DESIGN AND DEVELOPMENT OF ENHANCED BANDWIDTH MULTI FREQUENCY SLOTTED ANTENNA FOR 4G LTE, Wi-MAX, WLAN AND S/C/X BAND APPLICATIONS

A Thesis submitted in partial fulfillment of the requirement for the Award of the Degree of

MASTER OF ENGINEERING

In

Electronics and Communication

Submitted By

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JULY, 2019

DECLARATION

I, **Bharat kumar sah** hereby declare that the work presented in this project "**DESIGN AND DEVELOPMENT OF ENHANCED BANDWIDTH MULTI FREQUENCY SLOTTED ANTENNA FOR 4G LTE, Wi-MAX, WLAN AND S/C/X BAND APPLICATION**" in partial fulfillment of the requirement for the award of degree of **Master of Engineering (ECE)** submitted at **Electronics and Communication department**, Thapar Institute of Engineering & Technology (Deemed to be University), Patiala is an authentic record of work carried out under supervision of **Dr. Surbhi Sharma (Associate Professor, ECED, TIET)** and **Dr. Geetanjali (Lecturer, ECED, TIET)** from 2018 to 2019. The matter presented in this has not been submitted either in part or full to any other university or institute for the award of any other degree.

Date: 10/7/19

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ABSTRACT

In recent years, the uses of wireless communication systems have increased rapidly. With the development of wireless communication system, it is preferable to consolidate as many standards such as 4G LTE (long term evolution), WiMAX (worldwide interoperability for microwave access), WLAN (wireless area network) and S/C/X-band standards into a single wireless device. Hence microstrip slot antenna, which is operational at microwave frequencies, is an appropriate choice for implementing such systems. It is simple in construction, have low profile structure and low fabrication cost. It is also capable of supporting multiple frequency bands (dual, triple and multiband) with enhanced bandwidth and compact in size which can be accommodated with other devices. Microstrip antenna is effective in achieving the desired radiation pattern, reasonable gain and enhanced impedance bandwidth. This report present a new approach for the design of a multiband microstrip patch antenna which is designed by using FR-4 substrate, relative permittivity of εr =4.4, a thickness of 1.6 mm and a loss tangent of 0.02 .The proposed antenna is composed of rectangular slot, a pair of E-shape stubs, an inverted T-shape stub and staircase feed line to excite the antenna. By using these structures, the antenna generates four different frequency bands. The multiband slot antenna is designed and simulated using microwave studio CST version 17 software. To verify the simulated results, the antenna is fabricated and tested. The experimental results shows that the antenna resonates at 2.24 GHz, 4.2 GHz, 5.25GHz and 9.3 GHz with impedance bandwidth of 640 MHz (2.17-2.82 GHz) covering WiMAX (802.16e), Space to Earth communications, 4G-LTE, IEEE 802.11b/ g WLAN systems defined for C-band applications. Also the proposed antenna exhibits bandwidth of 280 MHz (4.1-4.38GHz) for Aeronautical and Radio navigation applications, 80 MHz (4.2 to 4.28 GHz) for uncoordinated indoor systems, 1060 MHz (5.04–6.1 GHz) for the IEEE 802.11a WLAN system defined for S-band applications and 2380 MHz (7.9-10.28 GHz) defined for X-band applications. The antenna shows the bidirectional at one resonating frequency and directional radiation pattern at three other operating frequencies. The simulated and measurement results are found to agree well with each other.

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LIST OF ABBREVIATIONS

WLANs	Wireless Local Area Networks
Wi-MAX	Worldwide Interoperability for Microwave Access
FM	Frequency Modulation
GSM	Global Systems for Mobile Communications
TDMA	Time Division Multiple Access
CDMA	Code Division Multiple Access
GPRS	General Packet Radio Service
MMS	Multimedia Messaging Services
WAP	Wireless Application Protocol
ITU	International Telecommunication Union
IMT	International Mobile Telecommunications
UMTS	Universal Mobile Telecommunications Service
HSPA	High Speed Packet Access
ITU-R	International Telecommunications Union-Radio communications sector
IP	Internet Protocol
OFDMA	Orthogonal Frequency Division Multiple Access
FDE	Frequency-Domain Equalization
MIMO	Multiple-Input Multiple-Output
LTE	Long Term Evolution
TDD	Time-Division Duplexing
FDD	Frequency Division Duplexing
IEEE	Institute of Electrical and Electronics Engineers
LOS	Line-of-Sight
NLOS	Non-Line-of-Sight
SHF	Super High Frequency
UHF	Ultra-High Frequency
RFID	Radio Frequency Identification
VNA	Vector Network Analyzer
EMC	Electromagnetic Compatibility
RAM	Radar Absorbent Material
CST	Computer Simulation Technology
VSWR	Voltage Standing Wave Ratio

EDGE	Enhanced Data Rate For GSM
DSP	Digital Signal Processing
PSTN	Public Switched Telephone Network
EPC	Evolved packet core
WCS	Wireless Communication Service
AWS	Advance Wireless Service
Wi-Fi	Wireless Fidelity
QPSK	Quadrature Phase Shift Keying
QAM	Quadrature Amplitude Modulation
FTT	Fast Fourier Transform
SISO	Single Input Single Output
GPS	Global positioning system

CHAPTER 1
INTRODUCTION

1.1 AN OVERVIEW OF WIRELESS COMMUNICATIONS

Communication thoughts are essential for the benefit and advancement of a community. Human beings have been trying to discover an efficient manner to interact since the beginning of communication. Humans are thought to have started the exchange of ideas, expertise and data through the use of inexplicable sound conveyed by some sign language. When the objects like pictures/images were shown to the people, it start to predicated what these objects want to say and people start writing these things into the note which helps to begin the written communication. The written form has become the prominent mode of transmitting information from person to person. Communications can be divided into three categories: interactive, stored and broadcast. Interactive interaction defines the delivery of texts that have either been prejudiced by the previous texts obtained or have an impact on the complexity of potential texts. Today, through the use of telephones and remote computer access terminals, interactive communication is established [1]. Written or otherwise copied, stored and spread the stored message. Starting with stone gravure and tablet construction, the recorded data became the most important method of communication on which human beings created empires. A number of distinct techniques of storing data have been introduced to this community over the years. These include the compact disk, the magnetic tape, the gramophone record, the movie, the letter and the book. Exponential information development requires the expansion of small high density storage media in size. Remote broadcasting, the third team started with a cry to transmit messages and went on to develop radio and television by using smoke signals. The two ultimate types are the present means of transmitting data. In this case, the communication is immediate, i.e. it is received efficiently at the same time as it is transmitted.

In the pre-industrial age, the first wireless networks were developed. These technologies transferred data over line-of-sight distances. While transmitting the information it uses the smoke signals, flashing mirrors, torch signaling, signal flares or semaphore flags. In order to send complex messages with these fundamental signals, an elegant set of signal mixtures was developed. On hilltops and along roads, observation stations were made to convey these messages over long distances. Radio technology is rapidly progressing to enable broadcasting over larger distances. The reason to develop the radio technology is to communicate long distance with better quality of audio and video signal, less power utilization, smaller in size and with cheaper devices. Enabling wireless networking and public and private radio communications. Radio devices transferred analog signals on the early day of interaction. Most radio systems today convey digital signals. It consists of binary bits, where the bits are acquired directly from a data signal or an analog signal is digitized.

1.2 WIRELESS VISION

Wireless communication's vision is to support the exchange of information between humans or devices. This image will enable multimedia to interact with a tiny handheld device or laptop from everywhere in the world. Devices like laptop, palmtop and desktop computers will connects with each other with the help of wireless network. Within an office, building or campus, as well as any corner of the cafe, this sort of network is feasible anywhere. To allow these devices, it is necessary to link to the Internet in order to link desktop computers, telephones and security / monitoring devices. Such intelligent electronic devices will helps to patient monitoring, emergency response as well as it will helps to monitor the homes security continuously [2]. Also we will able to activate or deactivate the system far from the home when there is no use. In the building or between buildings that are blocks or continents apart, video teleconferencing will take place. Wireless network scheme will allow distant schools, clinics and teaching centers by linking video conferencing from anywhere in the globe. Wireless sensors made for commercial and military applications have a huge range. Commercial type of wireless sensors will self-configure into a network. After that, sensor readings are processed and taken and this data is then transferred to a centralized control room. Military applications include enemy target identification and monitoring. It also helps to detection of chemical and biological attacks. We can also use these sensor to support of unmanned robotic vehicles and counter-terrorism. Finally, Distributed control systems in wireless networks are enabled by connecting remote devices, actuators and sensors via wireless communication channels. All wireless vision modules are the different applications identified above.

So what are wireless communications exactly? There are various methods for dividing this complex topic into different systems, applications and regions of coverage. Wireless features include Internet access, internet browsing, and file transfer, video conferencing, and speech, data facilities for subscribers, leisure, detecting and distributed control. Cellular telephone systems, Wireless Local Area Networks (WLANs), Worldwide Microwave Access Interoperability (WiMAX), Fourth Generation (4 G), Cordless Phones, Satellite Networks, Low-Cost Low-Power Radios: Bluetooth and ZigBee. The coverage regions include global, regional, city, campus and in-building. Therefore, the reason is to division the different wireless system on the basis of the different application requirements.

- **LTE (LONG TERM EVOLUTION)**

Long-term evolution (LTE) is a norm that is based on GSM / EDGE and UMTS / HSPA techniques for wireless internet interaction for portable phones and information terminals. LTE is an ETSI (European Telecommunications Standards Institute) registered trademark for wireless data communication technology and GSM / UMTS standards development [3]. LTE is commonly referred to as 3.95 G. The objective of LTE technology is to increase ability and velocity using a distinct radio interface in conjunction with changes to the core network using new techniques and modulations for digital signal processing (DSP). The 3GPP (3rd Generation Partnership Project) develops the standard. LTE is the upgrade path for both GSM /

UMTS and CDMA2000 networked carriers. In order to support LTE frequency and bands in different country one should have multi-band phone.

In 2004, for the first time LTE was planned by japan NTT DoCoMo and publically started in 2005. The LTE situation provides 300 Mbps downlink maximum speeds and 75 Mbps uplink peak speeds [4]. Quality of service (QoS) requirements for a transfer latency in the radio access network of less than 5 ms. LTE has the ability to manage mobile, multi-cast and broadcast streams of fast-moving maintenance. LTE promotes 1.4 MHz to 20 MHz available carrier bandwidths. It also promotes duplexing of the time division (TDD) and duplexing of the frequency division (FDD). The IP-based network architecture intended to substitute the network is called the Evolved Packet Core (EPC). The reason for designing this network is to support ongoing voice and data transfers to cell phones with age-old network technology such as GSM, UMTS and CDMA2000.

Table 1.1 LTE frequency bands [3]

Band	**Duplex Mode**	**Frequency (MHz)**	Common Name	Subset of band	**Uplink (MHz)**	**Downlink (MHz)**	Duplex Spacing (MHz)	Channel Bandwidths (MHz)
1	FDD	2600	IMT-E		2500-2570	2620-2690	120	5,10,15,20
2	FDD	2300	WCS		2305-2315	2350-2360	45	5,10
3	TDD	2600	IMT-E	41	2570-2620		N/A	5,10,15,20
4	TDD	2300	S-band		2300-2400		N/A	5,10,15,20
5	TDD	2500	BRS		2496-2690		N/A	5,10,15,20
6	TDD	2400	S-band		2483.5-2495		N/A	1.4,3,5,10
7	SDL	2600	IMT-E		N/A	2570-2620	N/A	5
8	SDL	5200	U-NII-1		N/A	5150-5250	N/A	20

Table 1.2 LTE frequency bands and its covering region

Place	Frequency(MHz)	Bands
North America	600, 700, 750, 800 850, 1900, 2100(AWS), 2300 (WCS), 2500, 2600	2, 4, 5, 7, 12, 13, 17, 25, 26, 29, 30, 41, 66, 71
Latin America and Caribbean	750, 850, 900, 1700, 1800, 1900, 2100, 2600 MHz	1, 2, 3, 4, 5, 7, 8, 13, 17, 28
Europe	450, 700, 800, 900, 1500, 1800, 2100, 2300, 2600, 3500, 3700	1, 3, 7, 8, 20, 22, 28, 31, 32, 38, 40, 42, 43
Asia	450, 700, 800, 850, 900, 1500, 1800, 1900, 2100, 2300, 2500, 2600, 3500	1, 3, 5, 7, 8, 11, 18, 19, 21, 26, 21, 31, 38, 39, 40, 41, 42
Africa	700, 800, 850, 900, 1800, 2100, 2500, 2600	1, 3, 5, 7, 8, 20, 28, 41
Oceania (incl. Australia and New Zealand)	700, 800, 850, 1800, 2100, 2300, 2600	1, 3, 7, 12, 20, 28, 40

- **WLAN (WIRELESS LOCAL AREA NETWORK)**

Wireless LAN (WLAN) is a wireless computer network that connects two or more mobile communication equipment to create a local area network (LAN) within a restricted region such as a house, college, computer lab, university, office block, etc. ALOHA net was the first wireless communication network develop by Professor Norman Abramson at the university of Hawaii. In 1971, the system became operative and it consists of seven computers which are deployed over four island to communicate with each other without using phone lines at the Oahu Island [5]. Initial expansion involved industry-specific solutions and patented protocols, but they were interchanged by standards at the end of the 1990s, mainly the different versions of IEEE 802.11 but in products using the brand name Wi-Fi.

Table 1.3 802.11 Types and Frequency bands

IEEE 802.11 variant	Frequency bands used
802.11a	5 GHz
802.11b	2.4 GHz
802.11g	2.4 GHz
802.11n	2.4 GHz and 5 GHz
802.11h/j	5GHz
802.11y	3.65GHz
802.11j (WLAN)	4.9-5GHz
802.11p	5.9GHz
802.11ac	5 GHz
802.11ad/ay	60 GHz
802.11af	TV white space(below 1GHz)
802.11ah	700MHz, 860MHz, 902MHz etc. ISM bands Dependent upon country and allocation
802.11ax	2.4GHz and 5GHz

Device like smart phone and electronics device contain Bluetooth accesses the same channel. The radio frequency paly important role in wireless communication network. Different types of operation is done on the radio frequency spectrum which required the license. The license is provided by the government or the national body regulatory [6]. The IEEE 802.11 standards differentiated the radio frequency into different range with multiple channel for Wi-Fi communication. Some of the frequency is categories for Wi-Fi communication are 900MHz, 2.4GH, 3.6GHz, 4.9GHz, 5GHz and 60GHz [7] and [8]. Different country uses their own regulation to allow different channel, allowed different users with maximum levels of power within these frequency ranges.

- **Wi-MAX (WORLDWIDE INTEROPERABILITY FOR MICROWAVE ACCESS)**

In the mid-1990s, various cell phone companies and service providers began working on wireless broadband technology. This technology has been suggested to keep both velocity and strong network security, but the network's price is small [9]. In 1999, the IEEE (Institute of Electrical and Electronics Engineers) first developed the 802.16 standard. It was published in 2001 after the growth of this technique, but it has a tiny variety and restricted transmission line-of-site (LOS). The early IEEE 802.16 standard has been devoted to line-of-sight (LOS) applications that use 10 to 66 GHz high-frequency bands. However, recent efforts have focused on identifying changes to early standards to support non-line-of-sight (NLOS) applications ranging from 2 to 11 GHz. At the present 802.16 comes into two standards. First one is 802.16-2004 i.e. 802.16d standard which support the fixed broadband wireless and 802.16-2005 i.e. 802.16e standard which support the mobile broadband wireless access. But there was a problem with the 802.16d standard in the user, terminal and base station air interface. To overcome this problem 802.16e standard was developed which support mobility. It support both fixed as well as mobility broadband access. This model also supports the movement of the vehicle velocity in the customer terminal while maintaining the 802.16d specified wireless access.

Table 1.4 Comparison between different 802.16 IEEE standards

Specifications	802.16	802.16a	802.16d	802.16e
Frequency of operation	10 to 66 GHz	2 to 11 GHz	Less than 6 GHz	Less than 6 GHz
Mode of operation	LOS	Non LOS	Non LOS	Non LOS
Data rate	32 to 134 Mbps, (28 MHz BW channel)	less than 70 or 100 Mbps, (20 MHz BW channel)	up to 70 Mbps with no mobility	60-70 Mbps with mobility

Mobility	Fixed	Fixed	Fixed	less than and equal to 75 Miles/Hour
Modulation	QPSK, 16QAM, 64QAM	256 point FFT with QPSK, 16QAM, 64QAM, 256QAM	same as 16a	same as 16a with OFDMA modulation scheme with variable FFT sizes
Cell radius	1 to 3 miles	3 to 5 miles	3 to 5 miles	1 to 3 miles
Channel Bandwidth	20/25/28 MHz	Selectable 1.25 to 20 MHz	3.5 MHz, 7 MHz	1.25 to 28 MHz , OFDMA modulation scheme

The IEEE 802.16e standard was created in 2005 and its products are used all over the globe which is known as mobile Wi-MAX [10]. Whereas 802.16 m is the 802.16e-2005 beneficiary and is frequently referred to as Mobile WiMAX Release 2 or Wireless MAN-Advanced [11]. Currently approved as an IMT-Advanced technology by ITU-R. Basically different types of antenna is used in this standards among one of them is 4 by 2 MIMO antenna which has 20MHz bandwidth. IEEE 802.16m standard support both TDD and FDD. The targeted 802.16 m standard channel bandwidths are up to 20MHz and 40MHz channels feasible.

Table 1.5 Comparison between mobile WiMAX (16e) and WiMAX advanced (16m)

Specifications	**Mobile WiMAX(16e)**	**WiMAX advanced(16m)**
Data rate (aggregate)	About 60-70 Mbps	100 Mbps(Mobile subscribers) 1GBPS (Fixed subscribers)
RF Frequency	2.3GHz, 2.5 to 2.7GHz, 3.5GHz	<6GHz
Topology	FDD/TDD, H-FDD(in Mobile Subscriber)	FDD/TDD(BS), H-FDD(in Mobile Subscriber)
MIMO (Antennas)	up to 4 streams, no limit on number of antennas	up to 4/8 streams, no limit on number of antennas
Antenna Configurations support	Downlink: 1X1(SISO), 1X2,2X1,2X2, 2X4,4X2,4X4,8X8,4X8 Uplink:1X1(SISO), 1X2,1X4,2X4,4X4	Downlink: 2X2,2X4, 4X2,4X4, 8X8,4X8 Uplink:1X2,1X4, 2X4, 4X4
Distance coverage	About 10 km	3Km to 100 Km
Carrier Aggregation (multi-carrier) support	Not supported	Supported
Bandwidth	5-20MHz per RF Carrier	5-20MHz per RF carrier, CA(carrier aggregation) feature will help achieve BWs up to 100MHz.
Frame Length	2-20ms without any super frame	Fixed 5ms , With super frames frame duration of 20ms is used including 4 frames

Table 1.6 Different IEEE WiMAX standards with resonate frequency and their bandwidth

IEEE 802.16 standards	Frequency	Bandwidth(MHz)
802.16d	3400-3600MHz	200
	5250-5850MHz	600
802.16e	2300-2400MHz	100
	2500-2690MHz	190
	3400-3600MHz	200
802.16m	450-470 MHz	20
	698-960MHz	262
	1710-2025MHz	315
	2110-2200MHz	90
	2300-2400MHz	100
	2500-2690MHz	190
	3400-3600MHz	200
	5250-5850MHz	600

- **S-BAND**

The S band is a word for a portion of the microwave band of the electromagnetic spectrum spanning ranges from 2 GHz to 4 GHz by the Institute of Electrical and Electronics Engineers (IEEE). It thus crosses the conservative boundary between 3 GHz bands of super-high frequency (SHF) and ultra-high frequency (UHF) [12]. Weather radar, ground ship radar, airport surveillance radar for air traffic control, certain communications satellites and particularly those used by NASA to interact with the Space Shuttle and the International Space Station are the areas where S band is used.

The S band includes the 2.4–2.483 GHz ISM band which is commonly used for low-power unlicensed microwave appliances such as cordless phones, mobile headphones (Bluetooth), mobile networking (Wi-Fi), keyless car locks, child screens as well as medical diathermy equipment and microwave ovens (typically at 2,495 GHz).

- **C-BAND**

The C band is a word used by the Institute of Electrical and Electronics Engineers (IEEE) for a portion of the electromagnetic range microwave band that covers frequencies varying from 4.0 to 8.0 (GHz). This definition is generally used by radar producers and customers, but is not usually used by microwave radio telecommunications consumers [13]. C band is used for satellite communication transmission, surveillance and weather radar systems, Wi-Fi devices and cordless telephones. C band was initially allocated for commercial telecommunication via satellites. Use the frequency band from 3.7 GHz to 4.2 GHz for downlink and from 5.925 to 6.425 GHz for uplinks in the C band for satellite communication.

The 5.8 GHz ISM band between 5.725-5.875 GHz, which is used for medical and industrial heating reasons and many unlicensed short-range microwave communication systems, such as cordless phones, children's screens and keyless vehicle registration systems, are also included in the C band.

- **X-BAND**

The X band is the name for a frequency band in the electromagnetic spectrum area of the microwave radio. In some instances, for example in communication technology, the X band frequency range is set at nearly 7.0–11.2 GHz rather permanently.

The frequency range of 8.0–12.0 GHz in radar engineering is described by the IEEE. The X band is used for radar, satellite and mobile networks.

X band is used for single-polarization, dual-polarization, continuous-wave pulsed, synthetic radar aperture and phased array radar devices. X-band radar is used in civil, military and government organizations for weather surveillance, air traffic control, maritime traffic control, defense tracking and car velocity detection.

Some of the application of X-bands are traffic light crossing detectors at10.4 GHz, Motion detectors at10.525 GHz and Traffic Sensors as SRD at 10.450 GHz at the place known as Comreg in Ireland. Also X-band is used for Compact Linear Collider (CLIC) in the Europe.

1.3 SIGNIFICANCE OF ANTENNAS IN WIRELESS COMMUNICATION

The antenna was born when Heinrich Hertz first proved the presence of electromagnetic waves more than 113 years earlier. Since then, to promote the development of radiofrequency (RF) technology, many easy but effective antennas have been developed. An antenna is an element needed for any wireless device. Unlike classical dish like reflector antennas which are placed in the plane area or fishbone like Yagi antenna which are kept on the roof of building are large in size which is not feasible in modern wireless communication system. It should be small in size or low profile, high gain, high bandwidth with multiple input multiple output characteristics which will fit in the modern wireless device as a transmitting and receiving device. Antenna play important role in modern wireless communication by connecting the people over long distance with the help of antenna which will increase in the upcoming years [14].

Overall, here is the significance of wireless antenna making it a very important part of today's communication technologies:

- Antenna is used in wireless network for internet access such as Wi-Fi.

- Antenna is used in global navigation satellite systems such as COMPASS, Galileo and GLONASS for global positioning system (GPS).
- While doing research in body-centric communications such as surveillance technologies for the elderly and the disabled, e-healthcare, supporting technologies for specific occupations and entertainment etc. where antenna play important role in communication.
- It is use by Collision avoidance millimeter wave radar system for vehicle safety.
- The terahertz frequency technology play important role in the broadband communications, biosensors and material measurements. This technology will helps to detect hidden explosives biological and chemical agents remotely and to detect illegal drugs smuggling.
- Antenna is also used in the short-range point-to-point wireless connectivity as well as for mobile broadcasting systems.
- Antenna is used in the surveillance systems in order to communicate directly to the control room in order to transfer the information or message with high speed.

OVERVIEW OF ANTENNA

An antenna is a metal instrument used to radiate or receive radio waves (as a rod or wire). This term is defined by the Webster's. In other words, the antenna is the transient framework between free space and a guide device as shown in Figure 1.1 [15].

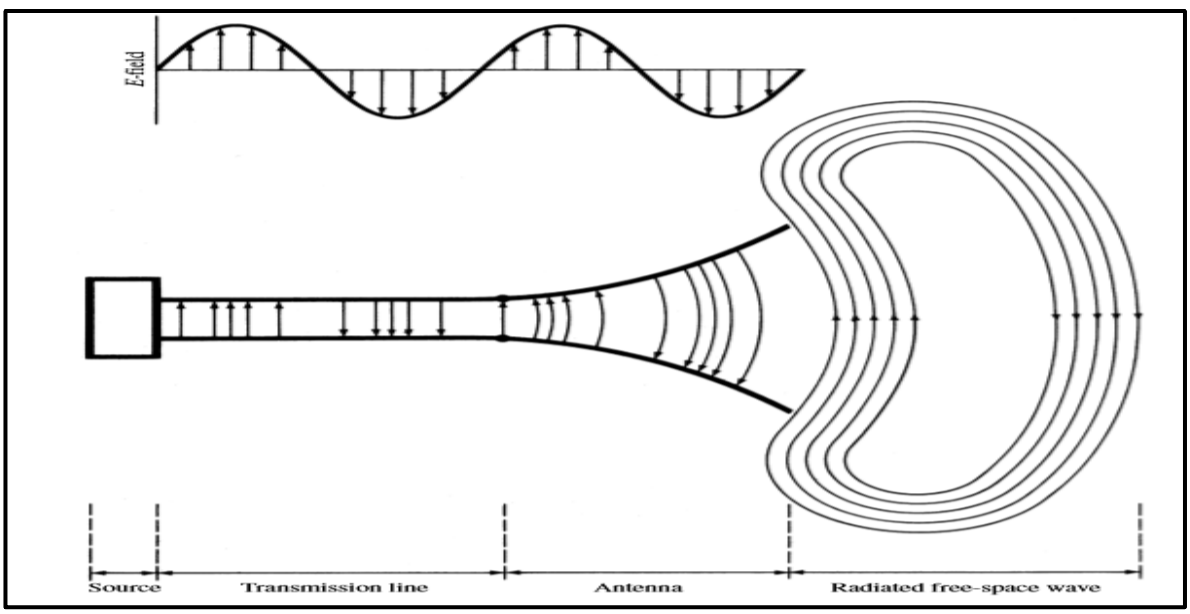

Figure 1.1 Antenna as a transition device.

Figure 1.1 represent the transition devices which is composed of source, transmission line, antenna and radiated free-space wave. The source is symbolized by an ideal generator, transmission is symbolized by line and antenna is symbolized by load Z_A. The antenna is represented by a load Z_A [$Z_A = (R_L + R_r) + jX_A$]

connected to the transmission line. Figure 1.2 indicate the transmission-line Thevenin equivalent circuit diagram of the antenna system and it parameter given below.

Z_A = Antenna is represented by a load

R_L= Load resistance

R_r= Radiation resistance

X_A = Imaginary part of the impedance

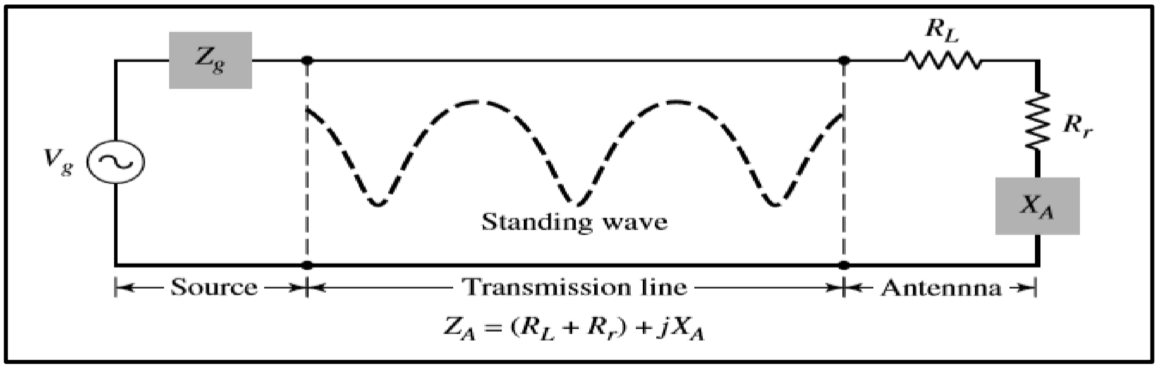

Figure 1.2 Transmission-line Thevenin equivalent of antenna in the transmitting mode.

Antenna can be classified based on the numerous parameter like geometrical size, shape, directivity, frequency, radiation pattern and the application based upon our requirement. The different types of antennas are wire antenna, microstrip antenna, Aperture antenna, Array antenna, Lens antenna and reflector antenna.

1.4 INTRODUCTION OF MICROSTRIP ANTENNA

The antenna which consists of the metallic patch placed on the dielectric and fed by the microstrip or coplanar transmission line is called microstrip antenna. The antenna be made up of radiating patch which is a tinny flat copper region on one side of the substrate and other side of the substrate consist of ground plane. Microstrip patch antenna uses half-wavelength long patch with a large ground plane to give better performance but at the cost of large antenna size. As microstrip antenna is printed on the printed circuit boards (PCB) so it is also called as printed antenna. Microstrip antenna is generally preferred in the high performance aircraft, spacecraft, satellite and missile application. For these purpose, the antenna should have small in size or low profile, light weight, easy for installation and aerodynamic profile are the main constraints.

1.4.1 Basic characteristics

Starting in the 1970s, microstrip antennas gained significant attention, while the concept of a microstrip antenna could be mark out back to 1953 and a patent in 1955. Microstrip patch antenna which is shown in the figure 1.3 consists of the very thin metallic patch ($t<<\lambda_o$ where λ_o is the free-space wavelength and t is the thickness of the patch) above the substrate ($h<< \lambda_o$ where h is the height of the substrate usually

$0.003\lambda_o \leq h \leq 0.05\lambda_o$) and ground plane back side of the substrate. The antenna was designed to normalize the pattern of radiation obtained from the antenna. This is accomplished by choosing the mode of excitation (field setup) under the patch correctly. It is also possible to perform end-fire radiation by carefully selecting mode. While designing the rectangular patch antenna, the length of the patch is chosen from $\lambda_o/3$<L $\lambda_o/2$(where L is the length of element).In the figure it also represent the side view as well as the coordinate system for each radiating slot of the patch antenna.

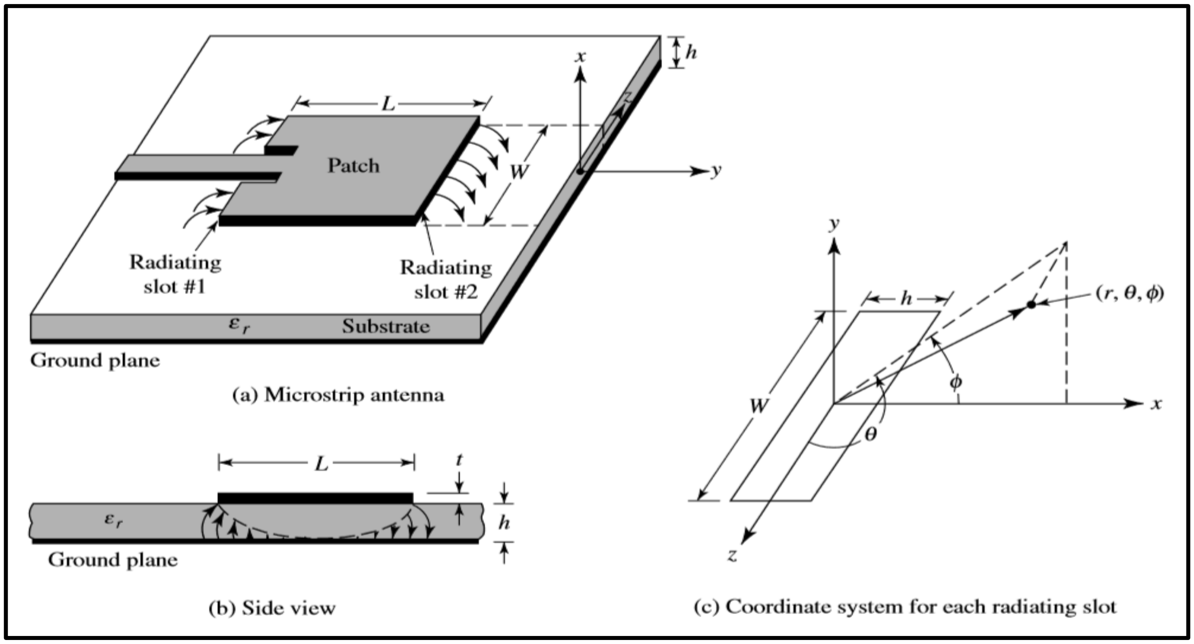

Figure 1.3 Microstrip antenna and its coordinate system.

Different types of substrate is used to design the microstrip strip antenna and their dielectric constant is in the range of $2.2 \leq \varepsilon_r \leq 12$.While designing the patch antenna one thing is consider i.e. height of the substrate and the dielectric constant. If there is thick substrate than automatically the dielectric constant will be low. Due to this the bandwidth of antenna will be wider and the obtained efficiency will be better. Also the obtained radiation pattern will not be loosely spread into the space but the antenna experience the large element size. When the patch antenna will be designed by considering the thin substrate than the dielectric constant will be high due to this the obtained bandwidth will be reduced, efficiency will be degraded, radiation pattern will be spread into the space but the size of element will be small. Microstrip patch antenna is often called as patch antenna. The feed line and the radiating patch usually photoetched on the dielectric substrate. The radiating patch may be different shape and size which is shown in the figure 1.4. The radiating patch's distinct form is rectangular, square, slender strip (dipole), circular, triangular and shown on. Out of all rectangular and square radiating patch is used to designed the antenna because of easy design, fabrication, attractive radiation pattern characteristics, easy installation, low cross polarization and small in size which make it to easily to fit in the system .

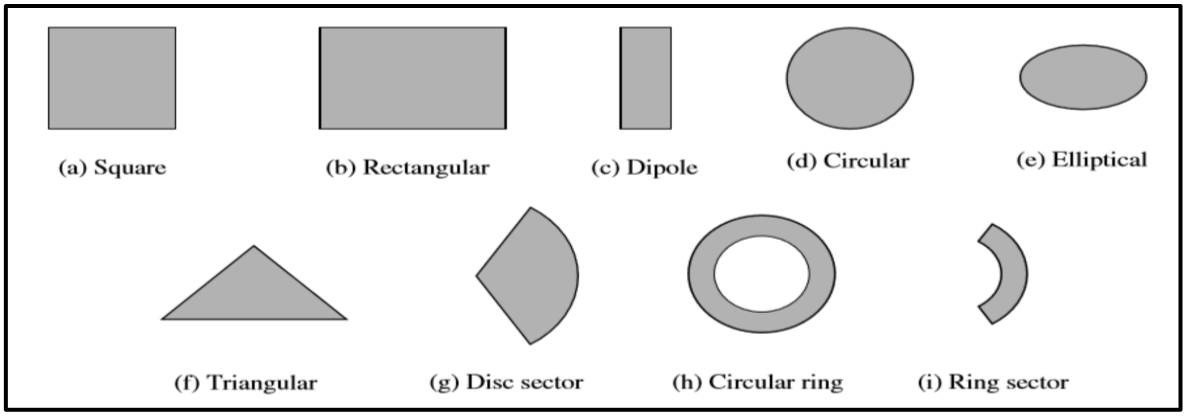

Figure 1.4 Different types of radiating microstrip patch.

1.4.2 Feeding Techniques

The most common feeding techniques is used to designed the microstrip antenna are coaxial feed/probe feed, microstrip feed, aperture coupling and proximity coupling. These feeding structure are discussed on the basis of configuration and equivalent circuit. Selection of the feeding techniques depends upon many factors such as range of frequency, bandwidth, radiation pattern, impedance bandwidth, efficient power transfer between radiating patch and feed line. Also it is consider for array application.

1.4.2.1 *Coaxial feed/Probe feed*

In the beginning the most common techniques is used to design the patch antenna was coaxial feed/probe feed. The inner conductor of the feed is attached to a radiating patch in the probe feed technique, while the outer conductor is attached to the ground plane shown in figure 1.5. This method of feeding is simple to manufacture and has small spurious radiation. The primary drawback of this feeding method is that it has limited bandwidth and difficulty to model as the thickness of substrates is increased ($h>0.02\ \lambda_o$).

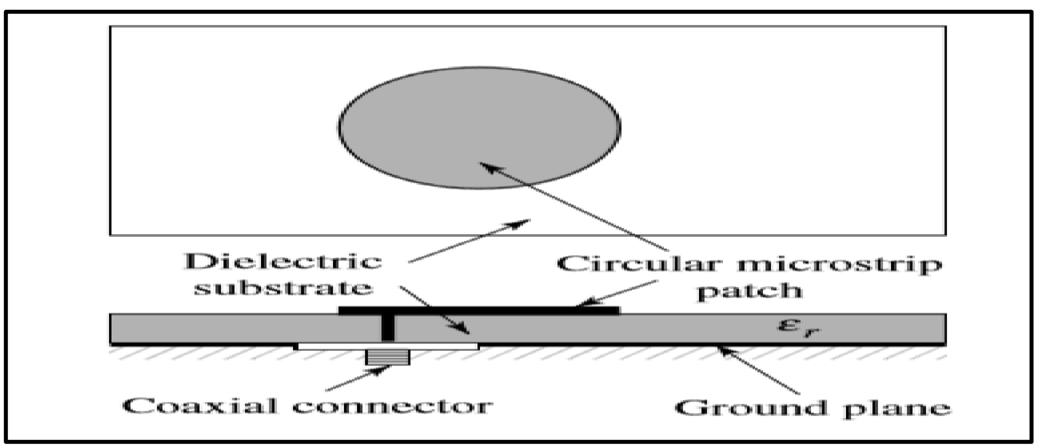

Figure 1.5 Coaxial feed/ Probe feed line

1.4.2.2 *Microstrip line feed*

Microstrip patch antenna design is simple. Here both patch and feed line is connected in a straight line to the edge of microstrip patch. The feed line for microstrip is also a conductive strip, usually much smaller than patch which is shown in the figure 1.6. The benefit of the microstrip feed line is that by regulating the insert location it is easy to design, easy to manufacture, easy to match impedance. However there is some disadvantage using this technique i.e. when the thickness of the substrate is increases the dielectric constant increase which cause surface waves and spurious feed radiation for which it bound the bandwidth by 2-5%. It also causes methods of greater order that generate cross-polar radiation.

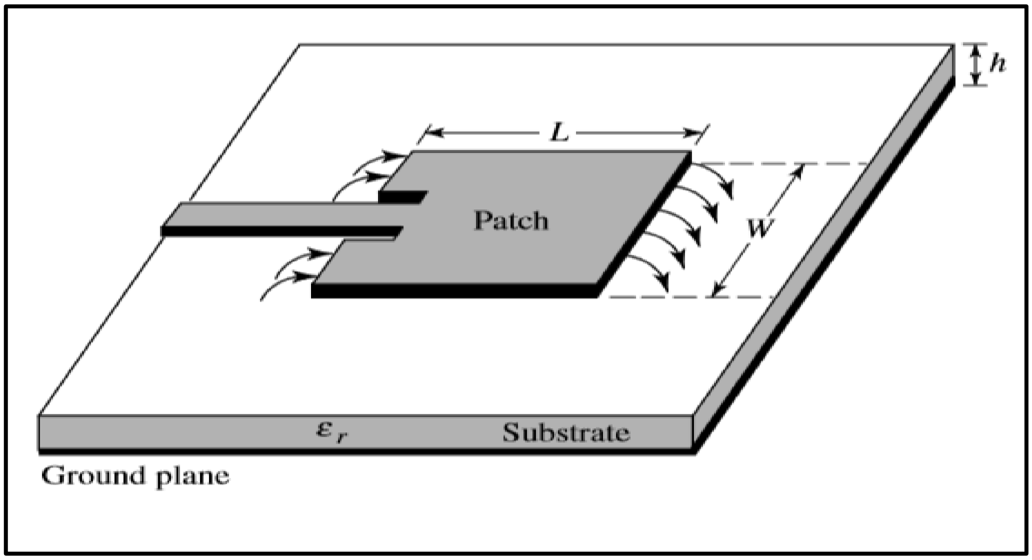

Figure 1.6 Microstrip line feed.

1.4.2.3 *Aperture-coupled feed*

To overcome the problem faced by the microstrip feed line and coaxial feed line, non-contacting aperture-couple feed line was introduced which is shown in the figure 1.7. It consists of two substrate one in the upper side and other in the lower side which is separated by the ground plane. The upper substrate have low dielectric constant and bottom substrate have high dielectric constant. There is a feed line in the lower substrate whose energy is combined to the radiating patch through the slot in the ground plane separating the two substrates. This configuration enables the feeding process and the radiating element to be independently optimized. The impedance is matched by regulating the feed line's slot size and width of feed line. Because the ground plane distinguished the patch and the feed line, the spurious radiation and polarization purity are minimized. The disadvantage of aperture coupling feed line is that it is difficulty to fabricate and also it has narrow bandwidth.

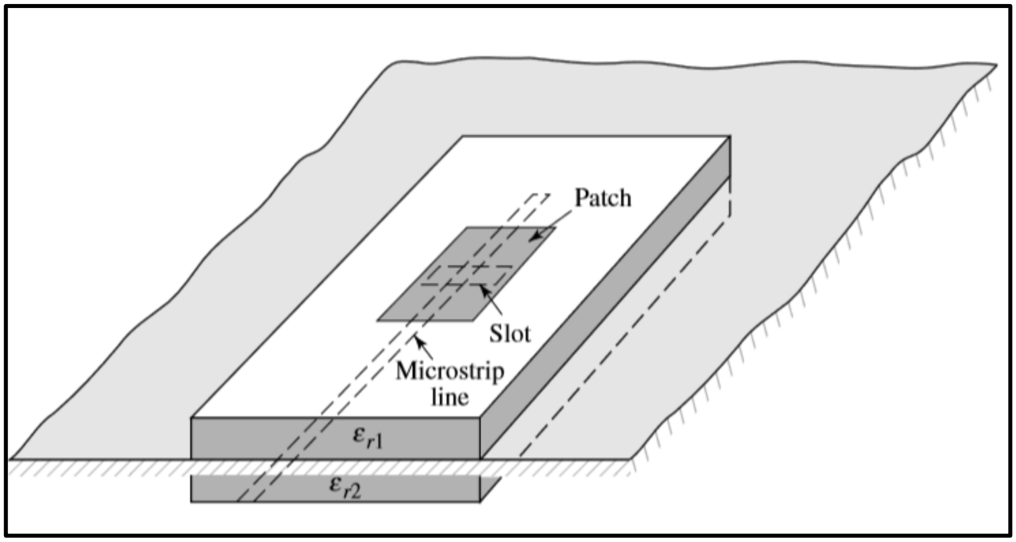

Figure 1.7 Aperture-coupled feed.

1.4.2.4 ***Proximity-coupled feed***

One of the techniques used to develop the antenna shown in figure 1.8 is the proximity-coupled feed line. It comprises of two substrate which is connected in the series above in the ground plane in which feed line is connected below of lower substrate and in the upper substrate radiating patch etched. This feeding techniques is also known as "electro-magnetically coupled" microstrip feed. The coupling between the radiating patch and the feed line of the microstrip is capacitive in nature. This method has the benefit that it has a large bandwidth (up to 13%), is simple to model and has small spurious radiation. The disadvantage of this method is that it is difficulty to fabricate. The impedance match is controlled by feeding stub and width-to-line proportion of the radiating patch.

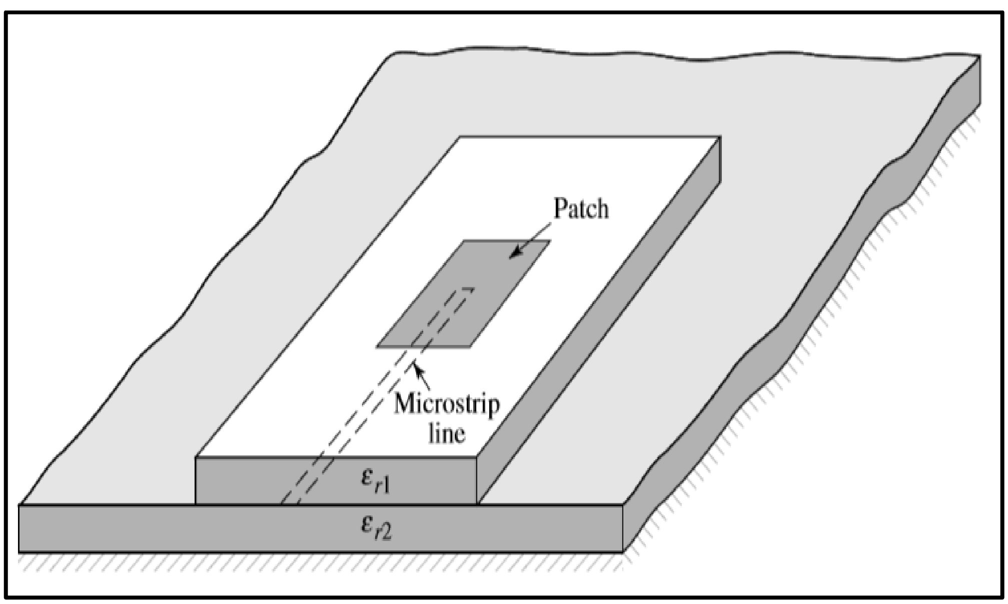

Figure 1.8 Proximate-coupled feed.

Table 1.7 Comparison between different feeding techniques.

Characteristics	Coaxial feed	Microstrip line feed	Aperture-coupled feed	Proximity-coupled feed
Spurious feed radiation	More	More	Less	Minimum
Reliability	Poor due to soldering	Better	Good	Good
Ease of fabrication	Soldering and drilling needed	Easy	Alignment Required	Alignment required
Impedance matching	Easy	Easy	Easy	Easy
Bandwidth	2-5%	2-5%	21%	13%

1.4.3 Application of Microstrip patch antenna

- Mobile and satellite communication
- Global Positioning system
- Radio frequency identification
- Worldwide Interoperability for Microwave Access (Wi-MAX)
- Radar
- Rectenna application
- Telemedicine application
- Medicinal application

1.5 MODEL FOR ANALYSIS OF MICROSTRIP PATCH ANTENNA

For the evaluation of microstrip patch antenna structure, there are distinct kinds of model. These models are transmission line, cavity line and full wave. Among them transmission line model is popular to design a patch antenna.

1.5.1 Transmission-line model

Transmission-line model is the simplest model of all three technique analyzes but the least precise and lacks the versatility. Despite shedding some physical understanding. The transmission-line model basically reflects two slots for the microstrip antenna, divided by a low-impedance Z_c transmission line L-length.

- ***Fringing Effects***

The patch's length and breadth is limited, the patch field is subjected to fringing in figure 1.9. The amount of fringing relies on the size of the patch and the height of the substrate.

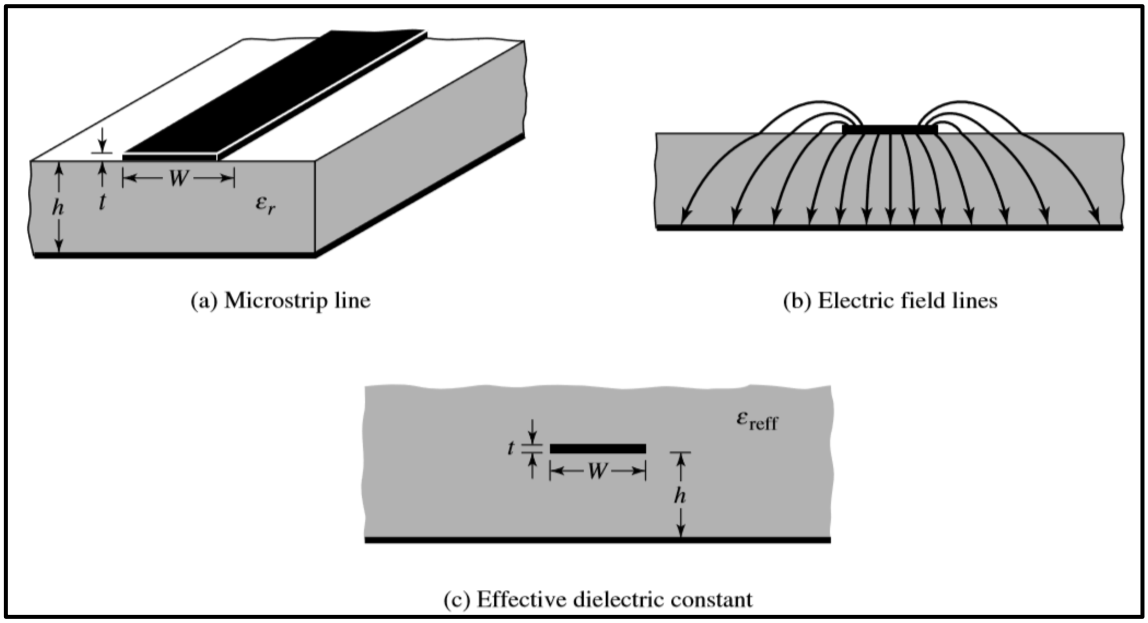

Figure 1.9 Microstrip line and its electric field lines, Effective dielectric constant.

For E-plane fringing is a function of dielectric constant (ε_r) and the length of the substrate to height (L/h>>1) of the substrate which cause the resonant the frequency of the antenna. Due to W/h>>1 and ε_r>>1, the field is mostly concentrated mostly in the substrate. An effective dielectric constant is introduce to account for fringing and the wave propagation in the line. It is in the range of $1< \varepsilon_{reff}< \varepsilon_r$. The value of dielectric constant is always closer to actual dielectric constant (ε_r >1). The effective dielectric constant is also known as static value and is given as

W/h>1

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

- ***Effective length, resonant frequency and Effective width***

Because of the fringing effect, the dimension of the patch looks increased compared to the actual dimension of the patch which is shown in the figure 1.10.

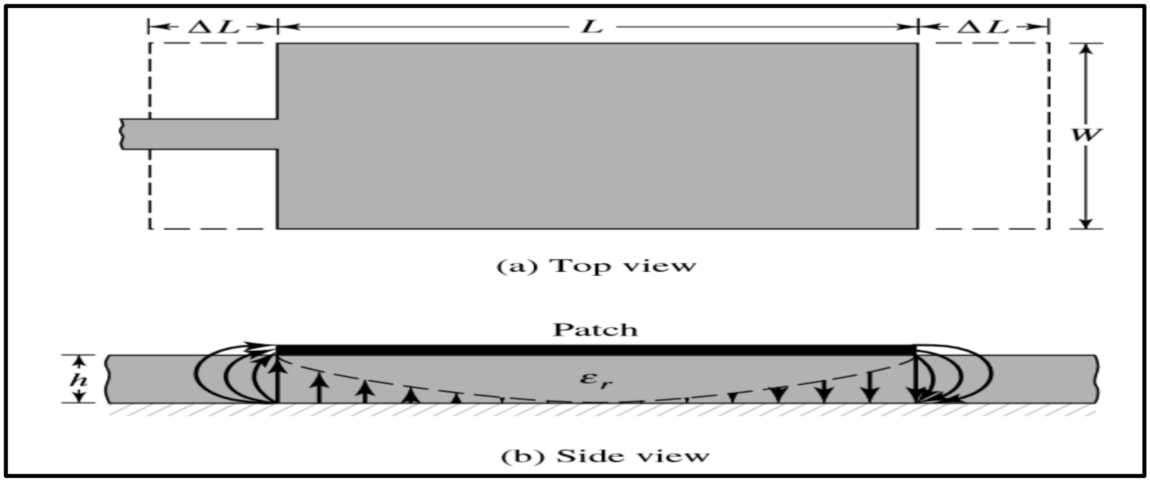

Figure 1.10 Physical and effective lengths of rectangular microstrip patch.

It is shown in the figure that patch along the length has been extended by a distance ΔL which is the function of width-to-height ratio and effective dielectric constant. The normalized extension of length is

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

The effective length of the patch (L=λ/2 for dominant mode TM_{010} mode with no fringing)

$$L_{eff} = L+2\Delta L \qquad (1.3)$$

For dominant mode TM_{010} mode, the resonant frequency is a function of length which is give as

$$(f_{rc})_{010} = \frac{1}{2L\sqrt{\varepsilon_r}\,\sqrt{\mu_0\varepsilon_0}} = \frac{v_0}{2L\sqrt{\varepsilon_r}} \qquad (1.4)$$

The value of length and width of the patch is given as

$$W = \frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}}\sqrt{\frac{2}{\varepsilon_r+1}} = \frac{v_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \qquad (1.5)$$

$$L = \frac{1}{2f_r\sqrt{\varepsilon_{reff}}\sqrt{\mu_0\varepsilon_0}} - 2\Delta L \qquad (1.6)$$

Hence this is transmission-line model in which infinite ground plane is consider. It is considered that the outcome of finite and infinite ground can be the same if the ground plane dimension is six times larger than the patch dimension by about six times the thickness of the substrate around the periphery. The length and width of ground plane is given as

$$L_g = 6h+L \qquad (1.7)$$

$$W_g = 6h + W \qquad (1.8)$$

Where

h= Height of the substrate

L= Patch Length

W= Patch width of

L_g = Ground plane length

W_g= Ground plane width

ε_{reff} = Effective permittivity

ε_r = Relative permittivity

L_{eff} = Effective length

v_o= speed of the light (3×10^8 m/sec)

1.6 OUTLINE OF THESIS

The thesis is divided into five chapter. Each chapter play important role in the thesis which are brief in the below section.

Chapter 1: This chapter brief about how the communication is done with different methods, what kind of communication system is used and vision of wireless communication. It also explain different bands on which communication is done. This chapter also explain the significance of antenna in wireless communication, types of antenna is used in wireless communication, microstrip patch antenna and it feeding techniques use to design antenna. Finally the transmission line model is explain.

Chapter 2: This chapter brief about the different types of microstrip antenna design with different techniques which is done through literature survey. Also by doing the literature survey on different antenna design paper it is found that there is so many research gaps and base on that research gaps, its objective is to design an antenna which is applicable to resonate the frequency for 4G LTE, Wi-MAX, WLAN and S/C/X-Bands application.

Chapter 3: This chapter explain the about the design a multiband enhanced bandwidth antenna for 4G LTE, Wi-MAX, WLAN and S/C/X-Bands application. Parametric studies is done on geometrical as well as structural variation of antenna. Also some of the parameter like return loss, VSWR, 2D and 3D far-field measure on gain and directivity is done on CST microwave studio software version 17.

Chapter 4: This chapter explain about the fabrication, testing and comparison of simulated and measured results using vector network analyzer.

Chapter 5: This chapter explain the conclusion and future scope of antenna.

CHAPTER 2
LITERATURE SURVEY

2.1 INTRODUCTION

In order to design an antenna, it is important to study and understand the present problem and its solution. It is also important to know that in which area antenna design progress is going on and what kind of antenna is design for what applications. In order to understand this, lots of journal paper, conference paper, google search on present work about antenna design, books, thesis and dissertations should refer or studies. To start writing the thesis, first of all literature survey is done about different types of antenna designed, different techniques is used to designed the antenna, it applications, what kind of material is used to designed the antenna. After doing all the review of paper, it was found that for my thesis microstrip patch antenna is simple to design and it can be design for multi-frequency application.

In 1953, the model of microstrip antenna was first proposed by Deschamps and the patent was issued in France in 1955 in the name of Gutton and Baissionot. But the development of antenna was accelerated in the 1970s because of the different types of substrate available. The practical antenna was developed by Howell and Munson. This chapter will give the idea about the evolution of microstrip patch antenna and the various improvement in the microstrip patch antenna.

Dang et al. (2010) presented the WiMAX / WLAN triple-band microstrip slot antenna [16]. This antenna has a simpler structure to attain triple-band characteristics than other antennas. The antenna consist of a substrate on which one side is microstrip feed line and other side is ground plane on which simple slots are engraved. The desired antenna can be considered a transformer of the slot antenna. A simple slots are engraved in the ground plane to attain all the operating bands. Rectangular slot are cut in the ground plane to realize the lower operating frequency band and Trapezoid slot is used to generate higher operating frequency band. By steady varying structure of trapezoid slot in the antenna, it supports to achieve impedance matching in a wideband range. For feeding and providing the middle working band, strips are inserted in the rectangular slot which produces the current flow path at the central operating frequency band. The experimental results expression that the antenna is resonating at three different frequencies 2.7 GHz, 3.5 GHz and 5.6 GHz. The achieved impedance bandwidths are 600 MHz, 430 MHz and 1300 MHz respectively which is worthy for WiMAX and WLAN applications. Furthermore, the antenna suggested has excellent radiation features and gains in the three working bands.

Saghati et.al. (2010) presented three switchable frequencies of the reconfigurable slot antenna [17]. The individuality of this configuration enables the electronic selection of different bands of its frequency resonances using three switches. While designing the antenna three sickle-shaped slots are cut in the ground plane and three pairs of p-i-n diodes are soldered between three metal strips inside the slots and the ground plane. The advantage of doing these thing will overwhelms the problem of conformist reconfigurable antennas of aiding one frequency band at a time. To modify the reconfigurability status of a slot, P-i-n diodes are used. The antenna design uses a distinctive method to use p-i-n diodes that do not contain any dc bias line, eliminating the impact of dc. By using this techniques the size of antenna is reduce as well as the co- to cross-polarized ratio of radiation pattern also. Thus the antenna supports 2.4 GHz for Bluetooth, 3.5 GHz for WiMAX and 5.8 GHz for WLAN systems. The observed boresight gain values of the antenna at 2.46 GHz, 3.59 GHz and 5.69 GHz are 2.33 dBi, 3.14 dBi and 2.89 dBi.

Hu et al. (2011) the triband square-slot antenna was presented with symmetrical L-strips and monopole radiator to in order to resonate the antenna at three different frequency bands for WiMAX and WLAN applications [18]. The structure of antenna is simple to construct and small in size. The square slot cut in the patch is used to generate lower frequency band a lower, monopole radiator is used to generate middle band and the symmetrical L-strips is used to yield higher frequency band. The measured results indicate that the antenna is resonating at 2.4 GHz, 2.5 GHz, 3.5 GHz and 5.2 GHz frequency bands. The bandwidths of antenna is 480 MHz (2.34–2.82 GHz), 900 MHz (3.16– 4.06 GHz) and 680 MHz (4.69–5.37 GHz). The proposed antenna is used for WLAN and WiMAX application. Also it explain about the gain obtained from the measurement results. The result shows that the gain fluctuated from 2.77 to 3.06 dBi at the lower operating frequency bands from 2.3–2.7 GHz, 2.98 to 3.13 dBi from 3.3–3.7 GHz in the middle operating frequency band and 3.10 to 2.78 dBi from 5.0–5.3GHz in the upper operating frequency band.

Cao et al. (2011) presented the compact multiband antenna. The antenna is designed by two printed open-ended slots in which a T-shaped slot and an E-shaped slot are made in the patch [19]. Due to simple in structure it was fabricated easily and measured the antenna results. It was found that the antenna is resonating at five different frequencies band which covers the GSM900, DCS1800, PCS1900, UMTS and 2.4 GHz based WLAN frequency bands for mobile handsets application. The five corresponding open-ended slots can control these five frequency bands separately. The benefit of these methods would assist the developer to optimize and adjust the resonant frequencies of this antenna by individually changing the geometric parameters of the corresponding slots without influencing others. The tested outputs also show that the gain differs from estimated 0.75 to 1.5 dBi for the smaller frequency band at 900 MHz, 1.2 to 3 dBi for the middle band including DCS, PCS and UMTS, and 1.25 to 1.6 dBi for the 2.4 GHz WLAN band.

Chiang et al. (2012) presented the coplanar waveguide (CPW)-fed multi-frequency antenna. The antenna consist of patch in which circular slot cut and it is loaded with arc-shaped metallic strips to generate multi-frequency bands for wireless application [20]. The reason to insert the arc-shaped metallic strips into patch to produce the multiple resonant modes for multiband vision. The lower resonant frequency helps to determine the size of any multi-frequency antenna, but in the case of proposed antenna the size of antenna is determined by the higher resonant frequency. To produce the extra operative frequencies it is necessary to insert the arc-shaped Metallic strips in the patch deprived of increasing the whole antenna space. The proposed antenna resonate at 2.4 GHz, 5.2 GHz and 5.8-GHz frequency bands for 802.11a/b/g/n WLAN standards. The suggested antenna has input impedance bandwidths of the working ranges ranging from 5.0% to 64.7%, achieved by changing the arc-shaped metal strip angles. In addition, the frequency bands acquired display broad-sided radiation models with greater efficiency than 45%, which is WLAN criteria.

Lu et al. (2013) presented the multi-band planar slot antenna. The antenna has simple structure in which C and inverted L-shaped slots are cut in the patch in order to generate the numerous frequency bands [21]. The obtained resonating frequency is related with compacted operation for IEEE 802.16m WiMAX system. The antenna is resonated at the three different 2.6 GHz, 3.5 GHz and 5.5 GHz frequency bands which run into the specifications of WiMAX system (IEEE 802.16m). The impedance bandwidth achieved through the working ranges are 525 MHz, 743 MHz and 813MHz. The effects of the experiments also indicate that the planar compact slot antenna has almost omni-directional radiation patterns. The maximum peak gains achieved through the working ranges are 3.0 dBi, 4.3 dBi and 5.2 dBi and total radiation efficiencies are 88 %, 95 % and 97% through these operating frequency bands respectively.

Li et al. (2014) Presented the four-band coplanar slot monopole antenna (CPW)-fed [22]. The antenna is designed using finite element method in which four L-shaped, two F-shaped and two U-shaped slots are cut in the radiating patch to achieve multiband operation for RFID/WiMAX/WLAN applications. The model is optimized using the technique of finite elements. The obtained consequence displays that the antenna is resonating at 0.94 GHz, 2.45 GHz, 3.50 GHz and 5.80 GHz frequency bands and its peak gain is -11.6 dBi, -0.46 dBi, 2.09 dBi, and 5.37 dBi respectively. Triple-band RFID applications and triple-band WiMAX / WLAN applications can also be combined in the future in a single device by changing parameters.

Sharma et al. (2015) present the stack microstrip multiband antenna. This is designed using HFSS software and use the microstrip feed line techniques to excite the antenna [23]. The antenna has H-shape structure is parasitic patch through which it radiates. It is found that the antenna is resonating at 4.06 GHz, 4.60 GHz, 5.95 GHz, 7.79 GHz frequency bands. The antenna is designed for different wireless application.

Mahmood et at. (2015) present the multiband miniaturized microstrip patch antenna using stack configuration [24]. The antenna comprise of patch in which L-shaped and H-shaped slots are cut into the patch to generate frequency bands. The antenna is resonating at 2.66 GHz, 2.87 GHz, 4.20 GHz, 6.05 GHz and 7.42 GHz frequency bands. The has bandwidth of 65MHz, 56 MHz, 45 MHz, 100 MHz and 92 MHz and it is use for S-Band and C-Band applications.

Wu et al. (2015) presented the multiband coplanar waveguide (CPW)-fed monopole antenna [25]. The antenna was designed using bow-tie patch in which slots of different length was etched in order to generate the multiple operating frequencies. The quarter wavelength resonance condition will helps to determine the length of each bent monopole. Because the bow-tie patch can be treated as a corresponding broadband impedance, the broadband feature can easily satisfy each frequency band. The measured results shows that the antenna is resonating at 2.5 GHz, 3.5 GHz and 5.5 GHz frequency for WLAN/WiMAX/LTE applications with impedance bandwidth of 300 MHz (2.4–2.7 GHz), 300 MHz (3.4–3.7 GHz) and 600 MHz (5.2–5.8 GHz). The obtained peak gains at 2.5 GHz, 3.5 GHz and 5.5 GHz are 3.75 dBi, 3.56 dBi and 3.93 dBi respectively. The simulated and measured results were in good covenant, confirming the possibility of the proposed antenna design approach.

Cao et al. (2015) presented the multiband slot antenna. The antenna consists of a rectangular slot in which an inverted T-shaped stub is attached to upper edge of the rectangular slot and a pair of E-shaped stubs are attached to both side of rectangular slot [26]. In order to excite the antenna, a T-shaped feed line is used to generate four frequency bands for GPS, WiMAX and WLAN applications. The size of the antenna and it radiating portion are less than those of the tri-band and multiband antenna. The antenna was design, it was fabricated and measured the results using computer simulation. It was found that the antenna is resonating at 1.575 GHz, 2.45 GHz, 3.5 GHz, and 5.4 GHz. The achieved bandwidth are 90 MHz (1.575–1.665 GHz), 145 MHz (2.4–2.545 GHz), 700 MHz (3.27–3.97 GHz) and 760 MHz (5.17–5.93 GHz). The obtained peak gain is 3.55 dBi, 3.93 dBi, 5.02 dBi, 4.86 dBi respectively.

Ahmed et al. (2016) present the multiband monopole antenna. The antenna is designed using HFSS software and it is comprised of L-shaped and C-shaped patch are combine together as radiator which helps to generate wideband frequency [27]. The C-shaped leads the smaller bands and the greater bands by L-shaped. The antenna has bandwidth of 55 MHz (745–800 MHz), 1300 MHz (1.7–3 GHz) and 400 MHz (3.4– 3.8 GHz) for LTE and WLAN bands application.

Liu et al. (2017) presented the compact coplanar waveguide fed multiband antenna. The antenna suggested is a rectangular radiating patch and dual meander lines with a defective ground plane [28]. The proposed antenna resonate at 2.4 GHz, 3.5 GHz and 5.5 GHz frequency bands. The obtained desire bandwidth are 340 MHz (2.29–2.63 GHz), 700 MHz (3.26–3.96 GHz), and 1130 MHz (4.97– 6.10 GHz). The antenna is use for TD-LTE, WLAN and WiMAX applications. The obtained peak gain at 2.4 GH, 3.5 GHz and 5.5 GHz frequency bands are 2.64 dBi, 4.48 dBi and 6.08 dBi respectively. The suggested antenna shows a curve of omnidirectional radiation in the H-plane and a model of dipole radiation in the E-plane.

Paul et al. (2017) present the multiband microstrip patch antenna using advance design system (ADS). To design the antenna different shape of patch is used like S, E, C and combination of all three shape together to generate the frequency bands [29]. The author has design antenna using each shape patch and using each single patch they have designed the array type antenna using each shape. It was found that the antenna which is design by using array provide better performance rather than single patch antenna.

Mehra et al. (2017) present the multiband antenna using asymmetrical slot in the patch [30]. The proposed antenna consist of patch in which different asymmetrical slot of different dimension are cut in the patch parallel to each other. The slot cut in the patch is helping to generate the resonating frequency bands. The antenna is resonating at 2.4 GHz, 5.5 GHz, 7.2 GHz and 8 GHz frequency bands which is applicable for Wi-MAX, WLAN, and Bluetooth and X-band application

Rajaram et al. (2017) present the multiband antenna with folded meandered loop [31]. The proposed antenna is designed using IE3D software in which patch is etched with meandered slit, L-shape patch and folded loop line. This type of structure helps to generate three bands which is at 0.73 MHz, 2.45 GHz and 5.35 GHz frequency bands. Antenna is design for LTE700, WiMAX, WLAN and unlicensed LTE band applications. The antenna has bandwidth of 20MHz (720–740 MHz), 95 MHz (2400–2495 MHz) and 365 MHz (3350–3715 MHz). The antenna has omni-directional radiation pattern in elevated plane and azimuthal plane, which is close to half dipole antenna

Rajmohan et al. (2017) present the single-layered multiband circular annular ring patch antenna [32].The antenna is designed using HFSS software. Antenna patch is circular in shape in which L-shaped orthogonal strips is etched in order to resonate the antenna at 2.4 GHz, 5.95 GHz, 7 GHz, 9.55 GHz and 11.35 GHz frequency bands. Antenna is design form numerous application like Bluetooth, WLAN, Wi-Fi, C-Band and X-band. The features of radiation are also appropriate throughout the resonating frequencies.

Roshan et al. (2018) present the dual wideband monopole antenna. It is intended using two parallel sickle-shaped radiator patches, feed by single microstrip feed line, defective ground plane and rectangular ground plane slot [33]. The bigger sickle radiator provides a bandwidth of (1.5-2.8 GHz), while the lower sickle radiator provides a bandwidth of (3.2-6 GHz). The proposed antenna is designed for numerous application such as GSM, UMTS, LTE, Wi-Fi, WI-MAX and lower UWB application. To improve the bandwidth different slot has been cut in the ground plane.

Mokal et al. (2018) present the X-shaped multiband antenna. The proposed antenna is designed by using coaxial feeding techniques in CAD FEKO suit (7.0) software. The antenna is realized using simple patch to generate single band [34]. To generate dual and triband, a slot is cut in rectangular patch. Finally to generate quad band an X-shaped patch is design. The antenna is design for different application like GSM, Bluetooth, WI-MAX and WLAN. The bandwidth of antennas is 90 MHz (1.79-1.83 GHz), 98 MHz (2.395-2.493GHz), 78 MHz (3.468-3.546GHz), and 120 MHz (5.1743-5.2949GHz). In addition, to enhance antenna gain, an antenna assessment for variable substrate height was performed and the beneficial gain for all frequency bands was achieved.

Raobawale et al. (2018) present the quad band antenna. The antenna is designed using HFSS software and it is comprises of rectangular patch in which a pair of inverted T-shaped slot is cut into patch and in the ground plane rectangular slot is cut to generate quad band frequency[35]. The antenna has bandwidth of 50

MHz (0.93-0.98GHz), 90MHz (2.18-2.27GHz), 130MHz (3.29-3.42GHz) and 90MHz (4.85-4.94 GHz) which is used for different wireless application. The proposed microstrip antenna has stable omnidirectional radiation models, appropriate loss of exchange and VSWR at the required quad band frequency

Chiang et at. (2018) present the single band antenna. The antenna is comprise of rectangular patch in which slot is cut in the patch and microstrip feed line is used as feed to excite the antenna at 2.62 GHz frequency band [36]. The antenna has bandwidth of 60 MHz (2.59 GHz to 2.65 GHz) and it used for LTE#7 application. It has simple in structure and it has omni-directional radiation pattern in H-plane.

Dadhich et al. (2018) presented the compact multiband slotted Microstrip Patch Antenna. The proposed multiband slotted antenna etched Y-shape and U-shape slots in the rectangular patch in order to resonate the antenna at numerous frequency bands. In order to excite the antenna, insert feed is used. The proposed antenna has been designed, fabricated and simulated [37]. The measured result shows that the antenna is resonating at 2.4 GHz, 4.1 GHz and 7.98 GHz frequency bands and its impedance bandwidth is 300 MHz (2.2-2.5 GHz), 200 MHz (4-4.2 GHz) and 1400 MHz (6.7-8.1 GHz) respectively. The propose antenna is used for WLAN, Bluetooth/TD-LTE and X-band applications.

2.2 RESEARCH GAPS

From the literature survey, it is observed that there are dual-band, tri-band and multi-band antennas designed for various wireless applications. These antennas are designed by different methodology and multi-banding techniques like notching, stacking of patches, use of parasitic elements and slotting techniques.

1) Stacked patch geometry becomes bulky as it involves a number of stacked patches with substrate layers and using a number of parasitic patches also increases its dimensions, so cutting out slots of different shapes from the main radiating patch like E-shape, T-shape, H-shape, L-shape is a convenient and effective method which helps to generate multiple resonances at different frequency bands [23] and [24].

It is also observed that different feeding techniques like co-axial feedline, microstrip feedline, and CPW (coplanar waveguide) feedline can be used to excite these antennas.

2) The antennas designed by using co-axial feedline have narrow bandwidth and difficult to implement as complication in feeding may arise for locating the exact point where it has perfect impedance matching to the antenna structure [33] So microstrip feedline and CPW feedline, which have planar structure, are used to design antennas to generate multiband frequency.

3) From the reference paper [20], [22], [24] and [27], it was also observed that, the coplanar waveguide (CPW)-fed antenna structure has simple geometry structure but the bands obtained by these antenna covers only S-band and C-band application. The bandwidth of these antenna are not quite impressive. Also the results obtained from these antenna have low return loss, have low gain and non f of the antenna covers the X-band.

4) From the reference paper [16], [18], [21], [25] and [26], it is perceived that the antenna is design by using various shape or size of patch. The patch is comprise of numerous shaped of slots or different shape and size of stubs are attached with in the patch to generate the numerous frequency bands. The band obtained from these antenna is applicable for GPS/ WiMAX/WLAN application. But the obtained the result obtained from these antenna has narrow bandwidth, low return loss, low gain which not enough for today wireless system

5) From [21], it is seen that the antenna covers S/C/X all three bands for different wireless communication in this antenna but the bandwidth obtained is very narrow which is not applicable in real field.

2.3 OBJECTIVE OF THESIS

Based on the above research gaps, the main objective is to design the antenna which will covers all the application that was covering in the previous designed antenna along with some additional bands which was not cover in the previous designed antenna in this thesis work.

1) To design and simulate the multiband microstrip antenna for 4G LTE, WiMAX, WLAN and C/S/X-bands applications.
2) To optimize bandwidth and return loss using slot antenna embedded with E shaped and T shaped stubs.
3) To fabricate and test the proposed antenna structure at 2.24 GHz, 4.2 GHz, 5.25 GHz and 9.3 GHz on vector network analyzer and anechoic chamber.

CHAPTER 3
DESIGN AND SIMULATION OF ENHANCED BANDWIDTH MULTI-FREQUENCY ANTENNA FOR 4G LTE, Wi-MAX, WLAN AND S/C/S-BANDS APPLICATION

3.1 INTRODUCTION

This chapter explain about the design and simulation of enhanced bandwidth multi-frequency antenna using microstrip feed line techniques for 4G LTE, Wi-MAX, WLAN and S/C/X- bands application in CST microwave studio software version 2017. The results are analyze in term of return loss, vswr, impedance bandwidth, gain, directivity and surface current distribution. Multiband antenna has been achieved in this design. Microstrip antenna is resonating at 2.24 GHz, 4.2 GHz, 5.25 GHz and 9.3 GHz. The simulated results shows the impedance bandwidth obtained at difference frequency bands are 760 MHz (2.11-2.87 GHz) at 2.24 GHz resonating frequency, 210 MHz (4.09-4.30 GHz) at 4.2 GHz resonating frequency, 300 MHz (5.09-5.39 GHz) at 5.25 GHz resonating frequency and 2250 MHz (7.92-10.17 GHz) at 9.3 GHz resonating frequency. Also in order obtained the desire bandwidth, parametric studies has been done by varying different parameter which is also explain.

3.2 DESIGN OF MULTI-FREQUENCY RECTANGULAR PATCH ANTENNA

The final geometry of the proposed enhanced bandwidth multi-frequency antenna is shown in the figure 3.1(a) which consists of FR-4 substrate with dimension of 56 × 44mm^2. The FR-4 is glass-reinforced epoxy laminate material which is flame resistant and is easily avail8able in sheet form. The thickness of the sheet is chosen to be 1.6 mm. The relative permittivity of the substrate (ε_r) is 4.4 and a loss tangent of 0.02. The substrate consists of radiating patch on one side and ground on the other.

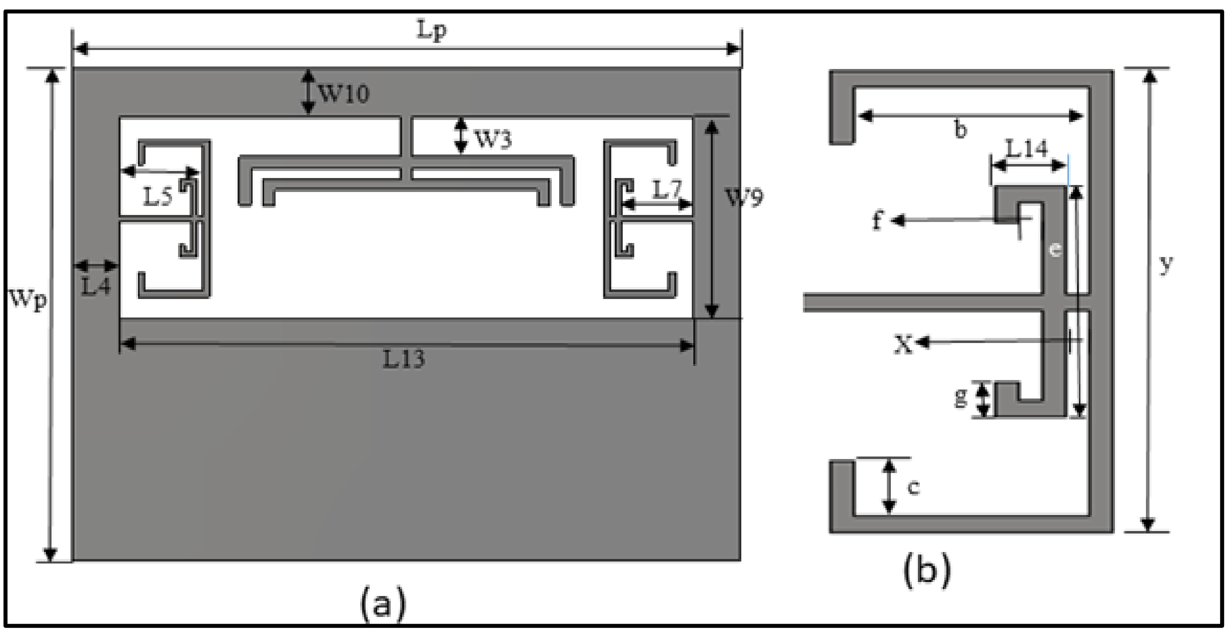

Figure 3.1 (a-b) Dimension of antenna (a) Front view (b) E-shape stub

The patch is formed of perfect electrical conductor (PEC) material with thickness of 0.035mm. It has a dimension of 56 × 44 mm^2. A rectangular slot with dimension of 48 × 18 mm^2 is cut from patch. In the rectangular slot, two E-shaped stubs figure 3.1(b) are attached to both left and right side of rectangular slot. An inverted T-shaped stub figure 3.1(c) with its two horizontal strips folded on both sides is embedded in the upper edge of the rectangular slot to achieve better impedance. Figure 3.1(d) shows the side view of the antenna.

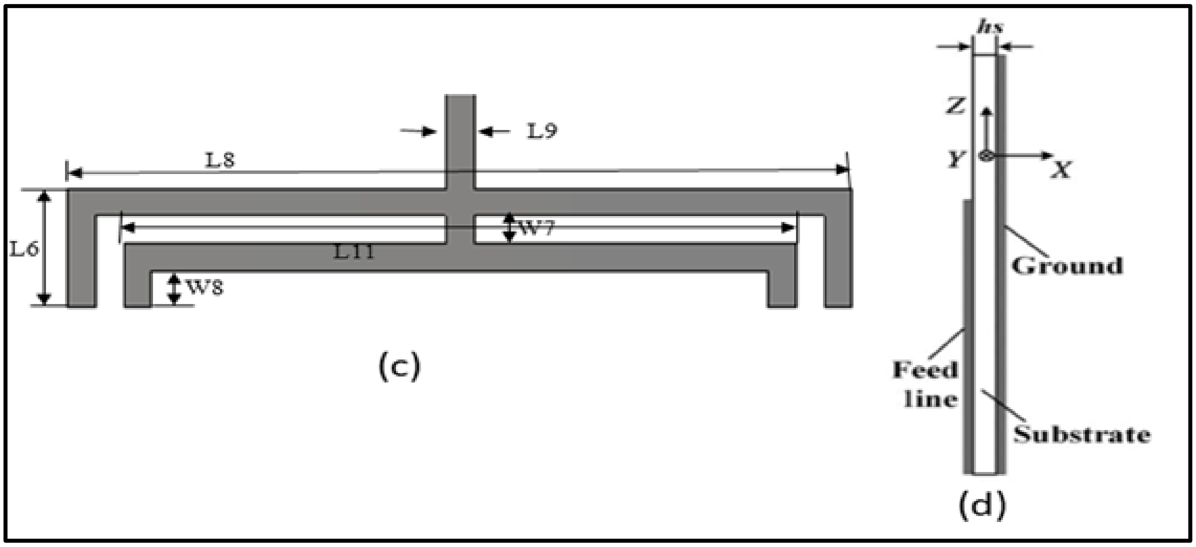

Figure 3.1 (c-d) Dimension of antenna (c) Inverted T-shape stub (d) Side view

A staircase feedline of thickness of 0.035 mm is implemented on the backside side of the substrate as shown in figure 3.1(e).

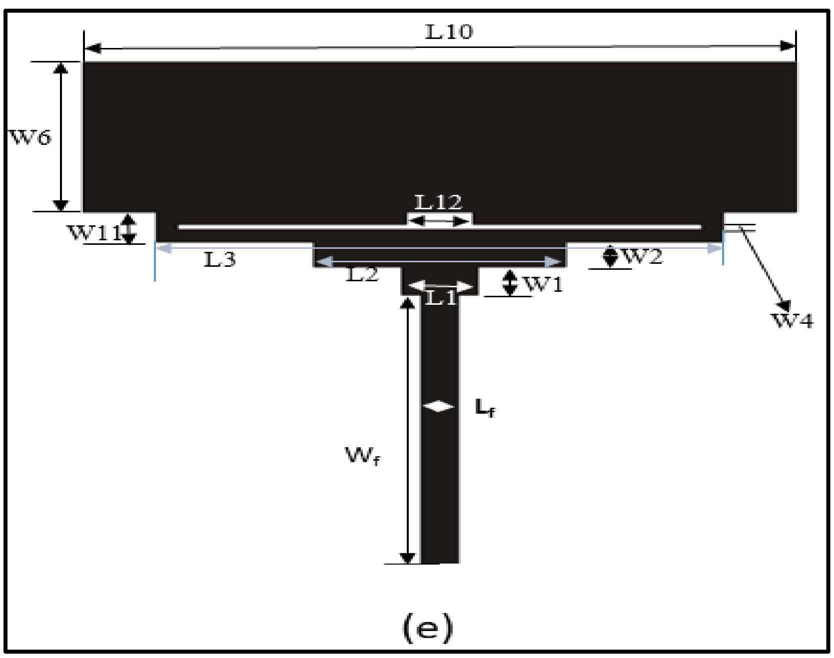

Figure 3.1 (e) Back view

A staircase feed line has width of w_f =1.76 mm is used to excite the antenna to achieve an impedance of 50 Ω. In the feed line, the different size of patch is added step by step one after another which looks like a staircase shaped feed line. A slot is made in the middle of the feed line patch for better impedance matching. An inverted T-shaped stub and two E-shaped stubs are used to generate multiple frequency bands for 4G LTE, WiMAX, WLAN and S/C/X-band applications. The final dimensions of the multi-frequency antenna are given in table 3.1.

Table 3.1 Final dimensions of the proposed antenna

Parameter	**L_p**	**W_p**	**L_f**	**W_f**	**L_1**	**W_1**	**L_2**	**W_2**	**W_4**
Dimension(mm)	56	44	1.76	21.7	12	1.9	12	2	0.4
Parameter	**L_3**	**L_4**	**L_5**	**L_6**	**W_3**	**L_8**	**y**	**B**	**C**
Dimension(mm)	27	4	7	3.3	3.5	28	14	5.5	1.7
Parameter	**L_9**	**Hs**	**E**	**f**	**G**	**L_7**	**L_{10}**	**W_6**	**W_7**
Dimension(mm)	1	1.6	7	1	0.6	6	34	12.1	1
Parameter	**L_{11}**	**W_8**	**L_{12}**	**L_{13}**	**W_9**	**W_{10}**	**W_{11}**	**L_{14}**	**X**
Dimension(mm)	24	1.3	3.2	48	18	4.4	2.4	2	0.5

3.3 PROPOSED ANTENNA DESIGN EVOLUTUION

To study the effects of different radiating elements on the performance of the antenna, the parametric study is done for each structural and geometrical variation. The final simulation of the designed antenna is carried out using CST Microwave Studio version 17.

3.3.1 Structural Variation studies

The different elements are added to the slotted patch design to achieve the desired results which is referred to as structural variations.

***First step*:** Initially a slotted rectangular patch is mounted on one side of the substrate. Two E-shaped stubs and an inverted T-shape stub is embedded in the upper edge of the rectangular slot. On back side of substrate, a staircase shaped feedline is used as to excite the rectangular slot which is shown in the figure 3.2 (a). Its simulated results in generation of multiple bands at 1.42 GHz, 2.1 GHz, 3.01 GHz and 4.26 GHz which is shown in the figure 3.2 (b). The return loss parameter (S_{11}) and impedance bandwidth is measured and shown in the table 3.2.

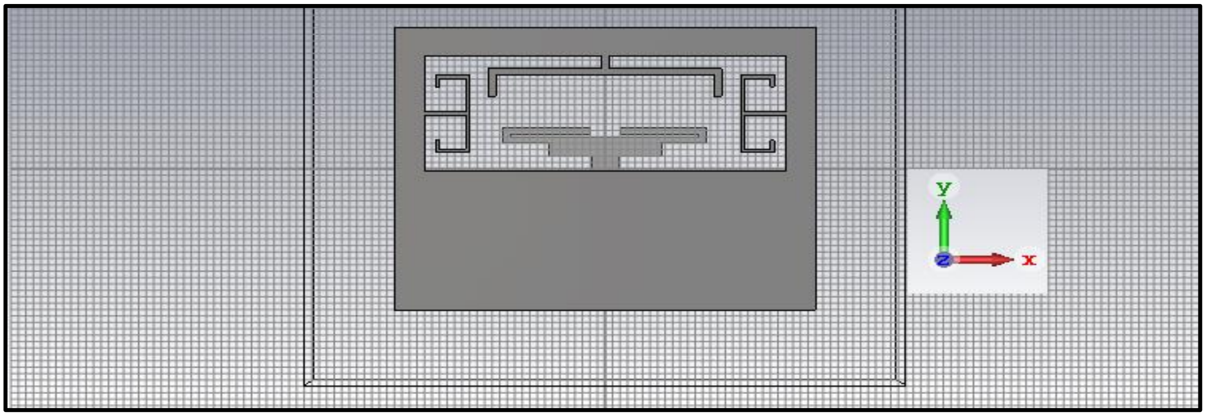

Figure 3.2 (a) First step to design antenna

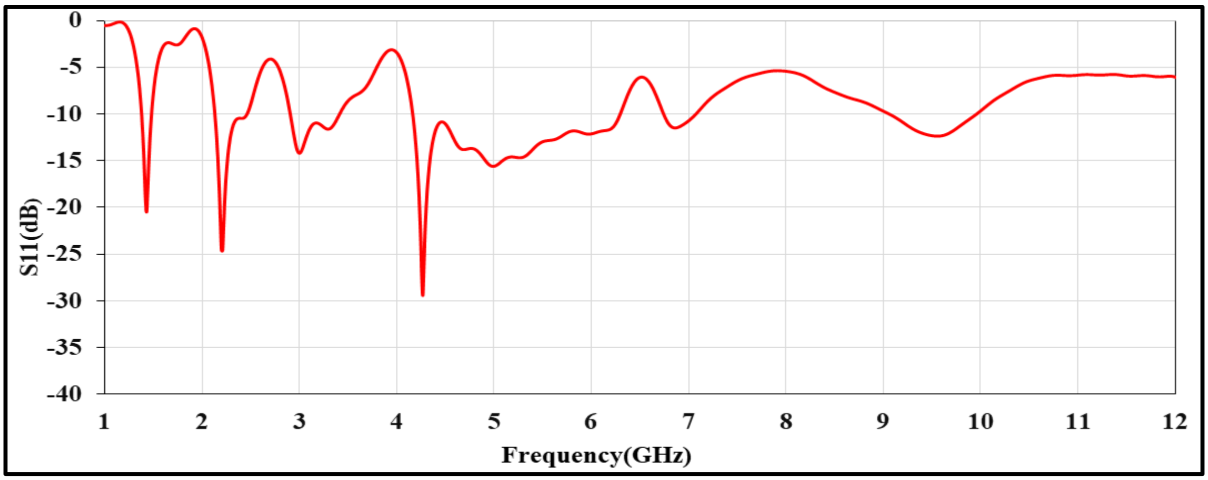

Figure 3.2 (b) First step simulated result

Table 3.2 First step simulated based Return loss and Bandwidth

	Band-1 (1.37-1.48 GHz)	**Band-2 (2.13-2.45 GHz)**	**Band-3 (2.90-3.40 GHz)**	**Band-4 (4.16-6.27 GHz)**
Resonant frequency(GHz)	1.42	2.1	3.01	4.26
Return loss(dB)	-20.47	-24.62	-14.071	-29.42
Bandwidth(MHz)	110	320	500	2560

Second step*: *Addition of smaller E-shaped stubs

Here another smaller E shaped stub is embedded on either side of E arm. The structure of inner E arm stubs is same as previous but the geometry is changed resulting in further shift of frequency band 3 and band 4 which is shown in the figure 3.3 (a). No change is made in the structure or geometry of the inverted T shape stub and a staircase shaped feed line. The simulated return loss result of second step of antenna design is shown in the figure 3.3 (b). The return loss parameter (S_{11}) and impedance bandwidth is measured and shown in the table 3.3**.**

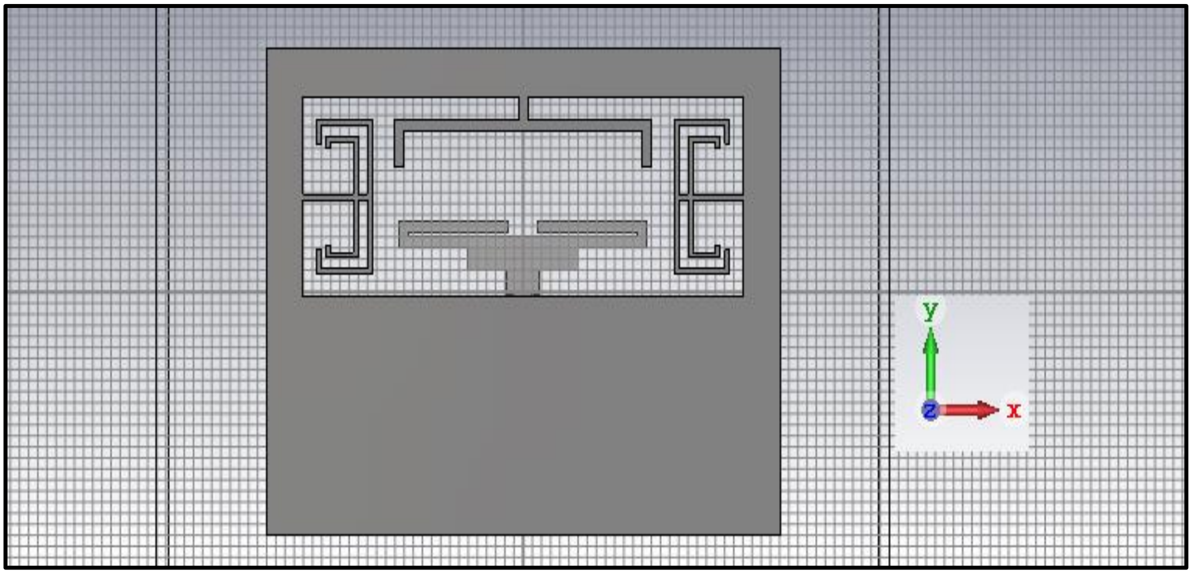

Figure 3.3 (a) Second step to design antenna

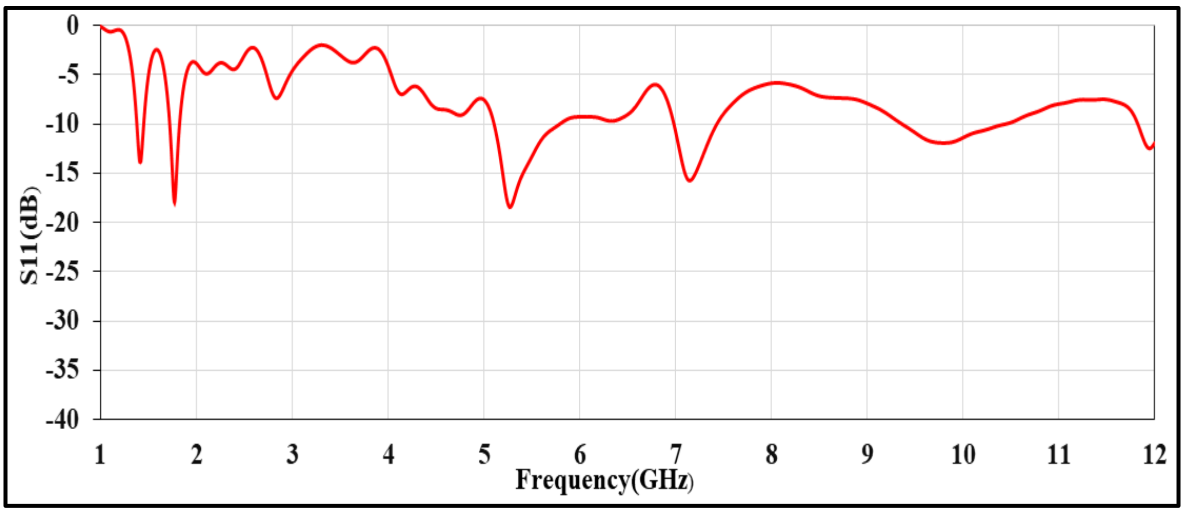

Figure 3.3 (b) Second step simulated result

Table 3.3 Second step simulated based Return loss and Bandwidth

	Band-1 (1.37-1.45 GHz)	**Band-2 (1.72-1.82 GHz)**	**Band-3 (5.12-5.77 GHz)**	**Band-4 (6.99-7.42 GHz)**
Resonant frequency(GHz)	1.4	1.77	5.26	7.13
Return loss(dB)	-13.780	-17.89	-18.38	-15.67
Bandwidth(MHz)	80	100	650	430

Third step*: *Adding of rectangle shaped element to staircase feedline

In the third step, one more rectangular element is embedded to staircase feed line and a slot is etched in the middle of staircase feed line to achieve enhanced bandwidth and return loss. Further, the dimension of smaller E shaped stub has been optimized to achieve the desired bandwidth of band 1 and band 4 which is shown in the figure 3.4 (a). The simulated return loss result of third step of antenna design is shown in the figure 3.4 (b).The return loss parameter (S_{11}) and impedance bandwidth is measured and shown in the table 3.4.

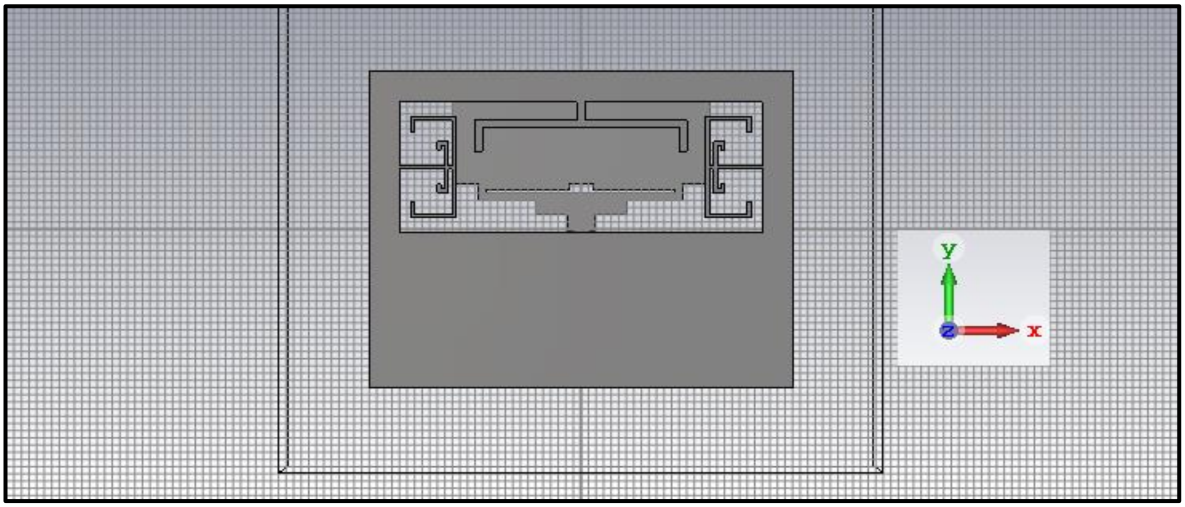

Figure 3.4 (a) Third step to antenna design

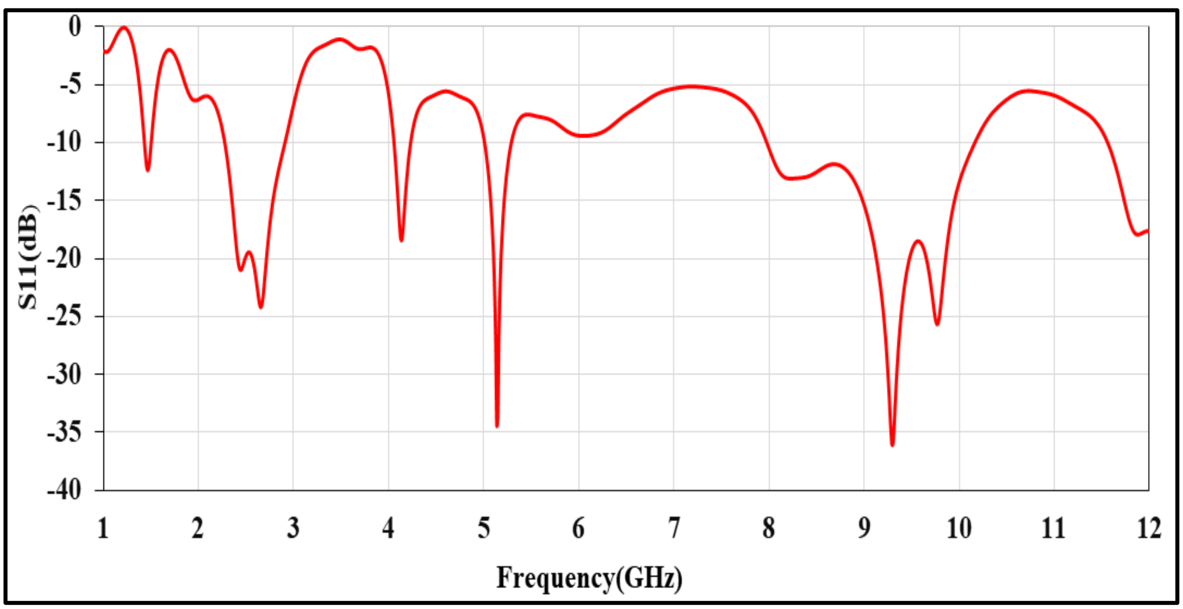

Figure 3.4 (b) Third step simulated result

Table 3.4 Third step simulated based Return loss and Bandwidth

	Band-1 (2.25-2.95 GHz)	**Band-2 (4.04-4.24 GHz)**	**Band-3 (4.99-5.31 GHz)**	**Band-4 (7.96-10.17 GHz)**
Resonant frequency(GHz)	2.66	4.13	5.14	9.3
Return loss(dB)	-23.94	-18.35	-33.64	-35.99
Bandwidth(MHz)	674	208	318	2207

Final step*: *Addition of a smaller stub in inverted T-stub

In the fourth step, one smaller inverted T shaped stub is embedded in the antenna design as shown in the fig 2. The addition of stub results in the better return loss and improved bandwidth for all bands which is shown in the figure 3.5 (a). The simulated return loss result of final step of antenna design is shown in the figure 3.5 (b). The return loss parameter (S_{11}) and impedance bandwidth of various bands are shown in the table 3.5.

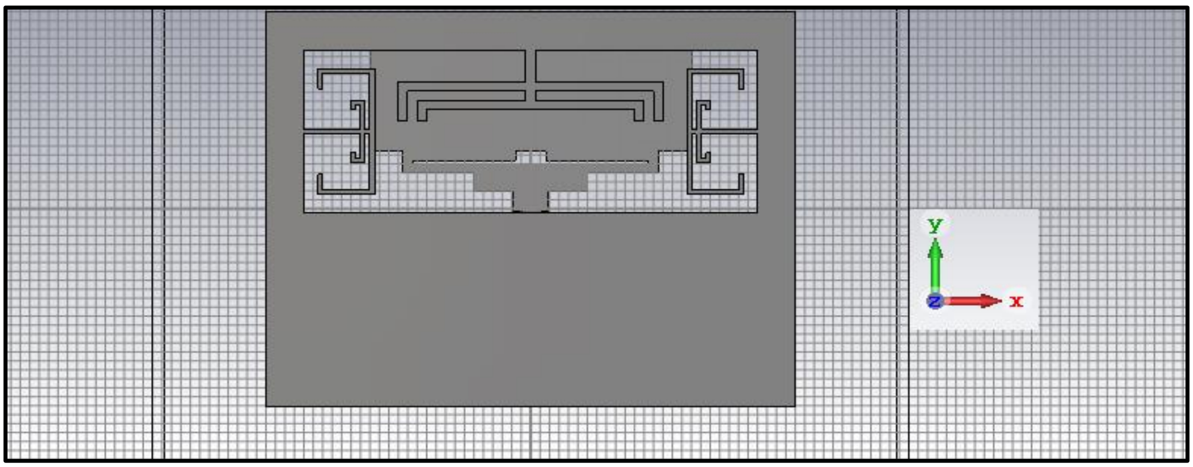

Figure 3.5 (a) Final step to antenna design

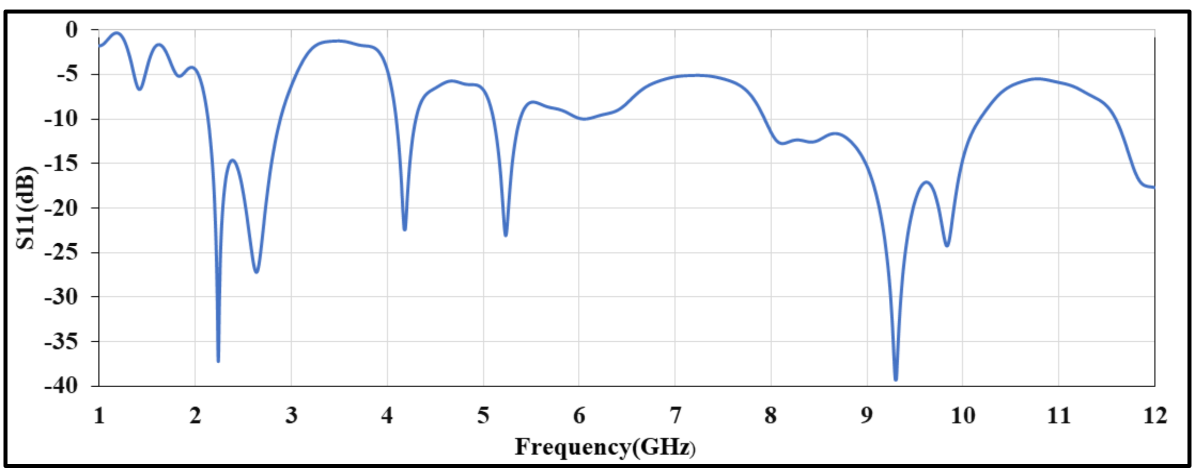

Figure 3.5 (b) Final step simulated result

Table 3.5 Final step simulated based Return loss and Bandwidth

	Band-1 (2.11-2.87 GHz)	**Band-2 (4.09-4.30 GHz)**	**Band-3 (5.09-5.39 GHz)**	**Band-4 (7.92-10.17 GHz)**
Resonant frequency(GHz)	2.24	4.2	5.25	9.3
Return loss(dB)	-37.17	-20.81	-21.22	-39.21
Bandwidth(MHz)	760	210	300	2250

3.3.2 Parametric studies

After the structural variations are done to achieve the desired bands, the final optimization is done by varying the dimensions of the various parameters affecting the performance of antenna which is referred to as geometric variations. In the study, the rectangular slot dimension are kept unaltered (i.e., the slot area $W_9 \times L_{13)}$ and some alterations are made in the geometry of antenna. Some of the parameters which affect the resonant frequency bands are W_3, L_5, L_7, and L_{10}. The different parameters which affect the performance of the antenna are optimized to obtain the desired results in terms of return loss (S_{11} parameter) (figure 3.6 (a-d)), impedance bandwidth, surface current density and radiation pattern at different frequencies.

Effect of varying length L_5 on the resonant frequency

To investigate the effect on bandwidth and return loss, the height L_5 of the outer E-shaped stubs is varied on either side of the rectangular slot from 6.5mm to 7.5mm with a step of 0.5 mm. It is evident from the figure 3.6 (a), it has major effect on the band 3 and band 4 but minor impact on band 1 and band 2.

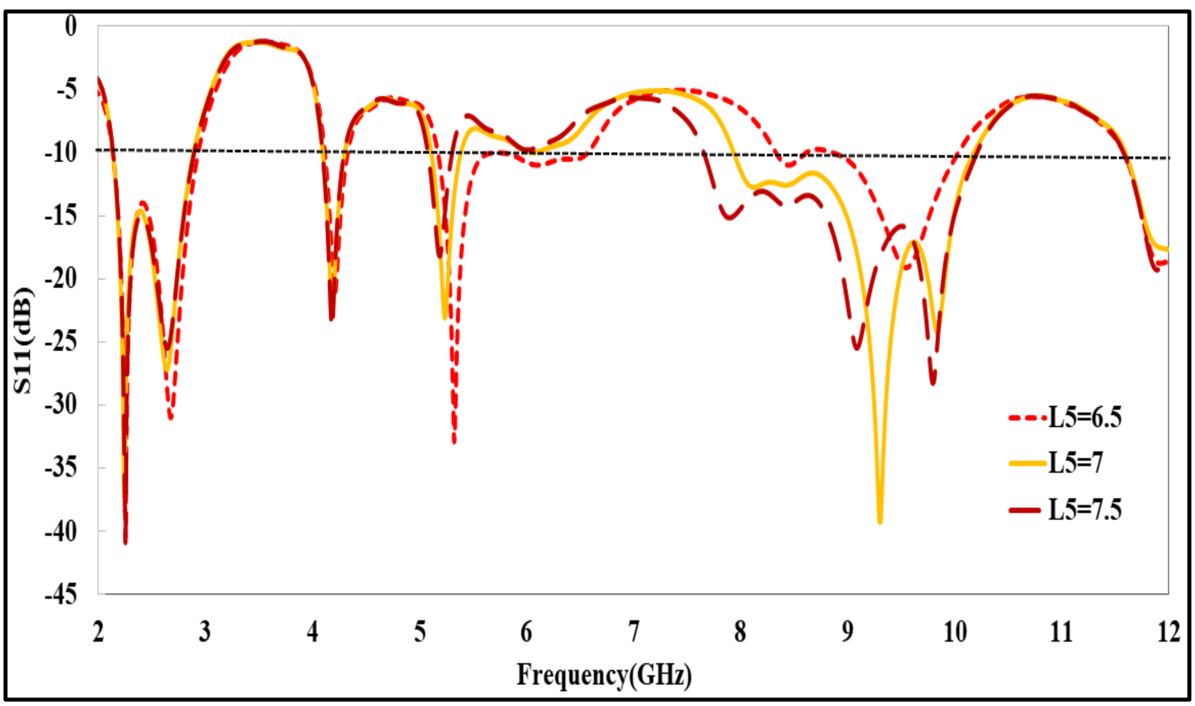

Figure 3.6 (a) Effect of varying length L_5 on the various bands

Table 3.6 presents the bandwidth and return loss for change in length L_5**.** It is concluded from table that the optimal dimension at L_5=7mm because at this dimension the desirable bandwidth and return loss is obtained. But if the dimension is selected at L_5= 6.5 mm, return loss and bandwidth is decreased at band 4 but increases at band 3. There is minor effect in the band 1- band 2. When dimension is selected at L_5= 7.5 mm that the return loss is decreased at band 4 but bandwidth is increased. Also there is shift in the return loss at the band 1, band 2 and band 3.

Table 3.6 Effect of varying length L_5 on the various bands

	Effect on band 1 at 2.24 GHz	**Effect on band 2 at 4.2 GHz**	**Effect on band 3 at 5.25 GHz**	**Effect on band 4 at 9.3 GHz**
At L_5=6.5 mm				
Bandwidth(MHz)	800 (2.13-2.93 GHz)	220 (4.11-4.33 GHz)	1380 (5.18-6.56 GHz)	1790 (8.23-10.02 GHz)
Return loss(dB)	-40.50	-21.22	-32.93	-19.15
At L_5=7 mm				
Bandwidth(MHz)	760 (2.11-2.87 GHz)	210 (4.09-4.30 GHz)	300 (5.09-5.39 GHz)	2250 (7.92-10.17 GHz)
Return loss(dB)	-37.17	-20.87	-21.22	-39.21
At L_5=7.5 mm				
Bandwidth(MHz)	760 (2.13-2.89 GHz)	180 (4.10-4.28 GHz)	220 (5.08-6.56 GHz)	2560 (7.65-10.21 GHz)
Return loss(dB)	-40.82	-23.90	-18.12	-28.22

Effect of varying length L_{10} on the resonant frequency

To understand the effect of varying the length of lower end of staircase feedline on the resonant frequency, the length L_{10}, is varied from 16 mm to 18 mm in steps of 1 mm. It is observed from figure 3.6 (b) that parameter L_{10} has major effect in all bands.

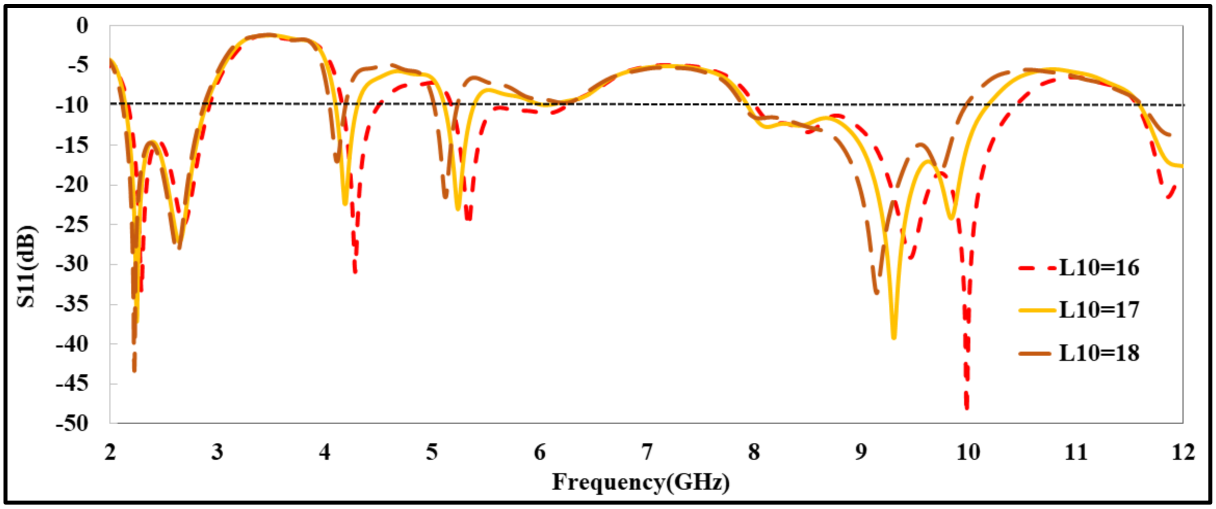

Figure 3.6 (b) Effect of varying length L_{10} on the various bands

Table 3.7 presents the bandwidth and return loss for change in length L_{10}**.** The optimal dimension is selected at L_{10}=17mm because at this dimension appropriate bandwidth and return loss is obtained. But if the dimension is selected at L_{10}=16 mm, the return loss is increased at the band 2, band 3 and band 4 but at band 1 it decreases. Also the band width is increased at the band 2, band 3 and band 4 but minor effect at the band 1. When dimension is selected at L_{10}=18, return loss decreases at the band 2, band 3 and band 4 however return loss increases at band 1 and bandwidth decrease.

Table 3.7 Effect of varying length L_{10} on the various bands

	Effect on band 1 at 2.24 GHz	**Effect on band 2 at 4.2 GHz**	**Effect on band 3 at 5.25 GHz**	**Effect on band 4 at 9.3 GHz**
At L_{10}=16 mm				
Bandwidth(MHz)	760 (2.15-2.91 GHz)	320 (4.16-4.48 GHz)	1150 (5.1-6.25 GHz)	2410 (8.23-10.02 GHz)
Return loss(dB)	-33.50	-30.93	-25.27	-48.76
At L_{10}=17 mm				
Bandwidth(MHz)	760 (2.11-2.87 GHz)	210 (4.09-4.30 GHz)	300 (5.09-5.39 GHz)	2250 (7.92-10.17 GHz)
Return loss(dB)	-37.17	-20.87	-21.22	-39.21
At L_{10}=18 mm				
Bandwidth(MHz)	760 (2.11-2.87 GHz)	160 (4.03-4.19 GHz)	210 (5.01-5.22 GHz)	2070 (7.89-9.96 GHz)
Return loss(dB)	-43.31	-16.98	-21.47	-33.56

Effect of varying inner height L_7 on the resonant frequency

To observe the effect of varying the length of the inner E shape stubs on the resonant frequency, the length 'L_7', is varied from 5.5 mm to 6.5 mm in steps of 0.5 mm. It is observed from figure 3.6 (c) that parameter 'L_7' has major effect on the band 3 and band 4 but minor effect in the band 1 and band 2 as summarized in table 3.8.

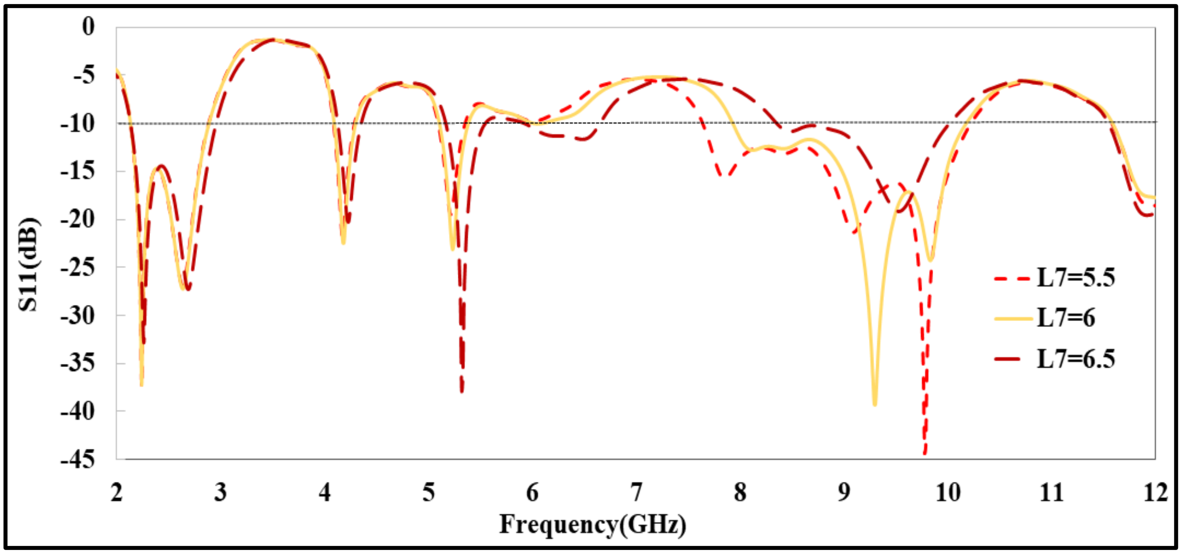

Figure 3.6 (c) Effect of varying length L_7 on the various bands

Table 3.8 presents the bandwidth and return loss for change in inner height 'L_7'. The optimal dimension is selected at L_7=6 mm as at this dimension desired bandwidth and return loss is obtained. However if the dimension is selected at L_7=5.5 mm, there is an increase in bandwidth at band 4 and minor changes in bandwidth of band 1, band 2 and band 3. when L_7=6.5 mm, there is decrease in the return loss at band 4 however there is increase in return loss at band 3.There is minor shift in the band 1 and band 2.

Table 3.8 Effect of varying length L_7 on the various bands

	Effect on band 1 at 2.24 GHz	**Effect on band 2 at 4.2 GHz**	**Effect on band 3 at 5.25 GHz**	**Effect on band 4 at 9.3 GHz**
At L_7=5.5 mm				
Bandwidth(MHz)	740 (2.13-2.87 GHz)	190 (4.09-4.28 GHz)	250 (5.10-5.35 GHz)	2540 (7.66-10.20 GHz)
Return loss(dB)	-37.55	-21.90	-19.37	-44.29
At L_7 =6 mm				
Bandwidth(MHz)	760 (2.11-2.87 GHz)	210 (4.09-4.30 GHz)	300 (5.09-5.39 GHz)	2250 (7.92-10.17 GHz)
Return loss(dB)	-37.17	-20.87	-21.22	-39.21
At L_7=6.5 mm				

Bandwidth(MHz)	550 (2.4-2.95 GHz)	220 (4.13-4.35 GHz)	410 (5.16-5.57 GHz)	1650 (8.35-10 GHz)
Return loss(dB)	-32.75	-20.23	-37.73	-19.04

Effect of varying length W_3 on the resonant frequency

To investigate the effect on bandwidth and return loss, the dimension W_3 which is the width between the inverted T-shaped stub and the upper edge of the rectangular slot from 3 mm to 4 mm with a step of 0.5 mm. It is evident from the figure 3.6 (d), it has major effect on the band 1 and minor effect on the band 2, band 3 and band 4. The effects are summarized in table 3.9

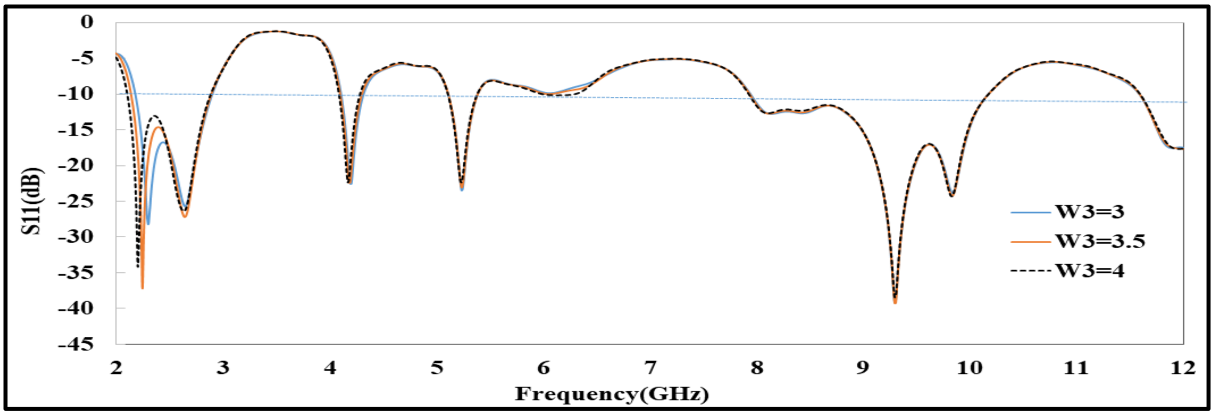

Figure 3.6 (d) Effect of varying width W_3 on the various bands

Table 3.9 presents the bandwidth and return loss for change in width W_3**.** The optimal dimension is selected at W_3=3.5mm because the desirable bandwidth and return loss are obtained at this dimension. However when the dimension is selected at W_3=3 and W_3=4 the bandwidth and return loss is shifted only at the band 1 one and on the other hand at the band 2, band 3 and band 4 there is minor effects.

Table 3.9 Effect of varying width W_3 on the various bands

	Effect on band 1 at 2.24 GHz	**Effect on band 2 at 4.2 GHz**	**Effect on band 3 at 5.25 GHz**	**Effect on band 4 at 9.3 GHz**
At W_3=3 mm				
Bandwidth(MHz)	730 (2.17-2.90 GHz)	190 (4.11-4.3 GHz)	260 (5.11-5.37 GHz)	2210 (7.96-10.17 GHz)
Return loss(dB)	-28.21	-22.51	-23.48	-38.92
At W_3=3.5 mm				
Bandwidth(MHz)	760 (2.11-2.87 GHz)	210 (4.09-4.30 GHz)	300 (5.09-5.39 GHz)	2250 (7.92-10.17 GHz)
Return loss(dB)	-37.17	-20.87	-21.22	-39.21
At W_3=4 mm				

Bandwidth(MHz)	780 (2.12-2.90 GHz)	240 (4.07-4.31GHz)	320 (5.08-5.40 GHz)	2290 (7.90-10.19 GHz)
Return loss(dB)	-37.17	-20.87	-21.22	-39.21

Hence, it is concluded that the desired resonant bands obtained by structural and geometrical variation of different parameters responsible are given as:

Band 1: W_3 and L_{10}.

Band 2: L_{10}.

Band 3: L_5, L_7 and L_{10}.

Band 4: L_5, L_7 and L_{10}.

3.4 VSWR (VOLTAGE STANDING WAVE RATIO)

VSWR stands for voltage standing ratio which means how well antenna impedance is matched with the radio or transmission line. It basically describes how much transmitted power is reflected back from the antenna. If vswr is 1 which means there is no power reflected from antenna. The value of vswr is always positive and real value. Figure 3.7 shows the simulated result of vswr are 1.029, 1.313, 1.172 and 1.023 which are obtained at 2.24 GHz, 4.2 GHz, 5.25 GHz and 9.3 GHz frequency bands. VSWR value lie in the range of 1 to 2 . From the results obtained, it confirms that the values range from 1 to 2 that fulfilled the condition of vswr.

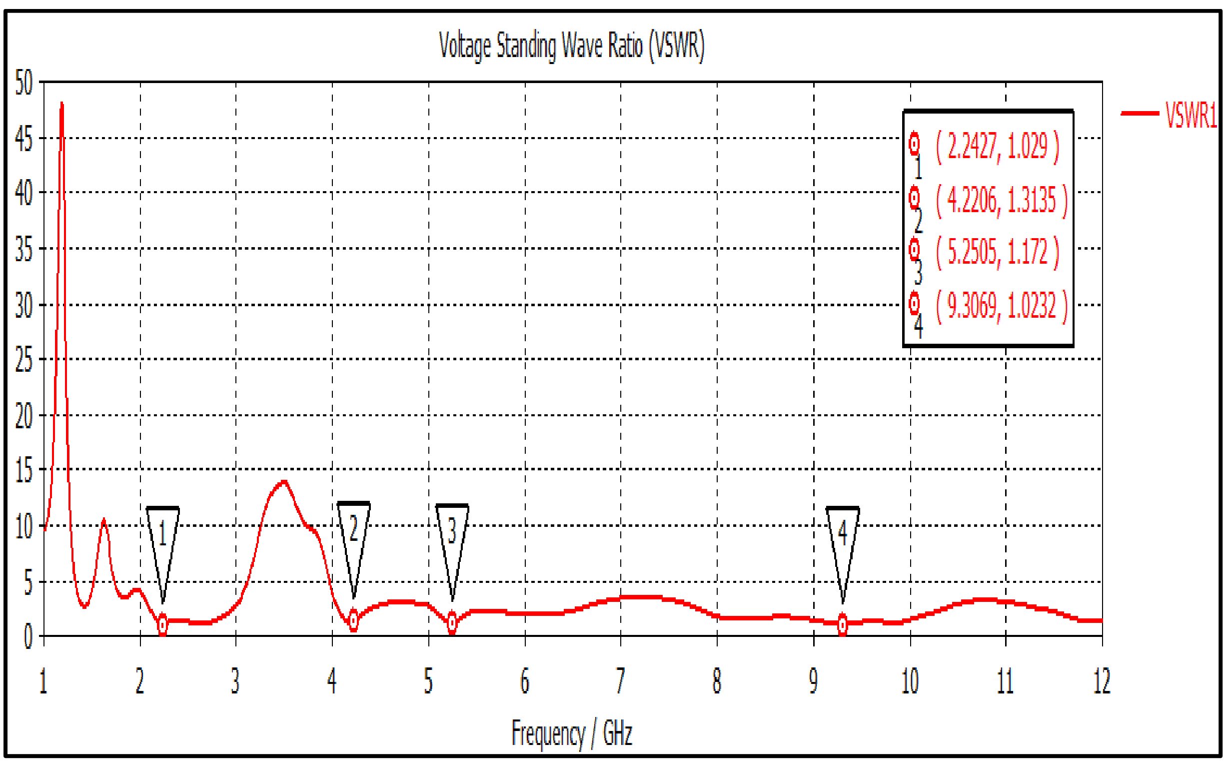

Figure 3.7 Simulate result of VSWR

3.5 DIRECTIVITY

Directivity is important parameter of antenna which basically describe how directional antenna radiation pattern is. Figure 3.8 (a-d) shows the 3D radiation pattern of directivity of antenna at 2.24 GHz, 4.2 GHz, 5.25 GHz and 9.3 GHz. From the figure it is observe that the obtained directivity at each bands have value greater than 1 i.e. the result is compared with isotropic antenna. Isotropic antenna is one who radiates all direction which means there is no directivity. The is obtained simulated result of directivity at each resonating frequency bands are 3.209 dBi, 4.217 dBi, 4.444 dBi and 5.518 dBi which satisfied the required condition of antenna design.

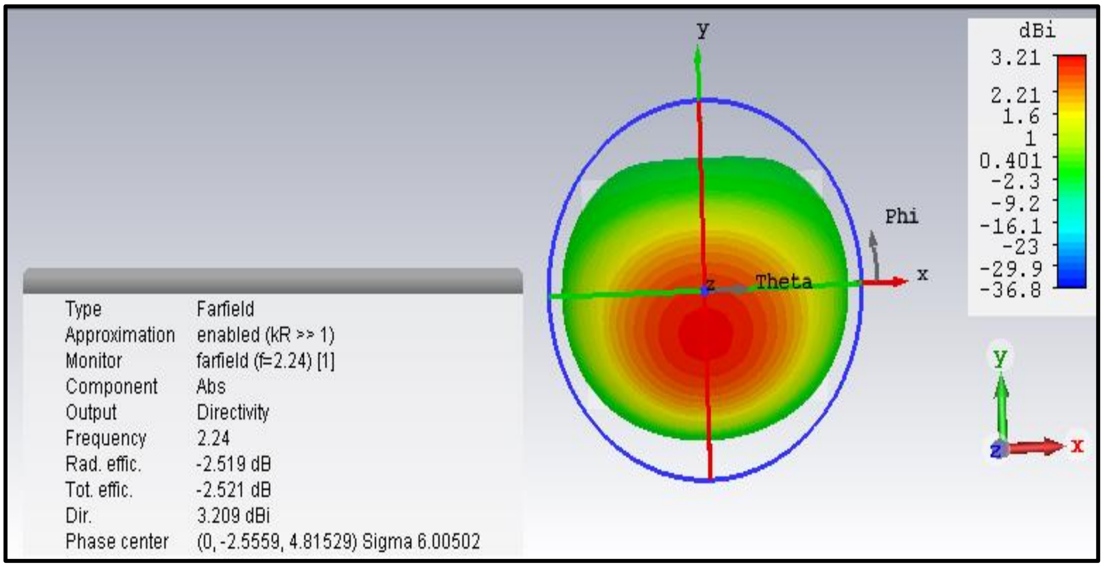

Figure 3.8 (a) 3D view of directivity at 2.24 GHz

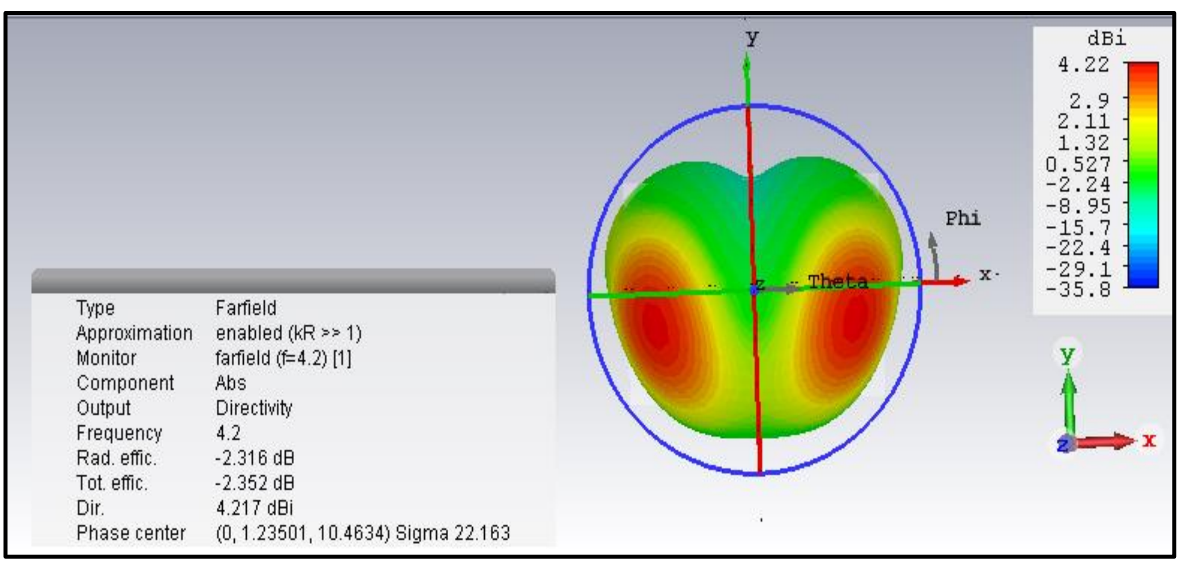

Figure 3.8 (b) 3D view of directivity at 4.2 GHz

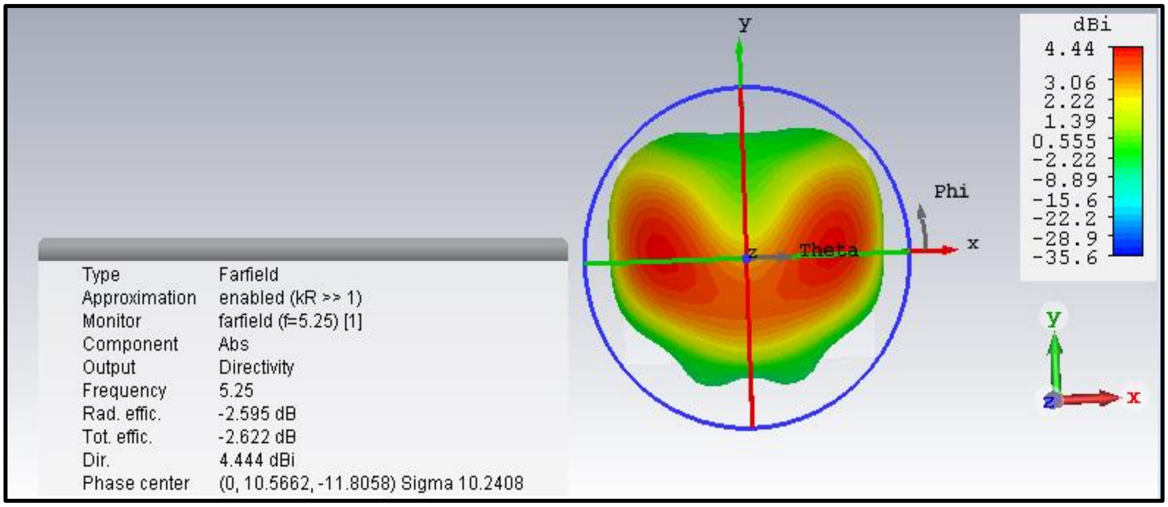

Figure 3.8 (c) 3D view of directivity at 5.25 GHz

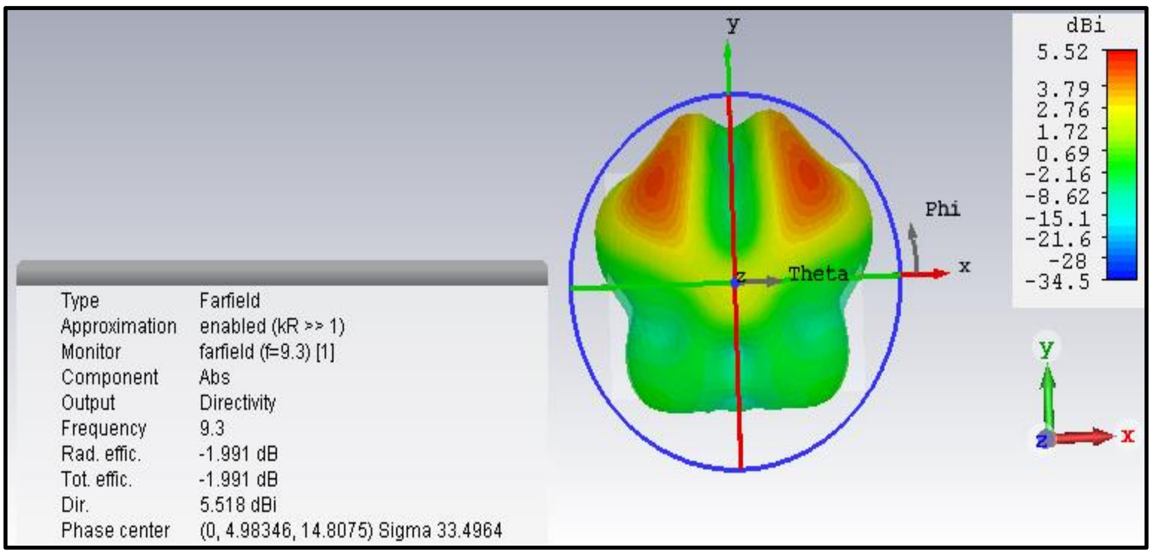

Figure 3.8 (d) 3D view of directivity at 9.3 GHz

3.6 GAIN

Gain is important parameter of antenna which combines the antenna directivity and electrical efficiency. The antenna may have 40- 50 dB gain for large dish antenna or it may have 1.76 dB for short dipole antenna. It should not be less than 0 dB. Figure 3 (a-d) represent the 3D view of gain of antenna which is resonating at 2.24 GHz, 4.2 GHz, 5.25 GHz and 9.3 GHz frequency bands. The simulated result are 0.6902 dB, 1.90 dB, 1.849 dB and 3.527 dB. The result show that the obtained value is greater than 0 dB which means the antenna is perfectly working for desire applications.

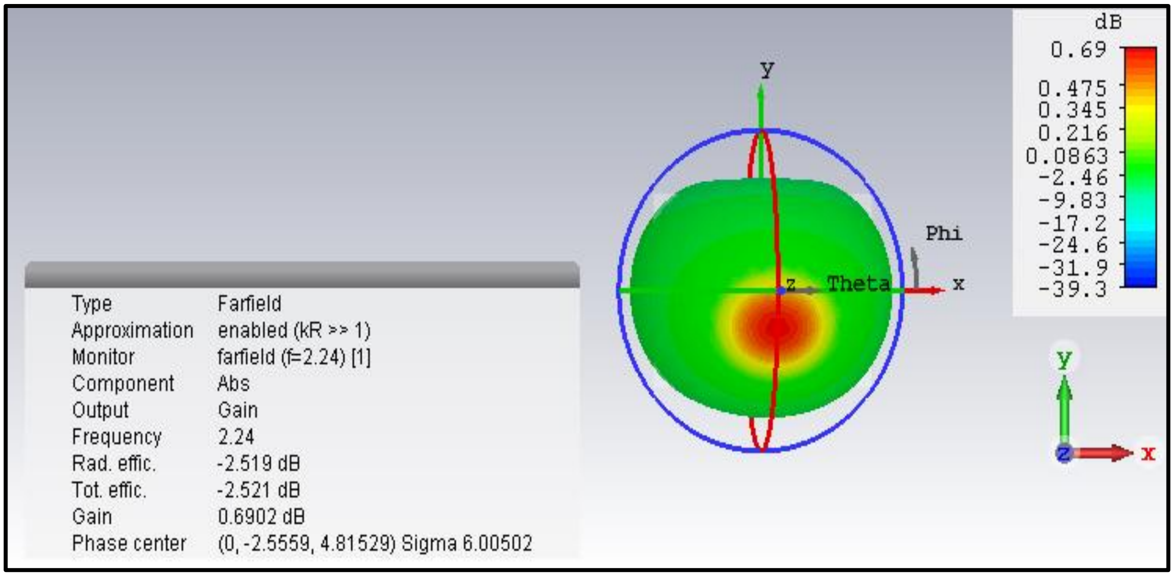

Figure 3.9 (a) 3D view of gain at 2.24 GHz

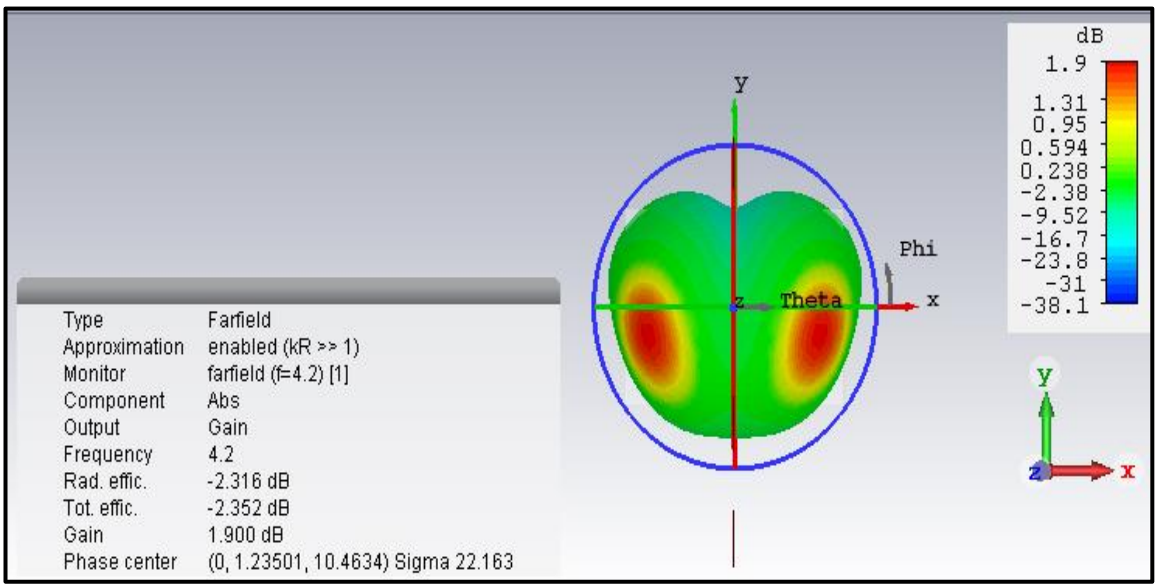

Figure 3.9 (b) 3D view of gain at 4.2 GHz

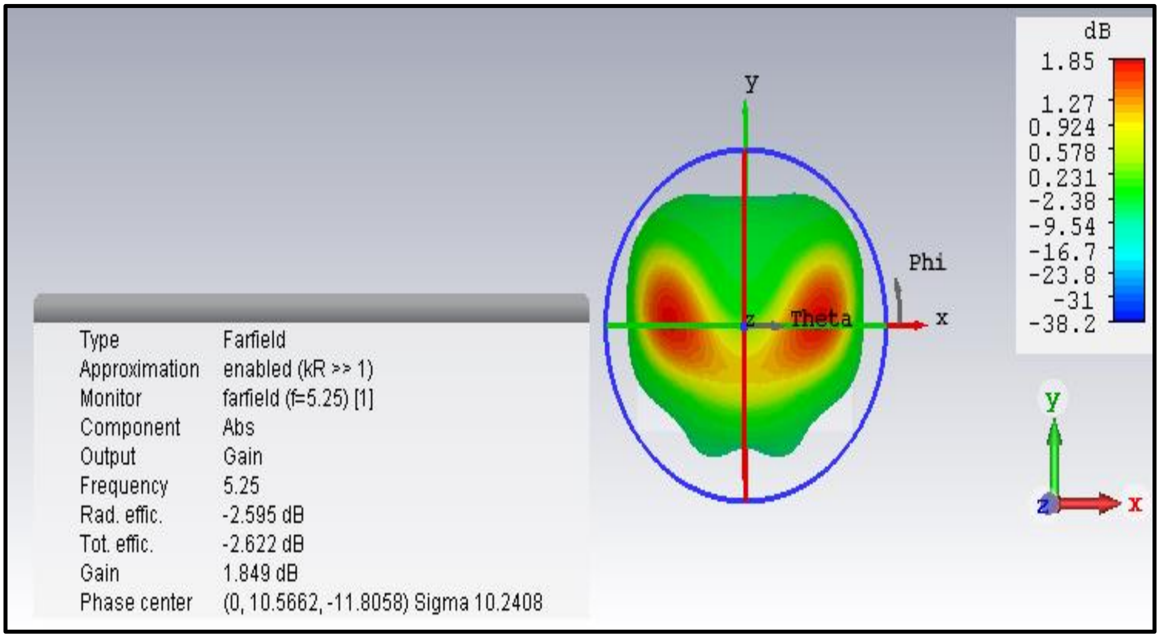

Figure 3.9 (c) 3D view of gain at 5.25 GHz

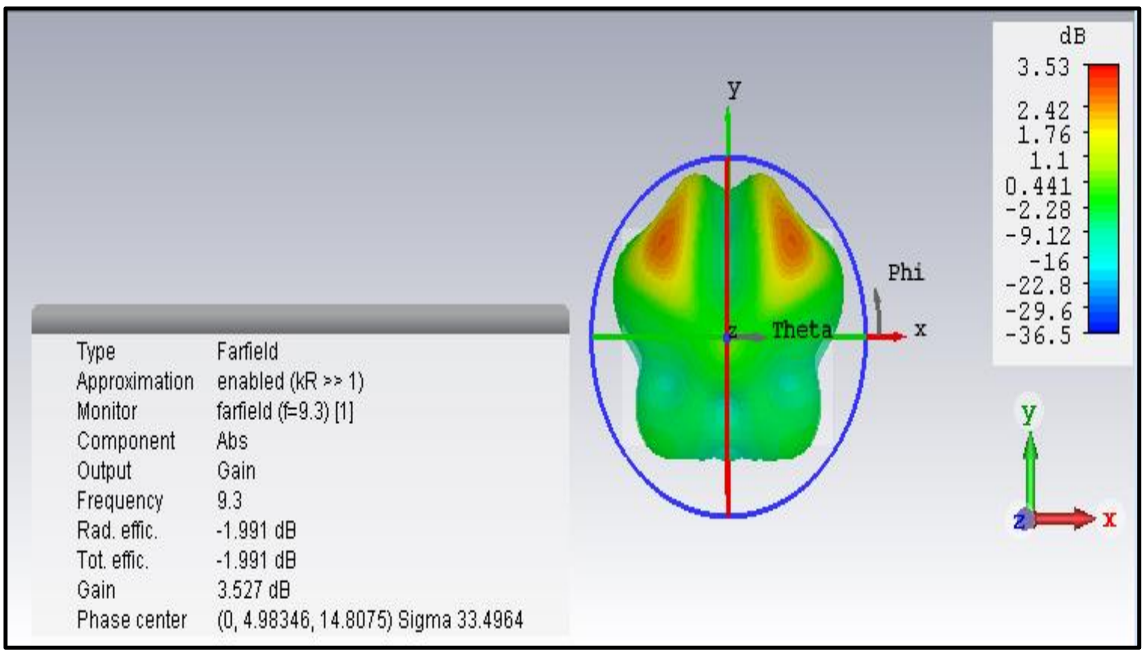

Figure 3.9 (d) 3D view of gain at 9.3 GHz

3.7 SURFACE CURRENT

The surface current distribution at the resonant frequencies is shown in Figure 3.10 (a-d). From Figure 3.10(a) it shows that at 2.24 GHz band, the surface current mainly distributes at the edges of the rectangular slot and the gap between the inverted T-shaped stub and the upper edge of the slot.

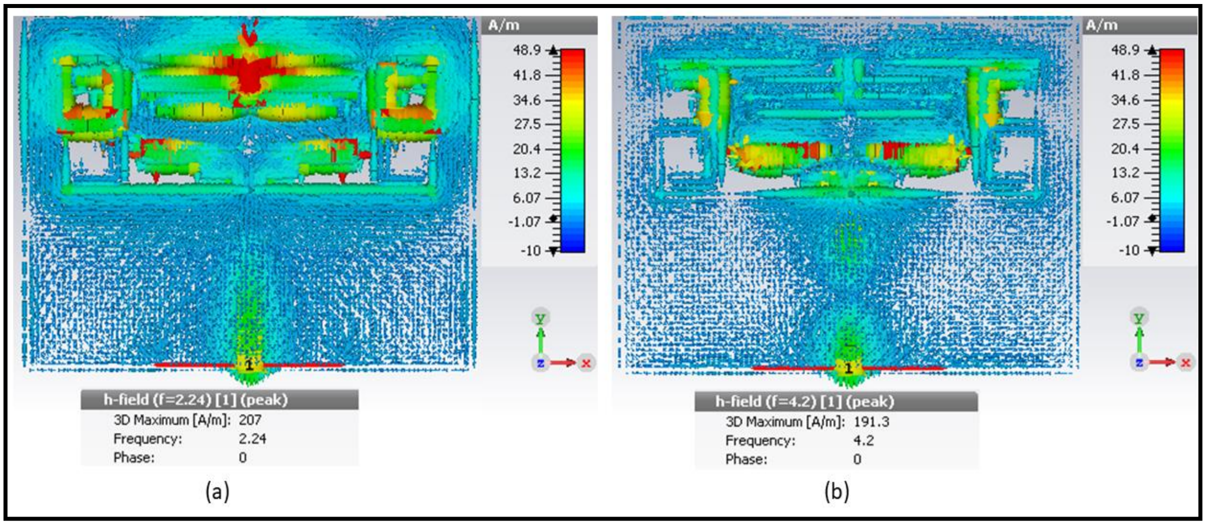

Figure 3.10 (a-b) Surface current distribution (a) 2.24 GHz (b) 4.2 GHz

From Figure 3.10 (b) it shows that at 4.2 GHz band, the surface current distributes at the upper portion of the E shaped stubs present on either side of the rectangular slot and also the slots made in the staircase feed line.

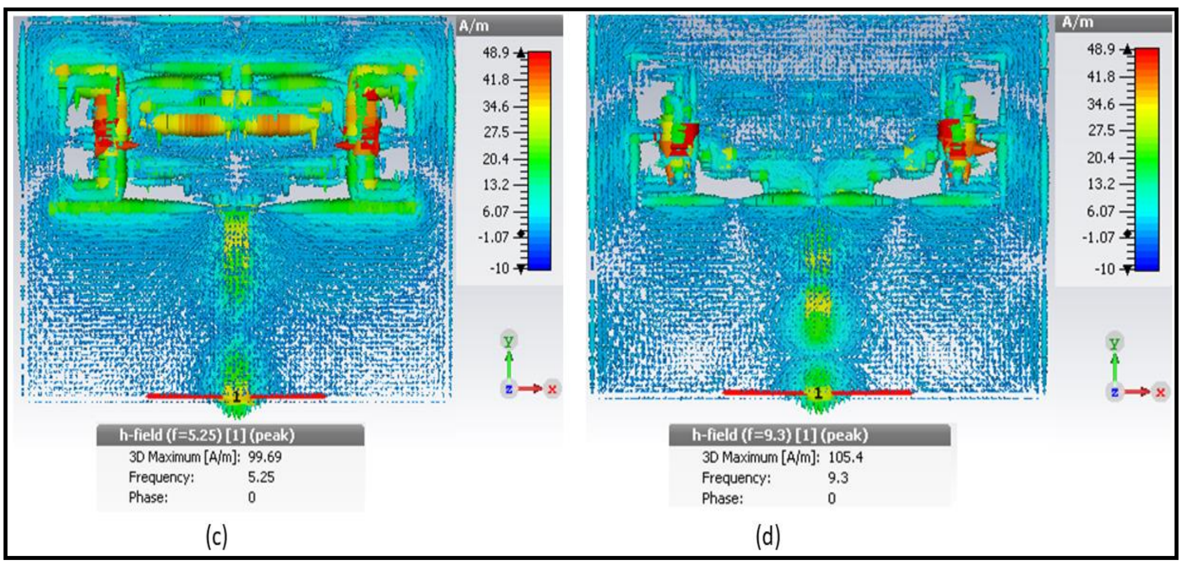

Figure 3.10 (c-d) Surface current distribution (c) 5.25 GHz (d) 9.3 GHz

From Figure 3.10 (c) it shows that at 5.25 GHz band, the surface current distributes in the gap between the inner and outer of E shape stubs on either side as well as the slots on the staircase feed line. From Figure 3.10 (d) it shows that at 9.3 GHz band, the surface current distributes somewhat in the central portion of the inner and the outer E shape stub.

CHAPTER 4

FABRICATION, TESTING /COMPARISON OF SIMULATED AND MEASURED RESULTS

4.1 INTRODUCTION

This chapter describes the entire process of fabrication and testing of enhance bandwidth multiple slot antenna using microstrip feed line for 4G LTE, WiMAX, WLAN and C/S/X-bands applications. Microstrip patch antenna is fabricated using Photolithography process which is also called optical lithography or UV lithography. It is a method of chemical etching that extracts the metallic layer's unwanted metal parts. The photo-lithographic technique generates very precise etching patterns for the microstrip patch. The precision of manufacturing is very critical since the microstrip patch antennas are narrow band resonant structures that generally work in microwave ranges. Fabrication errors in the patch dimensions will shift its resonant frequency.

4.2 STEPS TO DESIGN THE MICROSTRIP PATCH ANTENNA USING PHOTOLITHOGRAPHY AND CHEMICAL ETCHING METHOD.

1) The antenna is design in the microwave studio CST version 17 software which is shown in the figure 4.1

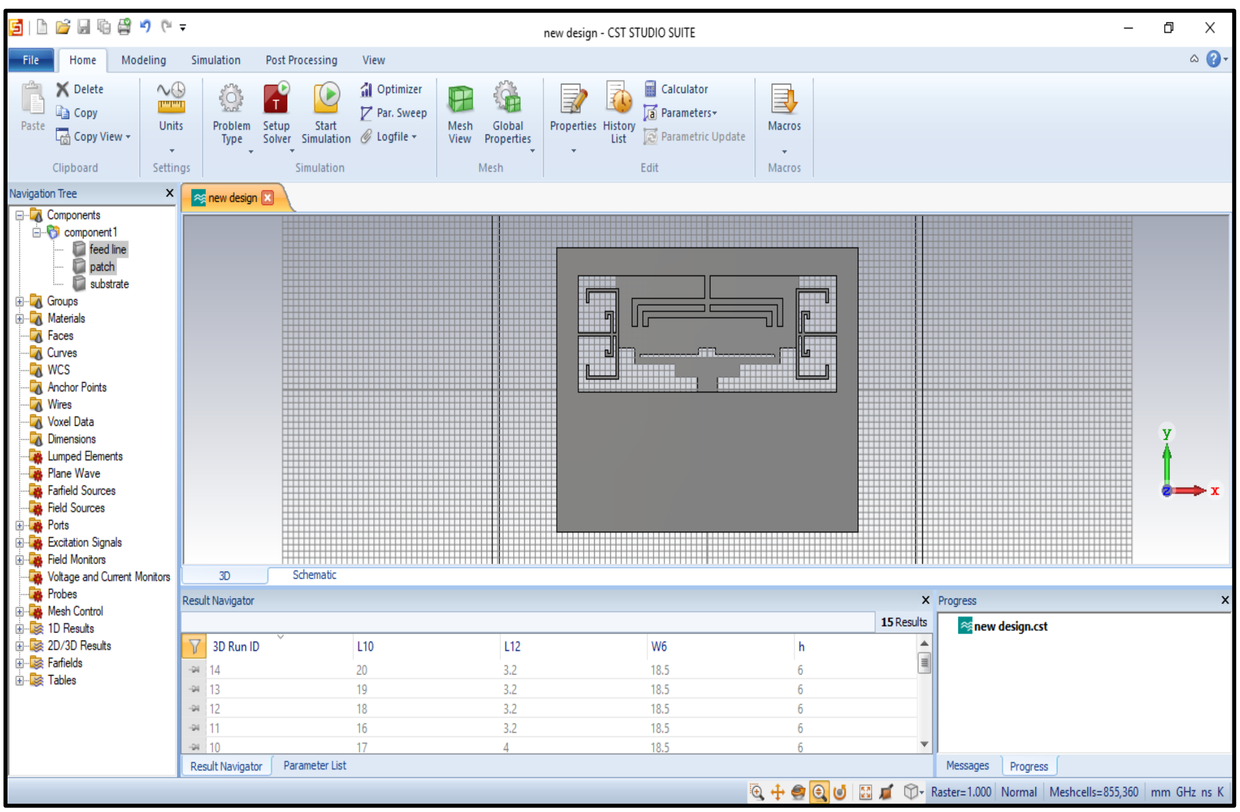

Figure 4.1 Antenna design using microwave studio CST version 17

2) The design is painted black by using drawing software CorelDraw 12 version.

3) The black footprint of front and back side of the antenna is printed on a transparent film and the dimension are controlled which is shown in the figure 4.2 and figure 4.3.

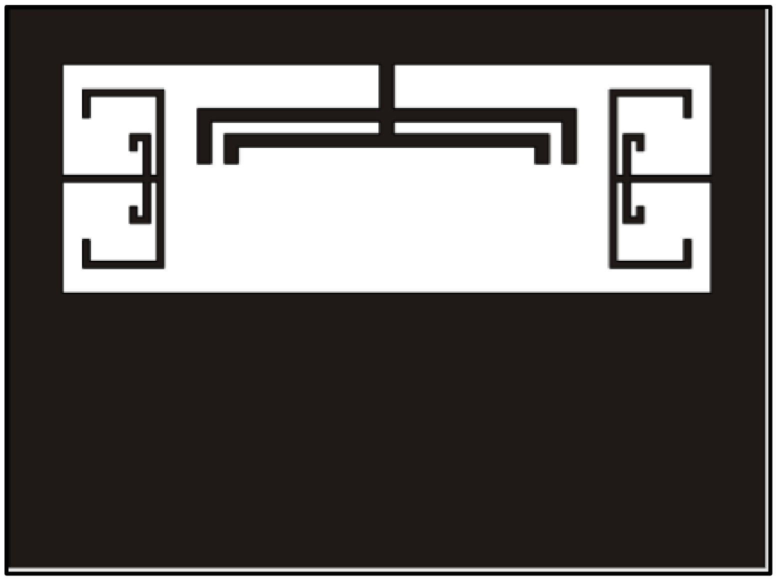

Figure 4.2 Front view on a transparent film

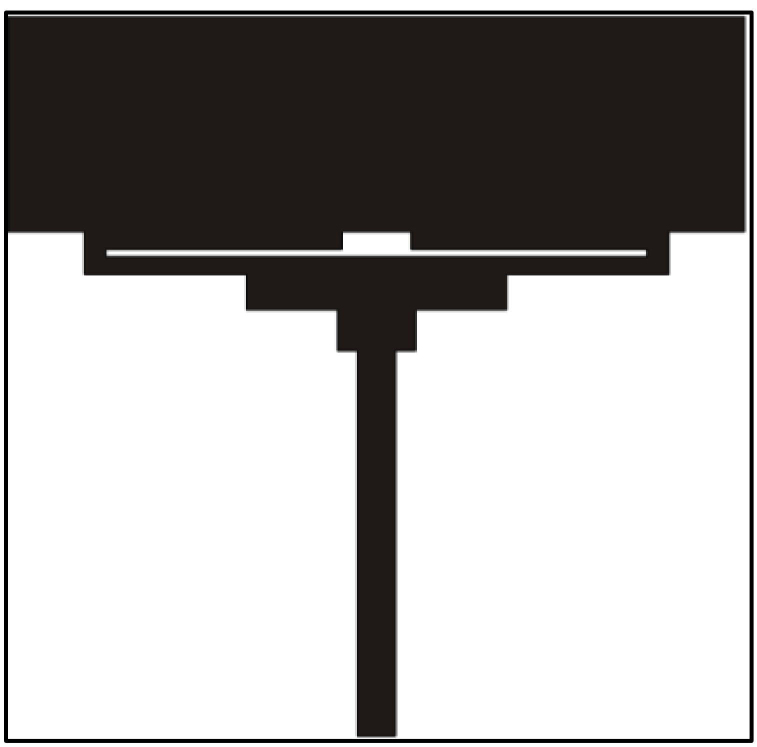

Figure 4.3 Back view on a transparent film

4) To do the fabrication of antenna two chemicals is used i) one for developing purpose and ii) second is used for etching the copper.

5) Both the chemical is inserted in the appropriate baths and it should be heated for approximately 20 minutes.

6) Meanwhile the film is rectangulary cut (slightly larger than the size of the ground plane).

7) The marks are drawn on the double sided copper-clad material (in this case a double sided FR-4 substrate of dielectric constant 0.002 ,relative permittivity 4.4 and height of the substrate is 1.6 mm).

8) The FR-4 is cut at the marked dimension using cutter which is shown in the figure 4.4.

Figure 4.4 FR-4 cutter

9) Remove the sticker from one layer and carefully attach the film on top of the FR-4 substrate.

10) The black part of the film will act as a shielding mask during the photo-exposure process.

11) The masked FR-4 is inserted in the UV-light exposure (the proper surface should face the light) and it should last for approximately 2 minutes.

12) Remove the sticker from the ground plane and attach the film on bank side of the FR-4 substrate. Again it is inserted in the UV-light exposure which is shown in the figure 4.5.

Figure 4.5 UV-light exposure

13) The chemical process begins by inserting the board in the developer and the board remains in the developer-tank for 1 minutes.

14) The board is washed inside water and again it is inserted into the etcher where copper will be etched by all UV-exposed areas.

15) It should remain in the etcher for enough time to etch the copper the copper (at least 10 minutes).

16) Copper has been etched according to the desired design and it is wash with water [36].

17) Photoresist is removed from copper using water and it is dried using PCB dryer which is shown in the figure 4.6.

Figure 4.6 PCB dryer

18) The fabricated antenna is shown in the figure 4.7.

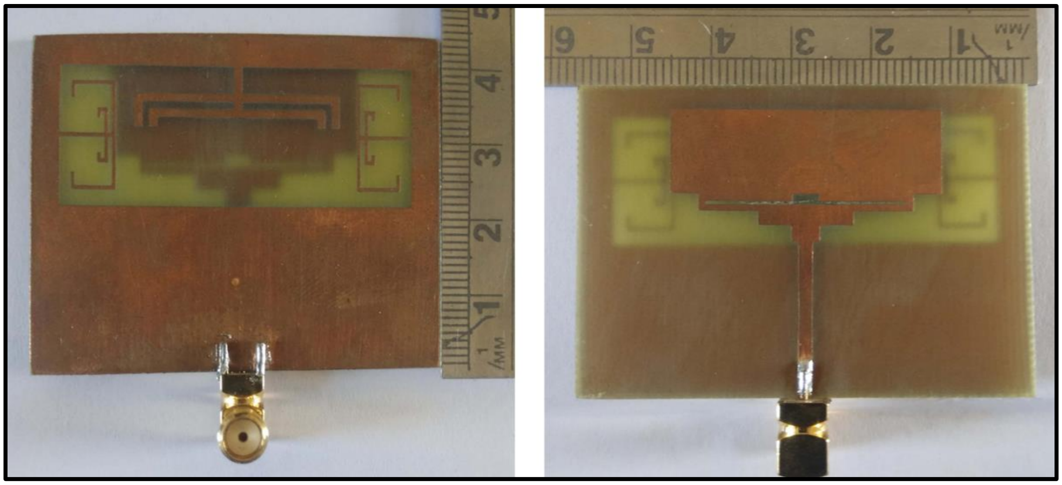

Figure 4.7 Front and back side of the fabricated antenna

4.3 TESTING OF ANTENNA

After the fabrication of the antenna, our job is to do the measurement of the antenna using device called vector network analyzer (VNA). Using this device, the simulated and measured results is compared. This device will helps to measure the parameter like return loss (S_{11}) and VSWR.

4.3.1 Return loss measured using vector network analyzer

To measure the return loss result, E5063A 100 kHz-18 GHz ENA services network analyzer is used which is shown in the figure 4.8. From the measured result, we can find antenna resonating frequency and return loss of the proposed antenna.

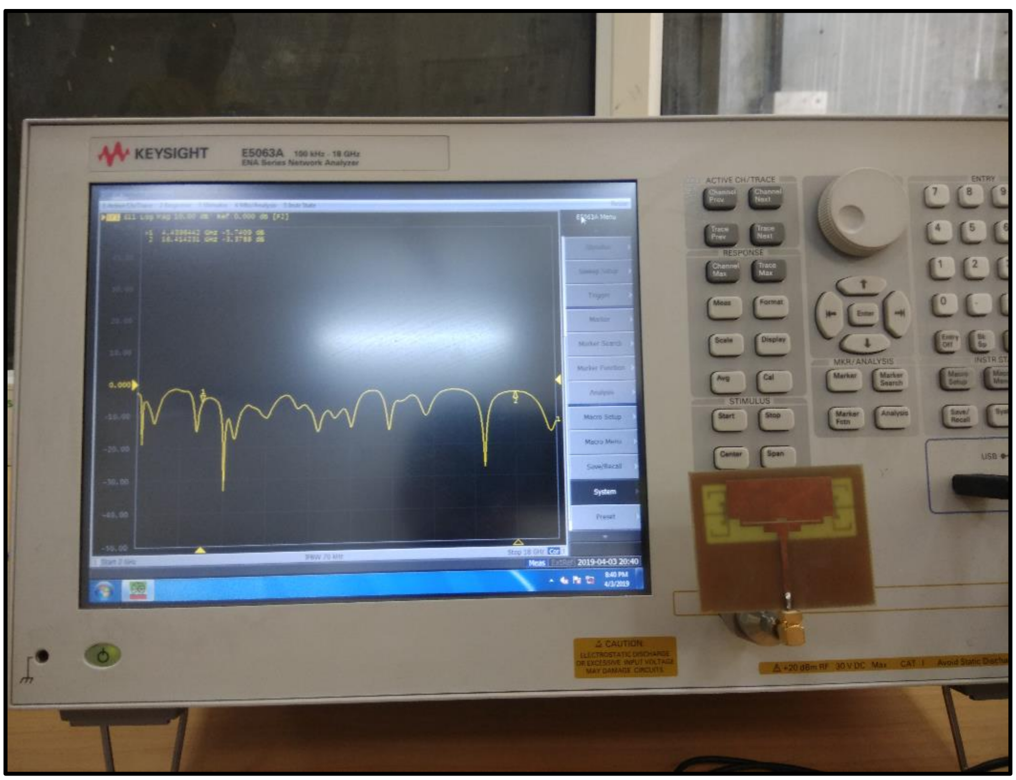

Figure 4.8 Return loss measured using VNA

4.3.2 VSWR measured using VNA

Using vector network analyzer, the measured VSWR is shown in the 4.9. From the results, it is concluded that antenna is resonating at 2.24 GHz, 4.2 GHz, 5.25 GHz and 9.3 GHz frequency bands and its measured value are 1.206, 1.39, 1.059 and 1.91

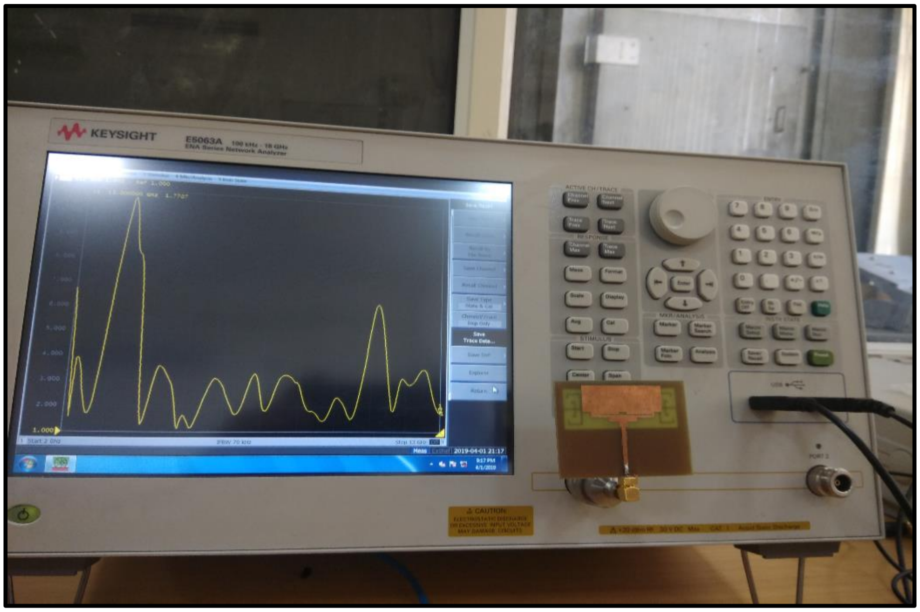

Figure 4.9 VSWR measured using VNA

4.3.3 Radiation pattern measured using UALR anechoic chamber

UARL anechoic chamber is used to house the equipment for performing the measurements of antenna radiation patterns, electromagnetic compatibility (EMC) and radar cross section measurements. It is a shielded room which is design to attenuate the electromagnetic energy or sound from the internal surfaces. The chamber is enclosed in faraday cages in order to lessen outside the electromagnetic interference. The chamber is lined with large foam pyramids called radar absorbent material (RAM) that work to nullify the reflection of radiation back to the sensors which would create errors in the results. Radar absorbent material in the form of foam absorbers is used in the UALR anechoic chamber.

Foam absorber is used as lining of anechoic chambers for electromagnetic radiation measurements. This material typically consists of a fireproofed urethane foam loaded with carbon black, and cut into long pyramids. The absorber is applied to the chamber walls with the tips of the pyramids pointing inward or toward the radar. As a radar wave strikes a pyramid, it experiences a gradual transition from free space at the tip of the pyramid to absorbing foam at the base.

Antenna at transmitter side

Horn antenna is used at the transmitter side in the UALR anechoic chamber which is shown in the figure 4.10. The antenna transmit the electromagnetic signal to the receiver side. It transmit the signal based on our requirement.

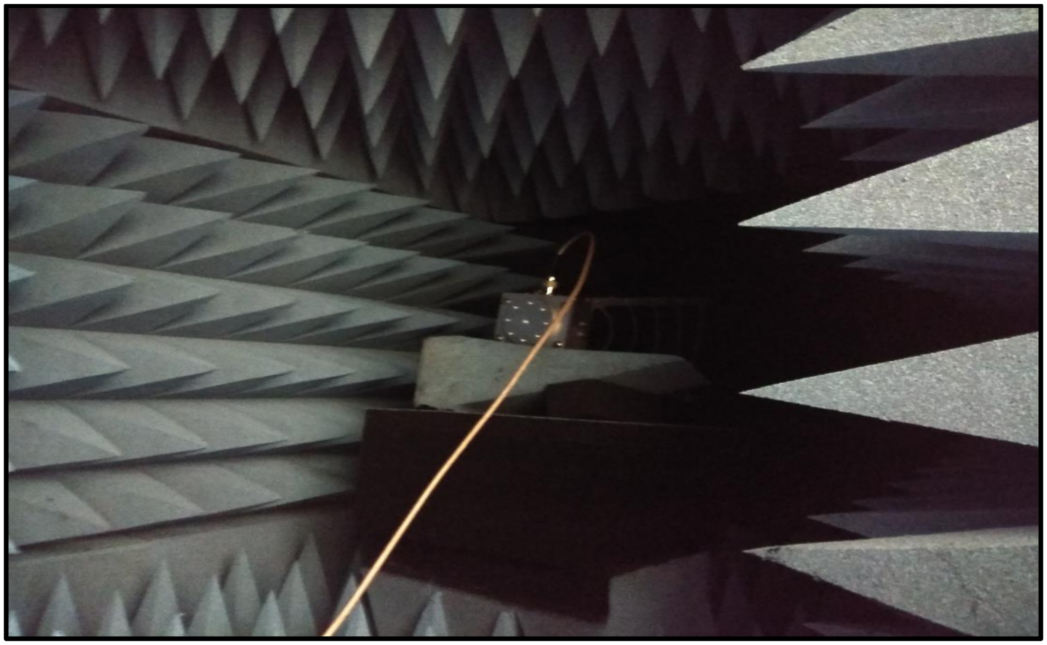

Figure 4.10 Horn antenna at the transmitter side in the UALR anechoic chamber

Antenna at the receiver side

At the receiver side, fabricated antenna is connected in the chamber which is shown in the figure 4.11. The reason is to connect the antenna in the chamber is that whether the antenna which was fabricated are resonating at the multiple bands or not. Whether the antenna have omni-directional radiation pattern or directional pattern.

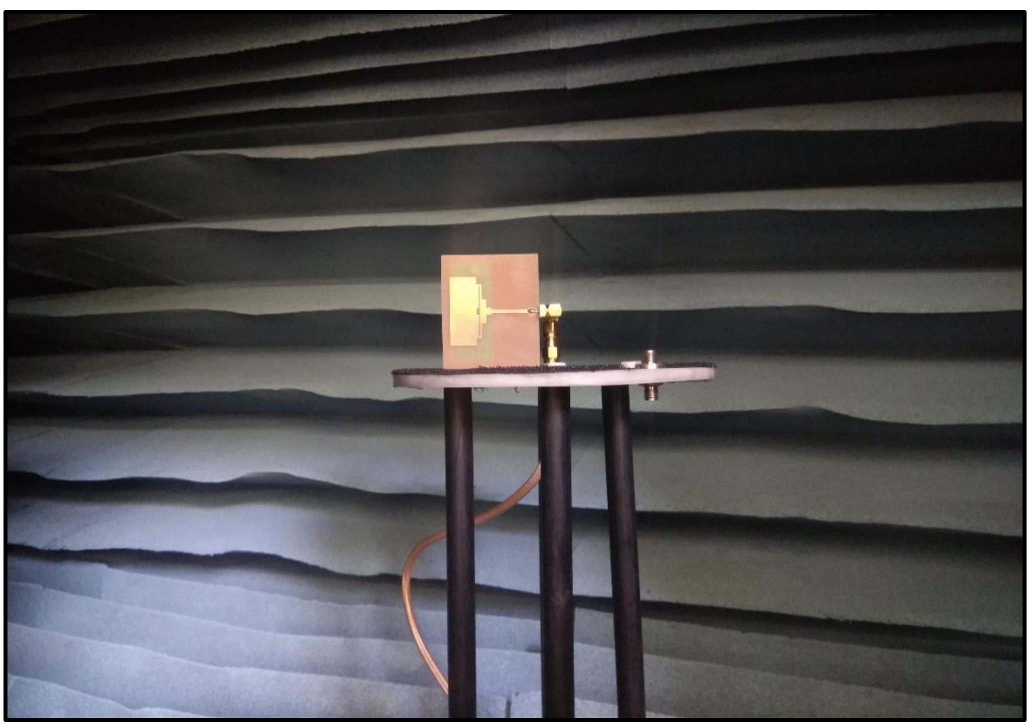

Figure 4.11 Fabricated antenna at the receiver side in the UALR anechoic chamber

This chapter describe the detail simulation and measured results which was tested using microwave studio CST 17 version software and vector network analyzer. In this chapter, the simulated and measured results is compared based on the return loss (S_{11}) and radiation pattern values. Also this chapter describes the surface current distribution, VSWR and gain results by using the microwave studio CST 17 version software.

4.4 RETURN LOSS (S_{11})

The antenna is fabricated using photolithography and wet etching technique. The prototype of the antenna is shown in figure 4.12.

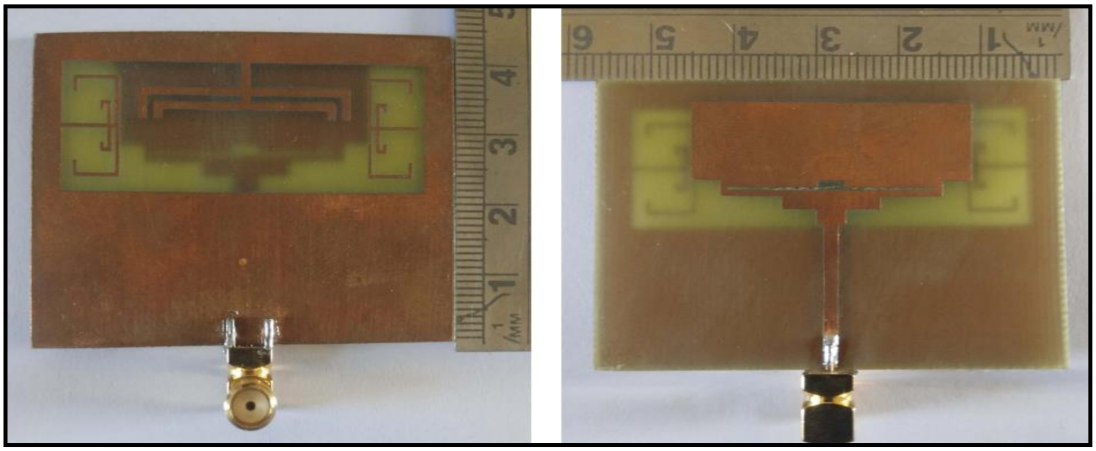

Figure 4.12 Prototype of antenna

The simulated results are obtained on CST Microwave Studio version 17 in terms of S_{11} parameter and compared with the measured results which are obtained after testing the fabricated antenna on VNA (vector network analyzer) as shown in Figure 4.13. The comparison of simulated and measured return loss is shown in Table 4.1.

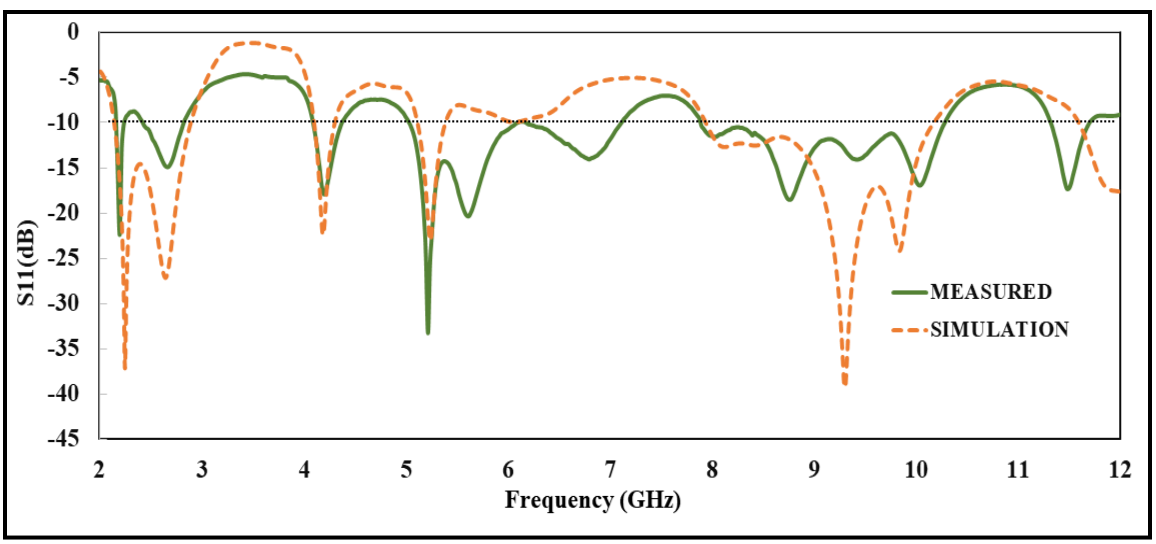

Figure 4.13 Comparison between simulated and measured results of return loss (S_{11})

Table 4.1 Comparison between simulation and measured return loss (S_{11})

Resonant Frequency (GHz)	Simulated Return loss(dB)	Simulated Bandwidth (MHz)	Measured Return loss(dB)	Measured Bandwidth (MHz)
2.24	-37.17	780	-22.42	640
4.2	-20.81	240	-17.95	260
5.25	-21.22	320	-33.29	990
9.3	-39.21	2290	-12.95	2390

Table 4.1 is used to represent the measured and simulated Return loss which are comparable in terms of S11 parameter except at some points. This difference is due to cabling effect, fabrication of the antenna and the quality of the substrate which is used to fabricate the antenna.

4.5 VSWR (VOLTAGE STANDING WAVE RATIO)

VSWR is another parameter defined for the antenna which shows that how well the antenna is matched. The value of VSWR for a good antenna is less than equal to 2 for practical antenna. The simulated and measured results are shown in the figure 4.14 and its value is shown in the Table 4.2. It was found that the obtained result is less than equal to 2 so the antenna is perfectly matched.

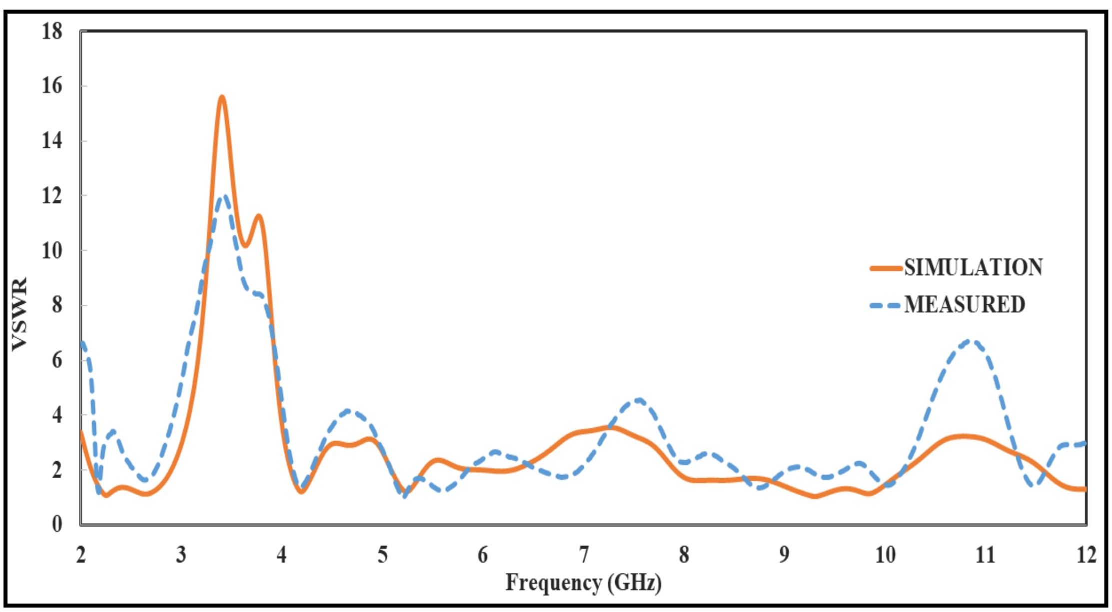

Figure 4.14 Comparison between simulation and measured results of VSWR

Table 4.2 Comparison between simulation and measured results of VSWR

Resonant frequency (GHz)	Simulated (VSWR)	Measured (VSWR)
2.24	1.029	1.206
4.2	1.31	1.39
5.25	1.172	1.059
9.3	1.02	1.91

4.6 SURFACE CURRENT DISTRIBUTION

The surface current distribution at the resonant frequencies is shown in Figure 4.15 (a-d). From Figure 4.15(a) it shows that at 2.24 GHz band, the surface current mainly distributes at the edges of the rectangular slot and the gap between the inverted T-shaped stub and the upper edge of the slot.

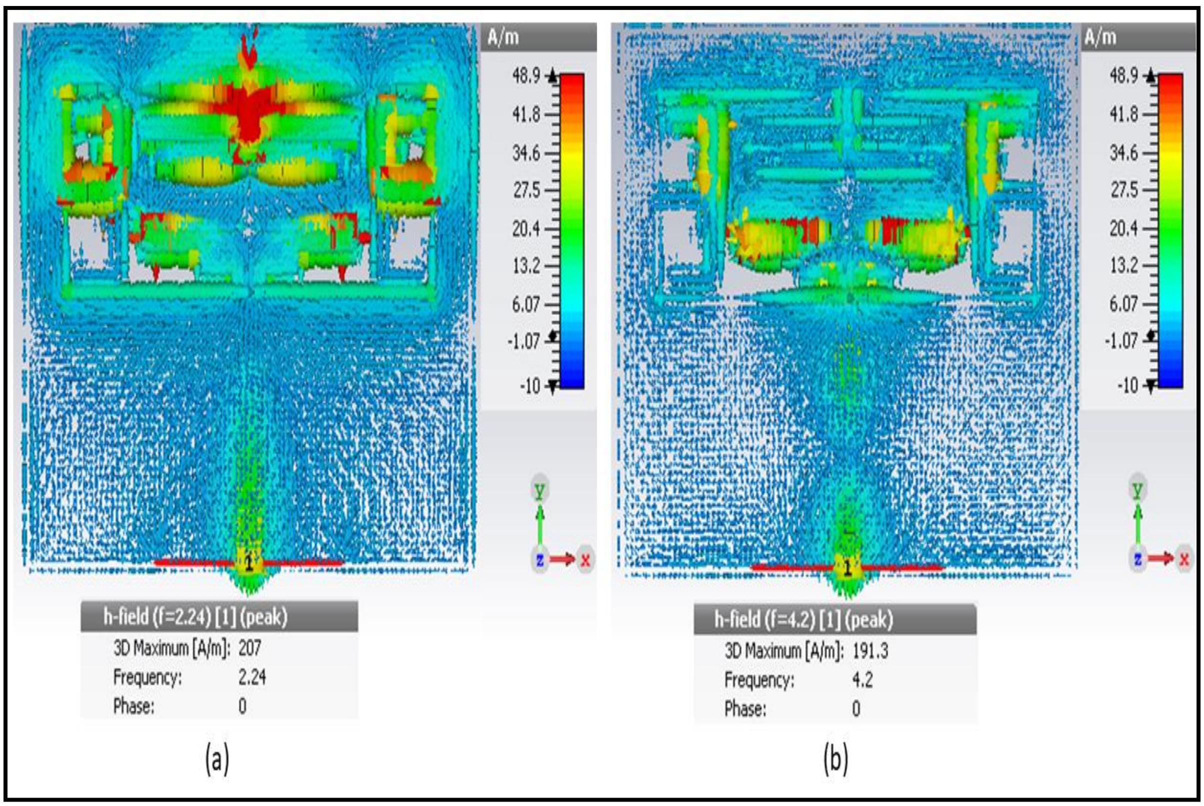

Figure 4.15 (a-b) Surface current distribution (a) 2.24 GHz (b) 4.2 GHz

From Figure 4.15(b) it shows that at 4.2 GHz band, the surface current distributes at the upper portion of the E shaped stubs present on either side of the rectangular slot and also the slots made in the staircase feed line.

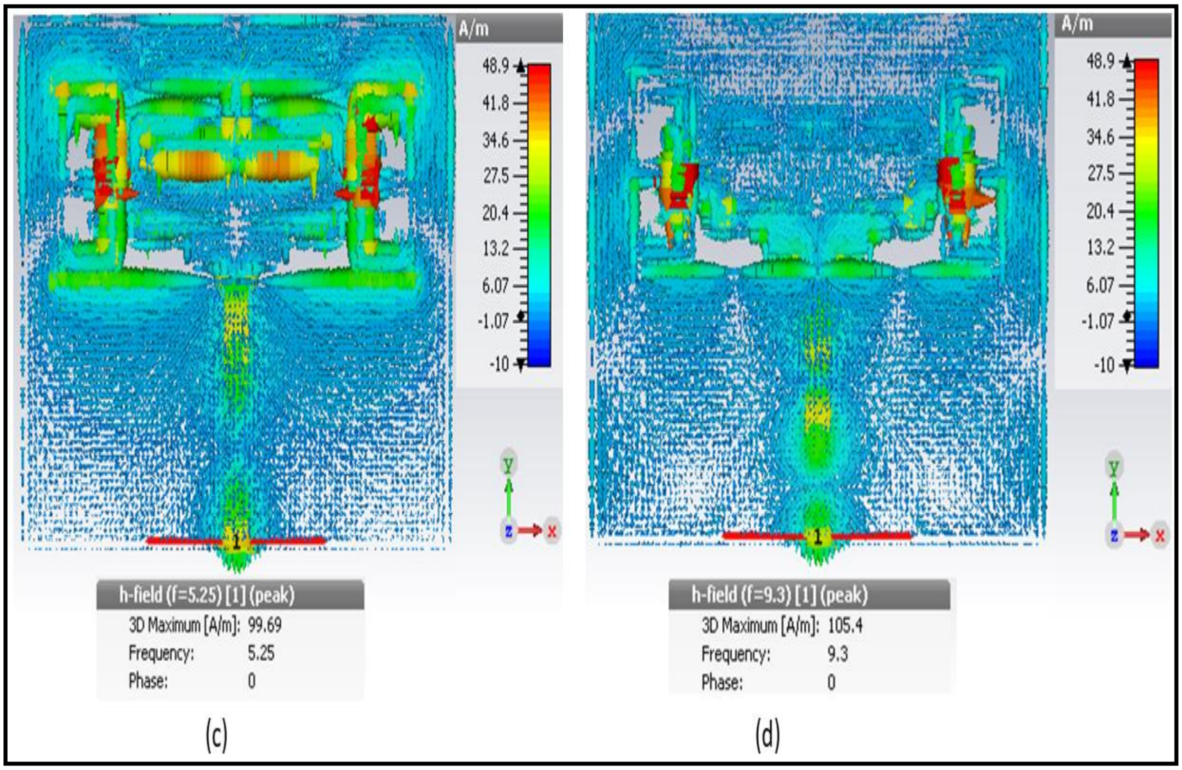

Figure 4.15 (c-d) Surface current distribution (c) 5.25 GHz (d) 9.3 GHz

From Figure 4.15(c) it shows that at 5.25 GHz band, the surface current distributes in the gap between the inner and outer of E shape stubs on either side as well as the slots on the staircase feed line. From Figure 4.15(d) it shows that at 9.3 GHz band, the surface current distributes somewhat in the central portion of the inner and the outer E shape stub.

It is observed from return loss measurement that multiband enhance bandwidth antenna has four frequency bands resonate at 2.24 GHz, 4.2 GHz, 5.25 GHz and 9.3 GHz bands respectively. The proposed multiband antenna presents measured results with respect to reference value (with $S_{11} < -10$dB) and resonates at the following bands

- **S-Band**: 2.17-2.82 GHz: (bandwidth of 640 MHz) for the WiMAX (802.16e), 4G-LTE, IEEE 802.11 (b and g) WLAN system and space to Earth communications applications
- **C-Band:** 4.1-4.38 GHz: (bandwidth of 280 MHz) for Aeronautical and Radio navigation, 4.2 to 4.28 GHz is used for uncoordinated indoor application
- **C-Band:** 5.04–5.6.1 GHz (bandwidth of 1060 MHz) for the IEEE 802.11a WLAN system.
- **X-Band:** 7.9-10.28 (bandwidth of 2380 MHz) GHz for the X band system.

4.7 RADIATION PATTERN

The radiation pattern of the antenna are shown in the Figure 4.16 (A) on the E-plane and Figure 4.16 (B) on the H-plane. Figure 4.16 (A) and Figure 4.16 (B) shows the radiation pattern of the proposed antenna at different resonant frequencies. It is observed that antenna radiation pattern is bi-directional at 2.24 GHz and directional at 4.2 GHz, 5.2 GHz and 9.3 GHz in E-plane. Further in H-Plane, proposed antenna exhibits bi-directional radiation pattern at 2.24 GHz and Omni-directional at 4.2 GHz, 5.2 GHz and 9.3 GHz. . The radiation pattern basically represent the distribution of radiated energy into space as a function of direction. It is plotted as a function of angular position and radial distance from the antenna.

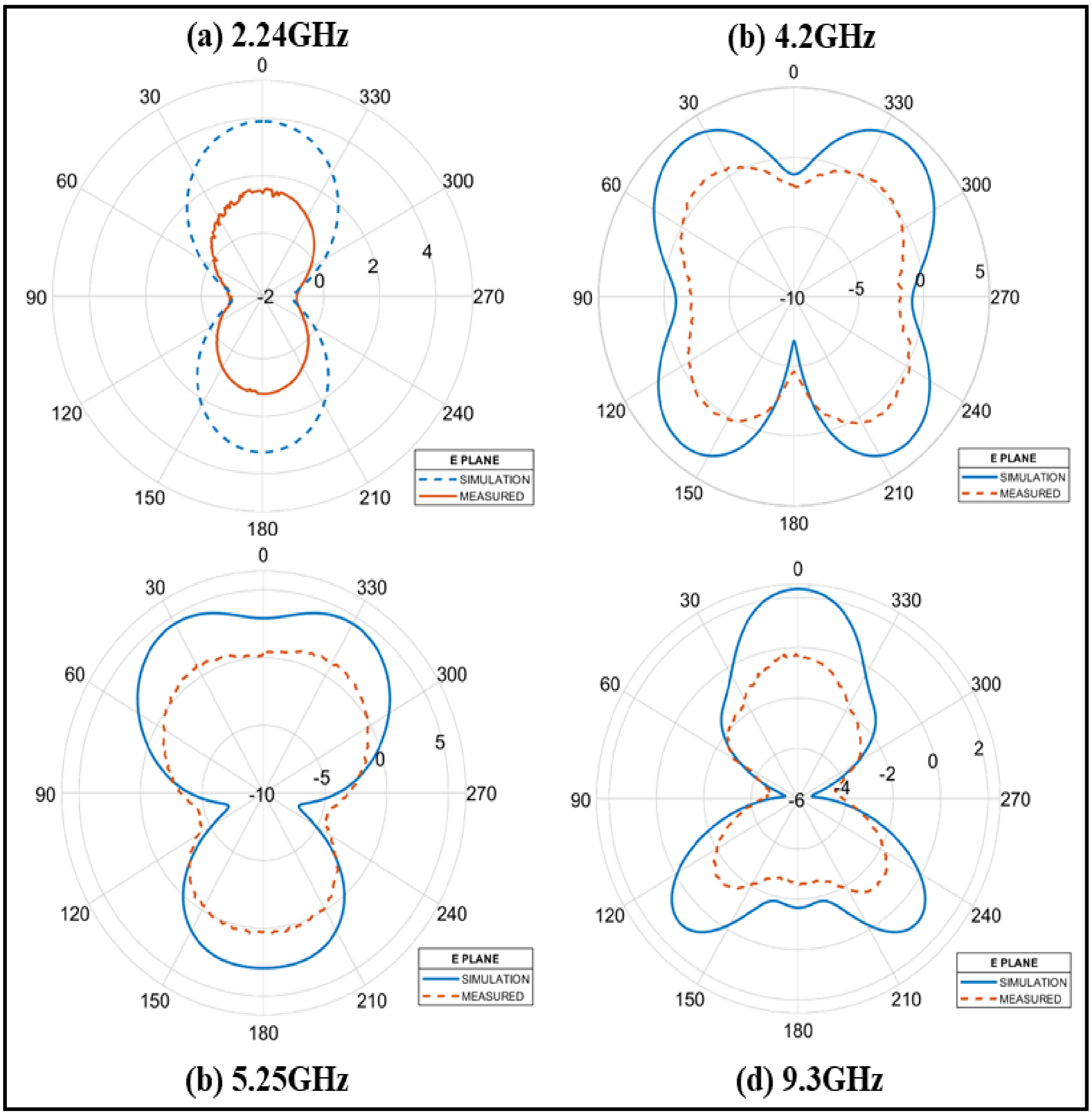

Figure 4.16 (A) Simulated and measured radiation pattern at (a) 2.24 GHz (b) 4.2 GHz (c) 5.25 GHz and (d) 9.3 GHz on E-plane

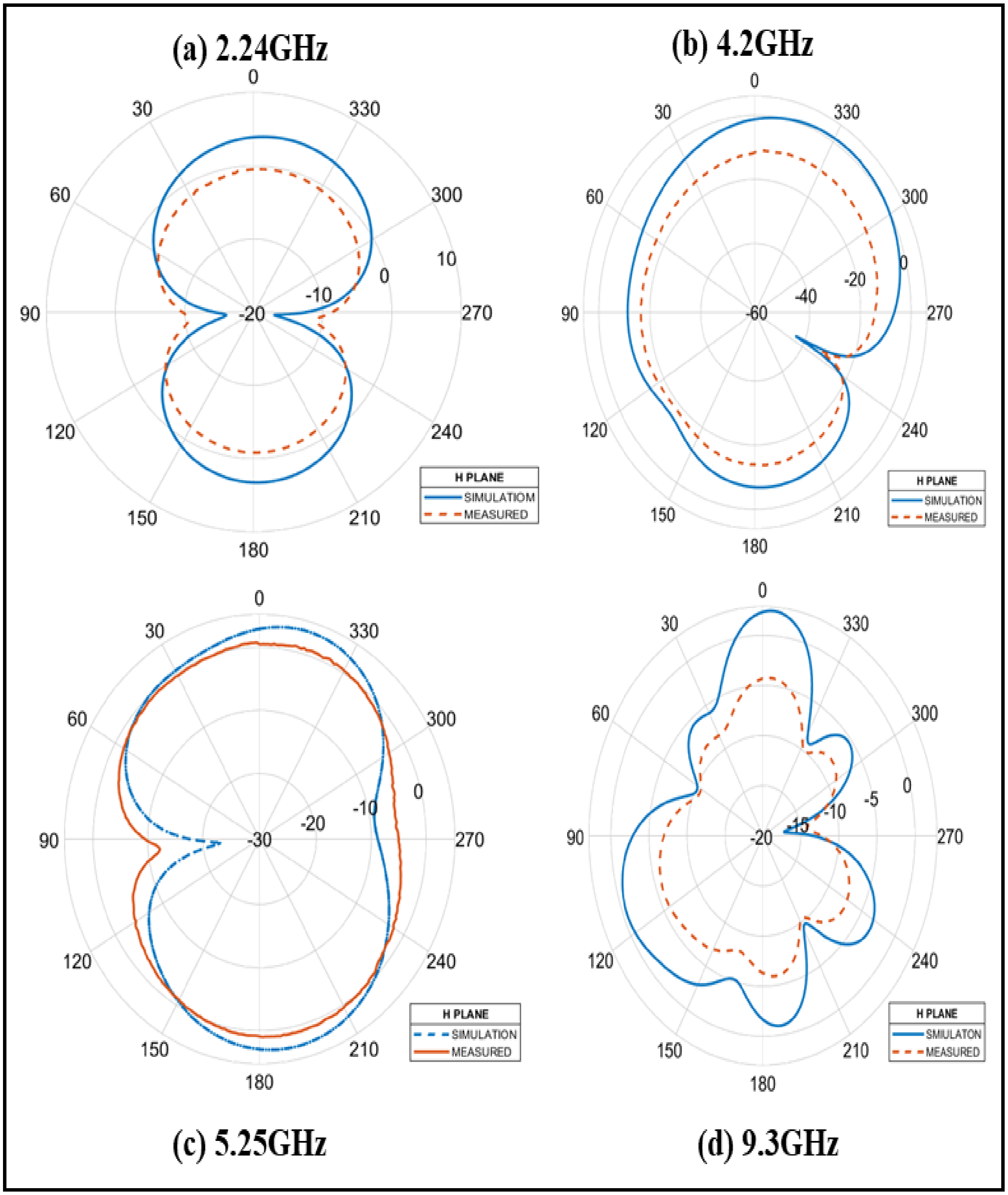

Figure 4.16 (B) Simulated and measured radiation pattern at (a) 2.24 GHz (b) 4.2 GHz (c) 5.25 GHz and (d) 9.3 GHz on H-plane

4.8 GAIN

Gain is another useful parameter which describes the performance of the antenna. Typically the higher the gain, the more efficient the antenna's performance and the farther the range of the antenna will operate. For every 6 dBi in gain, you double the range of the antenna. The simulated gain result of antenna is shown in the Figure 4.17 and it value is given in the Table 4.3.

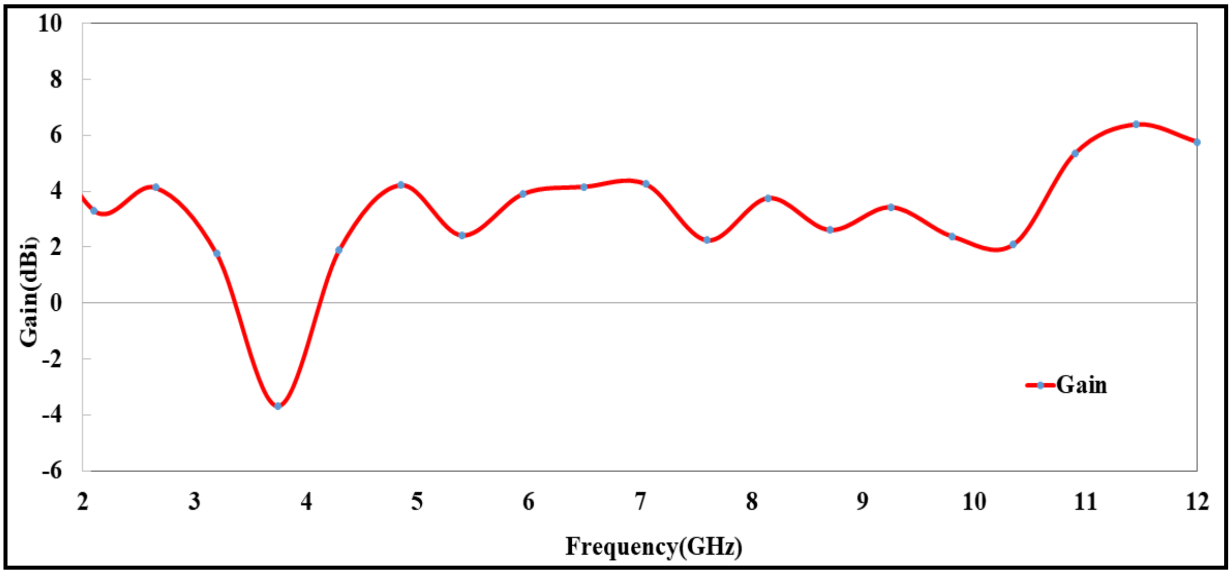

Figure 4.17 Simulated gain of the antenna

Table 4.3 Simulated gain of the antenna

Frequency	2.24 GHz	4.2 GHz	5.25 GHz	9.3 GHz
Gain (dBi)	3.84	0.94	2.89	3.32

CHAPTER 5
CONCLUSION AND FUTURE SCOPE

5.1 CONCLUSION

In this work, the design of an enhanced bandwidth multi band slot antenna for 4G-LTE/WiMAX/WLAN and C/S/X- bands applications is presented. The proposed antenna structure resonates at 2.24 GHz, 4.2 GHz, 5.25 GHz, and 9.3 GHz respectively. The impedance bandwidth obtained is 640 MHz (2.17-2.2 GHz) covering WiMAX (802.16e), Space to Earth communications, 4G-LTE, IEEE 802.11b/ g WLAN systems defined for S-band applications. Also the proposed antenna exhibits bandwidth of 280 MHz (4.1-4.38 GHz) for Aeronautical and Radio navigation applications, 80 MHz (4.2 to 4.28 GHz) for uncoordinated indoor systems, 1060 MHz (5.04–6.1 GHz) for the IEEE 802.11a WLAN system defined for C-band applications and 2380 MHz (7.9-10.28 GHz) defined for X-band applications. The fabricated antenna prototype is experimentally characterized to plot its return loss and radiation pattern. The simulated and measurement results are found to agree well with each other.

5.2 FUTURE SCOPE

The antenna which is design in this thesis work using microstrip feed line technique for 4G LTE, WiMAX, WLAN and C/S/X-band applications can be extended in future work.

- The dimension of radiating rectangular slot will be change into different dimension to generate the different frequency bands.
- The different shape of stubs will be added into the radiating patch.
- The different size, height of the substrate and different types of dielectric material will be use in the future work to generate frequency bands.
- The different structure of feed line will helps to obtain the frequency bands.

Also different techniques will be use in the future to optimize the antenna which are as follow

- **Metamaterials:** It is derived from the Greek word which is the combination of two words Meta and material in which Meta means something beyond normal, changed, something advance and altered. It is artificial material whose electric permittivity and permeability is negative. This characteristics helps the engineer to design the antenna with the enhance bandwidth, better radiation pattern, high gain and reduced the size of the antenna.
- Using split-Ring resonator structure the size of the antenna can be reduced and it can use to design high frequency application antenna.
- Feeding techniques like CPW fed, Aperture-coupled feed and proximity-coupled can also be used to design the antenna to improve the bandwidth, return loss, directivity and so on.
- Using electromagnetic band gap structure to obtained broadband frequency.

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