

**DESIGN AND ANALYSIS OF ENHANCED U-SHAPED MULTIBAND  
MICROSTRIP PATCH SLOTTED ANTENNA USING DGS**

A Dissertation Submitted in partial fulfilment of the requirements for the award of

the degree of

**Master of Engineering**

in

**Electronics and Communication Engineering**

Submitted by

**Navjot Singh Dhindsa**

**Roll No.-801461018**

Under the guidance of

**Mr. Sukhwinder Kumar**

**Lecturer**

**Thapar University, Patiala**



**ELECTRONICS AND COMMUNICATION ENGINEERING**

**DEPARTMENT**

**THAPAR UNIVERSITY**

**(Established under the section 3 of UGC Act, 1956)**

**PATIALA – 147004 (PUNJAB)**

## DECLARATION

I, Navjot Singh Dhindsa, hereby declare that the work which is being presented in the dissertation entitled "**DESIGN AND ANALYSIS OF ENHANCED U-SHAPED MULTIBAND MICROSTRIP PATCH SLOTTED ANTENNA USING DGS**" by me in partial fulfilment of the requirement for the award of degree of M.E. in Electronics and Communication submitted in Electronics and Communication Engineering Department of Thapar University, Patiala, is an authentic record of my own work carried out under the supervision of **Mr. Sukhwinder Kumar, Lecturer, Thapar University, Patiala.**

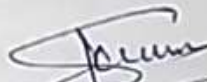
Date: 13/07/2016

  
NAVJOT SINGH DHINDSA

Roll no. - 801461018

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

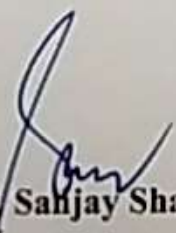
Date: 13/07/2016

  
Sukhwinder Kumar

Lecturer, ECED department

Thapar University, Patiala

Countersigned by:

  
Dr. Sanjay Sharma

Professor and Head

ECED, Thapar University

  
Dr. S.S. Bhatia

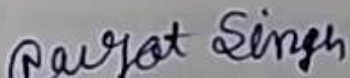
Dean of Academic Affairs

Thapar University

## ACKNOWLEDGEMENT

To discover, analyse and to present something new is to venture on an untrodden path towards and unexplored destination is an arduous adventure unless one gets a true torch bearer to show the way. I would have never succeeded in completing my task without the cooperation, encouragement and help provided to me by various people. Words are often too less to reveals one's deep regards. I take this opportunity to express my profound sense of gratitude and respect to all those who helped me through the duration of this thesis. I acknowledge with gratitude and humility my indebtedness to **Mr. Sukhwinder Kumar, lecturer**, Electronics and Communication Engineering Department, Thapar University, Patiala, under whose guidance I had the privilege to complete this thesis. I wish to express my deep gratitude towards him for providing individual guidance and support throughout the dissertation work.

I convey my sincere thanks to **Head of the Department, Dr. Sanjay Sharma** as well as **PG Coordinator, Dr. Amit Kumar Kohli, Associate Professor**, Electronics and Communication Engineering Department, entire faculty and staff of Electronics and Communication Engineering Department for their encouragement and cooperation. My greatest thanks are to all who wished me success especially my parents. Above all I render my gratitude to the almighty GOD who bestowed self-confidence, ability and strength in me to complete this work for not letting me down at the time of crisis and showing me the silver lining in the dark clouds. I do not find enough words with which I can express my feelings of thanks to my dear friends for their help, inspiration and moral support which went a long way in successful completion of the present study.

  
**NAVJOT SINGH DHINDSA**

**Roll No. - 801461018**

## ABSTRACT

From the last few years, wireless communication is growing very rapidly in the communication industry. The main aim of this thesis report is to design a rectangular metallic patch with two different shapes of slots that are symmetrical maze-shaped slots and swastika-shaped slot for different wireless communication networks. By using U-shaped and double U-shaped defected ground structure the impedance bandwidths of the two proposed antenna designs is enhanced. The simulation results for the first proposed antenna display three resonant bands at frequencies of 2.47/4.48/5.2 GHz for Bluetooth/IMT/WLAN communication networks, with impedance bandwidths of about 100 MHz (2.4–2.5 GHz), 500 MHz (4.4–4.9 GHz), and 200 MHz (5.1–5.3 GHz), respectively and having return loss value of -19.93 dB, -43.4 dB, -23.3 dB respectively. The simulation results for the second proposed antenna display three resonant bands at frequencies of 1.9/2.5/5.6 GHz for GSM/Bluetooth/WLAN/WiMAX communication networks, with impedance bandwidths of about 200 MHz (1.8–2.0 GHz), 300 MHz (2.4–2.7 GHz), and 1000 MHz (5.4–6.4 GHz), respectively and having return loss value of -18.04 dB, -17.39 dB, -27.13 dB respectively.

For each simulated proposed antenna graphs of return loss, VSWR, smith chart, Radiation pattern and current distribution have been plotted and studied. Both the proposed designs are simulated using computer simulation technology (CST) software. The triple band metallic patch antenna having symmetrical maze-shaped slots and U-shaped DGS fed by microstrip line is fabricated using PCB design technique and their return loss results are tested by VNA E5071C. The measured and simulated return loss results are compared and it is concluded that return loss of compact rectangular patch with symmetrical slot and defected ground is better than the different shapes of rectangular patch.

## TABLE OF CONTENTS

S.NO	TITLE	PAGE NO.
	<b>DECLARATION</b>	<b>i</b>
	<b>ACKNOWLEDGMENT</b>	<b>ii</b>
	<b>ABSTRACT</b>	<b>iii</b>
	<b>LIST OF FIGURES</b>	<b>viii</b>
	<b>LIST OF TABLES</b>	<b>xi</b>
	<b>LIST OF ABBREVIATIONS</b>	<b>xii</b>
<b>1</b>	<b>Introduction</b>	<b>1-22</b>
1.1	Preface of Wireless Communication Systems	1
1.2	IEEE Standards	3-4
1.2.1	WLAN IEEE Standard	3
1.2.2	WiMAX IEEE Standard	4
1.3	Different Types of Antennas	6-8
1.3.1	Based on Aperture Characteristics	6
1.3.2	Based on Radiation Characteristics	7
1.3.3	Based on Polarization Characteristics	8
1.4	General Introduction to Microstrip Patch Antenna(MPA)	9
1.5	Radiation Mechanism of Microstrip Antenna	10
1.6	Advantages of Microstrip Patch Antennas	12
1.7	Disadvantages of Microstrip Patch Antennas	12

1.8	Types of Feeding Technique	12-19
1.8.1	Microstrip-Line Feeding	13
1.8.2	Coaxial Probe Feeding	15
1.8.3	Proximity Coupled Feeding	16
1.8.4	Aperture Coupled Feeding	17
1.8.5	Coplanar Waveguide Feeding	19
1.9	Antenna Properties	20-22
1.9.1	Input Impedance	20
1.9.2	VSWR	20
1.9.3	Directivity	21
1.9.4	Gain	21
1.9.5	Radiation Pattern	21
1.9.6	Polarization	22
1.9.7	Return Loss	22
1.10	Organisation of Thesis	22
2	<b>Literature Review</b>	24-38
2.1	Research Work Based on Antenna Design	24
2.2	Objective of The Thesis	38
3	<b>Design Methodology of Rectangular Patch Antenna with Symmetrical Maze-Shaped Slots and DGS</b>	39-50
3.1	Introduction	39

3.2	Proposed Antenna Design	39
3.3	Results and Discussions	42-50
3.3.1	Return loss ( $S_{11}$ )	42
3.3.2	Radiation Pattern Characteristics	44
3.3.3	Voltage Standing Wave Ratio (VSWR)	48
3.3.4	Smith Chart	48
3.3.5	Current Distributions	49
<b>4</b>	<b>Patch Antenna with Swastika-Shaped Slots And DGS</b>	<b>51-60</b>
4.1	Introduction	51
4.2	Proposed Antenna Design	51
4.3	Results and Discussions	54-60
4.3.1	Return loss ( $S_{11}$ )	54
4.3.2	Radiation Pattern Characteristics	54
4.3.3	Voltage Standing Wave Ratio (VSWR)	57
4.3.4	Smith Chart	58
4.3.5	Current Distributions	59
<b>5</b>	<b>Fabrication and Testing of Antennas</b>	<b>61-63</b>
5.1	Antenna Fabricated Design	61
5.2	Testing of Antenna	62
5.3	Comparison of Results of Simulated and Fabricated Antenna	62

<b>6</b>	<b>Concluding Remarks and Future Scope</b>	<b>64-67</b>
6.1	Conclusions	64
6.2	Future scope	66
	<b>References</b>	<b>68</b>
	<b>List of publications</b>	<b>73</b>

## LIST OF FIGURES

<b>FIGURE NO.</b>	<b>FIGURE NAME</b>	<b>PAGE NO.</b>
1.1	Structure of Microstrip Antenna	10
1.2	Side View of Patch Antenna with E-fields	11
1.3	Microstrip-Line Feeding Technique (a) Direct Feed (b) Inset feed	14
1.4	Relative Equivalent of Microstrip-Line Feeding Technique	14
1.5	Coaxial Probe Feeding Method	16
1.6	Relative Equivalent Circuit of Coaxial Probe Feeding Method	16
1.7	Proximity Coupled Feeding Method	17
1.8	Relative Equivalent Circuit of Proximity Coupled Feeding Method	17
1.9	Aperture-Coupled Feeding Method	18
1.10	Relative Equivalent Circuit of Aperture-coupled Feeding Method	18
1.11	Coplanar Waveguide Feeding Method	19
1.12	Coplanar Waveguide Fed Antennas (a) Inductive Coupling (b) Capacitive Coupling	20
3.1	Configuration of Simulated Antenna (a) Front View (b) Bottom View	40
3.2	Configuration of Simulated Antenna with L-Shaped Ground Plane (a) Front View (b) Back View	41
3.3	Simulated S-Parameter Results of Simulated Antenna with L-Shaped Ground Plane	43

3.4	Simulated S-Parameter Results of Simulated Antenna	44
3.5	Simulated Radiation Pattern Characteristics of Simulated Antenna at Resonant Frequency 2.47 GHz (a) 3D View (b) Polar Plot	45
3.6	Simulated Radiation Pattern Characteristics of Simulated Antenna at Resonant Frequency 4.48 GHz (a) 3D View (b) Polar Plot	46
3.7	Simulated Radiation Pattern Characteristics of Simulated Antenna at Resonant Frequency 5.20 GHz (a) 3D View (b) Polar Plot	47
3.8	VSWR of Simulated Antenna	48
3.9	Smith Chart of Simulated Antenna	48
3.10	Current Distribution of Simulated Antenna at 2.47 GHz	49
3.11	Current Distribution of Simulated Antenna at 4.48 GHz	50
3.12	Current Distribution of Simulated Antenna at 5.20 GHz	50
4.1	Configuration of Simulated Antenna (a) Front View (b) Bottom View	52-53
4.2	Simulated S-parameter Results of Simulated Antenna	54
4.3	Simulated Radiation Pattern Characteristics of Simulated Antenna at Resonant Frequency 1.9 GHz (a) 3D View (b) Polar Plot	55
4.4	Simulated Radiation Pattern Characteristics of Simulated Antenna at Resonant Frequency 2.5 GHz (a) 3D View (b) Polar Plot	56

4.5	Simulated Radiation Pattern Characteristics of Simulated Antenna at Resonant Frequency 5.6 GHz (a) 3D View (b) Polar Plot	57
4.6	VSWR of Simulated Antenna	58
4.7	Smith Chart of Simulated Antenna	58
4.8	Current Distribution of Simulated Antenna at 1.9 GHz	59
4.9	Current Distribution of Simulated Antenna at 2.5 GHz	60
4.10	Current Distribution of Simulated Antenna at 5.2 GHz	60
5.1	Proposed Fabricated Antenna (a) Front View (b) Bottom View	61
5.2	Network Analyser for Testing	62
5.3	Simulated S-Parameter Results of Simulated Antenna	62
5.4	Measured S-Parameter Results of Fabricated Antenna	63

## LIST OF TABLES

<b>TABLE NO.</b>	<b>TABLE NO.</b>	<b>PAGE NO.</b>
1.1	Different Types of Wireless Communication Applications and Their Bandwidths	2
1.2	Different IEEE WLAN Standards	4
1.3	Different IEEE WIMAX Standards	5
3.1	Overall Dimensions of the Simulated Proposed Antenna (mm)	42
4.1	Overall Dimensions of the Simulated Proposed Antenna (mm)	53
5.1	Comparison of Simulation and Measured Results	63

## LIST OF ABBREVIATIONS

ACS	Asymmetric Coplanar Strip
AP	Access Point
BPSK	Binary Phase Shift Keying
CCK	Complementary Code Keying
CPW	Coplanar Waveguide
CSRR	Complementary Split Ring Resonator
CSSRR	Complementary Single Split Ring Resonator
CST	Computer Simulation Technology
dB	Decibel
DGS	Defected Ground Structure
DNG	Double Negative
DPS	Double Positive
DSL	Digital Subscriber Line
ECT	Electromagnet Coupling Theory
EBG	Electromagnetic Band Gap
FBR	Front to Backward Ratio
GHz	Giga Hertz
GPS	Global Positioning System
GSM	Global System for Mobile Communication
IEEE	Institute of Electrical and Electronics Engineering

IMT	International Mobile Telecommunication Band
LOS	Line of Sight
MHz	Mega Hertz
MMIC	Monolithic Microwave Integrated Circuits
MPA	Microstrip Patch Antenna
OFDM	Orthogonal Frequency Division Multiplexing
PCB	Printed Circuit Board
PIFA	Planar Inverted F-Antenna
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
RF	Radio Frequency
RFID	Radio Frequency Identification
RL	Return Loss
SRR	Split Ring Resonator
UWB	Ultra-Wideband
VNA	Vector Network Analyzer
VSWR	Voltage Standing Wave Ratio
Wi-Fi	Wireless Fidelity
WiMAX	Wireless Interoperability for Microwave Access
WLAN	Wireless Local Area Network

# CHAPTER 1

## INTRODUCTION

### 1.1 Preface of Wireless Communication Systems

In the modern world of technology, a channel or system which provides a medium of transferring of data from one position to another through some channel which may be wired or wireless is said to be wireless communication. Nowadays for long range communications, electromagnetic spectrum is used. Because electromagnetic spectrum is a natural resource, it is fully utilized in antenna applications. From the last few years, wireless communication is growing very rapidly in the communication industry. The cellular systems have grown exponentially and become an important part of our daily life all over the world. Because there are billions of users all over the world, wireless communications become an important requirement for cellular systems [1]. Wireless communication is that in which there is a medium available for transferring of important information between two or more mobile systems or points through a channel which is implemented without using wires. The term “Wireless” is basically used to refer a radio transmitter or receiver (can be used both as transmitter and receiver) in order to provide comfort and connectivity to wide number of mobile broadband and internet network users in the modern communication world. The term wireless also refers to that type of application in which the whole network is employed without using wires. Examples of wireless communication are different types of fixed, mobile and portable duplex radios, wireless computer peripherals, keyboards, headsets, mobile and portable cellular phones, global positioning system (GPS), satellite and broadcast television [2].

Wireless communication provides services, such as long range communications between two portable points through laptop or mobile phones users who travel across the world through antennas or via satellite communication.

Different modes of Wireless communication are:

1. Radio frequency communication like cellular phones, radio and television broadcast stations, satellite communications systems, and duplex radio services.
2. Microwave communication like long range line-of-sight high directional antennas, and satellite and ground-based communications.

**Table 1.1 Different Types of Wireless Communication Applications and Their Bandwidths**

Communication Channels		Band Covered (GHz)	Bandwidth Obtained (GHz)
Global system for Mobile communication (GSM) Band	GSM 900	0.890-0.960	0.070
	GSM 1800	1.705-1.800	0.95
	GSM 1900	1.840-1.980	0.140
International Mobile Telecommunication (IMT) Band		2.300-2.400	0.100
		2.700-2.900	0.200
		3.400-4.200	0.800
		4.700-4.900	0.500
Bluetooth Band		2.400-2.500	0.100
WLAN Standard Band		2.400-2.485	0.084
		5.150-5.350	0.200
		5.725-5.825	0.100
WiMAX Standard Band		2.500-2.690	0.190
		3.400-3.690	0.290
		5.250-5.850	0.600

## **1.2 IEEE Standards**

### **1.2.1 WLAN IEEE Standards**

A WLAN defined for 2.4/5.1/5.7 GHz frequency bands provides medium of communication which may be a link or channel in order to connect two or more networks or systems using wireless distribution technique which uses either OFDM radio or spread spectrum method. A number of wider internet users are connected to each other in a network (such as homes or offices) through an access point (AP) for the means of communicating. Due to access point, people can move anywhere within the local coverage area network (home, offices etc.) connected with each other through their wireless portable devices such as laptops, mobile phones, notebooks or PCs and the connection will not be disconnected or distorted as they can move anywhere within the range of the network with their portable modern devices. Because use of laptops and PCs are increasing day by day and WLAN system is very easy to install, WLAN has gained so much importance. The IEEE developed the WLAN standards and divides them into five subsets of Ethernet based protocol standards in order to improve this standard [3]:

- WLAN 802.11 resonates at 2400 MHz
- WLAN 802.11a resonates at 5000 MHz
- WLAN 802.11b resonates at 2484 MHz
- WLAN 802.11g resonates at 2400 MHz

In the year 1997, IEEE organization proposed the first standard which is 802.11 for WLANs application. For most applications, IEEE 802.11 standard is slow because unfortunately (operating frequency-2.4 GHz), this standard only supported a maximum network data rate of 2 Mbps. After few years of research a modified standard is proposed which is basically known as Wi-Fi. This new standard compatible with previous version 802.11 is later given an official name i.e. 802.11b standard covering the 2.4-2.84 GHz band with resonating frequency of 2.4 GHz. Due to the use of the complementary code keying (CCK) modulation technique 802.11b standard can achieve higher 11 Mbps data rates. In the year 1999 the next standard which is 802.11a was approved to cover 5.1-5.3 GHz and 5.7-5.9 GHz frequency band with the operating frequency of around 5 GHz and 6Mbps, 12 Mbps or 24 Mbps data rates range. Higher data rates range of 54 Mbps can be achieved by implementing OFDM

multiplexing. Both previously discussed standards are not compatible with each other due to difference in the range values of their respective frequency bands. Hence, in the year 2002 and 2003, a new modified IEEE standard which is officially known as 802.11g supporting WLAN systems and remove the compatibility issue with both previous proposed standards emerged in communication market. Modification is done to join the frequency bands of both 802.11a and 802.11b IEEE standard to achieve 54 Mbps higher data rates. Since coverage frequency ranges for discussed standards offers two bands, therefore there is a need to propose a dual/multiband antenna satisfying WLAN communication devices or networks. Due to high-speed transfer rate there is an increase in popularity of WLAN and the development of broadband antennas.

**Table 1.2 Different IEEE WLAN Standards**

Parameters		WLAN Standard Bands		
		802.11a	802.11b	802.11g
Coverage Band (MHz)		5000-6000	2400	2400
Data rate (Mbps)		54	11	54
Range (m)	Indoor	35	35	38
	Outdoor	120	140	140
Type		WLAN	WLAN	WLAN

### 1.2.2 WiMAX IEEE Standard

WiMAX IEEE 802.16 standard present the next generation of wireless technology design to enable prevalent, high speed fixed and mobile internet access to PCs, smart phones, tablets and electronic devices such as gaming devices (play stations), cameras, music players, and more. With different types of devices WiMAX gives broadband internet connectivity in

almost all over the world. WiMAX provide the higher data transmission rate up to 35 to 45 Mbps covering 50 km communication distance. In the June month of year 2001 the WiMAX organization officially gives the WiMAX name to the standard to provide comfort to the users of communication world. The organization explains the official name as "a standards-based technology allowing the delivery of last mile wireless broadband internet access as an alternate option to cable and digital subscriber line (DSL)".

**Table 1.3 Different IEEE WIMAX Standards**

Parameters	WiMAX Standards		
	802.16	802.16a	802.16e
Spectrum Bandwidth Allocated (MHz)	10000-66000	2000-11000	2000-6000
Channel bandwidth (MHz)	1.25 to 28	1.5 to 20	5
Modulation Technique	16 and 64 QAM, QPSK and BPSK	16 and 64 QAM, and QPSK	QPSK and 16 and 64 QAM
Transmission Rate (Mbps)	Up to 134	Up to 75	Up to 15
Channel conditions	LOS	Non-LOS	Non-LOS
Coverage area (km)	2-5	7-10	2-5
Application	Fixed	Fixed and Portable	Pedestrian Mobility ( $\leq 75$ mph)
Completed	December,2001	January,2003	August,2005

WiMAX was not globally assigned any licensed consistent frequency bands, however the organization has published three WiMAX globally licensed frequency bands profiles for the users which covers the bands ranging from 2.5 to 2.69 GHz, 3.4 to 3.69 GHz and 5.25 to 5.85 GHz [4].

The 802.16 standards describe the general preface of WiMAX standard by describing the formally corresponding terms. Explanations of these terms are as follows:

- IEEE 802.16-year 2004 is generally referred as FIXED WiMAX or WiMAX 802.16d standard, due to no mobility support and elementary organization.
- IEEE 802.16e-year 2005 is referred as MOBILE WiMAX or WiMAX802.16e standard, due to mobility support.

### **1.3 Different Types of Antennas**

**1.3.1 Based on Aperture Characteristics:** The antennas based on aperture characteristics are defined as follows

- **Wire Antennas**

Wire antennas are basic type of antennas used by common users around the world in homes or school and office buildings or in the automobile and aircraft industry. These antennas can be configured with any regular shapes, for example rectangle which leads to divide them into different types, for example straight wire.

- **Aperture Antennas**

Because of the configuration of aperture antennas they are mainly used in aircraft industry. Since the dielectric material present in the substrate of these antennas that isolate them from dangerous surroundings, antennas can be easily mounted on the aircraft surface [5].

- **Microstrip Patch Antennas**

In the year 1970, an antenna was designed with three layers consisting of a perfect electric conductor ground plane, a dielectric substrate element and a patch having metallic property. This three layer configuration is known as Microstrip Patch Antenna. The patch with metallic property can take any form or shape. But due to its simple structure, rectangular and circular metallic patches are commonly used in the

communication world. In the recent last few years, a wide research is done on the microstrip antenna due to its properties and it became popular in the communication industry due to its low cost and simple fabrication technique.

- **Reflector Antennas**

Parabolic reflector antenna is to communicate between two networks or channels having thousands of miles of travelling distance between them. The configuration of these antennas include large dimension with diameter value can be taken up to 305 m. These antennas can be used for distance communication networks as they provide high gain when important data is transferred between two or more channels or networks having thousands of miles of travelling distance between them.

- **Array Antennas**

An array antenna is used when we have to get the antenna maximum radiation pattern which can't be achieved by a single monopole antenna. A group of radiating patches or elements is arranged in a particular way to obtain maximum radiation pattern characteristics towards a specified point. These arrangement of radiating elements helps to accumulate radiations in order to get maximum radiations in the desired directions and minimum radiations in other directions as desired [5].

**1.3.2 Based on Radiation Characteristics:** The antennas based on radiation characteristics are defined as follows

- **Directional Antennas**

These types of antennas transmit and receive a signal by focusing the RF energy in that particular specific direction i.e. in the direction of the signal. Directional antennas are designed to increase overall antenna gain of communication system in order to obtain maximum radiations in a particular direction and to increase the coverage distance, however the angular coverage angle decreases. They are also called as beam antennas. These types of antenna is useful in near line of sight coverage, such as covering corridors, long hallways etc. As the angular coverage angle is less, coverage areas will not be large. These antennas are difficult to mount as the antenna has to face in the particular direction where the coverage is required.

- **Omni Directional Antennas**

In a two dimensional geometric ground plane, Omni directional antennas transmit and receive signals in a communication channel or network uniformly well in all horizontal directions (360 degrees). Omnidirectional antennas are used in cellular phones, wireless routers because they are easy to install. Also, because of its shape it is very easy to mount these antennas upturned from a ceiling inside the home or office. The Omni-directional antennas cannot be used in cross polarization mode in order to reduce the effect of interference because of its vertically polarized configuration. A perfect more coverage is obtained near access point in case of low gain antenna to increase the probability of obtaining signals with low interference for multipath inside conditions.

**1.3.3 Based on Polarization Characteristics:** The antennas based on polarization characteristics are defined as follows

- **Circularly Polarized**

Circularly polarized antennas can radiate electromagnetic electric field waves in any direction. One rotation is completed by radiating filed vectors in both horizontal and vertical plane in corkscrew pattern. Circularly polarized antenna loses around 3 dB per read when compared to linearly polarized antennas because they divide their power between two separate planes. Criteria for Circular polarization are that the E-field must have two orthogonal components of same magnitude with  $90^\circ$  out of phase. As antenna is rotated in all directions, the axial ratio measured in decibels (dB) by calculating the difference in angle created between maximum and minimum peaks and should be near to zero for circularly polarized antenna.

- **Linearly Polarized**

These antennas radiate electromagnetic waves either in vertical plane or in horizontal plane (i.e. in the direction of propagation). Linear polarized antennas are smaller, low cost and simple to manufacture and they work conveniently well in daily applications. An antenna exhibit linearity property when its electric field lines make  $90^\circ$  with the plane. In order to get constant read, these antennas must know their radio-frequency identification tag orientation and this RFID tag should be constant in the antenna orientation plane. Due to the continuous emission, the same

gain linearly polarized antennas generally have larger read range than circularly polarized antennas. Examples of linearly polarized antennas are the MTI MT-263003 Outdoor Antenna, broadcast tower for AM radio and the Times-7 A5531 Indoor Antenna [6].

#### **1.4 General Introduction to Microstrip Patch Antenna (MPA)**

In the year 1970, an antenna was designed with three layers consisting of a ground plane (perfect electric conductor), a dielectric substrate and a patch (perfect electric conductor) having metallic property. This three layer configuration is known as Microstrip Patch Antenna as shown in figure 1.1. The radiating patch with metallic property can take any form or shape. But due to its simple structure, rectangular and circular metallic patches are commonly used in the communication world. In the recent last few years, a wide research is done on the microstrip antenna due to its properties and it became popular in the communication industry due to its low fabrication cost and simple fabrication design technique. Small compact size or small height antennas are required in aircraft, spacecraft, missile and satellite industry where main constraints are low cost, light weight, ease of installation and fabrication, aerodynamic nature [7]. Some other same specifications applications are commercial radio mobile communication systems and government defense applications. These antennas are compatible with planar and non-planar surfaces, and monolithic integrated circuit technology. These antennas are easily and simply fabricated on a dielectric substrate using printed circuit technique to calculate a set of parameters like resonant frequency, impedance bandwidth and radiation patterns etc. A particular patch is designed to obtain the desired resonant frequency. Moreover, additional resistive, capacitive or inductive loads, varactor diodes or stack of metallic patches can be added to increase the impedance bandwidth. Microstrip antennas can achieve multiband frequencies because they support both polarizations. The major disadvantages include low efficiency and power, poor polarization purity and scan performance, less temperature tolerance and unwanted feed radiation, narrow bandwidth and high Q (greater than 100). For better performances, good quality of dielectric substrate and good temperature tolerance characteristics is required. Due to complex feed systems and polarization purity, high-performance arrays are difficult to achieve. Due to this, antennas gain becomes low and power handling capacity and surface wave excitation become less. In government security applications, there is a need for narrow

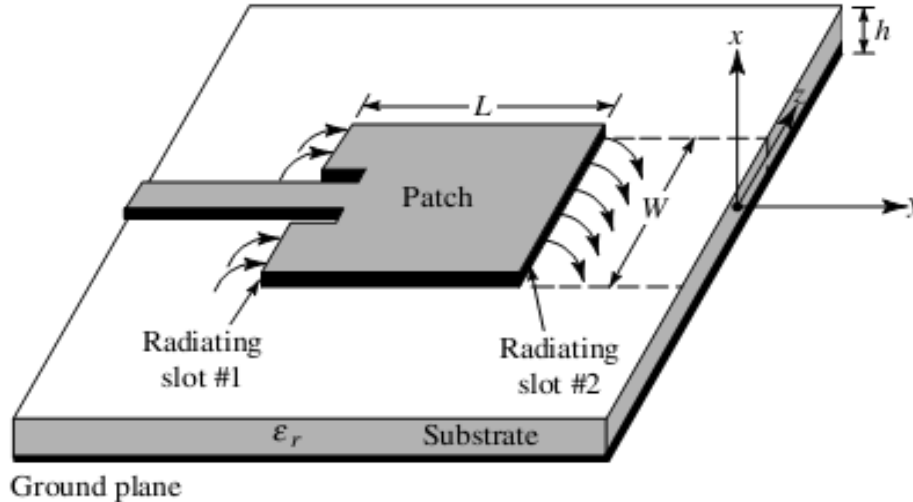
bandwidth which can be achieved by changing the overall dimensions of dielectric. However unwanted surface waves are introduced inside the metallic patch as dielectric height increases. These unwanted surface waves travel across the dielectric substrate and it increase around bends and junctions and thereby degrading the antenna characteristics such as radiation pattern, gain etc. While maintaining large bandwidths through various methods as discussed above, surface waves can be eliminated.

A microstrip antenna configuration has three layers:

- A radiating patches having metallic property (perfect electric conductor).
- Dielectric substrate.
- Ground plane (perfect electric conductor).

Important factors used for designing microstrip antennas are:

- Shape of patch having metallic property.
- Thickness, permittivity and tangent loss of dielectric constant.
- Type of feed technique used.

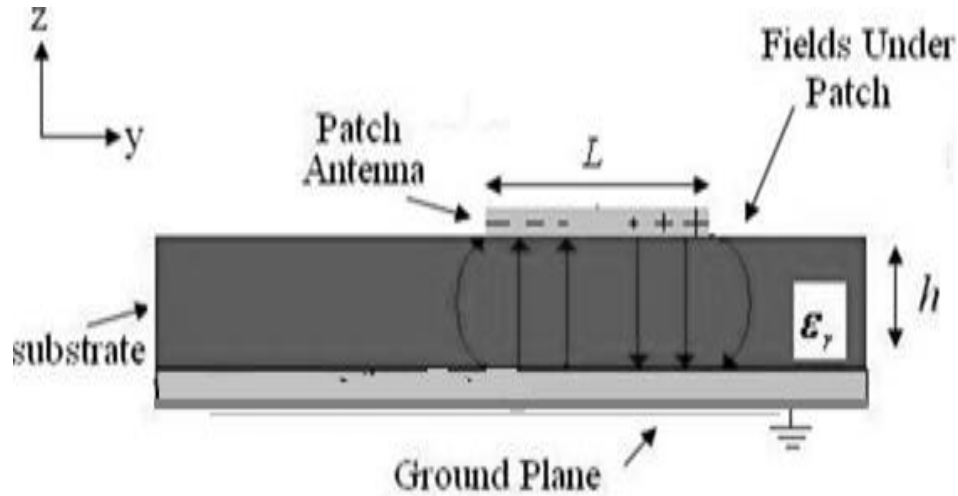


**Figure 1.1: Structure of Microstrip Antenna [7]**

### 1.5 Radiation Mechanism of Microstrip Antenna

Generally, a microstrip antenna consists of a radiating patch having metallic property on the upper surface of a substrate dielectric material which is made considering substrate thickness, dielectric constant and tangent loss of an element and on the lower bottom surface

of the substrate dielectric material, a perfect electric conductor ground plane is embedded. The patch with radiating nature is basically selected by taking good metallic property element like copper of attainable shape. The patch with radiating metallic property, microstrip feeding line technique and the ground plane with perfect electric conductivity is basically fabricated by a photo chemical process on the dielectric substrate.



**Figure 1.2: Side View of Patch antenna with E-Fields [7]**

The patch antennas undergo fringing effects at edges of metallic patch as overall dimensions of metallic patch are finite. Voltage and currents measured in microstrip patch antennas are out of phase in nature because patch antenna is equivalent to open transmission line model for which voltage reflection coefficient is calculated to be -1. Hence the maximum (+V volts) and minimum voltages (-V volts) are obtained at the end and start of metallic patch respectively. For a rectangular radiating patch having metallic property, the length 'L' of the radiating patch having metallic property is usually calculated by keeping in mind the standard range of antenna length i.e.  $0.3\lambda_0 < L < 0.5\lambda_0$ , where  $\lambda_0$  is the free-space wavelength. The thickness of rectangular radiating patch having metallic property is selected to be very small such that thickness  $t \ll \lambda_0$  (where t is the thickness of the patch). The height 'h' of the dielectric substrate is very important parameter for the antenna design and usually in the range of  $0.003\lambda_0 \leq h \leq 0.05\lambda_0$ . The permittivity of the substrate ( $\epsilon_r$ ) is basically in the range of  $2.2 \leq \epsilon_r \leq 12$  [6]. Hence, the fringing E-fields present around the edge of the patch antenna are added up in phase and produce the radiation characteristics of the patch antenna as shown in figure 1.2.

## **1.6 Advantages of Microstrip Patch Antennas**

- Low volume and less weight which can be changed.
- Easy to manufacture because fabrication cost is less and it can be done in PCB lab and easily available for mass production.
- Easily integrated with microwave integrated circuits (MICs) technology that can be transformed into arrays and electronic components.
- Easily change to conformal for host surface because of low and thin profile planar configuration.
- Supports dual polarization (linear and circular polarization) because of simple feed.
- Conveniently used for multiple frequencies band operations.
- Mechanically rugged when mounted on stiff surfaces.
- There is no need for cavity backing with the antenna structure.
- The antenna structure can be fabricated simultaneously with feed lines and matching network.

## **1.7 Disadvantage of Microstrip Patch Antennas**

- Biggest drawbacks are low efficiency, gain (around 6 dB), impedance bandwidth, and power handling capacity.
- Very narrow frequency bandwidth and related tolerance problems which is the biggest disadvantage.
- Poor scan performance and surface wave excitation.
- Unwanted radiations from feeds lines, slots and junctions.
- Except for tapered slot antennas it has poor end fire radiator.
- Polarization purity is difficult to obtain and it has low front to backward ratio (FBR).
- Complex feed structure of arrays is required for high performance; however it causes large ohmic losses.

## **1.8 Types of Feeding Techniques**

The most popularly used feeding methods used in the modern communication world is listed as follows

- Microstrip feed-line technique
- Coaxial probe feeding technique
- Proximity coupling feeding technique
- Aperture coupling feeding technique
- Coplanar waveguide technique

Another category which is used to classify the feeding methods is listed as follows

- Contacting schemes- Microstrip Feed-line, Coaxial probe feeding and Coplanar waveguide feeding method
- Non-contacting schemes- Aperture coupling feeding method and Proximity coupling feeding method

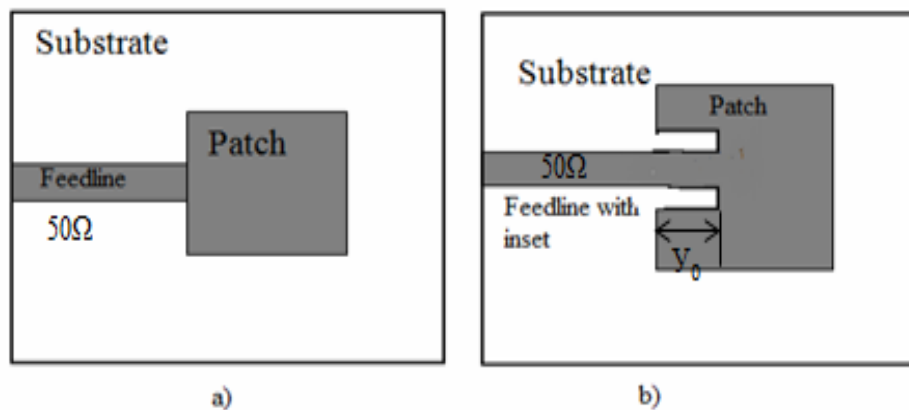
Microstrip- line feeding and coaxial probe feeding method for a constant dimension of metallic radiating patch and substrate dielectric material offers only one degree of freedom. That's why these two feeding methods have similar working. Proximity coupling feeding method offers two degrees of freedom i.e. ratio between metallic patch width and line feed width, and dimension of stub feeding across length. Aperture coupling feeding method offers at least four degrees of freedom i.e. slot dimension, slot position, parameters of feed substrate and dimension of line feed across width.

**1.8.1 Microstrip-Line Feeding:** The configuration and equivalent of this feeding method are defined as follows

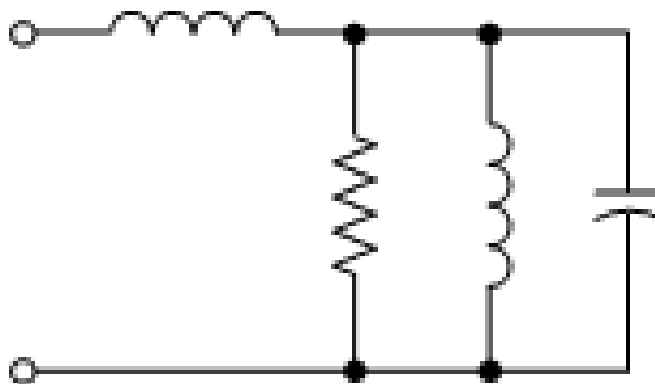
- The microstrip-line feeding method is a radiating metallic strip line connected to radiating patch with metallic property to obtain planar design, having small dimensions across width of the line strip when compared to dimensions of radiating patch having metallic property as shown in the figure 1.3. The major merit of microstrip-line feeding method is that it is easy to fabricate and implement, and easy to match input impedance by regulating inset position (present between touching point and width of the patch having metallic property) without the requirement for another matching element. However as for practical designs due to increase in the undesirable surface waves and unwanted feed radiation because of increase in dimension substrate dielectric material which leads to limit the bandwidth and lead

to increase in spurious cross polarized radiation level. Such antennas are limited in bandwidth to about 2%-5%.

- The relative equivalent circuit that applies to this feeding technique is the parallel RLC network (i.e. two inductors, one resistance and one capacitor) is shown in the figure 1.4, representing the resonant patch and the inductor connected in series represents feed inductance of the microstrip feed-line. In order to oppose the excited surface waves guide waves are radiated by concentrating the electromagnetic field vectors existing between the gap of feed line and ground plane [7].



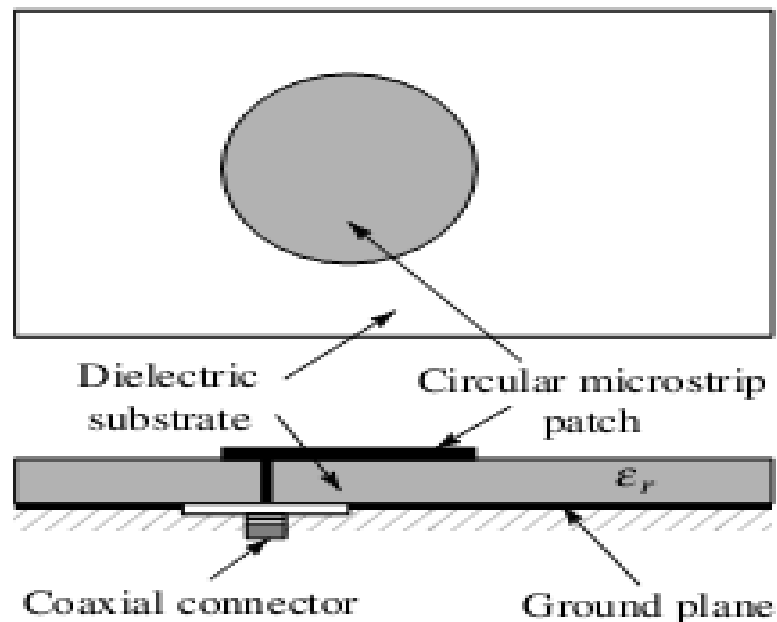
**Figure 1.3: Microstrip-Line Feeding Technique (a) Direct Feed (b) Inset feed [7]**



**Figure 1.4: Relative Equivalent of Microstrip-Line Feeding Technique [7]**

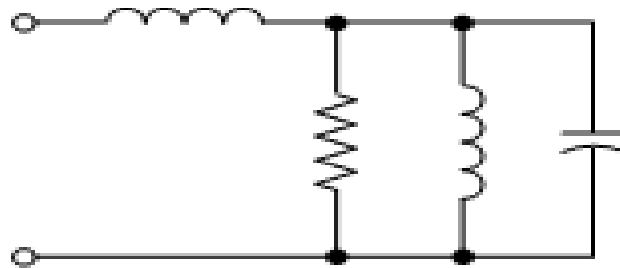
**1.8.2 Coaxial Probe Feeding:** The configuration and equivalent of this feeding method are defined as follows

- This feeding method is used to feed patch elements having metallic property through the ground plane having perfect conductivity from the substrate dielectric material connected in parallel feed. The inner (center) metallic conductor of the coaxial cable is attached to the radiating patch having metallic property while the outer conductor of the cable is connected to the perfect electric conductor ground plane as shown in figure 1.5 [7]. The major merit of this feeding method is that it can easily be manufactured and matching the input impedance by placing the feed at a suitable location within the metallic patch and it has low unwanted radiation. The main demerit of this feeding method is that it does not support exact planar structure because to connect the feeding probe with the perfect electric conductor ground plane and the radiating patch having metallic property, a slot is created in the substrate dielectric material and the coaxial connector expands outside the perfect electric conductor ground plane. However, for thick substrate having greater thickness dimension than  $0.02\lambda$ , it offers narrow bandwidth because a large number of solder joints is needed to fabricate the design having thousands of array elements which is difficult and therefore reduces reliability .



**Figure 1.5: Coaxial Probe Feeding Method [7]**

- Its relative equivalent circuit as shown in figure 1.6 is same as that is applied to the microstrip feed line i.e. two inductors, one resistance and one capacitor connected in parallel RLC network. Spurious cross-polarized radiations waves are generated because of creating higher order of dominant modes of patch having metallic property due to irregularities in the feeding methods.

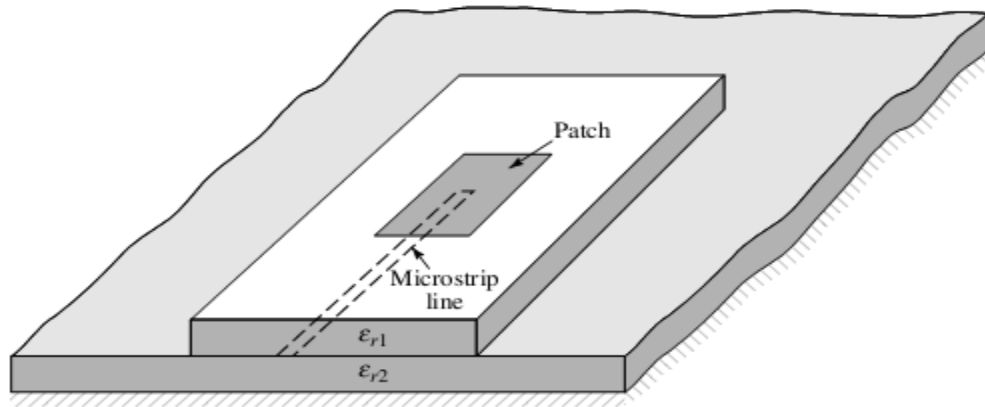


**Figure 1.6: Relative Equivalent Circuit of Coaxial Probe Feeding Method [7]**

**1.8.3 Proximity Coupled Feeding:** The configuration and equivalent of this feeding method are defined as follows

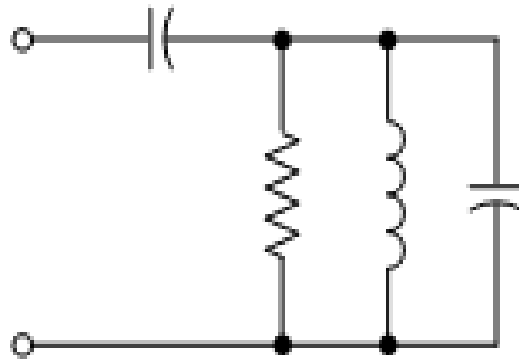
- As shown in Figure 1.7, this type of feeding technique lies under non contacting scheme category as there is no physical contact between metallic patch and microstrip feed line. This feeding method is often known as the electromagnetic coupling method. In proximity coupled feeding method two-layer substrate dielectric materials are used such that the microstrip line feed is placed between separation gap between the two substrate dielectric materials and the radiating patch having metallic property is placed on top surface of the upper substrate dielectric material. The main merit of this feeding method is that it allows metallic patch to place on an effectively thick dielectric substrate for a better bandwidth (up to 21%); on the other side the microstrip feed line is on an relatively thin dielectric substrate, which reduces unwanted feed radiations and electromagnetic coupling due to change in overall dimensions of antenna [7]. The major demerit of this feeding method is that the difficulty level is high in order to fabricate this feeding method, because of the need for proper arrangement between dielectric substrates. The line impedance matching

is controlled by selecting the accurate ratio of width and length dimension of the radiating patch having metallic property and length of the microstrip line feed.



**Figure 1.7: Proximity Coupled Feeding Method [7]**

- Its relative equivalent circuit has a capacitor (coupling capacitor  $C_c$ ) connected in series with the RLC parallel resonated network as shown in figure 1.8 that represents the patch having metallic property. The capacitive coupling depends on two conditions, the inset position of the feed and the metallic patch width.

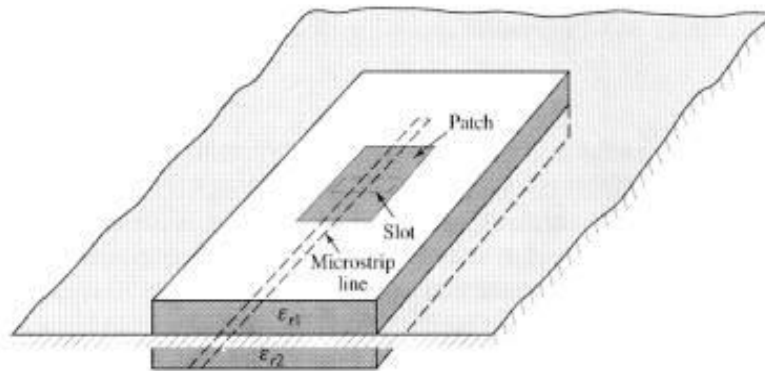


**Figure 1.8: Relative Equivalent Circuit of Proximity Coupled Feeding Method [7]**

**1.8.4 Aperture Coupled Feeding:** The configuration and equivalent of this feeding method are defined as follows

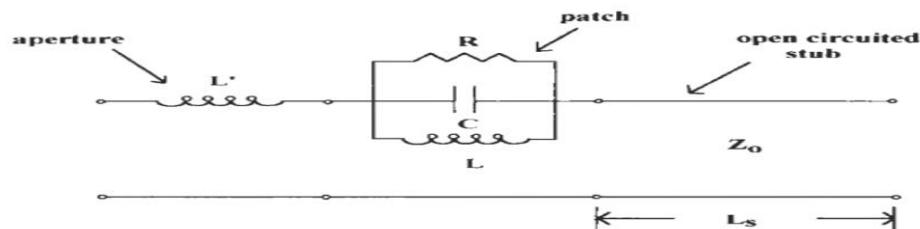
- As shown in figure 1.9, the arrangement for the aperture-coupled feeding technique is done by separating the microstrip feed line from the radiating patch having metallic property through the perfect electric conductor ground plane. A cut is made in the ground plane through a slot or an aperture in order to provide coupling of electromagnetic nature between the radiating patch having metallic property and the

microstrip line feed. The aperture or slot is generally placed at the center beneath the metallic in order to obtain low level of cross polarization due to planar symmetry of the structure. The amount of coupling of electromagnetic nature from the patch having metallic property to the microstrip line is determined by selecting the dimensions of coupling aperture, and position and size of the slot.



**Figure 1.9: Aperture-Coupled Feeding Method [7]**

- The spurious feed radiations reduce in this feed technique as it provide a separation gap between the radiating patch having metallic property and the microstrip line feed. Normally a low value of dielectric constant thick substrate is used as the upper (top) surface substrate material and a high value of permittivity dielectric material is used as the lower (bottom) surface substrate material. The main demerit of this feeding method is that its fabrication difficulty is high because of addition of multiple layers, which lead to increase in the overall antenna size. A relative equivalent circuit diagram for this feeding method is shown in figure 1.10. The equivalent circuit is a parallel RLC network where L represents the inductance related with the beneath resonance slot.

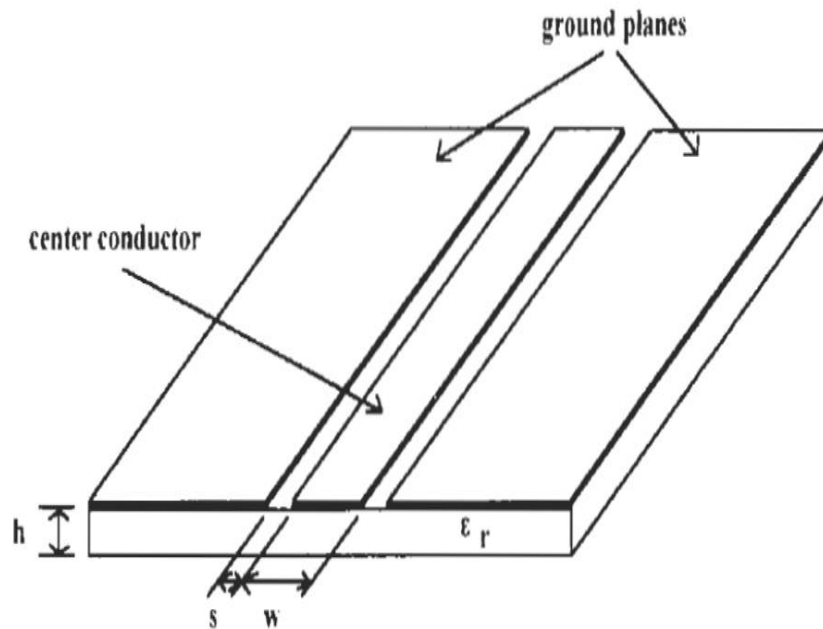


**Figure 1.10: Relative Equivalent circuit of Aperture-Coupled Feeding Method**

[8]

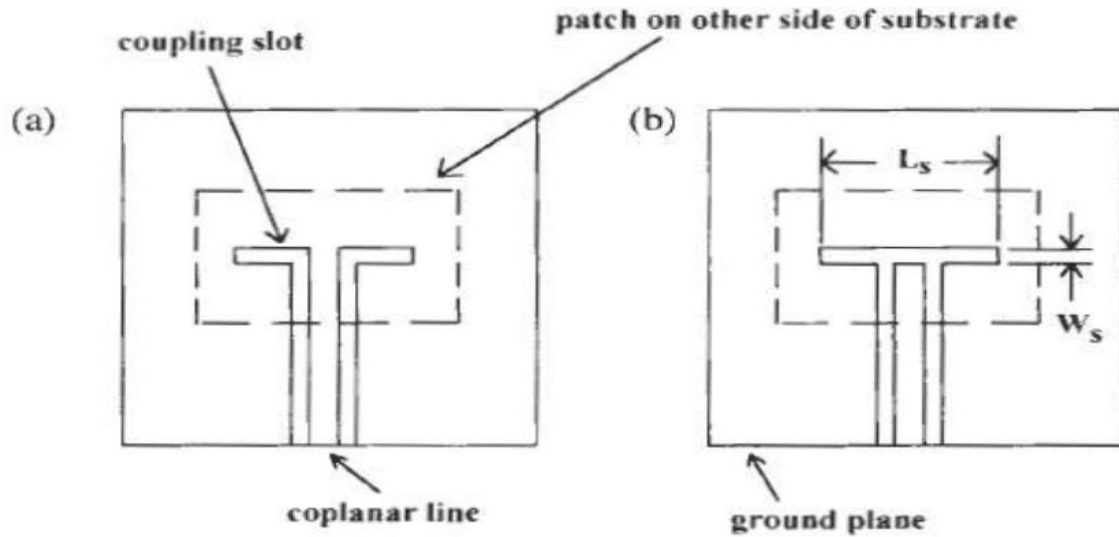
**1.8.5 Coplanar Waveguide Feeding:** The configuration and equivalent of this feeding method are defined as follows

- This type of feeding technique is equivalent to a transmission line model that contains a central current carrying component on the top of the dielectric substrate, which have coplanar geometry with side grounds that can expand to a symmetric space to either side of components as shown in figure 1.11. This feeding method is selected equivalent transmission line model for monolithic integrated circuits (MMIC) technology. The main requirement of this feeding method is planar geometry. Hence, for combining patch antennas with coplanar waveguide (CPW) feed, it is required to provide the feed to the microstrip patch antenna with a coplanar waveguide (CPW). The CPW fed patch antenna have been famously used for wireless communications applications due to their many characteristics such as simplest geometry of a single layer having metallic nature, easy integration with MMICs technology, no soldering junctions, and wide bandwidth.



**Figure 1.11: Coplanar Waveguide Feeding Method [8]**

- Here, in this feeding method the coplanar feed is etched in the perfect electric conductor ground plane of the microstrip patch antenna. The coupling between coplanar waveguide (CPW) and metallic patch is inductive in nature as shown in figure 1.12(a) while in figure 1.12(b) it is capacitive in nature.



**Figure 1.12: Coplanar Waveguide Fed Antennas (a) Inductive Coupling (b) Capacitive Coupling [8]**

## 1.9 Antenna Properties

### 1.9.1 Input Impedance

It is defined as the ratio of voltage and current values or ratio of magnetic and electric field values or impedance calculated for an antenna defined at the pair of terminals. Input impedance is represented in the general complex equation form having real and complex values are represented in the following equation:

$$Z_{in} = R_{in} + jX_{in} \quad \dots (1.1)$$

### 1.9.2 VSWR

It stands for Voltage Wave Standing Ratio. It is the ratio of maximum to the minimum radio frequency voltage measured on the transmission line. It is defined as:

$$VSWR = \frac{V_{max}}{V_{min}} \quad \dots (1.2)$$

We can calculate VSWR by using return loss also, which is an indicator that VSWR is also the measure of antenna's efficiency also. The mismatch between the terminal input impedance of antenna and the characteristic impedance of transmission line can be determined with the return loss. VSWR can be determined as given below if the magnitude of reflection coefficient is known.

$$VSWR = \frac{1+|S_{11}|}{1-|S_{11}|} \quad \dots (1.3)$$

As the mismatch between the antenna and transmission line increases, the value of VSWR increases and similarly, as the mismatch decreases, means good matching, the value of VSWR decreases. The minimum value of VSWR is '1', and practically equipment can afford its value up to '2', which means, return loss is '-10 dB' or lower.

### 1.9.3 Directivity

The ratio of maximum antenna radiation intensity in a particular specific direction to the averaged antenna intensity taken over all the radiation directions is defined as directivity of the antenna. Directivity is represented in mathematical equation 1.4

$$D(\theta, \phi) = \frac{U(\theta, \phi)}{U_0} = \frac{4\pi U_{max}}{P_{rad}} \quad \dots (1.4)$$

Where,  $D(\theta, \phi)$  and  $U(\theta, \phi)$  represents the directivity of antenna and radiation intensity respectively.  $U_0$  is the radiation intensity of the isotropic antenna

### 1.9.4 Gain

There are two types of antenna gains, namely relative gain and absolute gain. Absolute antenna gain is defined as ratio of the radiation intensity in a particular direction to the intensity which is generated by an isotropic antenna when the input feed given to both the antennas is same whereas the relative gain is taken with respect to some reference antenna.

$$\text{Gain} = \frac{4\pi \times \text{radiation intensity}}{\text{total input power}} = \frac{4\pi \times U(\theta, \phi)}{P_{in}} \quad \dots (1.5)$$

Gain is generally measured in decibels with respect to other antenna either an isotropic antenna (dBi) or a dipole (dBd).

### 1.9.5 Radiation Pattern

A function of space coordinates of antenna properties are represented in terms of graphical representation or mathematical function is defined as antenna radiation pattern. The graphical representation shows the relationship between transmitted and received relative field strengths of an antenna. The graphical representation is plotted in polar or rectangular form at one resonant frequency with measure scale of dB and considering the effect of polarization and one plane cut.

### 1.9.6 Antenna polarization

It is defined as the orientation or path followed by electromagnetic wave electric field vector radiated from the antenna as a function of time. Polarization on a wave is the orientation or path traces by the electric field vector as a function of time. Three categories of antenna polarization is defined as follows

- Linearly polarized (vertically and horizontally polarized)
- Circularly polarized (left hand clockwise rotation polarized and right hand anticlockwise rotation polarized)
- Elliptical polarized

### 1.9.7 Return Loss

Return loss basically represent the difference value between the forward and the reflected back power of a transmitted signal in a communication system and is generally calculated in terms of decibels (dB). The small value of return loss is equivalent to the maximum power is transferred between two communicable devices. Therefore, it should have greater negative value for better communication. The RL is defined as

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

### 1.9 Organization of Thesis

The thesis report is organized as follows:

**CHAPTER 1** discusses the preface of wireless communication and an introduction to different IEEE wireless standards. The chapter also discusses different types of antennas, a basic introduction to microstrip patch antenna, its radiation mechanism, and their merits and demerits in the field of communication industry. The types of feeding methods that can be applied to different antennas are also discussed and different antenna properties that can be affected due to these feeding methods are also discussed.

**CHAPTER 2** presents the literature survey of many researchers in the field of antenna communication. In this chapter various concepts of antenna are studied and based on that thesis objective is defined.

**CHAPTER 3** presents the design of the proposed triband antenna with symmetrical-shaped slot and DGS for Bluetooth/IMT/WLAN communication networks. The design steps and overall dimensions are discussed and different simulated results are studied and compared.

**CHAPTER 4** presents the design of the proposed quad band antenna with swastika-shaped slot and DGS for GSM/Bluetooth/WLAN/WiMAX communication networks. The feeding method, design steps and overall dimensions are discussed and different simulated results are studied and compared.

**CHAPTER 5** presents the fabricated design of the proposed triband antenna. Simulated and measured results are compared and studied.

**CHAPTER 6** concludes the thesis report and future scope of the work is discussed.

## CHAPTER 2

### LITERATURE REVIEW

#### 2.1 Research Work Based on Antenna Design

**A.K. Sharma et al.** proposed the design and analysis of compact square patch with  $\pi$  slotted microstrip antenna singly aperture coupled fed for dual band WLAN/WiMAX communication network. The proposed design antenna exhibit square shaped radiating patch having metallic property with narrow slot in the design of symmetrical  $\pi$ -shaped which is singly fed through aperture coupled feeding method to obtain dual band WLAN/WiMAX communication network. The proposed design antenna geometry operates at 2400-2484 MHz, 2500-2690 MHz, and 3.5 GHz WiMAX band to cover the frequency bands for WLAN/WiMAX communication network. Overall 35% size reduction is obtained in this letter as compared to overall dimension of regular square patch when reactive loading is used with the slot antenna [9]. **Y. F. Cao et al.** proposed a design and analysis of four band slot antenna for GPS/WLAN/WiMAX communication network. The proposed design antenna exhibits rectangular patch embedded with a feed match in the design of T-shaped, a metallic stub in the designed inverted T-shaped, and two metallic stubs in the design of E-shaped to operate at four frequency bands. It operates at 1575 to 1665 MHz for GPS communication network, 2400 to 2545 MHz and 5170 to 5930 MHz for WLAN communication network and 3270 to 3970 MHz for WiMAX communication network [10].

**Seyed Amir Hossein et al.** proposed the design and analysis of a compact sized planar antennas having four cells of metamaterial loaded in the substrate dielectric element for dual band communication network. The proposed design antenna exhibits a radiating patch having metallic property, metamaterial loaded dielectric material substrate, coplanar waveguide and microstrip line feed at the input, and back electric conductor ground plane. Two layers of antenna are formed by loading the dielectric substrate with design in the shape of U-shaped and inverted U-shaped to make simple configuration of structure. Overall 77% size reduction is obtained in this letter when compared with overall dimension of normal regular patch antennas [11].

**Sajjad Ojaroudi et al.** proposed the analysis of I-shaped and T-shaped antenna having compact and novel design for ultra-wideband communication network with band-notched

dual performances. Hence, the wideband compact I-shaped and T-shaped proposed antenna is designed with overall dimension  $12 \times 18 \text{ mm}^2$  printed on a FR4 substrate dielectric element having overall thickness dimension of 1.6 mm. The proposed design antenna exhibits a pair of slots in the design of I-shaped embedded on the perfect electric conductor ground plane and a pair of slots in the design of rotated T-shaped slots connected at the center of slot in the design of I-shaped in order to obtain band-notched dual performances. The proposed design antenna offers rejection bands i.e. 5000-600 MHz and 7250-7750 MHz for the operating bandwidth of 3000-15700 MHz which provide prevention of getting interferences with the bandwidth ranges of down satellite link of X-band and wireless local area network communication systems respectively [12].

**Mohammad Tariqul Islam et al.** proposed the analysis of inverted modified A-shaped patch antenna having compact and novel design for C-band/WiMAX communication network. Hence, the wideband of inverted modified A-shaped proposed antenna is designed with overall dimension  $20 \times 20 \text{ mm}^2$  printed on a FR4 substrate dielectric element having overall thickness dimension of 1.6 mm fed by 4 mm long line feed having  $50\text{-}\Omega$  characteristic impedance [13].

**H. Mopidev et al.** proposed the design and analysis of reconfigurable four band frequency antenna for wireless communication networks. In this letter, the proposed design antenna offers four frequency bands covering-220,470, 800 and 4960 MHz in two reconfigurable modes. The proposed design antenna is overall small in dimension and operated mainly at 220 MHz. Mode 1 provides operation over 220 MHz, 470MHz, and 4960 MHz bands. In mode 2, 800-MHz and 4960-MHz bands are excited. Two radio frequency micro electromechanical systems switches provide dynamic frequency reconfiguration that is strategically located within the antenna architecture [14]. **Peng Wang et al.** proposed the design and analysis of a compact and uniplanar monopole antenna fed by asymmetric coplanar strip (ACS) for Bluetooth and ultra-wideband communication networks. The dual band compact novel uniplanar proposed antenna is designed with overall dimension  $32.5 \times 10 \text{ mm}^2$  printed on a FR4 substrate dielectric element overall thickness dimension of 1.6 mm. The ultra-wideband (UWB) from 2.87 to 11.67 GHz having impedance bandwidth of 8.8 GHz is realized by fabricated a staircase-shaped metallic patch on a dielectric substrate with compact dimension of  $32.5 \times 10 \text{ mm}^2$  and making structure simple and modified because of

feeding method. Furthermore, the additional frequency band (2.35–2.51 GHz) having impedance bandwidth of 0.16 GHz used for Bluetooth applications is obtained by etching a slot in the design of snake-shaped on the staircase shaped patch having metallic property [15].

**Le Kang et al.** proposed the analysis of a uniplanar SRR monopole antenna fed by ACS having compact design for triband WLAN/WiMAX communication network. The main radiating patch is etched by cutting two split ring resonators on its surface and overall antenna is reduced due to ACS feeding method for better performance across triband WLAN/WiMAX communication network. The proposed design antenna provide impedance bandwidths of 340 MHz, 390 MHz and 1110 MHz for 2360-2700 MHz, 3350-3740 MHz and 5010-6120 MHz frequency bands respectively for triple band WLAN/WiMAX communication network [16].

**Kumar Goodwill et al.** proposed the design and analysis of CSRR patch antenna for WLAN communication system. Dual band operation is obtained by introduction of capacitive matching in the proposed design antenna instead of previously used feed matching. In this letter, both overall antenna and CSRR dimensions are important parameters for selecting resonating frequency and due to these parametric variations, resonant frequency separation distance between dual bands can be controlled and can be modified to CSSRR. Dominant mode current does not get disturbed when compared CSSRR to CSRR, hence better radiation pattern is obtained in CSSRR [17]. **R. Nilavalan et al.** proposed the design and analysis of a compact and low-profile compact printed antenna for wireless communication networks. The proposed design antenna exhibits a main radiating patch having metallic property, four metallic sub-patches, and the electric conductor ground plane. The proposed design antenna offers five fixed frequency bands i.e. at 0.92, 1.73, 1.98, 2.4, and 2.9 GHz for wireless communication network. The reconfigurable is obtained by adding four varactor diodes to each of four metallic sub patches to provide independent tuning to five bands over wide range wireless communication network [18].

**J. Nourinia et al.** proposed the design and the analysis of a square-shaped slot antenna having novel and compact design with reconfigurable functions having band-notched switchable characteristics and multi resonance functions for ultra-wideband (UWB)

frequency operations. In this letter, a  $\pi$ -shaped slot is proposed to be etched from center of the square metallic radiating stub design to achieve single band-notched performances. Moreover, to generate reconfigurable characteristics and multi resonance functions, a p-i-n diode is embedded on the surface of the  $\pi$ -shaped slot design in the square radiating stub of metallic nature. In order to transform the  $\pi$ -shaped slot into a couple of C-shaped slots, the p-i-n diode is forwardly biased which create a shorting path to the upper segment of the  $\pi$ -shaped slot and due to this transformation into new design, an additional resonance frequency is introduced to improve the overall impedance bandwidth. The diode biasing of p-i-n diode is done by introducing a metal strip inside the  $\pi$ -shaped slot and a dc blocking capacitor with capacitance value of 100-pF is used inside the surface of  $\pi$ -shaped slot so that the dc biasing voltage cannot interfered the RF signal. Based on the phenomenon of electromagnet coupling theory (ECT), in order to achieve the ultra-wideband performances, two L-shaped slots with modified dimension is inserted on the microstrip feed line. Due to this an additional resonance is excited because of the adjustments of the coupling effects of electromagnetic nature between the radiating patch having metallic property and the perfect electric conductor ground plane and hence without any expense regarding antenna dimensions, wider impedance is produced especially for the higher band. Hence, the wideband compact proposed antenna is designed with overall dimension  $20 \times 20 \text{ mm}^2$  printed on a FR4 substrate dielectric element having overall thickness dimension of 0.8 mm. The fabricated wide band antenna exhibits good radiation characteristics in the ultra-wideband frequency range from 3.05 to 11.10 GHz but having band-rejection switchable characteristics in the frequency range from 5.05 to 5.90 GHz [19].

**Wen Jiang et al.** proposed the design and analysis of a compact printed monopole antenna consists of radiating patch having metallic property having square with modified electric conducted ground structure (DGS) for ultra-wideband communication systems with dual band-notched characteristics. By adjusting the separation gap between radiating patch having metallic property and modified electric conducted ground plane, a wide impedance bandwidth is obtained. Dual notched frequency bands characteristics are generated by adding a set of parasitic components in the design of U-shaped besides feeding line and by embedding a stub in the design of T-shaped in the square shaped radiating patch having metallic property. The frequency band for the proposed designed antenna is defined for the

range 2.8 to 11.0 GHz, with first notch frequency band at 3.3–4.0 GHz and the second at 5.05–5.90 GHz [20].

**J. Nourinia et al.** proposed the design and analysis of a printed monopole antenna having novel and compact design for ultra-wideband communication systems with band-notch performances. The proposed antenna design exhibits a main square radiating patch of metallic nature with a pair of slots in the L-design and E-shaped slot and stick out V-shaped slot on the perfect electric conductor ground plane with an overall size reduction of 30% when compared to other regular antenna dimensions operating for UWB. The proposed antenna design offers a wide frequency band from 2.89 to 17.83 GHz having an impedance bandwidth improvement of 140% with two rejection bands of 3.44–4.30 GHz and 5.1–5.8 GHz range. The first single band notch WLAN characteristic at 5 GHz is obtained by cutting two L-shaped design slots from the radiating patch having metallic property. The second band notch WiMAX characteristic is obtained by adding E-shaped design slot to the center of radiating patch having metallic property. Furthermore, in order to obtain wider impedance bandwidth and additional resonances, a stick out V-shaped design strip is inserted on the perfect electric conductor ground plane. Hence, the dual band compact L-shaped and E-shaped slot proposed antenna is designed with overall dimension  $10 \times 16 \text{ mm}^2$  printed on a FR4 substrate dielectric element having overall thickness dimension of 1.6 mm [21].

**Bimal garg et al.** proposed the design and analysis of rectangular patch antenna with metamaterial substrate and ground plane for WLAN communication systems. The proposed design antenna exhibit rectangular patch having metallic property, dielectric substrate of dimension 3.2 mm loaded with interconnected metamaterial in the design of frame shape and perfect electric conductor. The proposed design antenna offers 4.65 GHz resonant frequency for WLAN communication network. Overall 30% size reduction is achieved due to introduction of frame shaped metamaterial in the dielectric substrate [22]. **Manouchehr Kamyabm et al.** proposed the analysis of a patch antenna having two novels design fed by proximity coupling for wireless communication systems with band-notched and polarized dual characteristics. The first approach provides band-notched and polarized dual functions by connecting open end of line feed with equivalent open circuit stub of the proposed design antenna. Two resonant frequencies are obtained by connecting open end of the line feed with the equivalent circuit of stub. The proposed design antenna offers first resonant frequency at

5.8 GHz, however the value of second resonant frequency changes due to variation in the location and length dimension of the open stub in the corresponding equivalent circuit and location of feed with respect to metallic patch width dimension. Thereby the proposed design antenna can control the ratio of two resonant frequency obtained [23].

**Xianglong Liu et al.** proposed the design and analysis of a compact printed monopole and novel tri-band modified rectangular antenna for WLAN/WiMAX wireless communications systems. The structure of the proposed design antenna consists of a set of symmetrically equal inverted-L metallic strips, a modified rectangular metallic patch slot, and a monopole radiator having metallic nature in the design of Y-shaped with split-ring slot in the design of zigzag pattern. The proposed antenna is designed, fabricated and analyzed while keeping in mind two factors i.e. small size and simple design. Hence, the triband antenna is designed with overall dimension  $23 \times 36.5 \text{ mm}^2$  printed on a FR4 substrate dielectric element having overall thickness dimension of 0.8 mm fed by CPW line feed having  $50\text{-}\Omega$  characteristic impedance and metallic strip width dimension of 3.5 mm and 0.35 mm separation gap distance between coplanar ground plane and strip. The proposed antenna can operate over both the WLAN/WiMAX communication networks by controlling the dimensions and positions of the metallic strips. The proposed design antenna can operate at three different frequency bands i.e. 2.33-2.76 GHz, 3.05-3.88 GHz and 5.57-5.88 GHz having impedance bandwidths of 430 MHz, 730 MHz and 310 MHz respectively [24].

**Shun Gao et al.** proposed the design and analysis of a novel and miniaturized multi frequency band monopole antenna is to cover the entire WLAN/WiMAX standards. The propose antenna design configuration exhibit a circular radiating ring with outer and inner radius are defined by  $R_1$  and  $R_2$  parameters respectively with a Y-shaped design metallic strip embedded on isosceles shape triangle design defect on a cambered perfect electric conductor defected ground plane operating at three separate bandwidths. Without affecting the miniaturized overall dimension of proposed design antenna, a Y-shape design metallic strip is embedded with the radiating circular ring to excite the first two resonant modes (2.5 and 3.5 GHz). By introducing isosceles shape triangle design defect on a cambered perfect electric conductor defected ground plane, the third resonant wide band mode (5-6 GHz) is excited with excellent impedance matching. Hence, the triple band compact circular ring with defected ground proposed antenna is designed with overall dimension  $38 \times 25 \text{ mm}^2$

printed on a FR4 substrate dielectric element having overall thickness dimension of 1.6 mm fed by a feed line having characteristic impedance of  $50\text{-}\Omega$  and overall dimension of  $2.4 \times 12.06 \text{ mm}^2$ . It provides three impedance bandwidths of 0.3 GHz (2.7–2.10 GHz), 1.05 GHz (3.1–4.15 GHz), and 0.96 GHz (4.93–5.89 GHz) centered at 2.61 GHz, 3.5 GHz, 5.4 GHz resonant frequencies, and relative bandwidths of about 12%, 29% and 12% respectively. The value of return losses at respective three resonant frequencies are about -31 dB, -27 dB, and -37 dB, respectively. The maximum value of antenna gain is 1.7 dBi defined for the lower working band (2.4–2.7-GHz). The maximum value of antenna gain is 2.05 dBi with small gain variation of 0.26 dBi for the medium band (3.1–4.15 GHz). The maximum value of antenna gain is 2.57 dBi with gain variation value of 0.73 dBi for highest operating band (4.93–5.89 GHz) [25].

**Chao-Ming Wu et al.** proposed the analysis of a monopole antenna having compact and low-profile design consists of a rectangular radiating patch having metallic property embedded with a pair protrude strips in the design of inverted L-shaped and defected ground plane (DGS) fed by a cross-shaped line feed to excite triple frequency resonances for WLAN/WiMAX applications. DGS is used to avoid large surface-wave loss in order to decrease its effect on coupling effects. Hence, the triple band compact rectangular radiating patch having metallic property with defected ground proposed antenna is designed with overall dimension  $20 \times 20 \text{ mm}^2$  printed on a FR4 substrate dielectric element having overall thickness dimension of 1.6 mm. It provides three impedance bandwidths of 0.380 GHz (2.13–2.51 GHz), 0.570 GHz (3.26–3.83 GHz), and 0.880 GHz (5.03–5.91 GHz) centered at 2.61 GHz, 3.5 GHz, 5.4 GHz resonant frequencies, and 0.380 GHz (2.13–2.51 GHz), 0.570 GHz (3.26–3.83 GHz), and 0.880 GHz (5.03–5.91 GHz). The average measured efficiencies are about 50, 60 and 71%, at the respective three resonant frequencies whereas the average directivity at the three resonant frequencies is about 5.5 dB, 4.7 dB and 4.5 dB, respectively. The average value of antenna gains 2.46 dBi, 2.45 dBi, and 3.0 dBi, with ranges from 2.2–2.6 dBi, 2.1–2.6 dBi, and 2.5–3.4 dBi, at the respective three resonant [26].

**Chih-Yu Huang et al.** proposed analysis of a slot antenna having novel design with parasitic components having rectangular shape fed by CPW feed for multiple frequency operations in WLAN communication systems. For WLAN frequency band operations applications, the main focus of this letter is to provide multi frequency bands such as IEEE

802.11 b/a WLAN frequency bands. Due to the rectangular radiating patch having metallic property fabricated on the novel design of slot monopole antenna, an upper 5.8 GHz resonant frequency mode band can be excited to improve impedance wide bandwidths operations at higher band in order to get closer to the natural resonant frequency mode band of monopole slot antenna. Thus, the proposed slot monopole antenna can present two different large operating impedance bandwidths of 0.124 GHz (2386–2510 MHz, which is nearly about 3.4% of required bandwidth 5.1% and centered at 2.45 GHz resonant frequency) and 1.124 GHz (4878–6002 MHz, which is nearly about 22.4% centered at 5.5 GHz and 13% of required bandwidth), which can easily cover the upper and lower frequency bands of WLAN bands. The gains are measured at operating frequency bands which lies in 1.4–1.9 dBi range for the lower band whereas for upper band, it lies in 3.2–4.3 dBi range. Moreover, the designed proposed monopole slot antenna has a low profile of  $50 \times 30 \text{ mm}^2$  which is fabricated on FR4 substrate dielectric element having overall thickness dimension of 1.6 mm, which can be suitably, used for installation in wireless communication devices. Acceptable radiation patterns can be obtained at two resonating operating frequency bands of IEEE WLAN band [27].

**Peng Fei et al.** proposed the design and analysis of a compact and novel triband rectangular patch antenna with square slot and symmetrical L slots for modern communication systems. Proposed design antenna exhibit a monopole radiator, a square shaped slot and a set of symmetrical L-shaped strips. With the help of these resonant structures, the antenna can be employed and produce three different resonant frequencies of WLAN/WiMAX. Therefore, proposed antenna is designed, fabricated and analyzed while keeping in mind two factors i.e. small size and simple design. Hence, the triband antenna is designed with overall dimension  $28 \times 32 \text{ mm}^2$  printed on a FR4 substrate dielectric element having overall thickness dimension of 1 mm and is fed by 3.5 mm strip line CPW. The proposed triband antenna can achieve two different large operating impedance bandwidths of 0.480 GHz (2340–2820 MHz) and 0.9 GHz (3160–4060 MHz) and 0.680 GHz (4.60–5.28 GHz), defined for communication channels for WLAN/WiMAX. The gains are measured at operating frequency bands which lies in 2.77–3.06 dBi range for the lower operating band (2.3–2.7 GHz) whereas it lies in 2.98–3.13 dBi range for the middle operating band (3.3–3.7 GHz) and it lies in 3.10–2.78 dBi range for the upper operating band (5.0–5.3 GHz). Therefore, the

proposed design triband square shaped slot antenna provides stable antenna gain at operating bandwidths so that it can be used to install in the wireless communications systems for WLAN and WiMAX applications [28].

**Malcolm Ng Mou Kehn et al.** proposed design and analysis of compact short-circuited split ring resonators (SRRs) antenna for wireless communication network. The proposed design antenna exhibits two concentric split rings, dielectric constant with desired permittivity and ground plane. The proposed design antenna offers two bands of operation which is dependent on overall dimension of split rings and the permittivity value of dielectric substrate. Moreover, the key parameters that strongly affected the resonant frequency are thickness dimension of dielectric substrate and separation gaps of the split rings. Due to introduction of grounded pins, the overall antenna dimension reduces. The maximum and minimum differences between frequencies of operations are limited by maximum and minimum separation distance between split rings respectively that permits electromagnetic coupling between them [29].

**K. M. Ma et al.** proposed the design and analysis of broadband patch antenna using U-slots for dual and triple band communication network. The proposed design antenna exhibit one or more metallic patches, substrate dielectric element and perfect electric conductor ground plane. The dual band is obtained in the proposed design antenna by cutting U-slot from the surface of metallic patch fed by any of four feed i.e. M-probe, aperture couple, L-probe and coaxial cable feeding. Similarly triple band is obtained by cutting another U-slot from the surface of metallic patch [30]. **Ian J. Craddock et al.** proposed the design and analysis of a slotted UWB antenna used in the detection scheme applications (breast cancer detection system). The objective of synthetically focused UWB radar is used by author for presented antenna, established at the University of Bristol. The proposed antenna's simulated results describe that the wide-slotted antennas have excellent input and radiation characteristics performance across the required frequency range. Detection array can be compactly populated due to the compact behavior of the slotted antenna. Additionally, the proposed antenna offers excellent radiation coverage of the breast. The patch antenna offers fidelity of 58% for angles up to  $60^\circ$ . The measured and stimulated shows that it is an excellent candidate for breast cancer detection system in UWB radar [31].

**G. Dadashzadeh et al.** proposed the analysis of a monopole antenna with modified ground structure (DGS) having compact printed design for ultra-wideband systems with dual band-notched characteristics. A wide impedance bandwidth (up to 123%) and additional resonances are generated by embedding two I-shaped notches with proper overall dimensions on the perfect electric conductor ground plane connecting with both sides of the microstrip feed line. In the radiating patch having metallic property, a set of metallic strips is embedded in the design of  $\Gamma$ -shaped with a defect in the design of G-slot in the perfect electric ground plane fed by microstrip line feed to obtain two notched characteristics. Hence, the dual band compact  $\Gamma$ -shaped radiating patch having metallic property with defected ground proposed antenna is designed with overall dimension  $20 \times 18 \text{ mm}^2$  printed on a FR4 substrate dielectric element having overall thickness dimension of 1.0 mm. The frequency band for the proposed antenna is between 2.8 and 11.8 GHz, with first notch frequency band at WiMAX band (3.3–3.8 GHz) and the second at WLAN band (5.1–6 GHz). The proposed antenna offers average antenna efficiency of 79% with maximum and minimum value of 92% and 27% respectively at the 3–11 GHz frequency range [32].

**Te-Shun Wang et al.** proposed the design and analysis of a compact size planar monopole square shaped slot patch having metallic property antenna with a vertical coupling slot for UWB communication systems with band notched characteristics. Hence, the wideband compact square shaped slot proposed antenna is designed with overall dimension  $15 \times 15 \text{ mm}^2$  printed on a FR4 substrate dielectric element having overall thickness dimension of 1.6 mm fed by microstrip-feed line technique. By properly adjusting the position coupling strip placed at the center of the patch having metallic property, a good wide band ranging from 3.1 to 11.20 GHz having stop band ranging from 5.15 to 6.08 GHz can be obtained. Due to its simple planar structure, the proposed antenna can be easily adjust its band-notched property in order to achieve better omnidirectional radiation characteristics and to reduce the issues caused due to frequency interferences when compared to other compact prior antenna designs. The proposed wideband square shaped slot antenna exhibits radiation efficiency more than 82% and the stable antenna gain varies from 3.10 to 3.98 dBi at passband frequency [33].

**Alireza Pourghorban Saghati et al.** proposed novel reconfigurable slotted antenna with three different frequencies. This design has some unique feature as it provides three

electronic switches which select various groups of resonant frequency. Possibility of occurrence of different resonances can be achieved at same time as before. The ground plane of antenna is etched by slots having sickle-shape and three similar p-i-n diodes. Slots etched from the metal strip are embedded with pin diodes and also incorporated in ground plane. The antenna provides different resonance frequency such as 2.4-GHz for Bluetooth, 3500 MHz WiMAX and 5800 MHz for WLAN systems. This antenna design has overcome the problem of serving single frequency band at a time. Similar radiation patterns having lesser cross polarization are obtained at all the operating frequencies that was analyzed in this paper [34].

**G. Singh et al.** proposed the design and analysis of compact size antenna with metamaterial substrate for wireless communication network. The proposed design antenna exhibits double negative and double positive metamaterials with corresponding negative and positive dielectric permittivity and magnetic permeability and dielectric substrate loaded with DNG metamaterials to provide phase compensation. By combining both DNG and DPS metamaterial forms a cavity resonator whose dispersion relation is independent of the sum of thickness of the slabs that fills the cavity but it depends on the ratio of their thicknesses [35].

**Gemma Roqueta et al.** proposed the analysis of planar integrated antenna fed by microstrip line feed having compact and novel design for Bluetooth and UWB communication networks. The dual band compact novel planar proposed antenna is designed with overall dimension  $42 \times 46 \text{ mm}^2$  printed on a FR4 substrate dielectric element overall thickness dimension of 1 mm. The proposed antenna operates at dual frequency band i.e. 2.4-2.484 GHz (Bluetooth) and 3.1-10.6 GHz (UWB). The proposed design antenna shows acceptable antenna gain and stable omnidirectional radiation patterns measured across the three frequencies (2, 5 and 10 GHz) for the integrated Bluetooth and UWB communication networks [36].

**Ahmed A. Kishk et al.** proposed the design and analysis of two novel antennas for single and dual band notches respectively in order to reduce interference within an ultra-wideband (UWB) due to presence of other communication systems. The proposed design antenna is fabricated on a  $24 \times 36 \text{ mm}^2$  substrate material. The proposed design antenna is analyzed by

cutting a notch from the radiator of metallic nature in order to reduce effects of electrically conducted ground plane and by adding independent separated controllable strips, band-notches are introduced on the metallic radiator. The dimensions and position of the metallic strips can controlled the notch frequency characteristics and width of band notches. First single band-notch characteristic antenna is designed with independent separated controllable strip to cover the wideband (5.150–5.825 GHz). The second dual band-notches characteristics antenna is designed with independent separated controllable strip to cover the upper WLAN band (5.72–5.82 GHz) and lower WLAN band (5.150–5.350 GHz) [37].

**Wen-Shan Chen et al.** proposed the analysis of open slot monopole antenna having two band rejected novel and compact printed design and analysis for WLAN/WiMAX communication networks. By selecting the proper suitable dimensions of metallic nature which is going to be embedded on wideband compact printed open slot monopole antenna, the band rejection function can be implemented for dual/triple frequency in WLAN/WiMAX communication networks. Open slot proposed design antenna is inserted with strips of metallic nature to reject dispensable band. The band-rejected function is performed due to the metallic nature of strip attached to the ground plane which will concentrate the entire current distribution on the strip of metallic nature. The center frequency of dispensable band is calculated by deciding the length dimension of the inserting metallic nature strip which is comparable to  $\lambda/4$ . Hence, the dual band compact open slot proposed antenna is designed with overall dimension  $30 \times 35 \text{ mm}^2$  printed on a FR4 substrate dielectric element having overall thickness dimension of 0.8 mm. A single strip of metallic nature is inserted in the open slot compact size monopole antenna to obtain first rejection band from 3.56 to 4.58 GHz in the wide 2.3-6 GHz frequency band. Similarly, a pair of different length strips of metallic nature is inserted in the open slot compact size monopole antenna to obtain triple wide frequency band (2.3-6 GHz) for WLAN/WiMAX communication networks [38].

**Dalia M. Nashaat et al.** proposed the design and analysis of a new configuration of V-shaped patch having metallic property with unequal sides having coupled property of electromagnetic nature with planar inverted F-antenna (PIFA) isosceles triangular single feed through V-shaped slots of unequal dimensions for ultra-wideband (UWB) applications. In this letter, coaxial cable is used to feed PIFA. Due to different varying dimensions (length and width) of the V-shaped metallic and two electromagnetically coupled V-shaped slots i.e.

by controlling the feeding point position ( $d_f$ ), this configuration can achieve six multiband frequency operations with resonating frequencies at 2.95, 3.64, 3.95, 4.38, 4.65, and 5.5 GHz. Two more resonating modes of operation can be added by inserting two unequal V-shaped slot on the surface of the isosceles triangular PIFA. Reflection coefficients and impedance bandwidths of the proposed of V-shaped patch having metallic property antennas at the six resonating frequencies are -21.7 dB, -20.4 dB, -26.9 dB, -24.8 dB, -19.5 dB, and -22.3 dB and 3.5%, 4%, 4.25%, 5.5%, 4%, and 7.7%, respectively. Therefore, the average impedance bandwidths of six resonating frequencies are about 4%. In order to achieve wideband characteristics, the feeding point is simply moved away from the shorting wall, thus the staggered excited resonating modes are generated. This will increase the bandwidth up to 27% at 4.65 GHz resonating frequency. This wide bandwidth can be increased up to 53% by simply folding the shorting wall with proper dimensions of the isosceles triangular PIFA. The average antenna gain is 10.5 dBi [39].

**R. karimzadeh Baeel et al.** proposed a compact microstrip patch Antenna (MPA) in which involvement of metamaterials helps to decrease the antenna size. Resonant frequency of this antenna decreases by introducing CSSR which further helps to reduce size of antenna. Return loss graph and radiation pattern performances also improved by this technique. Complementary Split-Ring Resonator (CSRR) overcomes the use of Split-Ring Resonator (SRR). To distinguish the Complementary Split-Ring Resonator author presents the equivalent circuit in metamaterials. Microstrip patch antenna full with CSRRs has been modelled by means of circuit model containing lumped elements. Circuit model described that the expenditure of a metamaterial can effectively diminish the dimensions of the patch antenna. Metamaterials reduce the size of radiating patch antenna to one-fourth as compared to conventional antenna without increasing substrate dimension [40].

**Jin-Sen Chen** proposed the design and analysis of a triangular-ring slot coupled patch antennas having a slot etched from it of triangular ring shape. Tuning stub is applied to coaxial feeding which will give to antenna for its excitation. For this triangular ring slotted antenna adjusted with tuning-stub, the impedance matching can be achieved only by adjusting by tuning stub length that is combined with CPW. Analyzation of back patch and tuning stub of two triangular ring slot antenna is done by the author by giving coplanar feeding method. The fundamental frequency of the presented antenna with CPW-fed

adjusted with tuning-stub occurs when the perimeter of slotted-ring is nearly one guided wavelength. To achieve bi-directional radiation patterns characteristics, size of the back patch should be nearly similar to the slotted ring size [41].

**Kwai-Man Luk et al.** proposed the design and examination of miniaturized microstrip patch antennas with multilayers. Coaxial feeding technique is applied to this presented antenna which will excite this antenna and gave better simulation results having desired return loss graph. The main advantage of this antenna offered by the author is often used because of low cost and lesser weight. For lower microwave frequencies, physical size is larger in size. Two layer patch antenna with rectangular structure is firstly used. The projection area of the single-layer patch antenna and two-layer rectangular patch antenna is reserved the same. Results obtained by simulation and measured results of the constructed antenna shows that the resonant frequency of the two-layer rectangular patch antenna is decrease to half and has achieved bandwidth of five percent which is wider than the single-layer antenna. In the next structure, the upper patch is cut into a bow-tie shape, which gave results of resonant frequency by 60 % reduction level and a 12% bandwidth is achieved. Both the small size designed antennas have good radiation patterns characteristics. Both the designed antenna has lower cross-polarization level in comparison with the co-polarization level by more than 20dB [42].

**S. Maci et al.** proposed the design and analysis of dual-frequency microstrip patch antennas that works on dual frequency range which may offer an another solution to applications where planar antennas with wider bandwidth is required. This will helps for transmission and reception for two different frequency bands. When there is too much difference between the operating frequencies, a dual frequency patch antenna is come into use in order to use too different antennas. The main area of interest has been focused on the geometry as well as on configurations of the radiators which will make the design too much flexible and simple. This will neglect the feed network difficulty of dual frequency antenna. The experiment that has been done in the area on this technique is not sufficient, and further work is desired. When the two frequencies are very close to each other, the use of a solo feed network may be applied. But, for huge gap between the two frequencies, then there is a need to design two different microstrip networks [43].

## 2.2 Objective of the Thesis

Based on the research work done in literature survey, following objectives are designed for thesis work:

- Design and simulation of a triple band antenna with symmetrical maze-shaped slots with microstrip line feed operating at 2.47/4.48/5.2-GHz for Bluetooth/IMT/WLAN communication networks.
- To improve the bandwidth and reduce the overall dimension of the proposed antenna using Defected Ground Structure (DGS).
- Design and simulation of a multi band antenna to improve the bandwidth and reduce the overall dimension of the proposed antenna using Defected Ground Structure (DGS) with swastika-shaped slots with microstrip line feed operating at 1.9/2.5/5.6-GHz for GSM/Bluetooth/WLAN/WiMAX communication networks.
- Fabrication and testing of triple band antenna with symmetrical maze-shaped slots and DGS operating at 2.47/4.48/5.2-GHz for Bluetooth/IMT/WLAN communication networks on a VNA tester.

## CHAPTER 3

### DESIGN METHODOLOGY OF RECTANGULAR PATCH ANTENNA WITH SYMMETRICAL MAZE-SHAPED SLOTS AND DGS

#### 3.1 Introduction

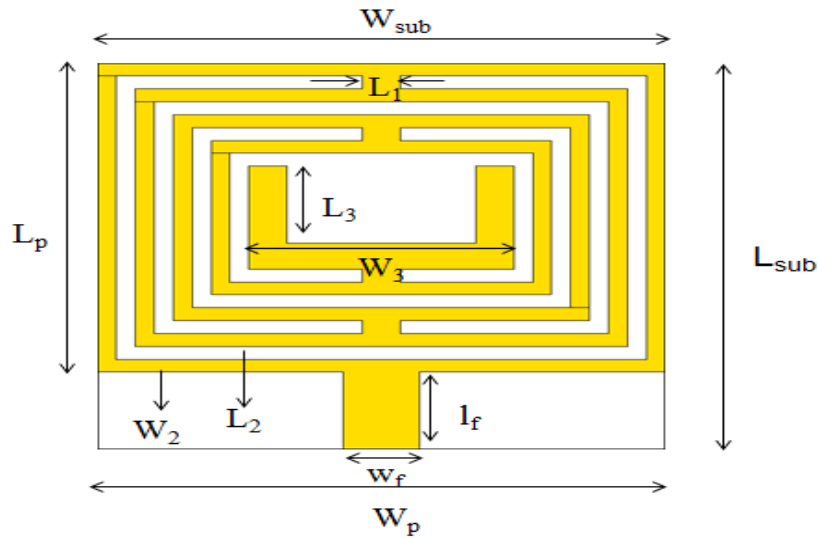
In the recent last few years, a wide research is done on the microstrip antenna due to its properties and it became popular in the communication industry due to its low cost and simple fabrication technique. Small size or small height antennas are required in aircraft, spacecraft, missile and satellite industry where main constraints are low cost, light weight, ease of installation and fabrication, aerodynamic nature. Some other same specifications applications are commercial radio mobile communication systems and government defense applications. These antennas are easily and simply fabricated on a dielectric substrate using printed circuit technique to calculate a set of parameters like resonant frequency, impedance bandwidth and radiation patterns etc. A particular patch is designed to obtain the desired resonant frequency. Moreover, additional resistive, capacitive or inductive loads, varactor diodes, a slot of any regular shape like U-shaped is cut from metallic patch or stack of metallic patches can be added to increase the impedance bandwidth.

This designed presents, a small compact size microstrip-fed antenna with defected ground plane and is designed for Bluetooth/IMT/WLAN applications. Hence, the triband of rectangular patch antenna with symmetrical maze-shaped slots and defected ground plane is designed with overall dimension  $15 \times 15 \text{ mm}^2$  printed on a FR4 substrate dielectric element having overall thickness dimension of 1.6 mm and is fed by microstrip line feed having  $50\text{-}\Omega$  characteristic impedance and overall dimension of  $2 \times 3 \text{ mm}^2$ . CST triband simulated results of rectangular patch antenna with symmetrical maze-shaped slots and defected ground plane are compared with measured triband results and both results show good agreement with each other.

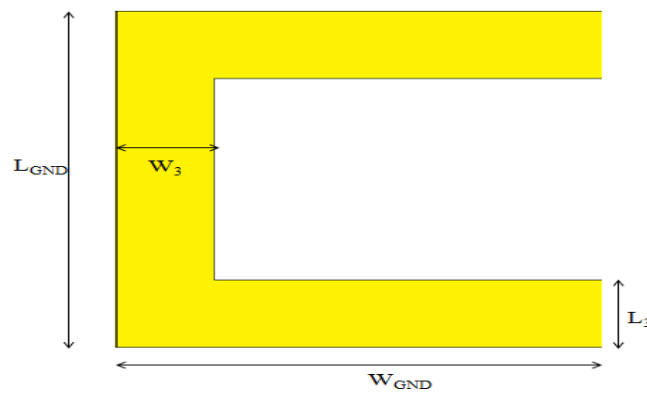
#### 3.2 Proposed Antenna Design

The schematic configuration of the proposed triband rectangular patch antenna with symmetrical maze-shaped slots and defected ground plane is shown in Figure 3.1, with overall dimension of  $15 \times 15 \text{ mm}^2$  printed on a FR4 substrate with substrate thickness

dimension  $t_{\text{sub}}=1.6$  mm, a loss tangent of 0.024 and permittivity of  $\epsilon_r=4.4$ . In this letter, the main principle in designing the proposed triband antenna is to provide compact size, therefore dimensions of each material is calculated based on this principle. The dielectric substrate is selected with overall dimensions as  $W_{\text{sub}} \times L_{\text{sub}} = 15 \times 15$  mm<sup>2</sup>. The proposed design antenna consists of three layers i.e. dielectric substrate, rectangular metallic patch having symmetrical maze-shaped slots and U-shaped defected ground plane. A rectangular metallic patch with overall dimensions of  $15 \times 12$  mm<sup>2</sup> is placed on the upper surface of dielectric substrate. A number of symmetrical slots in the form of maze are then cut through the metallic rectangular patch to obtain the desired design.



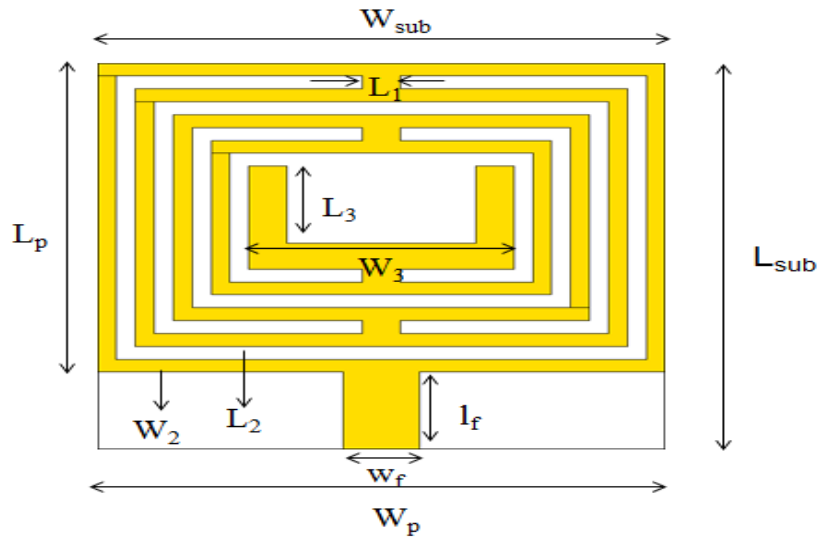
(a) Front View



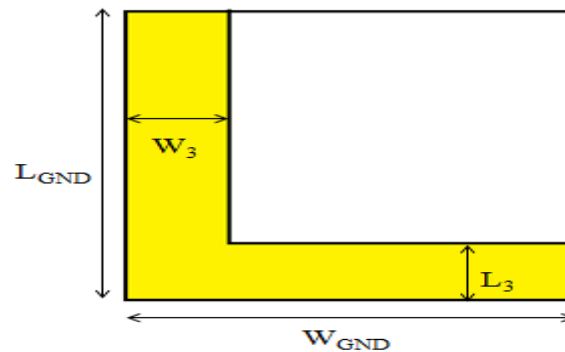
(b) Bottom View

Figure 3.1: Configuration of Simulated Antenna

The single frequency band (4.4-4.9 GHz) for IMT applications is obtained by designing a rectangular patch antenna with symmetrical maze-shaped slots and L-shaped ground plane as shown in Figure 3.2. A U-shaped defected ground plane with proper calculated dimensions is then placed on the bottom surface of the dielectric substrate to complete the design of triband antenna. U-shaped ground plane is used to provide additional current path and moreover due to defected ground plane capacitance and inductance values of input impedance changes which lead to change in antenna gain and bandwidth. Microstrip feeding method is used with  $50\text{-}\Omega$  characteristic impedance and overall dimensions of  $w_f \times l_f = 2 \times 3 \text{ mm}^2$ .



(a) Front View



(b) Bottom View

Figure 3.2: Configuration of Simulated Antenna with L-Shaped Ground Plane

In this design, all the designing parameters as shown in table 1 are calculated using standard patch relationship represented in equations 3.1, 3.2, 3.3, and 3.4 and then antenna is designed.

$$L = \frac{c}{2f_r\sqrt{\epsilon_{\text{eff}}}} - 2\Delta l \quad \dots\dots\dots 3.1$$

$$W = \frac{c}{2f_r\sqrt{\frac{\epsilon_r+1}{2}}} \quad \dots\dots\dots 3.2$$

$$\epsilon_{\text{eff}} = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2} \left(1 + \frac{12h}{w}\right) \quad \dots\dots\dots 3.3$$

$$\Delta l = \frac{0.412h [(\epsilon_{\text{eff}}+0.3)\left(\frac{w}{h}+0.234\right)]}{(\epsilon_{\text{eff}}-0.258)\left(\frac{w}{h}+0.8\right)} \quad \dots\dots\dots 3.4$$

Where c is velocity of light, and  $f_r$  is resonating frequency;  $\epsilon_r$  is dielectric permittivity;  $\epsilon_{\text{eff}}$  is effective dielectric constant.

**Table 3.1 Overall Dimensions of the Simulated Proposed Antenna (mm)**

$L_{\text{GND}}$	$W_{\text{GND}}$	$L_{\text{sub}}$	$W_{\text{sub}}$	$t_{\text{sub}}$
15	15	15	15	1.6
$l_f$	$w_f$	$L_p$	$W_p$	$L_1$
3	2	12	15	1.0
$W_1$	$L_2$	$W_2$	$L_3$	$W_3$
1.0	0.5	0.5	3	7

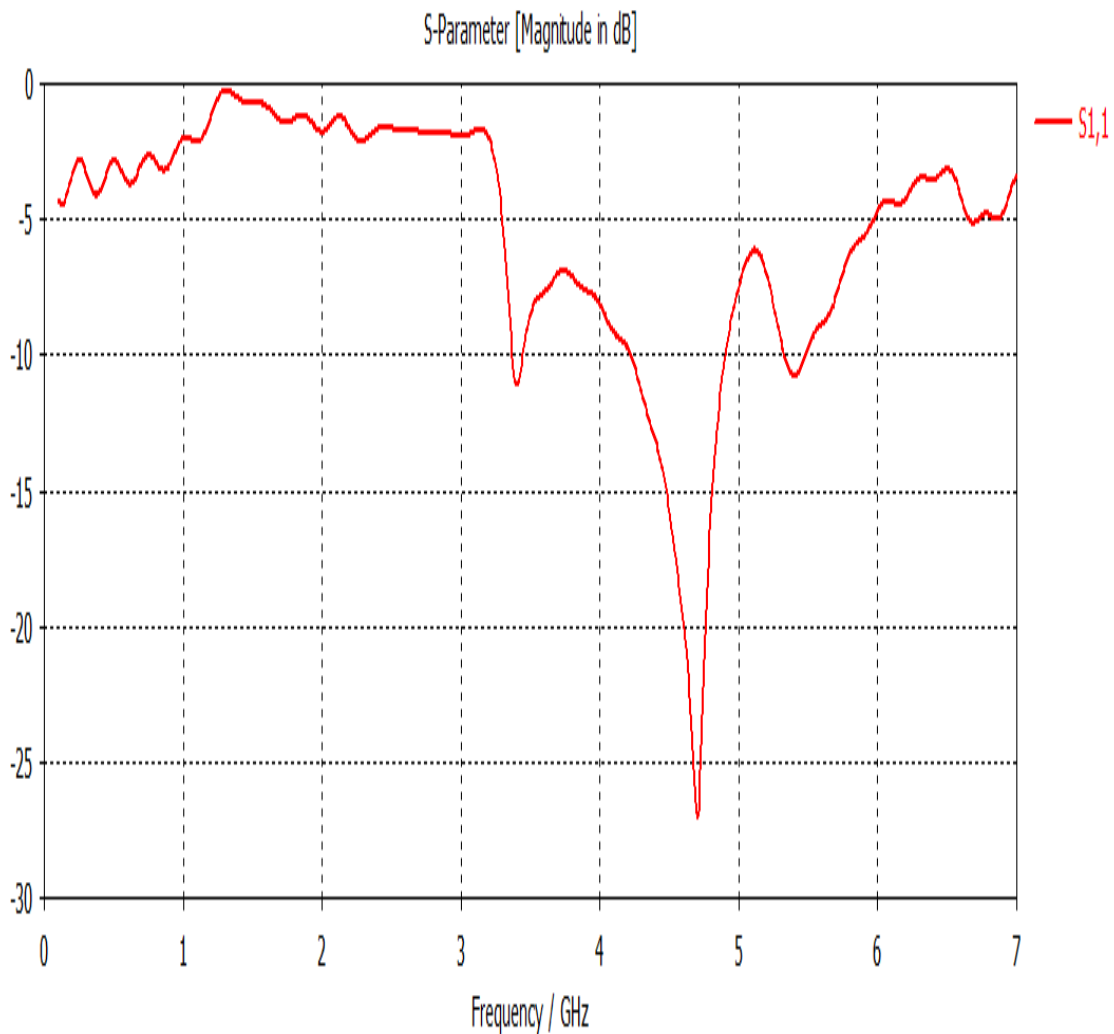
### 3.3 Results and Discussions

#### 3.3.1 Return Loss ( $S_{11}$ )

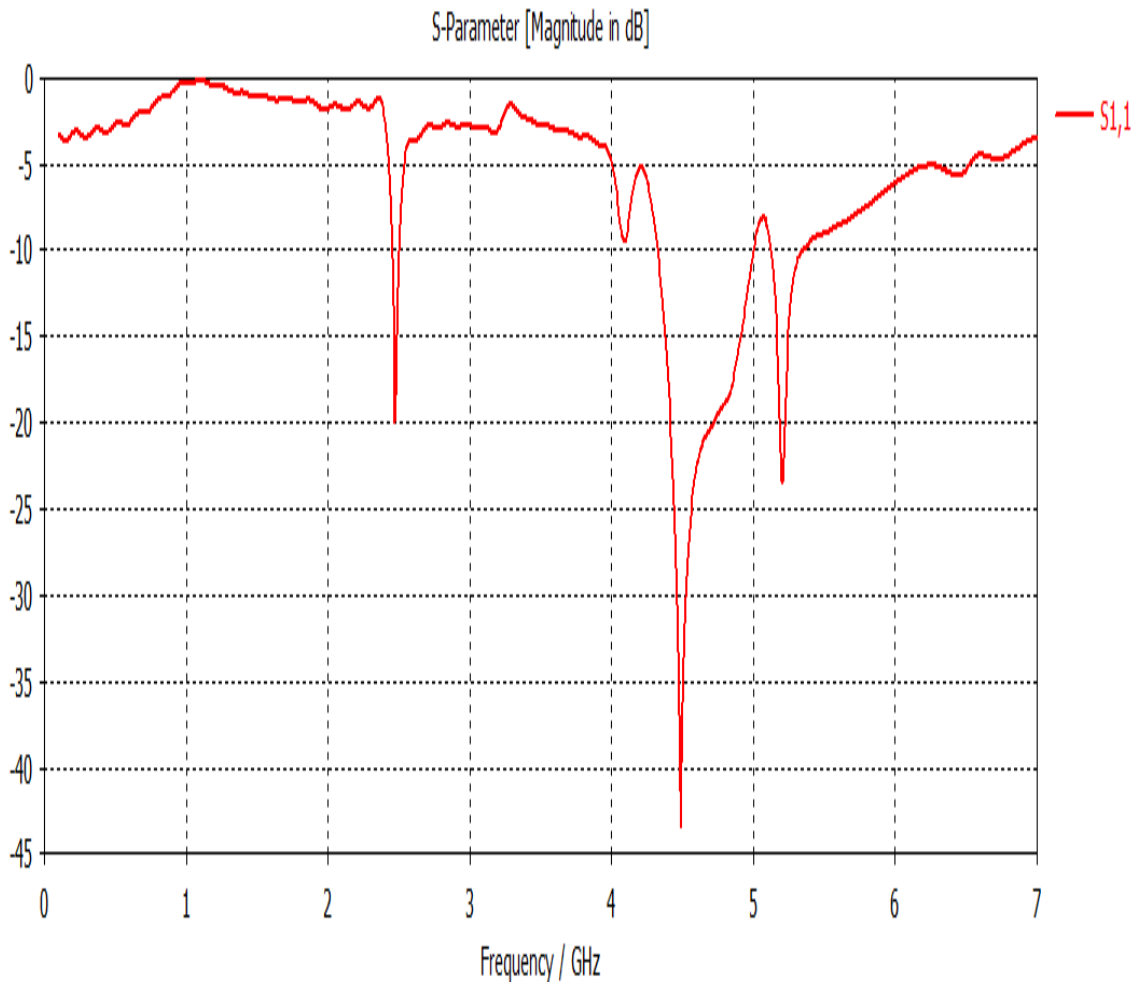
Return loss basically represent the difference value between the forward and the reflected back power of a transmitted signal in a communication system and is generally calculated in terms of decibels (dB). The small value of return loss is equivalent to the maximum power is

transferred between two communicable devices. Therefore, it should have greater negative value for better communication. The S-parameter results simulated at CST software for the L-shaped ground plane and U-shaped ground plane in the graph shown in Figure 3.3 and Figure 3.4 respectively.

As it is cleared from both the graph that, a single frequency band (4.4-4.9 GHz) for IMT applications is obtained by designing a rectangular patch antenna with symmetrical maze-shaped slots and L-shaped ground plane and triple frequency band for Bluetooth/IMT/WLAN applications is obtained by designing a rectangular patch antenna with symmetrical maze-shaped slots and U-shaped ground plane.



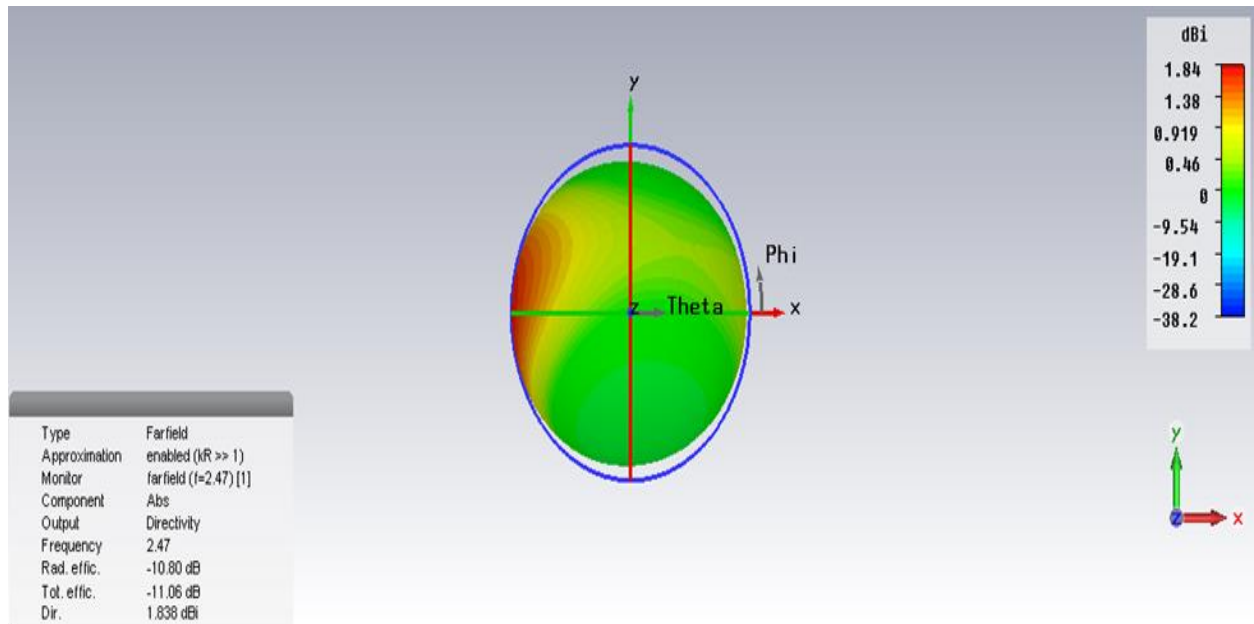
**Figure 3.3: Simulated S-Parameter Results of Simulated Antenna with L-Shaped Ground Plane**



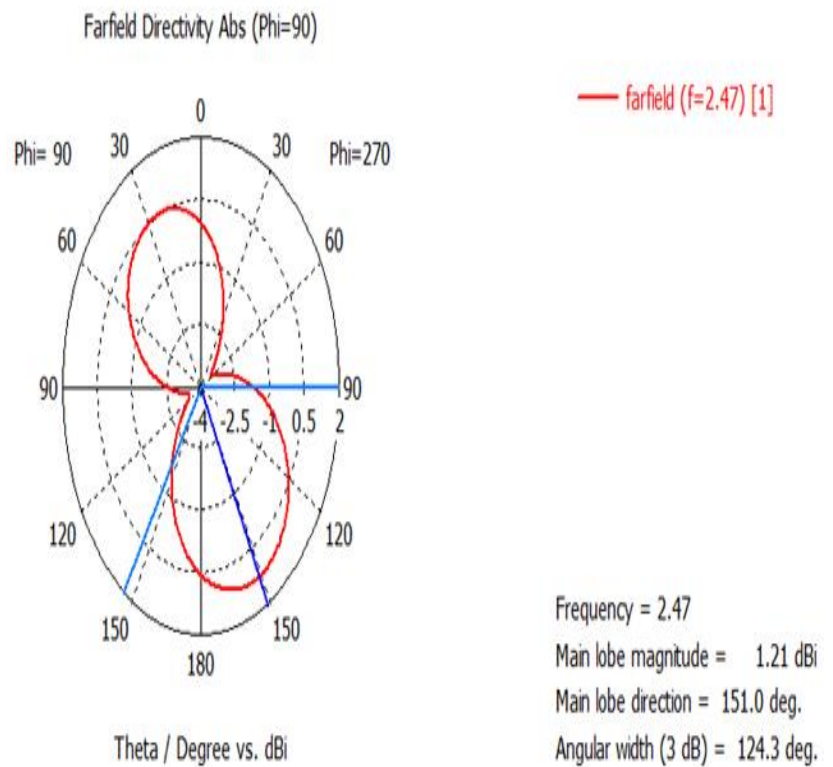
**Figure 3.4: Simulated S-Parameter Results of Simulated Antenna**

### 3.3.2 Radiation Pattern Characteristics

The radiation pattern showing the directivity (3D and polar plot) for the designed antenna has been represented in graphs shown in Figure 3.5, Figure 3.6 and Figure 3.7 for 2.47 GHz, 4.48 GHz and 5.20 GHz respectively. The polar plot figure of the directivity for 2.47 GHz frequency represents radiation pattern with magnitude of main lobe is 1.21dBi at an angle of 151 degree and angular beam width of 124.3 degree and the polar plot figure of the directivity for 4.48 GHz frequency represents radiation pattern with magnitude of main lobe is 2.86 dBi at an angle of 170 degree and angular beam width of 108.1 degree. Similarly the polar plot figure of the directivity for 5.20 GHz frequency represents radiation pattern with magnitude of main lobe is 3.12 dBi at an angle of 167 degree and angular beam width of 101.3 degree.

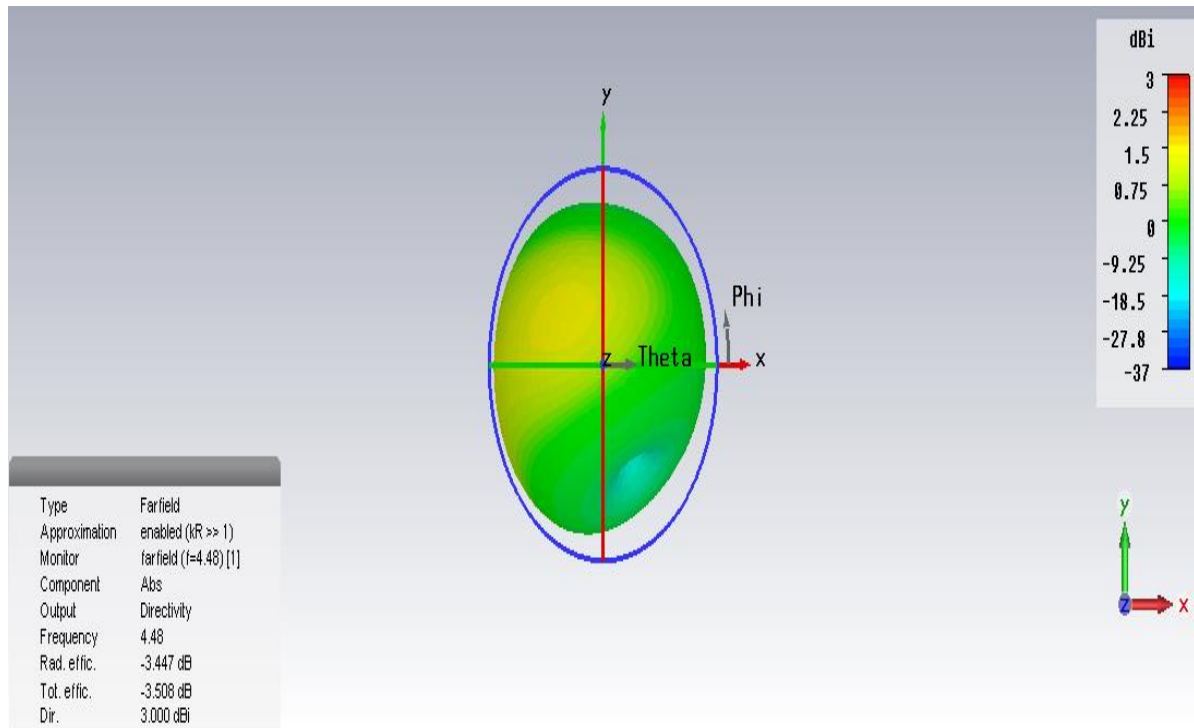


(a) 3D view

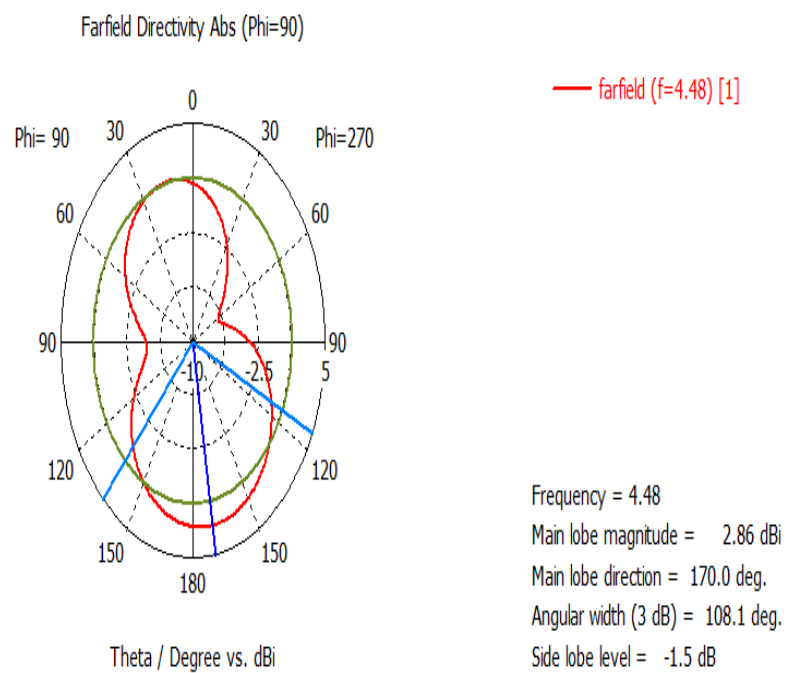


(b) Polar Plot

**Figure 3.5: Simulated Radiation Pattern Characteristics of Simulated Antenna at Resonant Frequency 2.47 GHz**

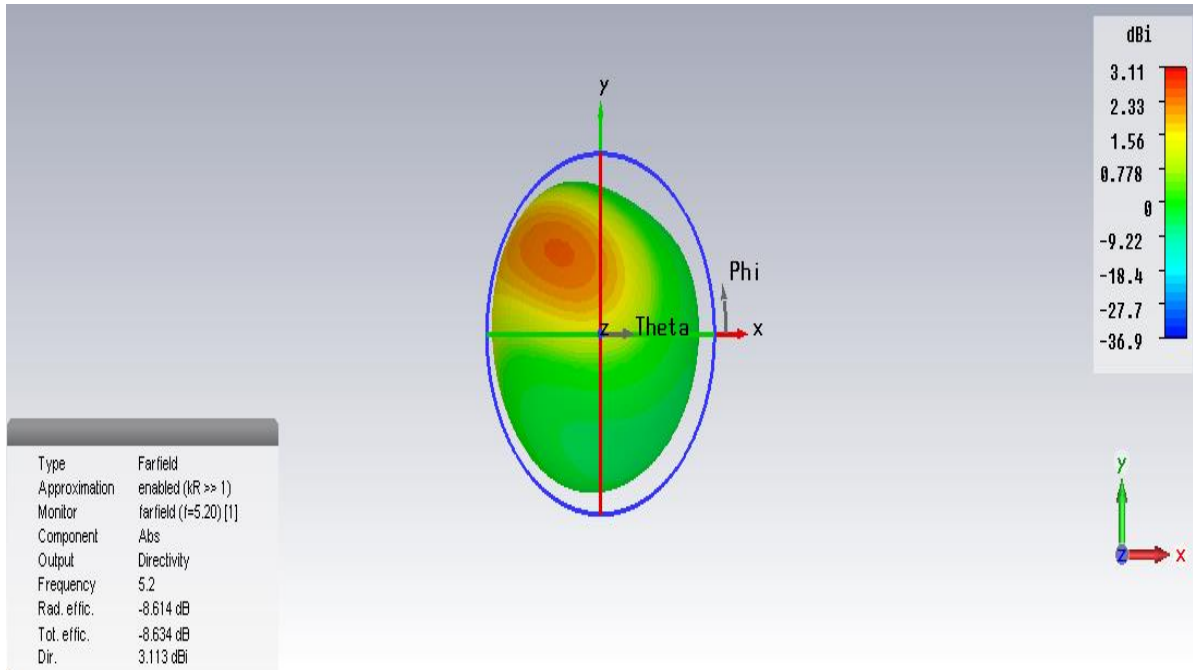


(a) 3D view

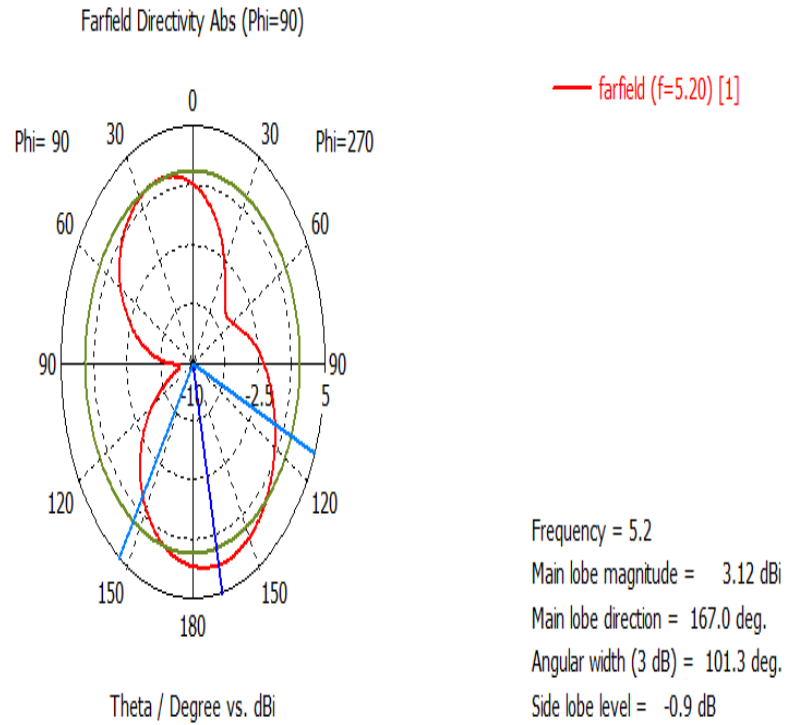


(b) Polar Plot

**Figure 3.6: Simulated Radiation Pattern Characteristics of Simulated Antenna at Resonant Frequency 4.48 GHz**



(a) 3D view

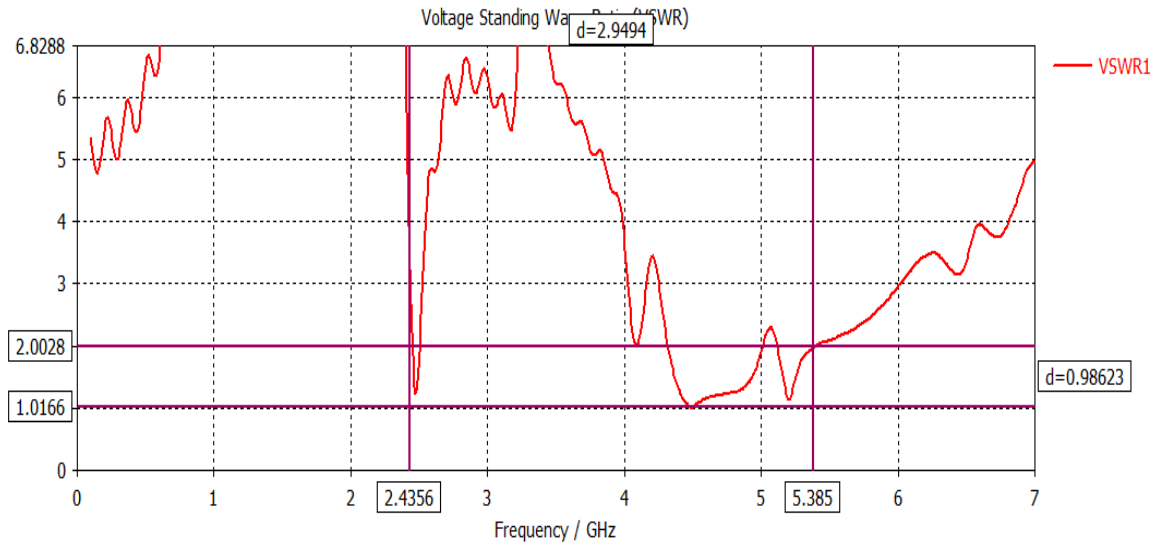


(b) Polar Plot

**Figure 3.7: Simulated Radiation Pattern Characteristics of Simulated Antenna at Resonant Frequency 5.20 GHz**

### 3.3.3 VSWR

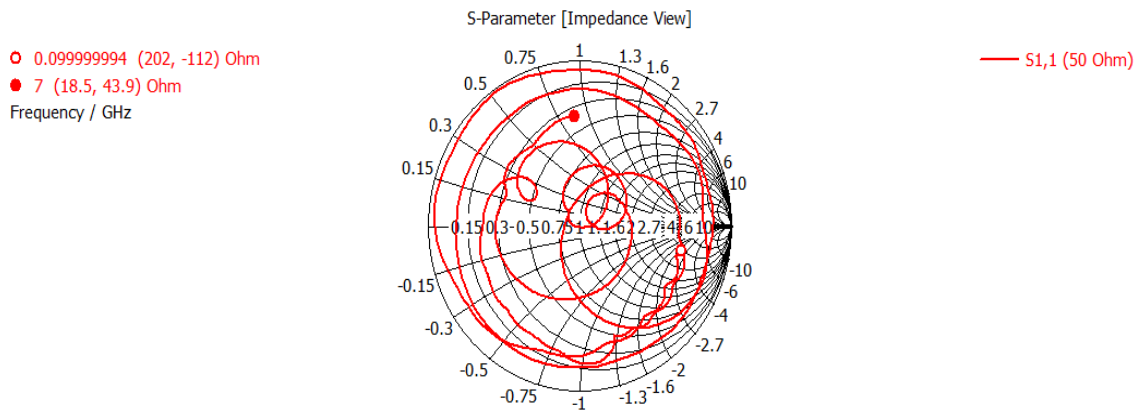
Practically the VSWR value must lie in the range of 1-2 which is obtained for 2.47 GHz, 4.47 GHz and 5.20 GHz resonating frequency of the proposed simulated antenna. The VSWR ratio value at 2.47 GHz, 4.47 GHz and 5.20 GHz resonating frequency is 1:1.257, 1:1.013 and 1:1.017 respectively.



**Figure 3.8: VSWR of Simulated Antenna**

### 3.3.4 Smith Chart

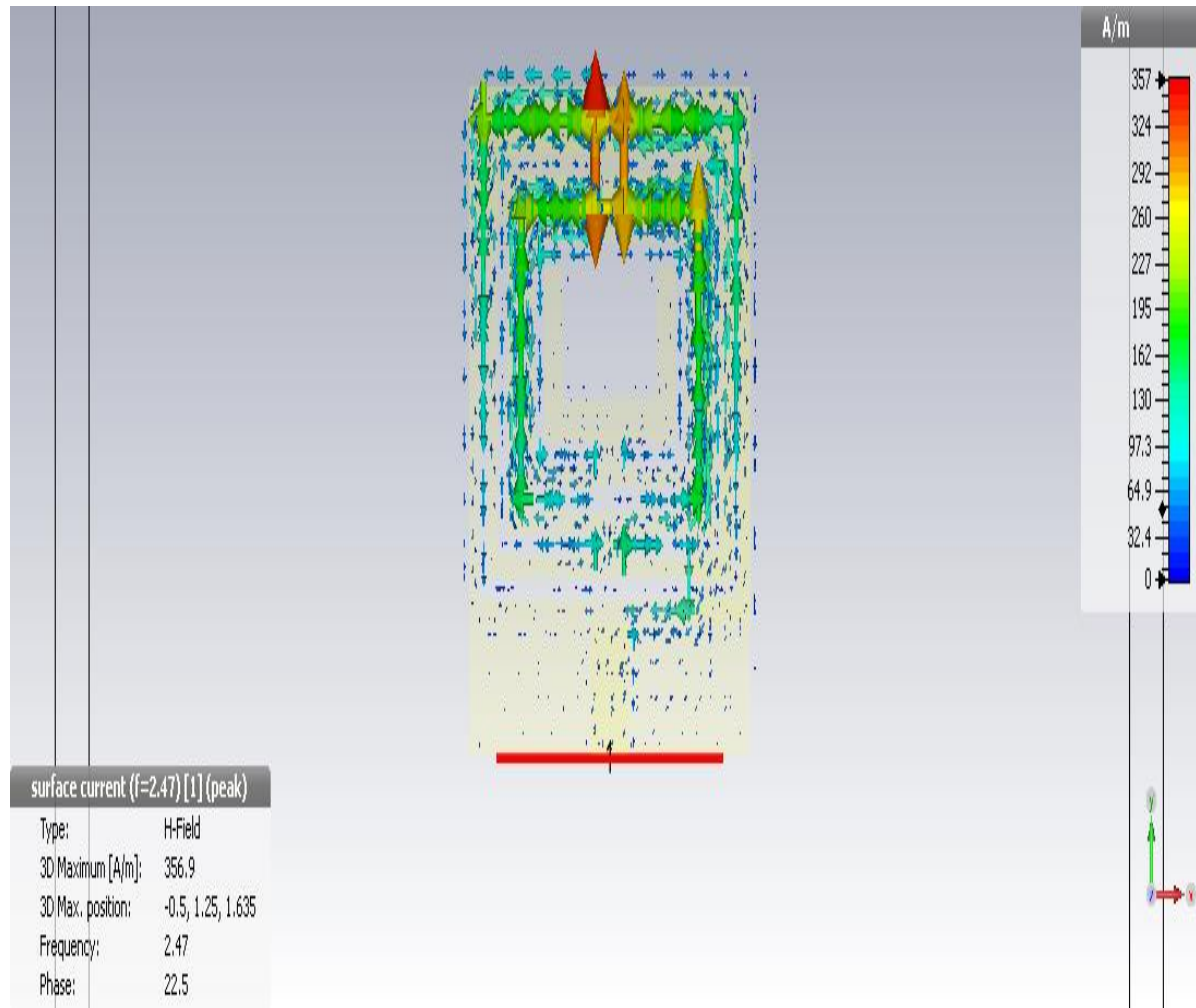
The Smith Chart graph signifies the relationship of antenna impedance with bandwidth frequency.



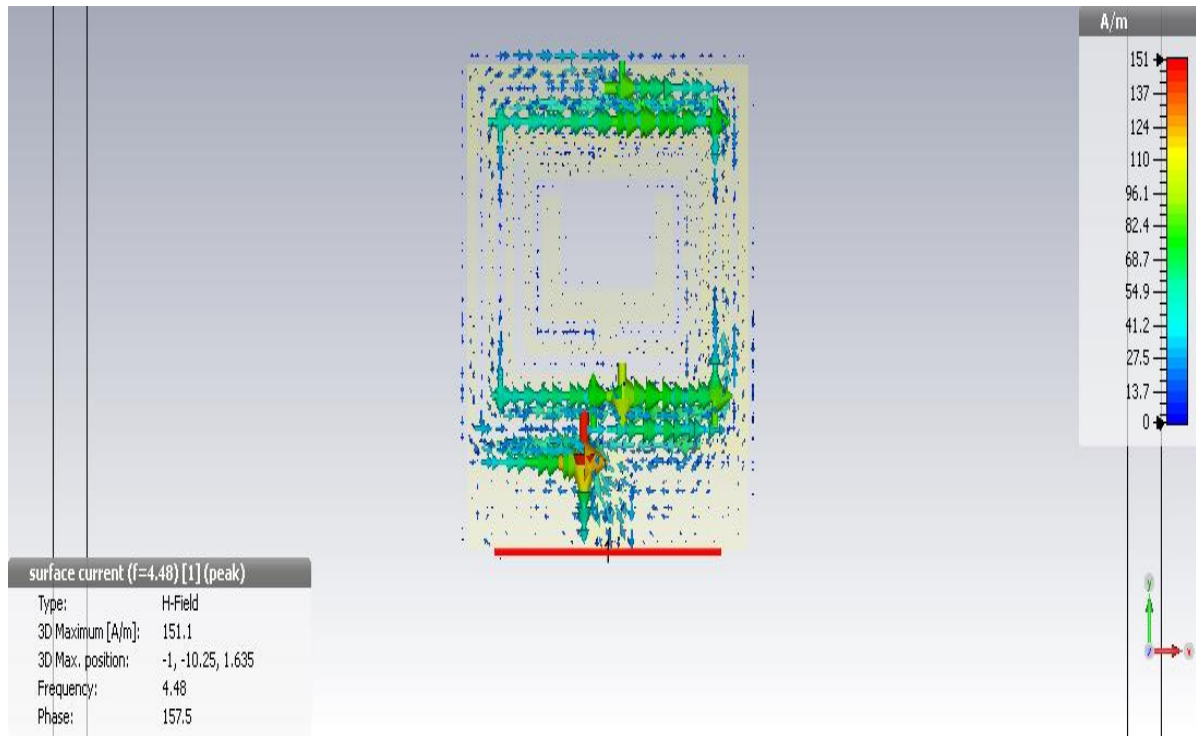
**Figure 3.9: Smith Chart of Simulated Antenna**

### 3.3.5 Current Distributions

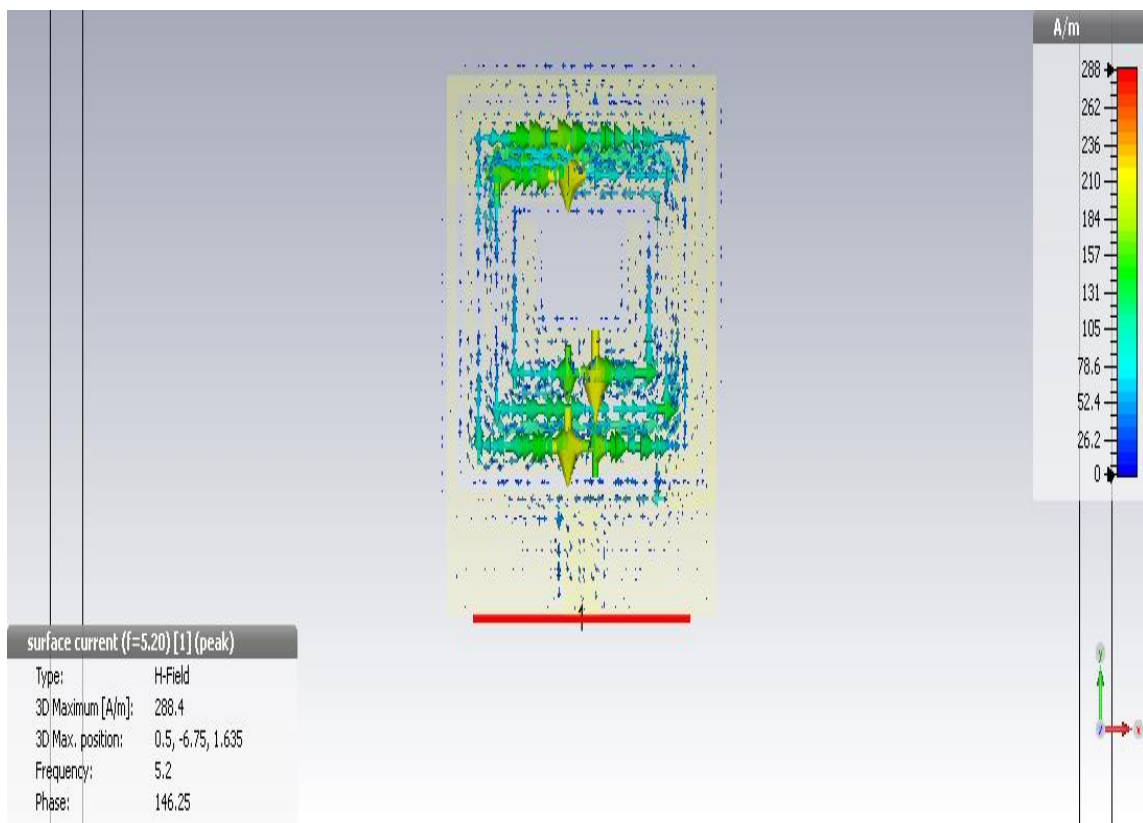
The current distributions at three resonant frequencies are given in Figure 3.10, Figure 3.11 and Figure 3.12. The surface current density at resonant frequency 2.4 GHz is highest near the maze-shaped strips and center of rectangular shaped patch and its maximum value is 356.9 A/m which is responsible to exhibit the Bluetooth band i.e. first frequency band (2.4-2.5 GHz). The surface current at 4.48 GHz is highest near the top of patch and around the feed line and its maximum value is 151.1 A/m which is responsible to exhibit the IMT band i.e. second frequency band (4.4 GHz-5 GHz). The surface current at 5.84 GHz is highest near the side corners of the rectangular metallic patch and its maximum value is 288.4 A/m which is responsible to exhibit the lower WLAN band i.e. third frequency band (5.1 GHz-5.2 GHz).



**Figure 3.10: Current Distribution of Simulated Antenna at 2.47 GHz**



**Figure 3.11: Current Distribution of Simulated Proposed Antenna at 4.48 GHz**



**Figure 3.12: Current Distribution of Simulated Antenna at 5.2 GHz**

## CHAPTER 4

### PATCH ANTENNA WITH SWASTIKA-SHAPED SLOTS AND DGS

#### 4.1 Introduction

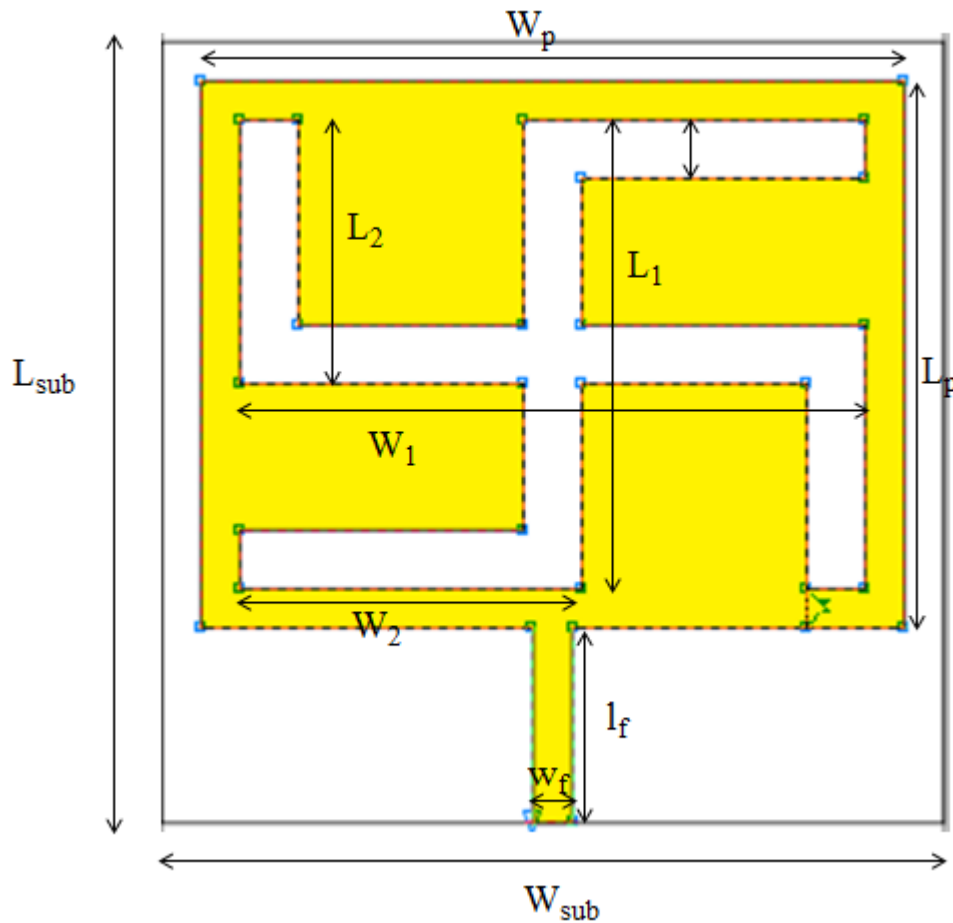
In the recent last few years, a wide research is done on the microstrip antenna due to its properties and small size or small height antennas are required in wireless communication networks. These antennas are compatible with planar and non-planar surfaces, and monolithic integrated circuit technology. These antennas are easily and simply fabricated on a dielectric substrate using printed circuit technique to calculate a set of parameters like resonant frequency, impedance bandwidth and radiation patterns etc. A particular patch is designed to obtain the desired resonant frequency. Moreover, a slot of any regular shape like U-shaped is cut from metallic patch, stack of metallic patches can be added or a defected shape is added to the perfect electric conductor ground plane increase the impedance bandwidth.

This designed presents, a small size microstrip-fed antenna with defected ground plane and is designed for GSM/Bluetooth/WLAN/WiMAX applications. Hence, the quad band of rectangular patch antenna with swastika-shaped slots and defected ground plane is designed with overall dimension  $40 \times 40 \text{ mm}^2$  printed on a FR4 substrate dielectric element having overall thickness dimension of 1.6 mm and is fed by microstrip line feed having 50- $\Omega$  characteristic impedance and overall dimension of  $2 \times 10 \text{ mm}^2$ . CST quad band simulated results of rectangular patch antenna with swastika-shaped slots and defected ground plane are compared with measured triband results and both results show good agreement with each other.

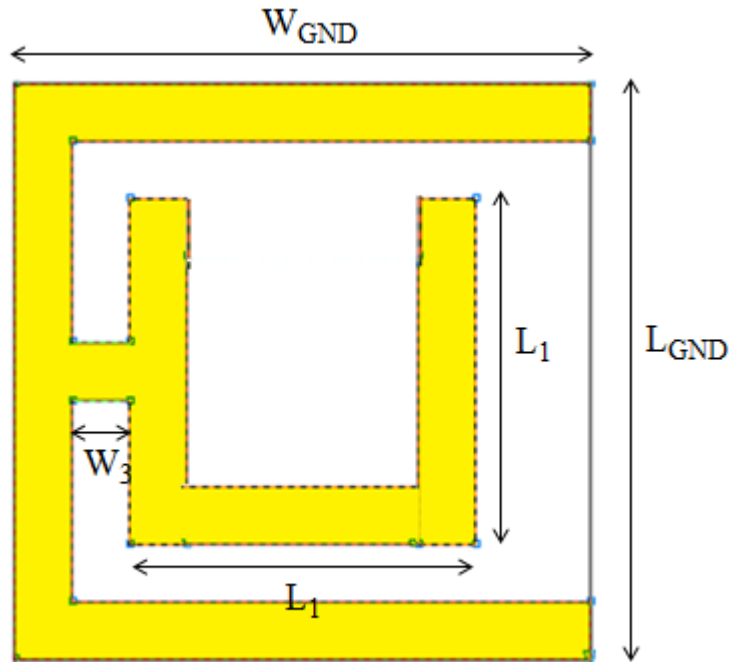
#### 4.2 Proposed Antenna Design

The schematic configuration of the proposed quad band rectangular patch antenna with swastika-shaped slots and defected ground plane is shown in Figure 4.1, with overall dimension of  $40 \times 40 \text{ mm}^2$  printed on a FR4 substrate with substrate thickness dimension  $t_{\text{sub}}=1.6 \text{ mm}$ , a loss tangent of 0.024 and permittivity of  $\epsilon_r=4.4$ . In this letter, the main principle in designing the proposed quad band antenna is to provide small size, therefore dimensions of each material is calculated based on this principle. The dielectric substrate is

selected with overall dimensions as  $W_{\text{sub}} \times L_{\text{sub}} = 40 \times 40 \text{ mm}^2$ . The proposed design antenna consists of three layers i.e. dielectric substrate, rectangular metallic patch having swastika-shaped slots and double U-shaped defected ground plane. A rectangular metallic patch with overall dimensions of  $36 \times 28 \text{ mm}^2$  is placed on the upper surface of dielectric substrate. A slot in the form of swastika is then cut through the metallic rectangular patch to obtain the desired design. A double U-shaped defected ground plane with proper calculated dimensions is then placed on the bottom surface of the dielectric substrate to complete the design of triband antenna. Double U-shaped ground plane is used to provide additional current path and moreover due to defected ground plane capacitance and inductance values of input impedance changes which lead to change in antenna gain and bandwidth. Microstrip feeding method is used with  $50\text{-}\Omega$  characteristic impedance and overall dimensions of  $w_f \times l_f = 2 \times 10 \text{ mm}^2$ .



(a) Front View



(b) Bottom View

**Figure 4.1 Configuration of the Simulated Antenna**

In this design, all the designing parameters as shown in table 1 are calculated using standard patch relationship

**Table 4.1 Overall Dimensions of the Simulated Proposed Antenna (mm)**

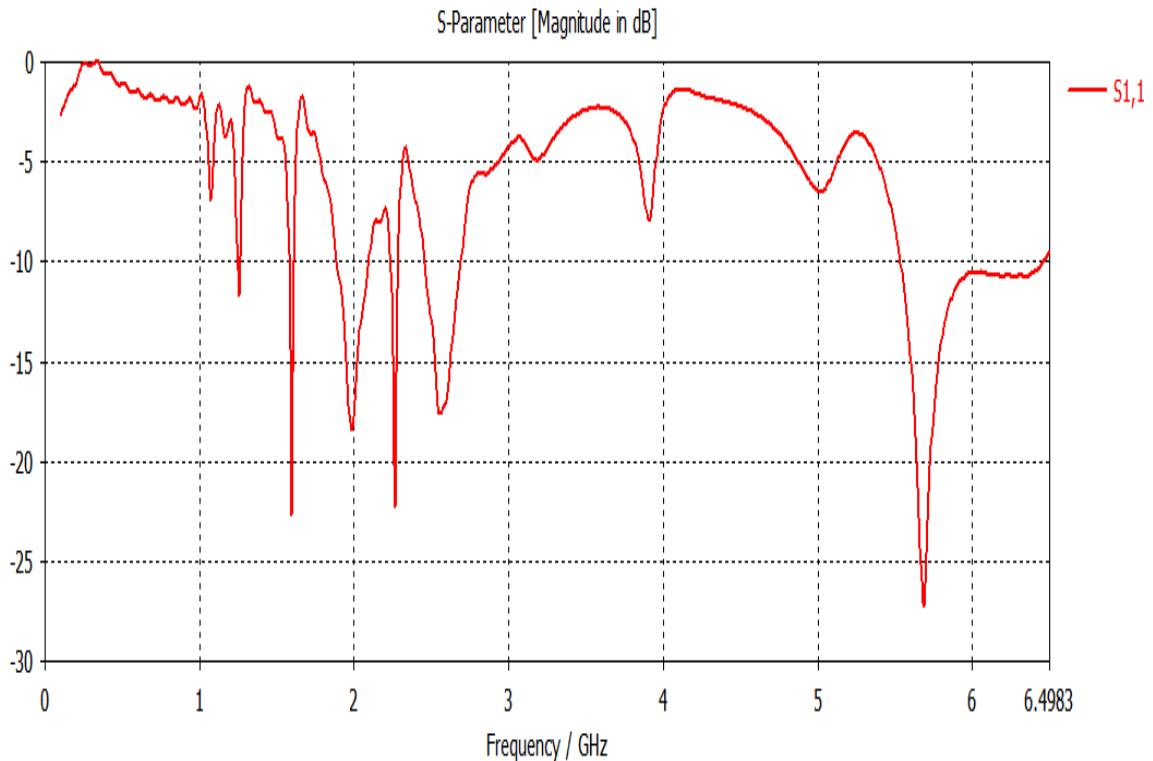
$L_{GND}$	$W_{GND}$	$L_{sub}$	$W_{sub}$	$t_{sub}$
40	40	40	40	1.6
$l_f$	$w_f$	$L_p$	$W_p$	$L_1$
10	2	28	36	24
$W_1$	$L_2$	$W_2$	$L_3$	$W_3$
32	13.5	17.5	3	4

## 4.3 Results and Discussions

### 4.3.1 Return Loss ( $S_{11}$ )

Return loss basically represent the difference value between the forward and the reflected back power of a transmitted signal in a communication system and is generally calculated in terms of decibels (dB). The small value of return loss is equivalent to the maximum power is transferred between two communicable devices. Therefore, it should have greater negative value for better communication.

The S-parameter results simulated at CST software are represented in the graph shown in Figure 4.2.

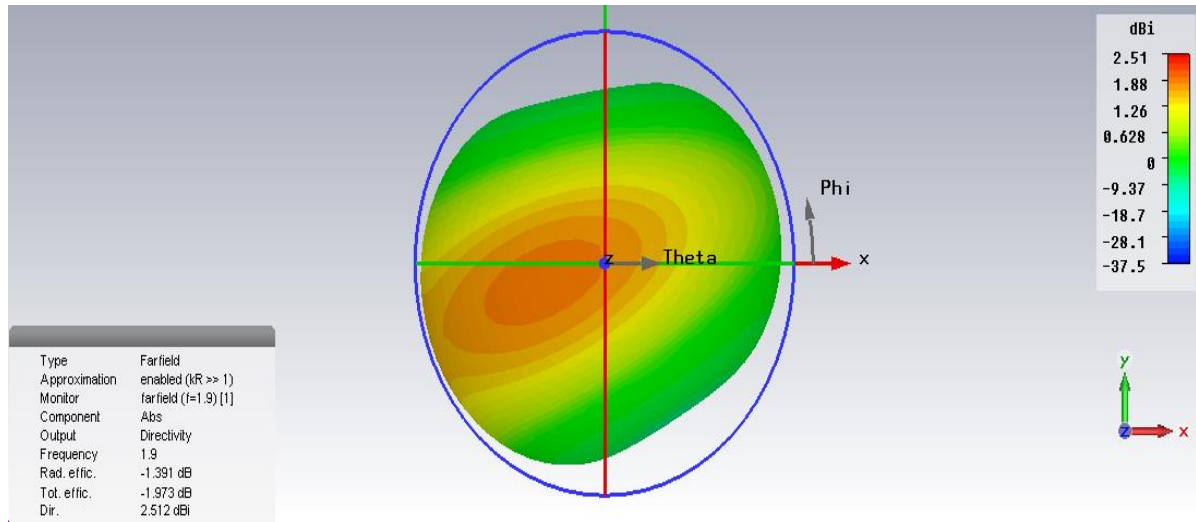


**Figure 4.2: Simulated S-parameter Results of Simulated Antenna**

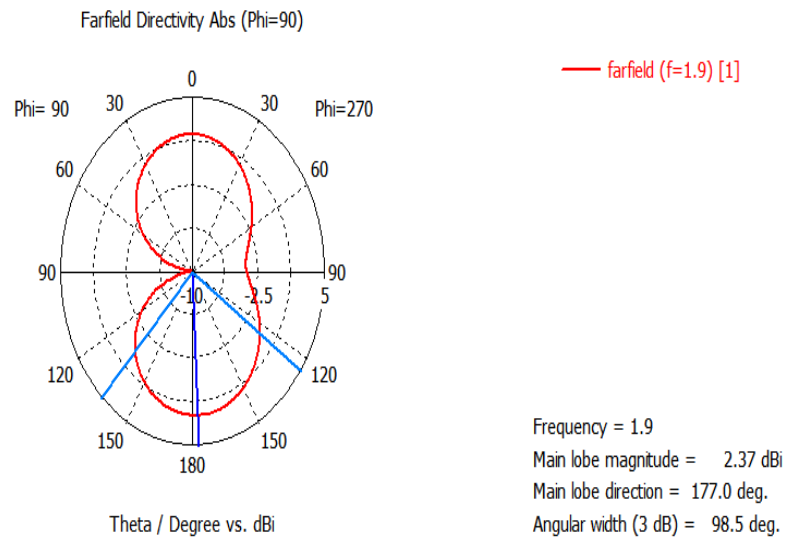
### 4.3.2 Radiation Pattern Characteristics

The radiation pattern showing the directivity (3D and polar plot) for the designed antenna has been represented in graphs shown in Figure 4.3, Figure 4.4 and Figure 4.5 for 1.9 GHz, 2.5 GHz and 5.6 GHz respectively. The polar plot figure of the directivity for 1.9 GHz frequency represents radiation pattern with magnitude of main lobe is 2.37 dBi at an angle

of 177 degree and angular beam width of 98.5 degree and the polar plot figure of the directivity for 2.5 GHz frequency represents radiation pattern with magnitude of main lobe is 3.62 dBi at an angle of 9 degree and angular beam width of 92.2 degree. Similarly the polar plot figure of the directivity for 5.6 GHz frequency represents radiation pattern with magnitude of main lobe is 5.29 dBi at an angle of 34 degree and angular beam width of 49.5 degree.

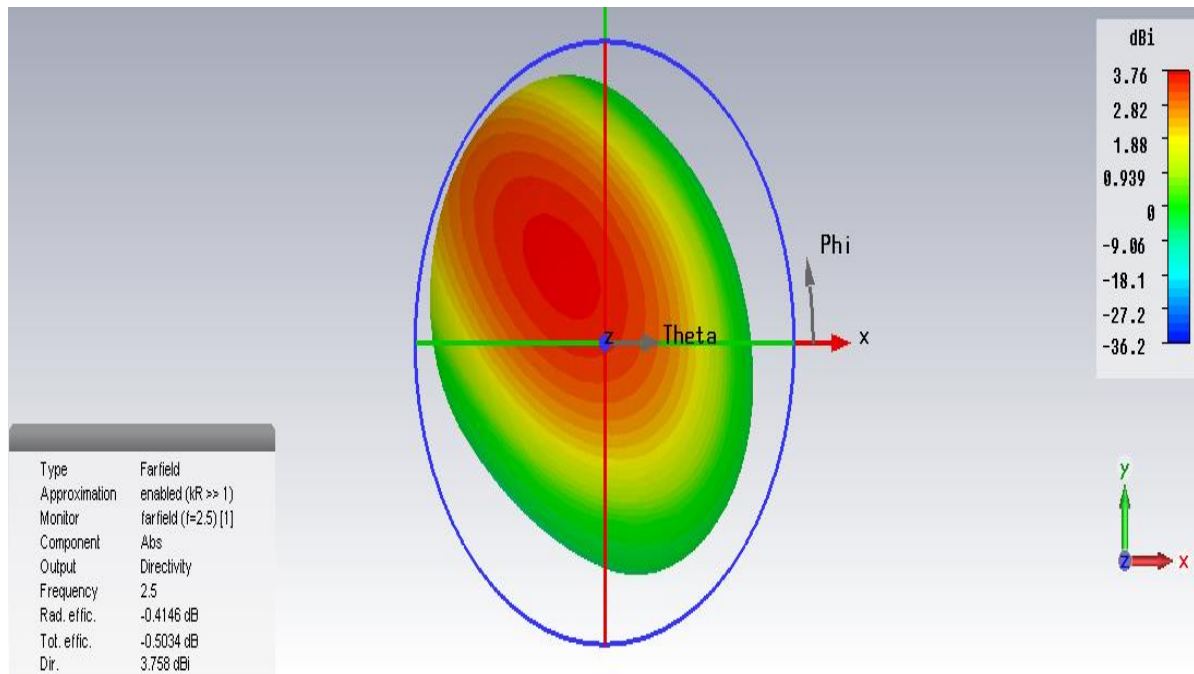


(a) 3D View



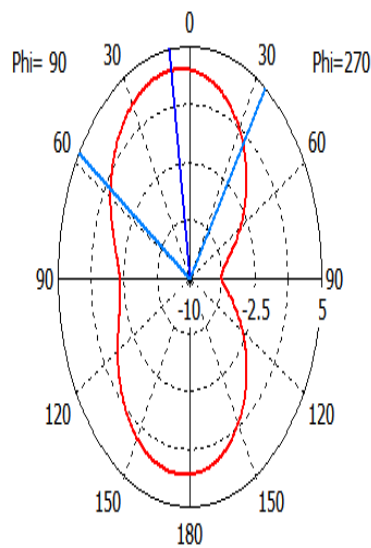
(b) Polar Plot

**Figure 4.3: Simulated Radiation Pattern Characteristics of Simulated Antenna at Resonant Frequency 1.9 GHz**



(a) 3D View

Farfield Directivity Abs (Phi=90)

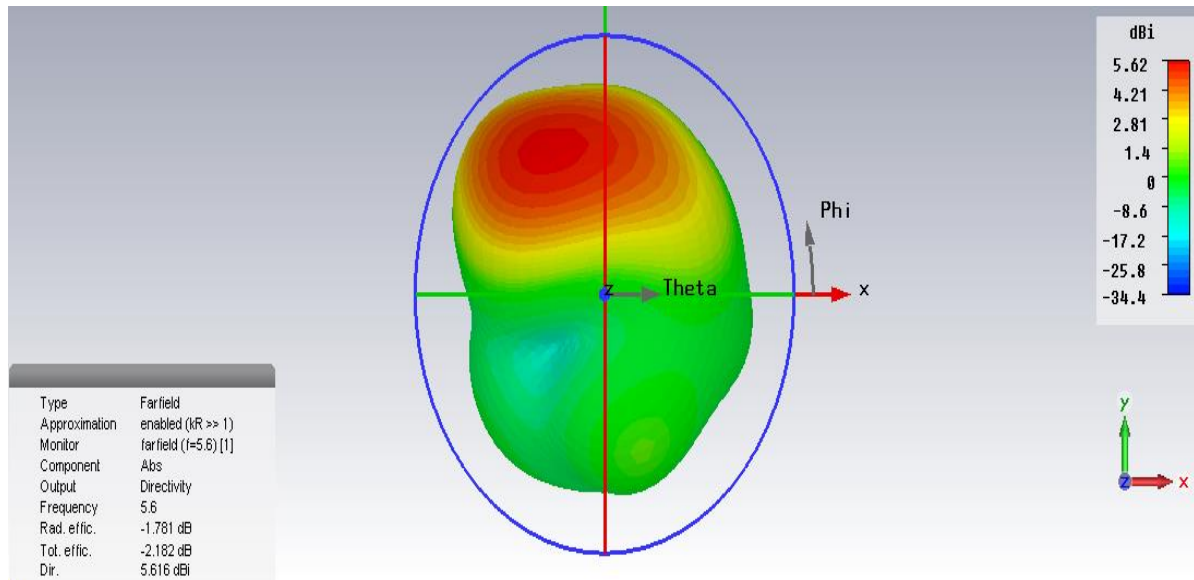


— farfield (f=2.5) [1]

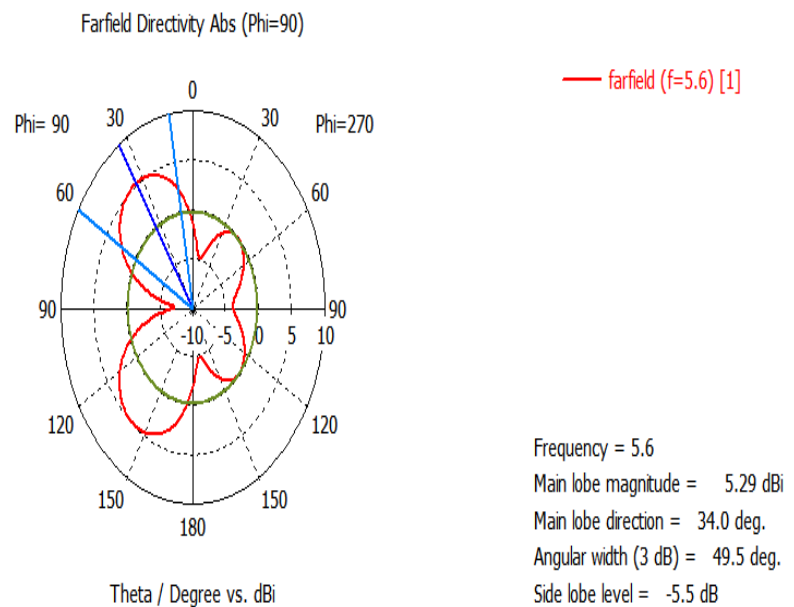
Frequency = 2.5  
 Main lobe magnitude = 3.62 dBi  
 Main lobe direction = 9.0 deg.  
 Angular width (3 dB) = 92.2 deg.

(b) Polar Plot

**Figure 4.4: Simulated Radiation Pattern Characteristics of Simulated Antenna at Resonant Frequency 2.5 GHz**



(a) 3D View



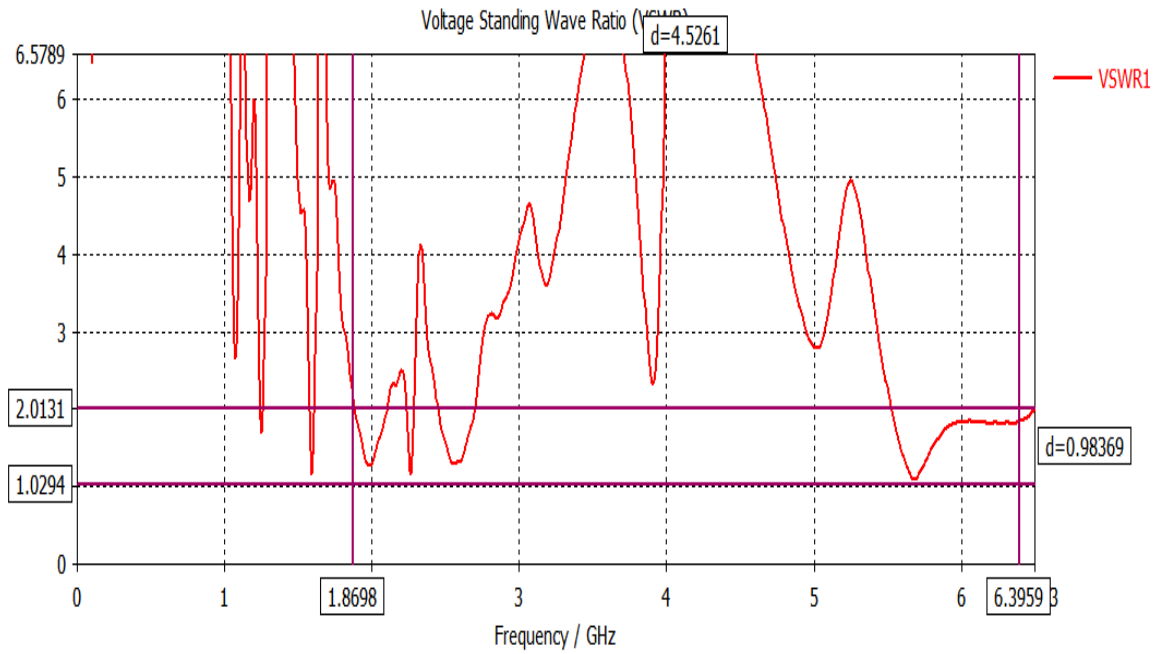
(b) Polar Plot

**Figure 4.5: Simulated Radiation Pattern Characteristics of Simulated Antenna at Resonant Frequency 5.6 GHz**

### 4.3.3 Voltage Standing Wave Ratio (VSWR)

Practically the VSWR value must lie in the range of 1-2 which is obtained for 1.9 GHz, 2.5 GHz and 5.6 GHz resonating frequency of the proposed simulated antenna. The VSWR ratio

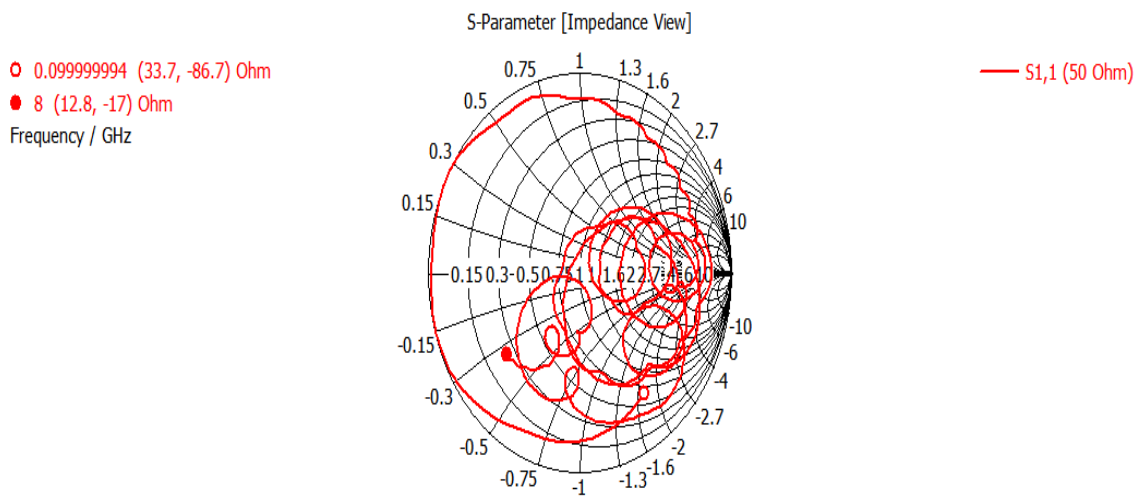
value at 1.9 GHz, 2.5 GHz and 5.6 GHz resonating frequency is 1:1.278, 1:1.324 and 1:1.018 respectively.



**Figure 4.6: VSWR of Simulated Antenna**

#### 4.3.4 Smith Chart

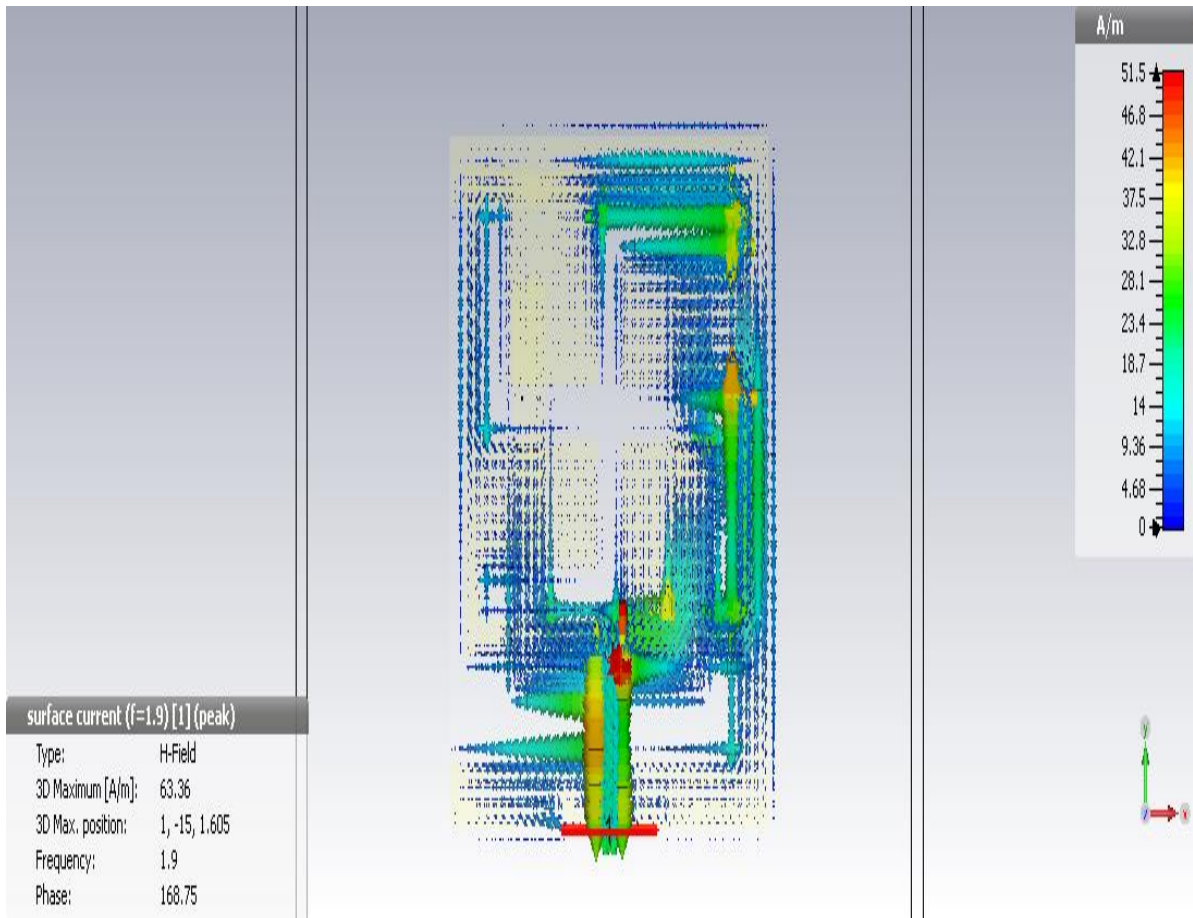
The Smith Chart graph signifies the relationship of antenna impedance with bandwidth frequency.



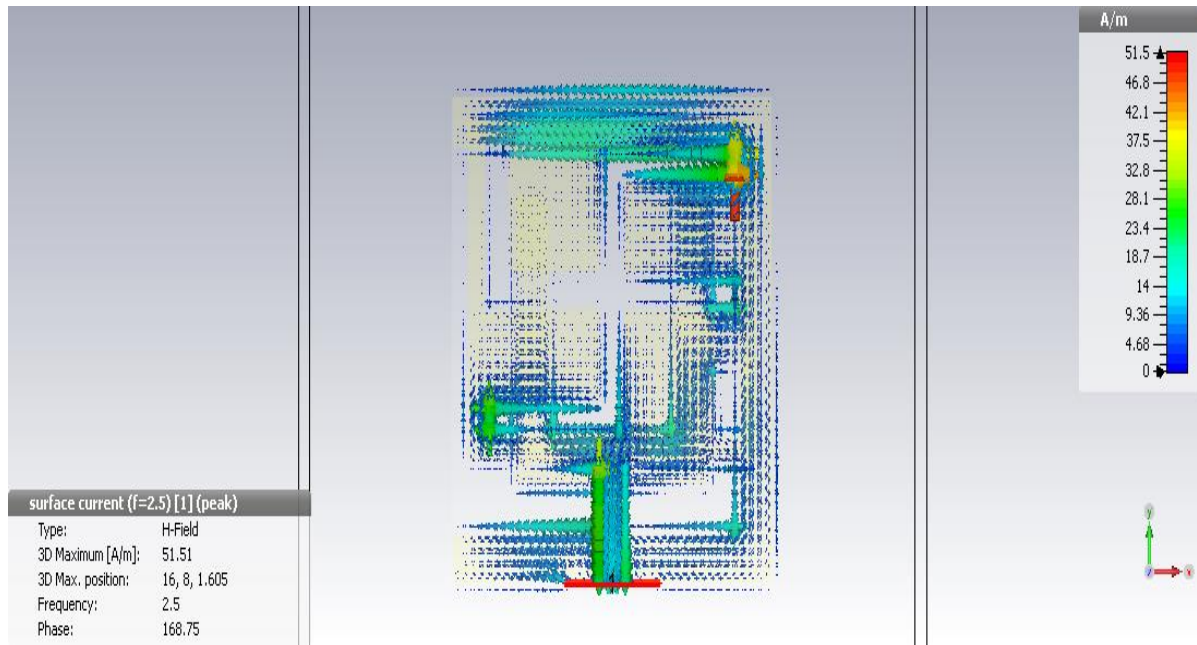
**Figure 4.7: Smith Chart of Simulated Antenna**

### 4.3.5 Current Distributions

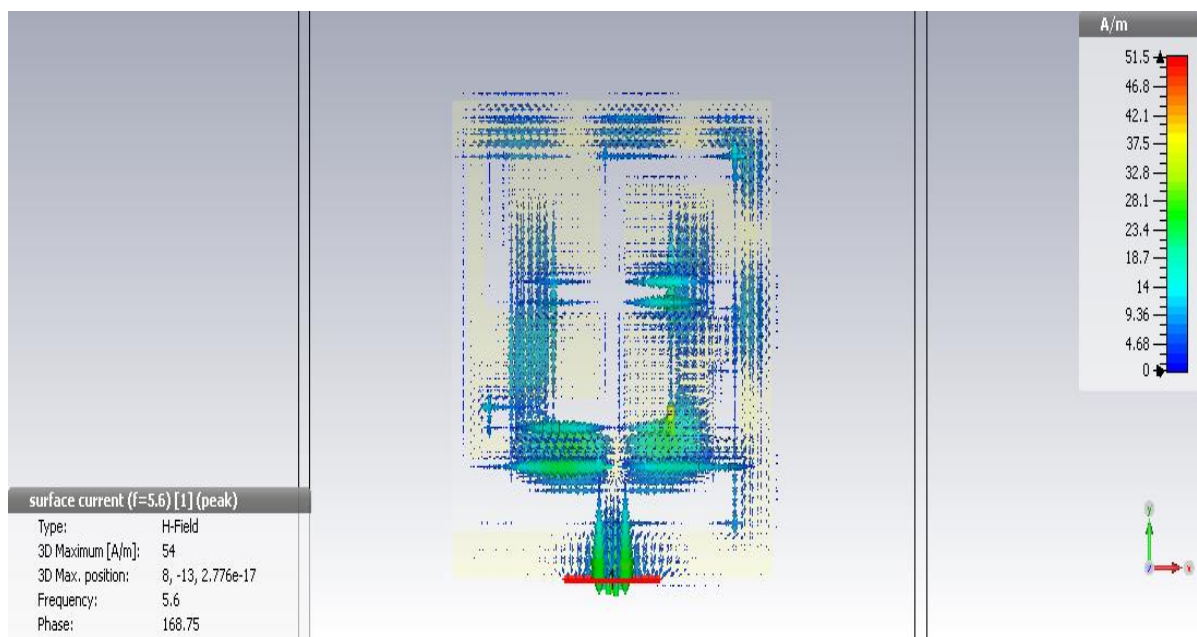
The current distributions at three resonant frequencies are given in Figure 4.8, Figure 4.9 and Figure 4.10. The surface current density at resonant frequency 1.9 GHz is highest near the double U-shaped strips and center of rectangular shaped patch and its maximum value is 63.36 A/m which is responsible to exhibit the GSM 1900 band i.e. first frequency band (1.850-1.990 GHz). The surface current at 2.5 GHz is highest near the top of patch and around the feed line and its maximum value is 51.51 A/m which is responsible to exhibit the 2.4 GHz BLUETOOTH/2.4 GHz WLAN/2.5 GHz WiMAX band i.e. second frequency band (2.4 GHz-2.7 GHz). The surface current at 5.6 GHz is highest near the side corners of the double U-shaped ground plane, the center of metallic patch and around the feed line and its maximum value is 54 A/m which is responsible to exhibit the higher 5.8 WLAN band/5.5 WiMAX band i.e. third frequency band (5.4 GHz-6.2 GHz).



**Figure 4.8: Current Distribution of Simulated Antenna at 1.9 GHz**



**Figure 4.9: Current Distribution of Simulated Antenna at 2.5 GHz**



**Figure 4.10: Current Distribution of Simulated Antenna at 5.6 GHz**

## CHAPTER 5

### FABRICATION AND TESTING OF ANTENNAS

#### 5.1 Antenna Fabricated Design



(a) Front View



(b) Bottom View

Figure 5.1: Proposed Fabricated Antenna

## 5.2 Testing of Fabricated Antenna

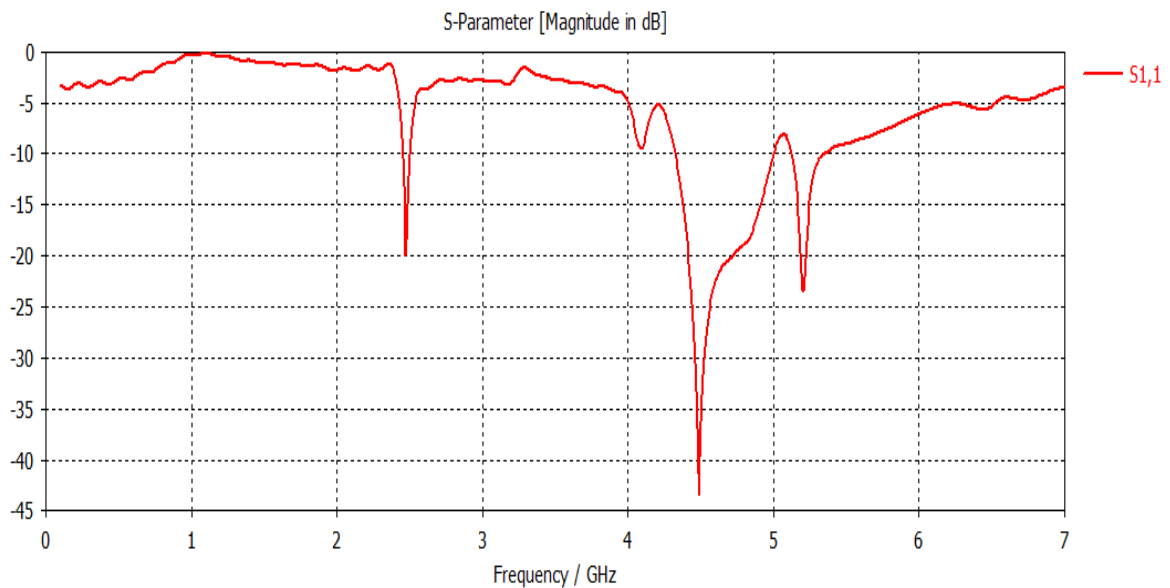
The testing of the fabricated antenna is done using VNA (Vector Network Analyzer) E5071C (ENA Series) which analyses one or two port communication networks. The frequency range of VNA is from 9 KHz to 8.5 GHz.



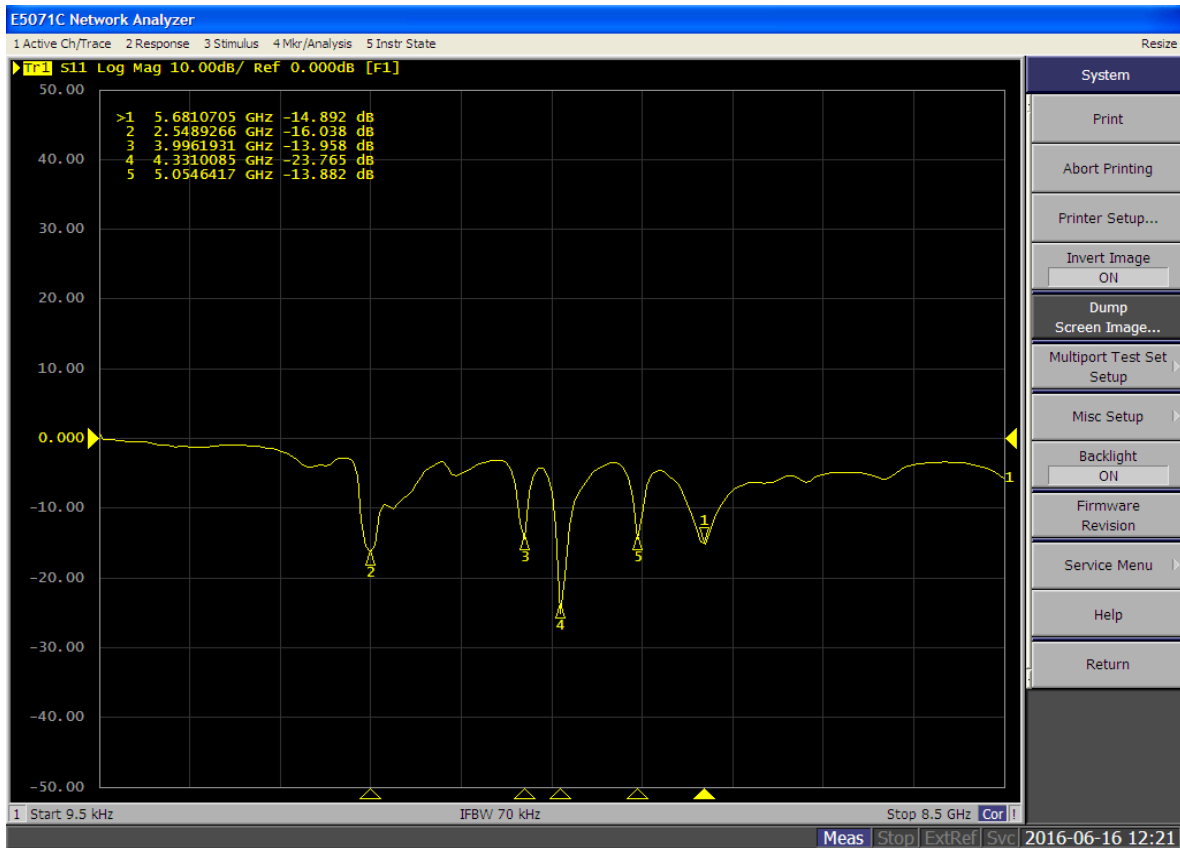
**Figure 5.2: Network Analyzer for Testing**

## 5.3 Comparison of Results of Simulated and Fabricated Antenna

The simulated and tested results are shown in Figure 5.3 and Figure 5.4 respectively and are compared in table 5.1.



**Figure 5.3: Simulated S-Parameter Results of Simulated Antenna**



**Figure 5.4: Measured S-Parameter Results of Fabricated Antenna**

**Table 5.1: Comparison of Simulation and Measured Results**

Parameters	Tested results at 2.47 GHz	Measured results at 2.47 GHz	Tested results at 4.48 GHz	Measured results at 4.48 GHz	Tested results at 5.2 GHz	Tested results at 5.8 GHz
Return Loss	-19.93 dB	-16.03 dB	-43.41dB	-23.76 dB	-23.33dB	-14.89 dB
Bandwidth obtained	100 MHz	200 MHz	500 MHz	300 MHz	200 MHz	300 MHz

## CHAPTER 6

### CONCLUDING REMARKS AND FUTURE SCOPE

In this thesis report, two designs of a compact rectangular patch antenna with different shaped slots and DGS are presented for different wireless communication network. The first design is presented with compact rectangular patch having symmetrical maze shaped slots and defected ground plane for Bluetooth/IMT/WLAN applications whereas the second design is presented with rectangular patch with swastika-shaped slots and double U-shaped ground plane for GSM 1900/BLUETOOTH/WLAN 2.5,5.8/WiMAX 2.5,5.5 applications. Conclusion of thesis report and the future work that can be done in the modern communication field of GSM/Bluetooth/IMT/WLAN/WiMAX systems are given in this chapter.

#### 6.1 Conclusion

A compact sized rectangular patch with symmetrical slots and defected ground is simulated and fabricated. In this thesis report, a preface of microstrip patch antenna is discussed in chapter 1 with factors used to obtain multiband frequency operations. Therefore, it is concluded that a compact size with symmetrical slots are used to obtain multiband frequency operations for Bluetooth/IMT/WLAN applications.

After general preface of microstrip patch antenna, literature survey for multiband frequency for different communication systems is studied in chapter 2. Different designs of antenna were studied published by number of authors to obtain multiband frequency operations in literature survey. After studying a sufficient number of designs, it is concluded that in the modern world a wide research is going on to reduce the antenna to obtain multi band frequency for different communication systems without affecting the antenna parameters. Hence, thesis objectives were defined to design a compact microstrip patch antenna for multiband frequency operations.

After study of computational analysis using transmission line model different designs were presented to obtain different frequency as the change in antenna dimension change the resonant frequency. Hence, an optimum antenna for Bluetooth/IMT/WLAN applications is simulated as discussed in chapter 3 and fabricated through PCB fabrication technique as

discussed in chapter 5. It is concluded from the simulated and measured results that return loss of compact rectangular patch with symmetrical slot and defected ground is better than the different shapes of rectangular patch.

- The simulation results display three resonant bands at frequencies of 2.47, 4.48, and 5.2 GHz, with impedance bandwidths of about 100 MHz (2.4–2.5 GHz), 500 MHz (4.4–4.9 GHz), and 200 MHz (5.1–5.3 GHz), respectively and having return loss value of -19.93 dB, -43.4 dB, -23.3 dB respectively.
- The polar plot figure of the directivity for 2.47 GHz frequency represents radiation pattern with magnitude of main lobe is 1.21dBi at an angle of 151 degree and angular beam width of 124.3 degree and the polar plot figure of the directivity for 4.48 GHz frequency represents radiation pattern with magnitude of main lobe is 2.86 dBi at an angle of 170 degree and angular beam width of 108.1 degree. Similarly the polar plot figure of the directivity for 5.20 GHz frequency represents radiation pattern with magnitude of main lobe is 3.12 dBi at an angle of 167 degree and angular beam width of 101.3 degree.
- VSWR ratio value at 2.47 GHz, 4.47 GHz and 5.20 GHz resonating frequency is 1:1.257, 1:1.013 and 1:1.017 respectively.
- The surface current density at resonant frequency 2.47 GHz is highest near the maze-shaped strips and center of rectangular shaped patch and its maximum value is 356.9 A/m which is responsible to exhibit the Bluetooth band i.e. first frequency band (2.4-2.5 GHz). The surface current at 4.48 GHz is highest near the top of patch and around the feed line and its maximum value is 151.1 A/m which is responsible to exhibit the IMT band i.e. second frequency band (4.4 GHz-5 GHz). The surface current at 5.84 GHz is highest near the side corners of the rectangular metallic patch and its maximum value is 288.4 A/m which is responsible to exhibit the lower WLAN band i.e. third frequency band (5.1 GHz-5.2 GHz).

In chapter 4, a new design of small rectangular patch with swastika-shaped slots and double U-shaped ground plane is presented for GSM/Bluetooth/WLAN/WiMAX applications. It is concluded from the simulated and measured results that return loss of compact rectangular

patch with swastika slot and defected ground is better than the different shapes of rectangular patch.

- The simulation results display three resonant bands at frequencies of 1.9, 2.5, and 5.6 GHz, with impedance bandwidths of about 200 MHz (1.8–2.0 GHz), 300 MHz (2.4–2.7 GHz), and 1000 MHz (5.4–6.4 GHz), respectively and having return loss value of -18.04 dB, -17.39 dB, -27.13 dB respectively.
- The polar plot figure of the directivity for 1.9 GHz frequency represents radiation pattern with magnitude of main lobe is 2.37 dBi at an angle of 177 degree and angular beam width of 98.5 degree and the polar plot figure of the directivity for 2.5 GHz frequency represents radiation pattern with magnitude of main lobe is 3.62 dBi at an angle of 9 degree and angular beam width of 92.2 degree. Similarly the polar plot figure of the directivity for 5.6 GHz frequency represents radiation pattern with magnitude of main lobe is 5.29 dBi at an angle of 34 degree and angular beam width of 49.5 degree.
- The VSWR ratio value at 1.9 GHz, 2.5 GHz and 5.6 GHz resonating frequency is 1:1.278, 1:1.324 and 1:1.018 respectively.
- The surface current density at resonant frequency 1.9 GHz is highest near the double U-shaped strips and center of rectangular shaped patch and its maximum value is 63.36 A/m which is responsible to exhibit the GSM 1900 band i.e. first frequency band (1.850-1.990 GHz). The surface current at 2.5 GHz is highest near the top of patch and around the feed line and its maximum value is 51.51 A/m which is responsible to exhibit the 2.4 GHz BLUETOOTH/2.4 GHz WLAN/2.5 GHz WiMAX band i.e. second frequency band (2.4 GHz-2.7 GHz). The surface current at 5.6 GHz is highest near the side corners of the double U-shaped ground plane, the center of metallic patch and around the feed line and its maximum value is 54 A/m which is responsible to exhibit the higher 5.8 WLAN band/5.5 WiMAX band i.e. third frequency band (5.4 GHz-6.2 GHz).

## 6.2 Future Scope

Since a wide research has done to optimize antenna designs for different communication networks but still there are different techniques that can be applied to microstrip patch

antenna to improve antenna performances. A number of optimized techniques can be applied to make the bandwidth of antenna broadband.

- In order to obtain multiple adjustable band-notched characteristics, different methods like an arc shaped loaded stub, an inverted T-shaped radiating element including cutting of different shaped slots like a pair of symmetrical U-shaped slots, L-shaped slots or C-shaped slots etc. can be used.
- In spite of microstrip line feed method a different feeding technique like coaxial probe feeding method or aperture coupling feeding method can be used to achieve high bandwidth.
- Electromagnetic band gap (EBG) technique or different metamaterial dielectric substrates can be used to achieve high gain and wideband characteristics for high transfer transmission communication networks.
- Split ring resonators (SRR) structure can provide high bandwidth front radiations for microstrip patch antenna that can be used for satellite communications networks.

## REFERENCES

- [1]. Andrea Goldsmith, "Wireless Communications", Cambridge University Press, 2005.
- [2]. Theodore S. Rappaport, "Wireless Communications and Practice," Pearson Education India, second edition, 2009.
- [3]. "Different IEEE standards"  
<http://compnetworking.about.com/cs/wireless80211/a/aa80211standard.html>
- [4]. "Introduction to WiMAX standard"  
<http://en.wikipedia.org/wiki/WiMAX>
- [5]. Randy Bancroft, "Microstrip antennas, the analysis and design of microstrip antennas and arrays," *John Wiley and Sons*, 2nd Edition, 2009.
- [6]. Ramesh Garg, Prakash Bharti and Inder Bahl, "Microstrip antenna design handbook," *Artech House*, Boston London.
- [7]. C. A. Balanis, *Antenna Theory*, 3rd ed., John Wiley & Sons Inc., 2005.
- [8]. C Wu, k. L. Wu, Z Bi, J. Litva, "Modelling of coaxial-fed microstrip patch antenna by finite difference time domain method", *Electronics Letters*, Vol. 27, issue 19, pp. 1691-1692, 1991.
- [9]. A.K. Sharma, A. Mittal and B.V.R. Reddy, "Slot embedded dual-band patch antenna for WLAN and WiMAX applications," *Electronics Letters*, Vol. 51, No. 8, pp. 608–609, 2015.
- [10]. Y. F. Cao, S. W. Cheung and T.I. Yuk, "A multiband slot antenna for GPS/WiMAX/WLAN systems," *IEEE Transactions on Antennas and Propagation*, Vol. 63, No. 3, 2015.
- [11]. Seyed Amir Hossein Saghanezhad and Zahra Atlasbaf, "Miniaturized dual-band CPW-Fed Antennas Loaded With U-Shaped Metamaterials," *IEEE Antennas and Wireless Propagation letters*, Vol. 14, pp. 658-661, 2015.
- [12]. Yasser Ojaroudi Sajjad Ojaroudi Nasser Ojaroudi, "A novel 5.5/7.5GHz dual band-stop antenna with modified ground plane for UWB communications," *Wireless Personal Communication*, Vol. 81, No. 1, pp. 319–332, 2014.
- [13]. Md. Rezwanul Ahsan, Mohammad Tariqul Islam and Mohammad Habib Ullah, "A new low-profile inverted A-shaped patch antenna for multi-band operations," *Wireless Personal Communication*, Vol. 81, No. 2, pp. 519–529, 2014.

- [14]. H. Mopidev, Y. Damgaci, D. Rodrigo, L. Jofre and B. A. Cetiner, "A quad-band antenna for public safety applications," *IEEE Antennas and Wireless Propagation Letters*, Vol. 13, pp. 1231-1234, 2014.
- [15]. Yuan-Fu Liu, Peng Wang and Hao Qin, "Compact ACS-fed UWB monopole antenna with extra Bluetooth band," *Electronics Letters*, Vol. 50, No. 18, pp. 1263-1264, 2014.
- [16]. Le Kang, Hao Wang, Xin Huai Wang and Xiaowei Shi, "Compact ACS-fed monopole antenna with rectangular SRRs for tri-band operation," *Electronics Letters*, Vol. 50, No. 16, pp. 1112–1114, 2014.
- [17]. Kumar Goodwill, Vishal N. Saxenal and M.V. Kartikeyan, "Dual band CSSRR inspired microstrip patch antenna for enhancing antenna performance and size reduction," *International Conference on Signal Processing and Communication (ICSC)*, pp. 495-497, 2013.
- [18]. Hattan F. Abutarboush, R. Nilavalan, S. W. Cheung, and Karim M. Nasr, "Compact printed multiband antenna with independent setting suitable for fixed and reconfigurable wireless communication systems," *IEEE Transactions on Antennas and Propagation*, Vol. 60, no. 8, pp.3867-3874, 2012.
- [19]. Valizade, Ch. Ghobadi, J. Nourinia, and M. Ojaroudi, "A novel design of reconfigurable slot antenna with switchable band-notch and multiresonance functions for UWB applications," *IEEE Antennas and Wireless Propagation Letters*, Vol. 10, pp. 1166-1169, 2012.
- [20]. Wen Jiang and Wenquan Che, "A novel UWB antenna with dual notched bands for WiMAX and WLAN applications," *IEEE Antennas and Wireless Propagation Letters*, Vol. 11, pp. 293-296, 2012.
- [21]. M. Mehranpour, J. Nourinia, Ch. Ghobadi, and M. Ojaroudi, "Dual band-notched square monopole antenna for ultra-wideband applications," *IEEE Antennas and Wireless Propagation Letters*, Vol. 11, pp. 172-175, 2012.
- [22]. Bimal Garg, Vijay Sharma, Nitin Agrawal, "size reduction of rectangular microstrip patch antenna incorporated with interconnected framed shaped metamaterial structure for WLAN applications," *Electrical, Electronics and Computer Science (SCEECS)*, pp. 1-4, 2012.

- [23]. Mehdi Veysi, Manouchehr Kamyab, and Amir Jafargholi, "Single-feed dual-band dual-linearly polarized proximity-coupled patch antenna," *IEEE Antennas and Propagation Magazine*, Vol. 53, No.1, pp. 90-96, 2011.
- [24]. Pingan Liu, Yanlin Zou, Baorong Xie, Xianglong Liu, and Baohua Sun, "Compact CPW-fed tri-band printed antenna with meandering split-ring slot for WLAN/WiMAX applications," *IEEE Antennas and Wireless Propagation Letters*, Vol. 11, pp. 1242-1244, 2012.
- [25]. Jing Pei, An-Guo Wang, Shun Gao, and Wen Leng, "Miniaturized triple-band antenna with a defected ground plane for WLAN/WiMAX applications," *IEEE Antennas and Wireless Propagation Letters*, Vol. 10, pp. 298-301, 2011.
- [26]. Wen-Chung Liu, Chao-Ming Wu, and Yang Dai, "Design of triple-frequency microstrip-fed monopole antenna using defected ground structure," *IEEE Transactions on Antennas and Propagation*, Vol. 59, No. 7, pp. 2457-2463, 2011.
- [27]. Chih-Yu Huang and En-Zo Yu, "A slot-monopole antenna for dual-band WLAN applications," *IEEE Antennas and Wireless Propagation Letters*, Vol. 10, pp. 500-502, 2011.
- [28]. Wei Hu, Ying-Zeng Yin, Peng Fei, and Xi Yang, "Compact triband square-slot antenna with symmetrical L-strips for WLAN/WiMAX applications," *IEEE Antennas and Wireless Propagation Letters*, Vol. 10, pp. 462-465, 2011.
- [29]. Óscar Quevedo-Teruel, Malcolm Ng Mou Kehn and Eva Rajo-Iglesias, "Dual-band patch antennas based on short-circuited split ring resonators" *IEEE Transactions on Antennas and Propagation*, Vol. 59, no. 8, pp. 2758-2765, 2011.
- [30]. K. F. Lee, K. M. Lu, K. M. Ma, and S. L. S. Yang, "On the use of U-slots in the design of dual-and triple-band patch antennas" *IEEE Antennas and Propagation Magazine*, Vol. 53, No.3, pp.60-74, 2011.
- [31]. David Gibbins, Maciej Klemm, Ian J. Craddock, Jack A. Leendertz, Alan Preece, and Ralph Benjamin, "A comparison of a wide-slot and a stacked patch antenna for the purpose of breast cancer detection" *IEEE Transactions on Antennas and Propagation*, Vol. 58, no. 3, pp. 665 - 674 , 2010.

- [32]. M. Abdollahvand, G. Dadashzadeh, and D. Mostafa, "Compact dual band-notched printed monopole antenna for UWB application," *IEEE Antennas and Wireless Propagation Letters*, Vol. 9, pp. 1148-1151, 2010.
- [33]. Hsien-Wen Liu, Chia-Hao Ku, Te-Shun Wang, and Chang-Fa Yang, "Compact monopole antenna with band-notched characteristic for UWB applications," *IEEE Antennas and Wireless Propagation Letters*, Vol. 9, pp. 397-400, 2010.
- [34]. Alireza Pourghorban Saghati, Mohammadnaghi Azarmanesh and Reza Zaker , "A novel switchable single and multi-frequency triple-slot antenna for 2.4-GHz Bluetooth, 3.5-GHz WiMAX, and 5.8-GHz WLAN, " *IEEE Antennas and Wireless Propagation Letters*, vol. 9, pp. 534-537, 2010.
- [35]. G. Singh, "Double negative left-handed metamaterials for miniaturization of rectangular microstrip antenna," *Journal of Electromagnetic Analysis and Applications*, vol. 2, no. 6, pp. 347-351, 2010.
- [36]. Bahadir S. Yildirim, Bedri A. Cetiner, Gemma Roqueta and Luis Jofre, "Integrated Bluetooth and UWB Antenna," *IEEE Antennas and Wireless Propagation Letters*, Vol. 8, pp. 149-152, 2009.
- [37]. Kenny Seungwoo Ryu and Ahmed A. Kishk, "UWB antenna with single or dual band-notches for lower WLAN band and upper WLAN band," *IEEE Transactions on Antennas and Propagation*, Vol. 57, No. 12, pp. 3942-3950, 2009.
- [38]. Wen-Shan Chen and Kuang-Yuan Ku, "Band-Rejected design of the printed open slot antenna for WLAN/WiMAX operation," *IEEE Transactions on Antennas and Propagation*, Vol. 56, No. 4, pp. 1163-1169, 2008.
- [39]. Hala Elsadek and Dalia M. Nashaat, "Multiband and UWB V-shaped antenna configuration for wireless communications applications," *IEEE Antennas and Wireless Propagation Letters*, Vol. 7, pp. 89-91, 2008.
- [40]. R. karimzadeh Baeel, G. Dadashzadehl, F. Geran Kharakhili, "Using of CSRR and its equivalent circuit model in size reduction of microstrip antenna," *Microwave Conference*, pp. 1-4, 2007.
- [41]. Jin-Sen Chen, "Studies of CPW-fed equilateral triangular-ring slot antennas and triangular-ring slot coupled patch antennas" *IEEE Transactions on Antennas and Propagation*, Vol. 53, no. 7, pp. 2208-2211, 2005.

- [42]. Ricky Chair, Kwai-Man Luk, and Kai-Fong Lee, "Measurement and analysis of miniature multilayer patch antenna," *IEEE Antennas and Propagation*, Vol. 50, no. 2, pp. 244-250, 2002.
- [43]. S. Maci and G. Bifji Gentili, "Dual-frequency patch antennas," *IEEE Antennas and Propagation Magazine*, Vol. 39, No. 6, pp. 13-20, 1997.

## LIST OF PUBLICATIONS

1. Navjot Singh Dhindsa, Sukhwinder Kumar and Sahil Gupta, “Compact and Small Planar Monopole Rectangular Patch Antenna with Symmetrical Maze-Shaped Slots for Bluetooth/WLAN/IMT Applications,” *International Journal of Latest Technology in Engineering, Management & Applied Science (IJLTEMAS)*, Volume V, Issue VI, pp 106-110, June 2016.
2. Ramanjeet, Sukhwinder Kumar and Navjot Singh, “An X-Fractal Patch Antenna with DGS for Multiband Applications,” *International Journal of Latest Technology in Engineering, Management & Applied Science (IJLTEMAS)*, Volume V, Issue VI, pp 81-85, June 2016.
3. Navjot Singh and Sukhwinder Kumar, “Small Planar Rectangular Patch Antenna with Swastika-Shaped Slots and DGS for GSM/Bluetooth/WLAN/WiMAX Applications,” **communicated** to *IEEE Wireless and Propagation Letters*.

# complete\_thesis\_report.pdf

## ORIGINALITY REPORT

18%

SIMILARITY INDEX

10%

INTERNET SOURCES

11%

PUBLICATIONS

6%

STUDENT PAPERS

## PRIMARY SOURCES

1

[dspace.thapar.edu:8080](https://dspace.thapar.edu:8080)

Internet Source

2%

2

[www.jpier.org](http://www.jpier.org)

Internet Source

1%

3

Submitted to Thapar University, Patiala

Student Paper

1%

4

[ijarece.org](http://ijarece.org)

Internet Source

1%

5

[dyuthi.cusat.ac.in](http://dyuthi.cusat.ac.in)

Internet Source

1%

6

Proceedings of the International Conference  
on Recent Cognizance in Wireless  
Communication & Image Processing, 2016.

Publication

1%

7

Submitted to Higher Education Commission  
Pakistan

Student Paper

<1%

8

[ethesis.nitrkl.ac.in](http://ethesis.nitrkl.ac.in)

Internet Source

<1%

9

Kaushik, Sumit, Sukhwinder Singh Dhillon,