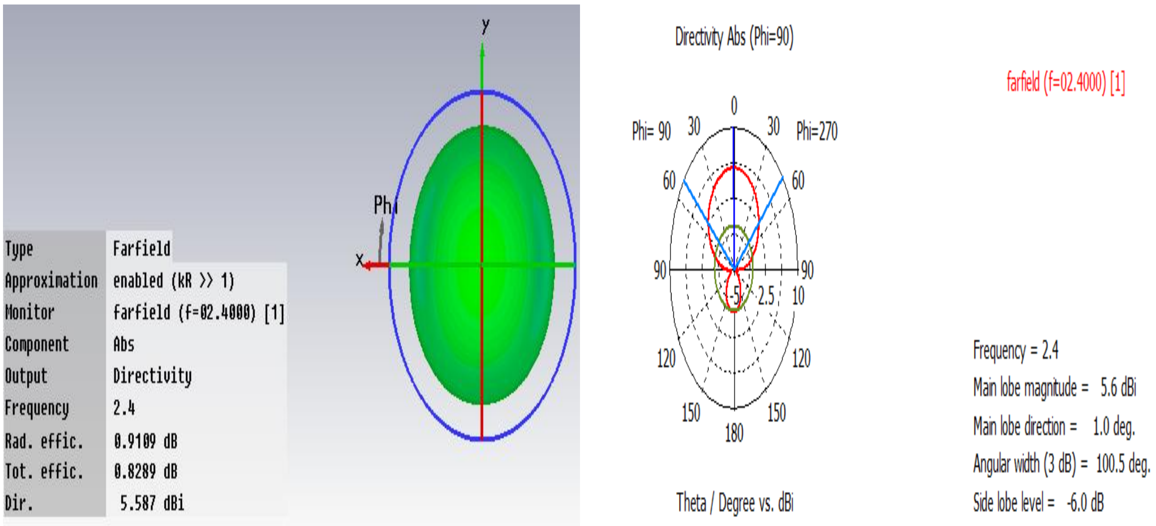


Fig. 7.6 Directivity (3D view and polar plot) at 2.4 GHz

7.6 Gain at 2.4 GHz

In Fig. 7.8 and 7.9 the 3D view and radiation pattern of gain of an aperture coupled microstrip stacked patch antenna has been discussed. The gain in this case is 6.498 dBi which is more than 5dBi. The bandwidth of this antenna is good and has applications in WLAN and WiMAX bands.

Fig. 7.9 shows the polar plot of gain with value 5.882 dBi and operating frequency is 2.4 GHz. The radiation pattern obtained is omnidirectional and the main lobe is directed at 0 degree angle. The angular beam width obtained is 100.5 degree and the magnitude of the main lobe 6.5 dB.

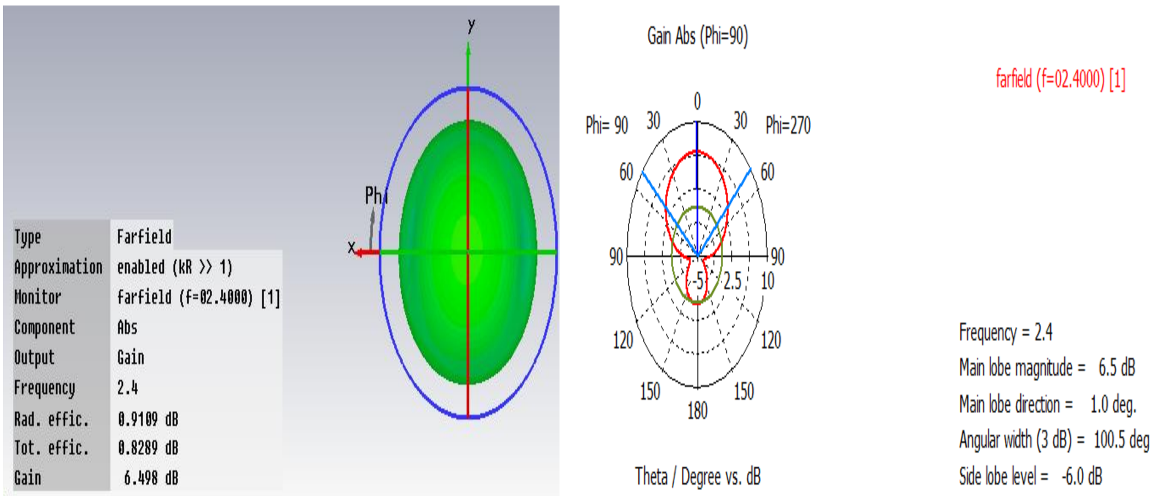


Fig. 7.7 Gain (3D view and polar plot) at 2.4 GHz

7.7 Current distribution at 2.4 GHz

At the frequency of 2.4 GHz peak surface current is shown in fig. 7.8. The maximum current is obtained at the upper patch as shown by red arrows because for lower frequency band upper patch is considered. Basically the current intensity is shown by the current distribution. The current should be maximum at the centre of the patch and minimum at edges which are achieved in this case.

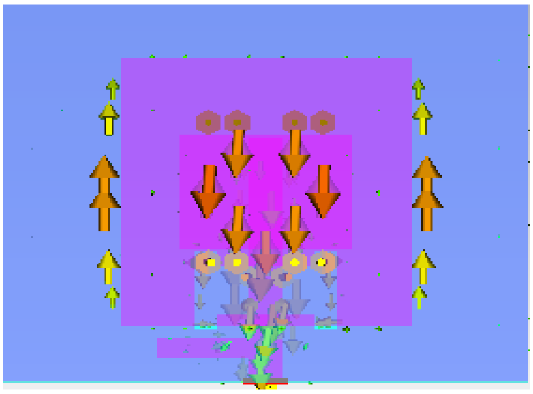


Fig. 7.8 Current distribution at 2.4 GHz

7.8 VSWR at 5.8 GHz

When both the transmitter and the antenna are connected through the feedline, the impedance matching should be proper in order to transfer maximum energy between the two. Due to mismatching the waves reflect back and are called reflected waves. The standing waves are formed due to interaction between the reflected waves and the forward waves. Ideally the value of VSWR should lie between 1 and 2 and in this case it is 1.806 which is satisfying the criteria.

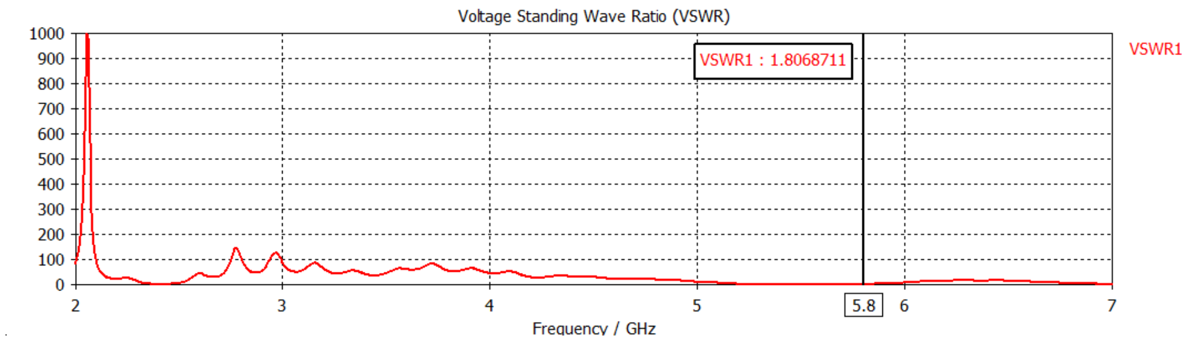


Fig. 7.9 VSWR at 5.8 GHz

7.9 Directivity at 5.8 GHz

The 3D view and the radiation pattern of the directivity of an antenna is shown in Fig. 7.10. The value of directivity is nearly equal to 5.035 dBi which is satisfactory. This antenna has good directivity and therefore used in WLAN and WiMAX applications.

The radiation pattern of directivity shows that at 5.8 GHz the directivity is 5.035 dBi and pattern is omnidirectional which has main lobe directed at 335 degree angle and the value of angular beam width of 82.4 degree. The main lobe has magnitude equal to 5dBi.

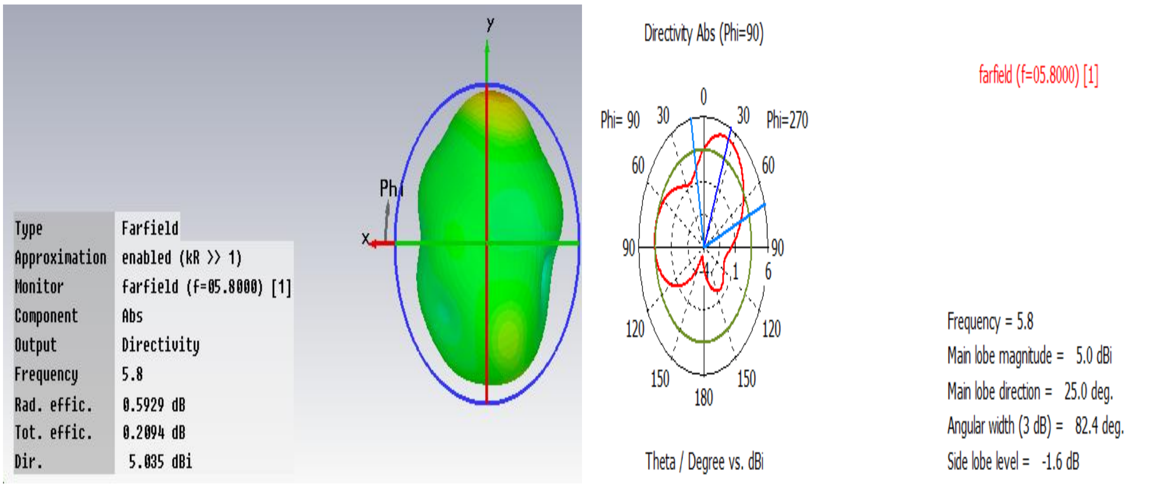


Fig. 7.10 Directivity (3D view and polar plot) at 5.8 GHz

7.10 Gain at 5.8 GHz

The Fig. 7.11 shows the 3D view and radiation pattern of the gain. In this design the gain comes out to be 5.548 dB which is more than 5 dB and this gain shows that this antenna is more directional. Therefore this design has application in WLAN and WiMAX bands.The radiation pattern has gain 5.548 dB as shown in fig. 7.15. The radiation pattern in the polar plot is omnidirectional and the main lobe is directed at 335 degree angle. The angular beam width obtained is 83.6 degree and the main lobe magnitude is 5.5 dB.

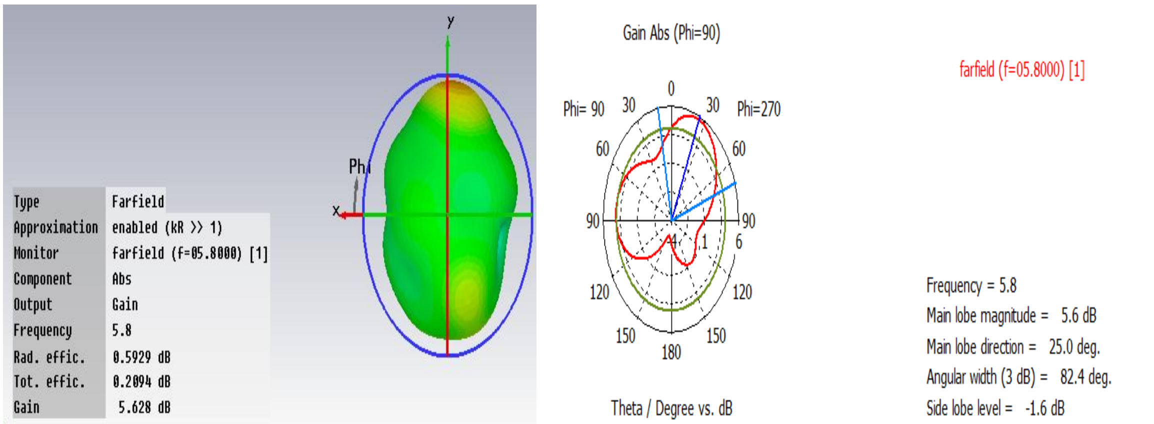


Fig. 7.11 Gain (3D view and polar plot) at 5.8 GHz

Conclusion: In this chapter dual band aperture coupled microstrip stacked patch antenna with defected ground structure has been discussed. The dual band is obtained due to stacking and the bandwidth is very good at 5.8 GHz band. It is covering the both WLAN bands and WiMAX bands. The DGS has also been used in this design which reduces the size and increases the gain of the antenna.

CHAPTER 8

8. FABRICATION AND TESTING OF ANTENNAS

8.1 Fabrication Procedure

The whole fabrication process of the microstrip patch antenna using aperture coupled feeding is covered in this topic. The process of fabrication of antenna is done in few steps and is discussed in the flow chart below. The flow chart makes the fabrication procedure easy to understand.

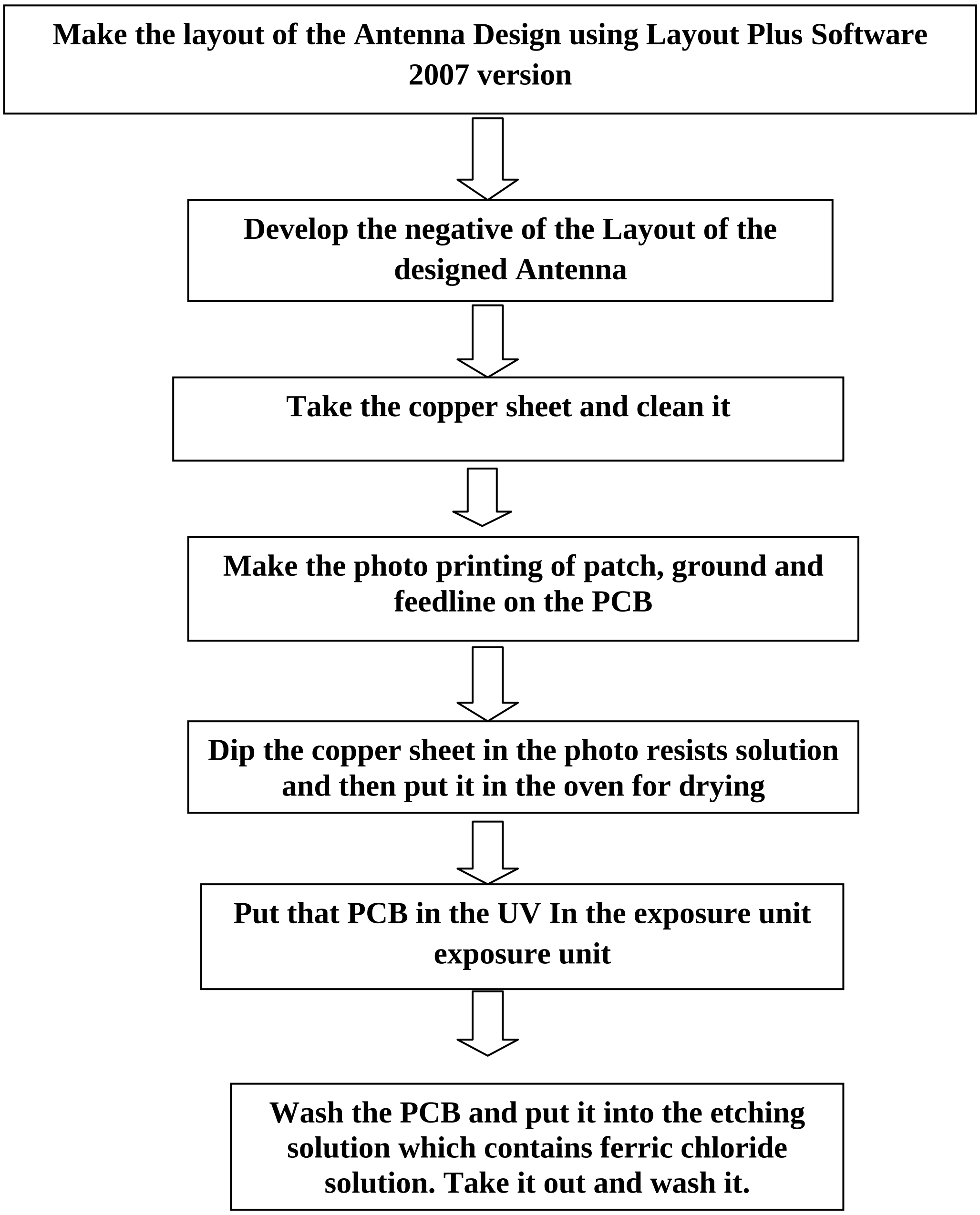


Fig. 8.1 Flow chart of Antenna Fabrication Process

8.2 Fabricated Antenna Design

The negative of the fabricated design of the microstrip stacked patch antenna is as shown in the figure below:

Top View

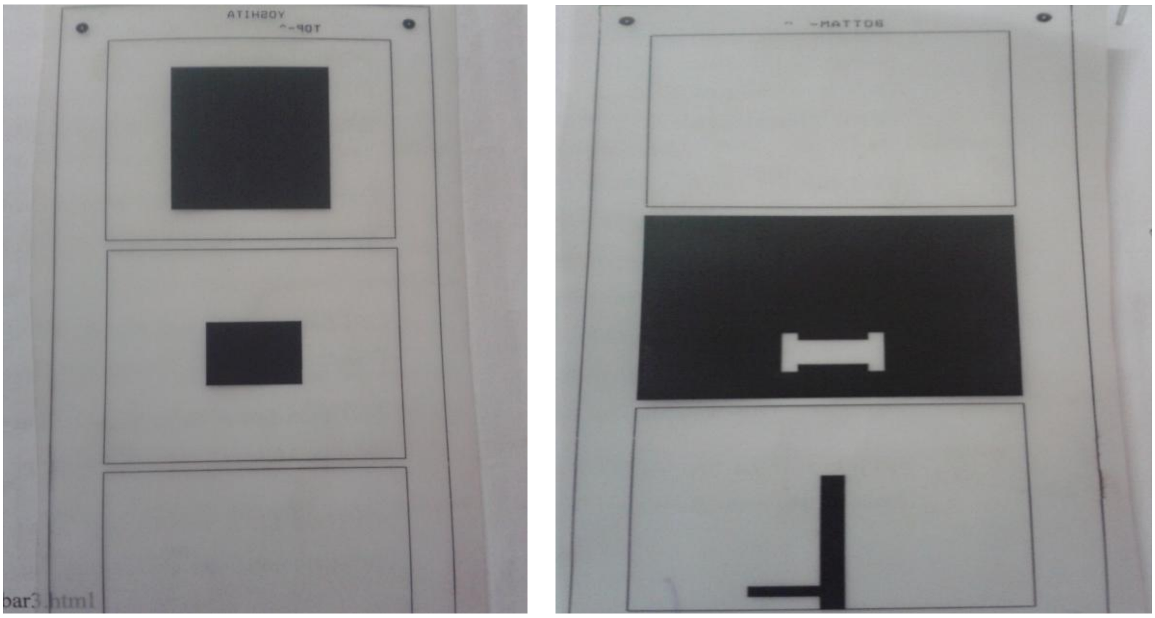


Fig. 8.2 Top View and Back view of the Antenna in negative

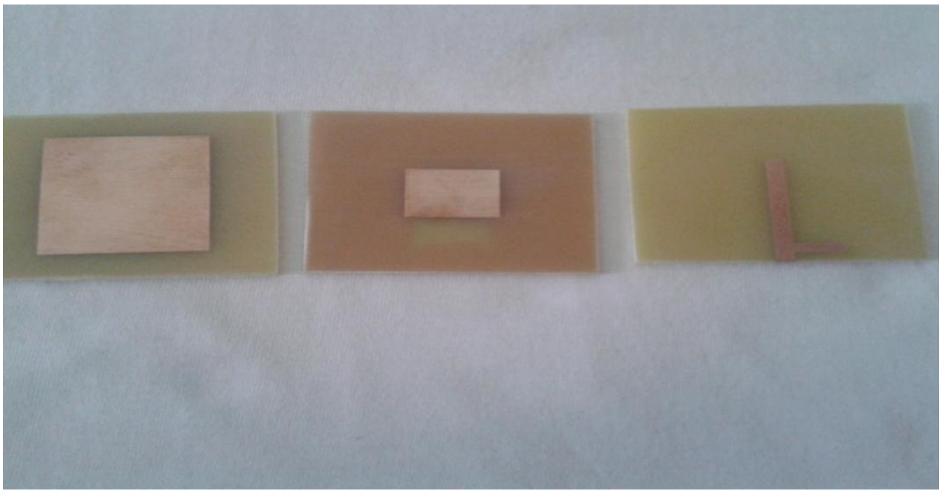


Fig. 8.3 Fabricated Antenna at 2.4 GHz and 5.8 GHz

8.3 Testing of Antenna

The testing of the antenna is done using VNA (Vector Network Analyser) E5071C (ENA Series) which analyses one or two port networks. The frequency range of VNA is from 9 KHz to 8.5 GHz.

Fig. 8.4 Network analyser for Testing

8.4 Comparison of Simulated and Fabricated Antenna

The antenna shows that testing results approximately matched with the simulated results as discussed in Chapter 8 namely Dual Band Aperture Coupled Microstrip Stacked Patch Antenna with DGS. The Figures below shows the tested results of designed antenna using network analyzer.

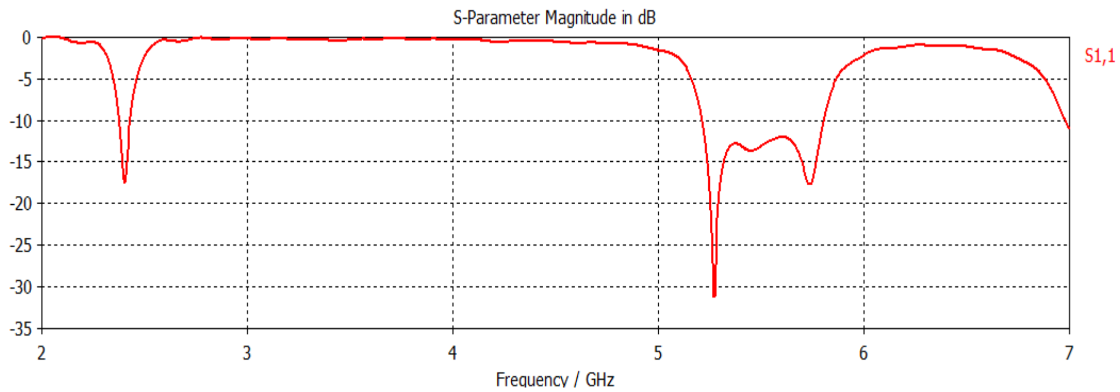


Fig. 8.5 Simulated Antenna Design

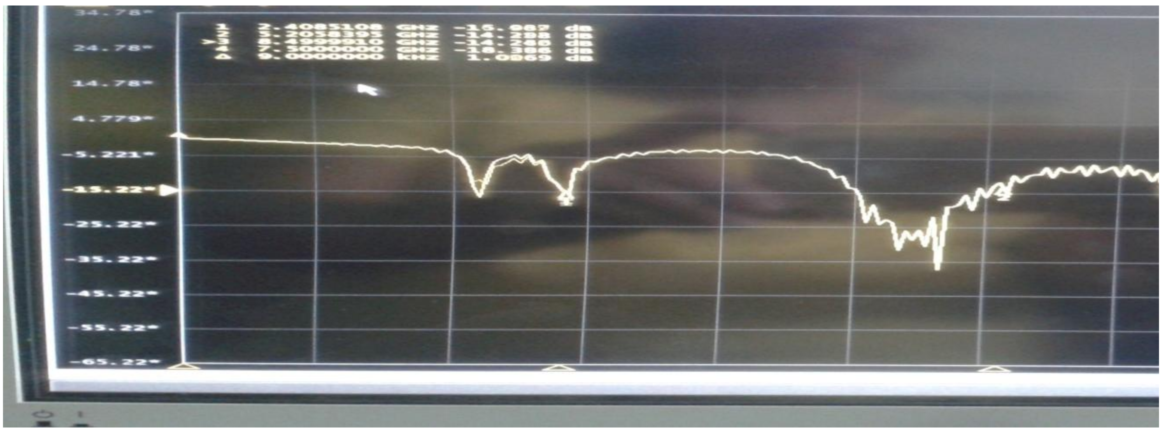


Fig. 8.6 Measured Return Loss using Network Analyzer

Table 8.1 Comparison of Simulated and Tested Results

Parameters	Tested results at 2.4 GHz	Simulated results at 2.4 GHz	Tested results at 5.8 GHz	Simulated results at 5.8 GHz
Return Loss	-16.687 dB	-17 dB	-24.2 dB	-18 dB
Resonating frequency	2.4 GHz	2.4 GHz	5.2 GHz	5.8 GHz
Bandwidth	55 MHz	55 MHz	570 MHz	600 MHz

Conclusion

The testing and the fabrication of the dual band Stacked Microstrip Patch Antenna is done and it is observed that there is some shifting in simulated and tested results. The return loss is approximately same at 2.4 GHz and at 5.8 GHz the return loss obtained in testing is more as compared to simulated results. The bandwidth obtained at 2.4 GHz is same and at 5.8 GHz the bandwidth obtained is less in tested results as compared to simulated antenna because the connector was not properly soldered and the wire was not calibrated also.

CHAPTER 9

9. CONCLUSION AND FUTURE SCOPE

9.1 Conclusion

In this report five configurations of microstrip patch antenna using aperture coupled technique is discussed for WLAN and WiMAX applications. Out of five configurations two are simple aperture coupled microstrip antennas and three are stacked patch aperture coupled microstrip antennas. The first design is single band aperture coupled microstrip patch antenna at 5.8 GHz, the second design is dual band aperture coupled microstrip patch antenna with defected ground structure at 3.62 and 5.772 GHz, the third design is based on the comparison of simple and stacked microstrip patch antenna at 5.8 GHz, the fourth design is dual band aperture coupled microstrip stacked patch antenna at 2.4 and 5.2 and GHz and finally the fifth design is dual band aperture coupled microstrip stacked patch antenna with DGS at 2.4 and 5.8 GHz. The various parameters of antenna like operating frequency, return loss, gain, VSWR, Smith Chart, Directivity and Current distribution are studied for designing of antenna. Parametric analysis is done to get performance improvement.

Initially, the single band aperture coupled microstrip patch antenna operating at 5.8 GHz which covers the WLAN and WiMAX bands are discussed. The designed antenna has return loss of -21.376 dB and bandwidth 346.5 MHz. It is concluded that various physical parameters like slot length, patch length, patch width, slot width and stub etc. affects the results of antenna. Secondly; the dual band aperture coupled microstrip patch antenna with U-slot is discussed. The results give return loss of -40 dB and -14 dB at 3.62 and 5.772 GHz respectively and band width of 74.5 MHz and 111 MHz respectively. This design has various applications in electronic devices, mobile phones and Satellite Communication. It is also observed that if these parameters are varied in a right manner the results can be optimised for desired operating frequency. The third design is the comparison between simple and stacked aperture coupled microstrip patch antenna and there is improvement in bandwidth of 80%. The return loss and bandwidth without stacking is -29.39 dB and 293 MHz respectively and with stacking comes out be -50 dB and 539 MHz. This design has applications in WLAN and WiMAX bands. In the fourth design the dual band is obtained using stacked patch aperture coupled microstrip antenna. The return loss and bandwidth is -29dB and 72 MHz at 2.4 GHz band and -24 dB and 165

MHz at 5.2 GHz. This antenna has also applications in WLAN and WiMAX bands. The fifth design is based on stacking as well as defected ground structure. In this design dual band is obtained. This antenna has bandwidth of 55 MHz and 600 MHz at 2.4 and 5.8 GHz respectively. This design has also been fabricated and the measured and simulated results are compared.

Table 9.1 Parameteric values of each design

Design	**Resonant Freq. (GHz)**	**Return loss(dB)**	**Band Width (MHz)**	**Gain (dBi)**	**Directivity (dBi)**	**VSWR**	**App.**	**DGS and Stacking**
Design 1	5.8	-21.37	346.5	5.861	5.307	1.19	WLAN and WiMAX	Not used
Design 2	3.62 GHz	-40	74.5	6.5	6.035	1.05	WiMAX	Not used
	5.772 GHz	-14	111	5.772	5.815	1.3	WLAN	
Design 3	5.8	-50	539	6.7	5.573	1.01	WLAN and WiMAX	Only Stacking is used
Design 4	2.4	-29	72	4.6	3.8	1.4	WLAN	Only Stacking is used
	5.2	-24	165	5.1	4.2	1.2	WLAN	
Design 5	2.4	-17.5	55	5.882	5.9	1.32	WLAN	Both DGS and Stacking is used
	5.8	-18	600	5.548	5.1	1.06	WLAN and WiMAX	

Conclusion based on analysis of the above table

In first and second design simple aperture coupled microstrip antenna is used and results come out to be satisfied but in third and fourth design stacking is used. The stacking has improved the bandwidth in a large manner therefore stacked antennas are preferred over MSA. In fifth design stacking as well as Defected ground Structure is used and bandwidth has been increased drastically for second resonant frequency.

9.2 Future Scope

The antennas which are designed and simulated in this thesis have use in various applications like WiMAX, WLAN, Direct Broadcast Satellite Communication and Microwave applications etc. Following are the techniques which can be used to design antennas in the future:

- **EBG (Electromagnetic band gap structure):** For Microstrip patch Antennas EBG **(**Electromagnetic Band Gap) substrates basically reduce the effect of surface waves which is a function of frequency and EBGs are also able to provide performance of broadband frequency. Electromagnetic Band Gap substrates are 3D objectives which prevent Electromagnetic Wave propagation for various polarisation states and in the frequency range of specific band for all angles. In Electromagnetic Band Gap structures either $\in_r$ or μ_r is negative.
- **SRR (Split-ring resonator structure):** A SRR (Split-ring resonator) is a component of a NIM (negative Index metamaterial) which is also known as DNG (Double Negative metamaterials) or LHM (Left-Handed metamaterial). Split-ring resonators have also use in research areas like Acoustic metamaterials, Terahertz metamaterials and Metamaterial Antennas. Single cell split-ring resonators have enclosed loop pairs and at opposite ends there are splits in them.
- **Metamaterials:** A metamaterial is basically a semiconductor or metallic substance whose properties do not depend on the composition of atoms but depends on its inter-atomic structure. There are some metamaterials which bend the visible light rays from basic refractive media to the opposite direction. Some metamaterials show this behaviour at IR (Infrared wavelengths) also. It has applications in optical communication systems, monitoring systems and medical diagnostic equipment etc. In metamaterials both $\in_r$ or μ_r are negative.

- **Feeding techniques:** In future other feeding techniques can also be used to design antennas such as microstrip line feed, coaxial probe feed, proximity coupled feed and CPW feeding technique.
- MSA can be used as a filter too because we can stop and pass the frequency bands according to our requirement.

LIST OF PUBLICATIONS

PUBLISHED

- Yoshita Gupta, Amanpreet kaur, "A Review on Microstrip Stacked Patch Antennas And Defected ground Structures", IJRAT, Vol. 2, No. 3, March 2014.
- Yoshita Gupta, Amanpreet Kaur, "A Novel Microstrip Patch Antenna at 5.8 GHz for WLAN and WIMAX Applications", IJARCCE, Vol. 3, Issue 5, May 2014.

COMMUNICATED

- Yoshita Gupta, Amanpreet Kaur, "Performance Analysis of a Aperture Coupled Microstrip Stacked Patch Antenna For WLAN Applications" IJAREEIE, Volume 3, Issue 7, July 2014.

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