

**STUDIES ON STACKED FRACTAL MICROSTRIP
ANTENNAS FOR WIRELESS COMMUNICATION**

Thesis submitted towards the partial fulfillment of the requirements for the award

of degree of

MASTER OF ENGINEERING

IN

WIRELESS COMMUNICATION

Submitted By

Rajesh Kumar

Roll No. 801363025

Under the guidance of

Ms. Amanpreet Kaur

Assistant Professor, ECED

Thapar University, Patiala



ELECTRONICS AND COMMUNICATION ENGINEERING

DEPARTMENT

THAPAR UNIVERSITY

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

PATIALA – 147004, PUNJAB, INDIA

July 2015

DECLARATION

I hereby declare that the thesis report entitled "STUDIES ON STACKED FRACTAL ANTENNA FOR WIRELESS APPLICATIONS" is an authentic record of my study carried out as requirement for the award of degree of M.E. (Wireless Communication Engineering) at Thapar University, Patiala, under the supervision of Ms. Amanpreet Kaur, Assistant Professor, Electronics and Communication Engineering Department.

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

Date: 14/07/2015

Rajesh Kumar
Rajesh Kumar

Roll No 8013630025

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

Date: 14/07/2015

Amanpreet Kaur
Ms. Amanpreet Kaur 14/7/2015

Assistant Professor,

ECED

Countersigned By:

(Dr. Sanjay Sharma)
(Dr. Sanjay Sharma)

Professor and Head ECED

Thapar University, Patiala

(Dr. S.S Bhatia)
(Dr. S.S Bhatia)

Dean of Academic Affairs

Thapar University, Patiala

ACKNOWLEDGEMENT

I would never been able to finish my thesis without the supervision of faculty of my department, help from friends, and provision from my family.

I would like to utter my deepest thankfulness to my guide, **Ms Amanpreet Kaur**, Assistant Professor ECED, Thapar University, Patiala, for her excellent guidance, caring, patience, and providing me with an excellent atmosphere for doing research.

I would like to thank **Dr. Sanjay Sharma**, Professor and Head, ECED, Thapar University, Patiala, for granting us with sufficient facilities and infrastructure to carry our work.

I would like to acknowledge **Dr. Hemdutt Joshi**, Assistant Professor and Program Coordinator (WC), ECED, Thapar University, Patiala, for being a source of inspiration for us during our research work.

I would also like to thank the entire faculty and staff of Electronics and Communication Engineering Department, and then friends who devoted their valuable time and help me in all possible ways toward successful completion of this work.

Finally, I would like thank my parents. They were always supporting me and inspiring me with their best wishes.

Place: TU, Patiala

Rajesh Kumar

Date:

Roll No 801363025

ABSTRACT

The wireless industry has undergone a volatile emergence today in present era. Antenna the most important component of wireless system demand versatility and unobtrusiveness. Need of multi-band antennas are increasing day by day due to the need of covering maximum applications. Fractal plays a prominent role for these requirements. Fractals have non-integral dimensions and their space filling capability could be used for miniaturizing antenna size and their property of being self-similarity in the geometry leads to have antennas which have a more number of resonant frequencies. Fractal geometries when applied to UWB generator patch, improves Gain, return loss and radiation characteristics. Often fractal antenna does not require any matching components to achieve multiband or broadband performance. In the research work presented a circular triangular fractal antenna, a stacked fractal antenna based on sierpinsiki carpet fractal geometry and a Tree shaped fractal antennas are designed and simulated using CST (computer simulation technology) microwave studio v10. Circular triangular fractal antenna operating in frequency band of 3.3 GHz to 13 GHz with B.W of 9.7 GHz is designed and simulated. The main constraint of UWB antenna is its low gain. Gain enhancement techniques i.e. stacking and high gain cavity are used to increase the gain of reference antenna. Stacked fractal antenna based on sierpinsiki carpet fractal geometry is designed and simulated. In The miniaturization of microstrip stacked antenna is achieved using DGS and fractal geometry. Antenna resonates at 3.6 GHz and 4.4 GHz with a gain of 6.334 dB and 6.114 dB. Tree shaped fractal antenna is designed, simulated and fabricated. This designed antenna suits the wireless application of WLAN and WiMAX band with band width of 3 GHz. In order to verify the antenna application in the practical scenario, the dual band antenna is fabricated and tested, the results are found to be closely matching with simulated ones; thereby allowing the antenna to be suitable for practical wireless scenario.

TABLE OF CONTENTS

Topic	Page no
Declaration.....	i
Abstract.....	ii
Acknowledgment.....	iii
Table of contents.....	iv-vi
List of figures.....	vii-viii
List of tables.....	ix
Abbreviations.....	x
Chapter 1 INTRODUCTION	
1.1 Introduction.....	1
1.2 Wireless communication system.....	1
1.2.1 First generation.....	1
1.2.2 Second generation.....	2
1.2.3 Third generation.....	2
1.2.4 Fourth generation.....	2
1.3 WLAN standards (Wireless local area network).....	3
1.4 WiMAX standards (Worldwide interoperability for microwave access).....	4
1.5 UWB standards (Ultra wide band).....	4
1.6 Micro strip antenna (MSA).....	5
1.7 Parameters for analyzing an antenna performance.....	6
1.7.1 VSWR and input impedance.....	6
1.7.2 Radiation pattern.....	6
1.7.3 Gain.....	6
1.7.4 Impedance Bandwidth.....	7
1.8 Fractal antenna.....	8
1.9 Properties of fractals.....	9
1.9.1 Space filling property.....	9
1.9.2 Multi band requirement.....	9
1.10 Iterated function system.....	10
1.11 Types of fractals.....	10

1.11.1 Koch Curve.....	10
1.11.2 Sierpinski triangle.....	11
1.11.3 Hilbert curve.....	11-12
1.12 Stacked Micro strip antenna.....	12-13
1.13 Brief overview of the report.....	13
Chapter 2 LITERATURE SURVEY	
2.1 Basics of fractal geometry.....	15-16
2.2 Basics of Sierpinski gasket fractal antenna.....	16
2.3 Application of fractal antenna.....	16-17
2.4 Stacked fractal microstrip antenna.....	18-19
2.5 Research gaps.....	19
2.6 Objectives of research.....	19-20
Chapter 3 DESIGN of TRIANGULAR FRACTAL ANTENNA EMBEDDED in a CIRCLE for UWB	
3.1 Introduction.....	21
3.2 Design of circular triangular fractal UWB antenna.....	21
3.2.1 Dimensions of circular patch.....	21-22
3.2.2 Dimensions of Substrate, Microstrip feed line and Partial ground plane.....	22-23
3.3 Simulation results.....	23
3.3.1 Return loss.....	23
3.3.1.1 Return loss of 1 st iterated proposed antenna.....	23
3.3.1.2 Return loss of 2 nd iterated proposed antenna.....	23-24
3.3.1.3 Return loss of final stage of iteration.....	24
3.3.2 Gain.....	24-25
3.3.3 Surface current.....	25
3.4 Design of circular triangular fractal antenna with stacking technique.....	26
3.4.1 Design of the antenna.....	26
3.4.2 Simulation results.....	26
3.4.2.1 Return loss.....	26-27
3.4.2.2 Gain.....	28-29
3.5 Design of circular triangular fractal UWB antenna with high gain cavity.....	29

3.5.1 Design of the antenna.....	29
3.5.2 Simulation results.....	30
3.5.2.1 Return loss.....	30
3.5.2.2 Gain.....	30-31
3.6 Conclusion.....	31-32

**Chapter 4 STACKED FRACTAL ANTENNA for WLAN and INSAT/ SUPER
EXTENDED C-BAND**

4.1 Introduction.....	32
4.2 Sierpinski carpet fractal geometry.....	32
4.3 Design of proposed antenna.....	32
4.3.1 DGS (Defected ground structure).....	34
4.4 Simulation results.....	34
4.4.1 Return loss.....	34
4.4.2 Gain.....	34
4.4.3 Return loss without using DGS.....	34
4.4.4 Surface current.....	35
4.5 Conclusion.....	36

Chapter 5 TREE SHAPED FRACTAL ANTENNA for WLAN AND WiMAX

5.1 Introduction.....	37
5.2 Design of proposed antenna.....	37
5.3 Simulation results.....	38
5.3.1 Return loss.....	39
5.3.2 Gain.....	39
5.4 Surface current.....	40
5.5 Conclusion.....	40

Chapter 6 FABRICATION and TESTING of DESIGNED ANTENNA

6.1 Introduction.....	41
6.2 Fabrication process steps.....	41
6.3 Equipment used.....	42
6.4 Fabricated Antenna Design.....	42

6.5 Testing Results.....	43
6.6 Comparison of simulated and tested antenna.....	43
Chapter 7 CONCLUSIONS and FUTURE SCOPE	
7.1 Conclusion.....	45
7.2 Future scope.....	46
References.....	47
List of Publications	53

List of Figures

S.No. Name of figure no	Page
1.1 Structure of Micro-Strip Patch Antenna.....	5
1.2 Example of radiation pattern.....	7
1.3 The fractal geometry of coastline, bronchial. Snowflake and lightening.....	8
1.4 Basic Koch geometry.....	11
1.5 Sierpinski gasket.....	11
1.6 Hilbert Curve.....	12
1.7 Stacking of micro strip antenna.....	13
3.1 Antenna design at different stages of iteration of fractal geometry.....	22
3.2 Return loss of 1st iterated proposed antenna	23
3.3 Return loss of proposed antenna after 2 nd iteration.....	24
3.4 Return loss of proposed antenna after 3 rd iteration.....	24
3.5 Gain of proposed antenna at 4 GHz, 9GHz and 11 GHz.....	25
3.6 (a) surface current distribution at patch.....	26
3.6 (b) surface current distribution at ground plane.....	26
3.7 Design of proposed antenna.....	27
3.8 Return loss characteristics of proposed antenna.....	28
3.9 Gain of proposed antenna at 4 GHz, 9GHz and 11GHz.....	28
3.10 Design of high gain cavity back UWB fractal antenna.....	29
3.11 Return loss characteristics of high gain cavity antenna.....	30
3.12 Gain of proposed antenna at 4 GHz, 9GHz and 11 GHz.....	30
3.13 The comparison of return loss characteristics of reference antenna, high gain cavity and superstrate antenna.....	31
4.1 The different stages of iteration of sierpinsiki carpet fractal geometry.....	33
4.2 Geometry of Patch and DGS based ground plane.....	34
4.3 Geometry of upper patch and overall antenna.....	34
4.4 The return loss graph of proposed antenna.....	36
4.5 Gain of proposed antenna at 3.6 GHz and 4.4 GHz.....	36

4.6 Return loss of proposed antenna without using DGS.....	37
4.7 Surface current on lower patch.....	37
4.8 Surface current on upper patch	37
4.9 Showing surface current on ground plane.....	38
5.1 Design of proposed tree shaped antenna.....	40
5.2 Return loss of proposed antenna showing resonant frequencies.....	41
5.3 Gain of proposed antenna at 3.6 GHz and 5.6 GHz.....	42
5.4 The surface current distribution of proposed tree fractal antenna	42

List of Tables

S.No. no	Name	Page
1.1	Different WLAN standards.....	3
1.2	Different WiMAX standards.....	4
3.1	Dimensions of proposed antenna	
3.2	The comparison of Gain of proposed antenna at different stages of iterati.	25
3.3	Comparison of gain b/w reference antenna and antenna with superstrate...	29
3.4	Showing the comparison of different techniques applied to antenna.....	32
4.1	The dimension of lower and upper patch at different stages of iteration.....	34
4.2	Showing dimensions of substrate and feed line.....	34
5.1	Dimensions of patch at different stages of iteration	40
5.2	Dimension of substrate, Ground plane and Feed line.....	40
7.1	Comparison of parameters of different proposed designs.....	44

ABBREVIATIONS

CDMA	Code Division Multiple Access
FDMA	Frequency Division Multiple Access
GSM	Global System for Mobile Communications
MPA	Microstrip Patch Antenna
VNA	Vector Network Analyser
WiMAX	Worldwide Interoperability Microwave Access
WLAN	Wireless Local Area Network
CST	Computer Simulation Technology
DGS	Defected Ground Structure
UWB	Ultra Wide Band
Wi-Fi	Wireless Fidelity
ISM	Industrial, scientific and medical radio frequency band
LOS	Line of Sight
B.W	Band Width

Chapter 1

INTRODUCTION

1.1 Introduction:

Wireless technology has undergone different stages of development since its emergence. It has covered many evolutionary paths and has improved performance and efficiency in mobile environment [1]. The electromagnetic spectrum is a natural resource and this resource is fully utilized by wireless communication systems. In the communication industry, wireless communication is growing very rapidly. From the last few years cellular systems have grown exponentially and there are billions of users all over the world. The cellular systems have become a major business tool in the world and an important part of our daily life in almost all the leading countries [1]. The name “Wireless” is basically used for referring a radio transmitter and receiver. An antenna forms an indispensable part of a wireless communication system & is used for transmission and reception of electromagnetic waves. It acts as a transducer to convert electrical energy to electromagnetic waves and vice versa.

1.2 Wireless Communication System:

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

1.2.1 First Generation

The First Generation of wireless technology was introduced in 1980. This generation used analog telecommunications standard which were used to transmit voice signals. Analog signals are basically radio signals sent in a wave like form. In this generation frequency division multiple access technology (FDMA) was used and all the users shared the given frequency spectrum within the system [1]. In First generation, the analog wireless

network is used which is narrowband and we can have voice calls and can send text messages. All the above services are provided with the help of circuit switching.

1.2.2 Second Generation

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

1.2.3 Third Generation

Later in the 20th century, third generation of mobile technology came into existence. It was developed to overcome the limitations of 2G. In third generation wideband wireless network is used which increases the clarity of voice and gives the perfection of real conversation. The technology used for sending data is packet switching [1]. The information transfer rate is 2 Mbps per second. Later development of 3G often denoted as 3.5G and 3.75G provides broadband access up to several Mbps for modems used in laptops and smart phones. The operating frequency range of 3G is 2100 MHz and bandwidth is 15-20 MHz. Applications of 3G wireless technology are mobile internet access, multimedia messaging service (MMS), video calling, voice telephony, mobile TV, gaming and fixed wireless internet access.

1.2.4 Fourth Generation

4G is the wireless telecommunication technology which is succeeding the 3G wireless technology. 4G promises a high downloading speed. It is expected to have a data transmission rate of 20,000,000 bit/sec. This is possible with the help of various techniques such as Orthogonal Frequency Division Multiplexing (OFDM), self-adaptive modulation, multiple carriers and so on. The technology used for sending data is packet switching. The capacity of fourth generation wireless technology is much more times greater than 3G technologies and therefore data transmission rate is high as compared to 3G. Two popular candidates of 4G are WiMAX (Worldwide interoperability for Microwave Access), WLAN (wireless local area network), UWB (ultra wide band) and

LTE (Long Term Evolution). WLAN is also very promising technology and provides various data services to the mobile users. These two technologies are explained in next section.

1.3 WLAN Standards (Wireless Local Area Networks):

A wireless local area network (WLAN) is a wireless computer network that links two or more devices using a wireless distribution method within a limited area such as a home, school, computer laboratory, or office building. This gives users the ability to move around within a local coverage area and still be connected to the network, and can provide a connection to the wider internet. Most modern WLANs are based on IEEE 802.11 standard, marketed under the Wi-Fi brand name. Using this wireless distribution method, two or more devices are linked in WLAN. The wireless distribution method is either OFDM radio or spread spectrum. It usually provides a connection to the wider internet through an access point (AP) [3]. Due to this users can move around inside the local coverage area and still they will be connected to the network. In WLAN people can use their laptops and computers anywhere within the local area network such as within a building, office and educational institutes same as people can use their cordless phones anywhere in the home. WLAN has gained so much importance because use of laptops and computers are increasing day by day and WLAN system is also very easy to install. IEEE 802.11 standard is the most widely used standard in WLANs and in market it is called as Wi-Fi.

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

Table 1.1 Different WLAN standards

1.4 WiMAX Standards (Worldwide Interoperability for Microwave Access):

WiMAX (Worldwide Interoperability for Microwave Access) is a wireless communication standard. The name "WiMAX" was created by the WiMAX Forum, which was formed in June 2001 to promote conformity and interoperability of the standard. The air interface of WiMAX technology is based on the IEEE 802.16 standards. This standard has a data transmission rate of 30 to 40 Mbps. For fixed stations WiMAX provide data rate up to 1Gbit/s. With variety of devices WiMAX gives broadband connectivity in almost all the cities as well as countries. It also provides data and telecommunication services and a source of internet connectivity.

Parameters	802.16	802.16 a	802.16 e
Spectrum	10-66 GHz	2-11 GHz	2-6 GHz
Data rate	32-134 Mbps	75 Mbps	15 Mbps
Channel conditions	LOS	Non-LOS	Non-LOS
Typical cell radius	2-5 km	7-10 km	2-5 km
Application	Fixed	Fixed and portable	Mobility

Table 1.2 Different WiMAX standards

1.5 UWB Standards (UWB):

The federal Communication Commission (FCC)'s allocation of the frequency band 3.1–10.6 GHz for commercial use has a sparked attention on ultrawideband (UWB) antenna technology. UWB technology facilitates high data rate of 500 Mbps. In the last decade, several ultrawideband (UWB) antenna types have been developed as a result of major advances in communication and narrow pulse applications. By means of UWB antennas, high data rate transmission can be transmitted in short-range local networks and short-duration pulses [4]. The UWB antennas are used in the applications of UWB communication, ground-penetrating radar, through-wall radar, medical imaging, and precision location systems [5].

Till now variety of antennas are used for different applications. Some of these antennas are wire antenna, Log periodic antenna, aperture antenna, travelling wave antenna and reflector antenna etc. All above mentioned antennas have common drawback of having very large size. Moreover different latest techniques like DGS, Fractal geometry, EBG cannot be applied to these antennas. Most of these antennas are single band antennas. Due

to requirement of multiband and low profile antenna, MSA are introduced. MSA is explained in next section.

1.6 Micro Strip Antenna (MSA):

A microstrip antenna (MSA) is a printed antenna on a dielectric substrate. Usually electrical permittivity of substrate ranges between 2 to 12. These antennas are low profile, conformable to planar and nonplanar surfaces, simple and inexpensive to manufacture using modern printed-circuit technology, mechanically robust when mounted on rigid surfaces [6]. G. A. Deschamps introduced the concept of microstrip antenna in 1953 at the third USAF symposium on antennas. It gained importance in 1970 and was used in various applications at that time [7]. After 1970 large number of authors explained the radiations coming from the ground plane with the dielectric substrate for different designs of antenna. Howell [8] and Munson [9] developed the first antenna which was practical antenna.

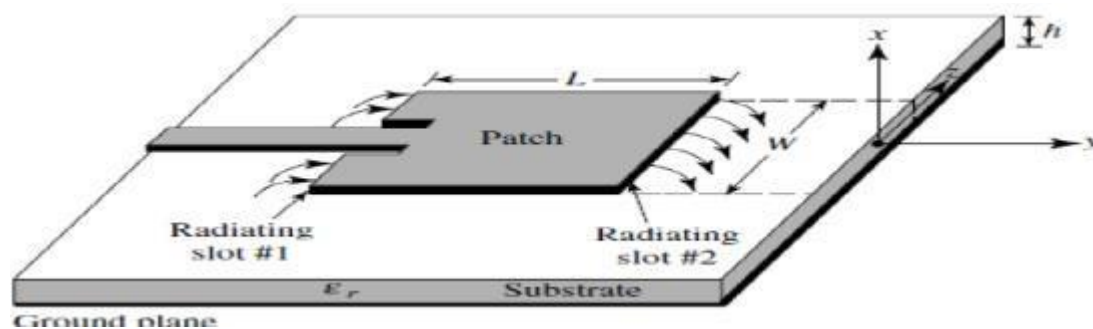


Fig 1.1 shows a MSA with a inset feeding technique [6]

However a MSA has several shortcomings; some of which are listed below:

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

Some techniques are introduced in the literature that helps in improving the antenna's performance. One of the techniques that can be used is the use of fractal geometry into microstrip antenna. Fractal geometry is one such technique that improves the gain, radiation pattern characteristics and return loss of a micro strip antenna [10].

1.7 Parameters for Analyzing an Antenna Performance:

In order to judge the antennas performance using the mentioned techniques, a few antenna parameters are referenced. If the antenna specifies an appreciable level at each parameter, it is supposed to be a good antenna.

1.7.1 .1 VSWR and Input Impedance:

VSWR gives the measure of matching between transmission line characteristic impedance and input terminal impedance of antenna. It can also be measured from return loss, which means that it is also an indicator of the antenna efficiency. The return loss graph of antenna gives information about these two parameters. Low value of return loss indicates maximum impedance matching between transmission line and patch. Antenna radiates efficiently when value of VSWR lies between 1 and 2.

Input impedance of antenna is given by expression given below

$$Z_{in} = R_l + R_r + j X_A \dots\dots\dots(1.1)$$

Where Z_{in} is the input impedance, R_l is the loss resistance; R_r is the radiation resistance and represents the reactance. The input impedance of an antenna is made equal to the transmission line characteristic impedance to facilitate the maximum power transfer between the transmission line and the antenna. If there is a mismatch between both impedances, power will be reflected back to the transmitter and results in low efficiency of an antenna [6].

1.7.2 .2 Radiation Pattern:

An antenna radiation pattern is defined as the graphical representation of the radiation properties such as radiation intensity, field intensity and polarization of antenna as a function of space coordinates. Radiation patterns are congenitally represented in spherical coordinates [6]. Fig 1.2 shows the radiation pattern of half wave dipole.

1.7.3 Gain:

The Absolute Gain of an antenna is defined as the ratio between the antennas radiation intensity in a certain direction and the intensity that would be generated by an isotropic antenna fed by the same input power, therefore it can given by:

$$G(\theta, \phi) = \frac{U(\theta, \phi)}{U_o} \dots\dots\dots(1.2)$$

Where $U_o = P_{in} / 4\pi \dots\dots\dots(1.3)$

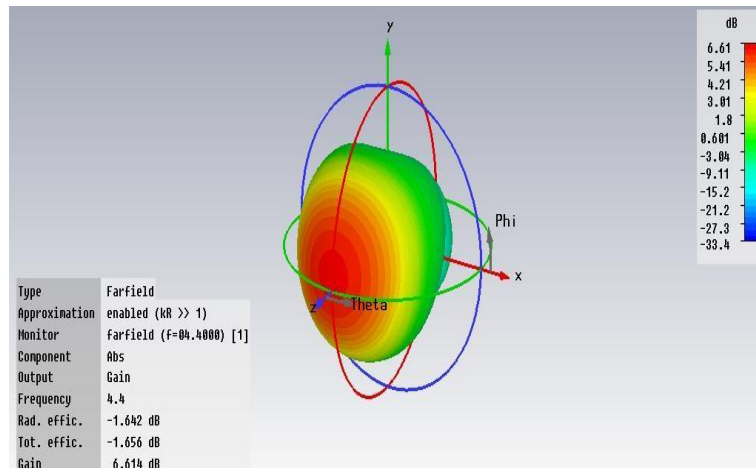


Fig 1.2 Example of radiation pattern

Where $G(\theta, \phi)$ the gain of the antenna in a certain direction is, $U(\theta, \phi)$ is the radiation intensity in a certain direction and U_0 is the radiation intensity of an isotropic antenna. P_{in} is the input power.

The Relative Gain of an antenna is defined as the ratio between the antenna radiation intensity in a certain direction and the intensity that would be generated by a reference antenna [6].

1.7.4 .4 Impedance Bandwidth:

It is defined as range of frequency over which VSWR (2:1 or less) or the coefficient reflection (less than 10 dB) remains in acceptable value. In other words it is a range of frequency in which antenna radiates efficiently.

$$B.W = \left(\frac{f^h - f^l}{f_c} \right) * 100 \dots\dots\dots (1.4)$$

$$f_c = \frac{f_h + f_l}{2} \dots\dots\dots (1.5)$$

Where, F_h represents the highest frequency and F_l represents the lowest frequency at which the VSWR (2:1 or less) or the coefficient reflection (10dB or less) is still acceptable; F_c represents the central frequency [6].

From the above parameters, VSWR and Gain are very crucial parameters required for any fractal antenna. Multiband antenna with $VSWR < 2$ and good gain is required for the concept of fractals to introduce.

1.8 Fractal Antenna:

The concept of Fractal Geometry was ideated by B.B.Mandelbort in 1975 and was derived from the Latin word “Fractus” which means “broken” or “Fractured”. Although fractals viewed as mathematical forums, they exist in all form of nature as shown in figure 1.3

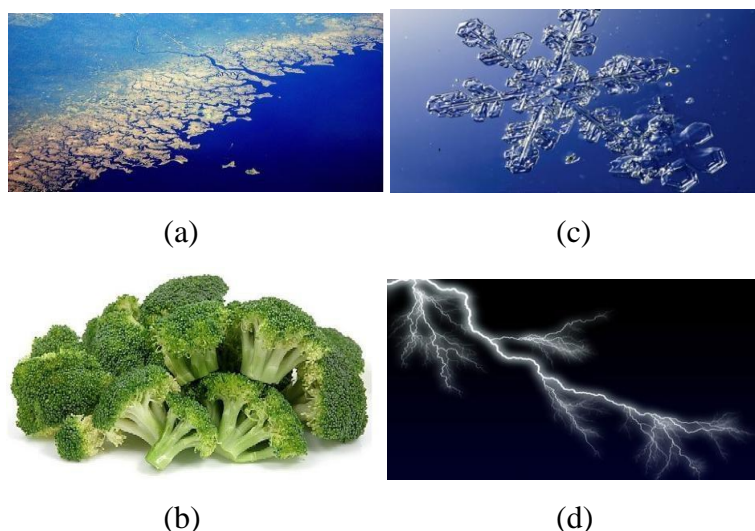


Fig 1.3 (a), (b), (c) and (d) show the fractal geometry of coastline, bronchial. Snowflake and lightening

Mandelbrot [11] discusses the basics of fractal theory as applied to the characteristics of a coastline. The length of a coastline depends on the size of the measuring yardstick. As the view of a coastline is brought closer, it was discovered that within the coastline there lie miniature bays and peninsulas. As coastline was examined on a down-scaled map, each of the bays and peninsulas contain sub-bays and sub-peninsulas. There is a self-similar trait observed at the coastline at various resolutions. The number of microscopic structures begins to approach infinity. This concept has been utilized in MSAs.

The application of fractal geometry to microstrip patch antenna was first introduced by Nathan Cohen in 1988, then a professor at Boston University. Cohen’s research work was first published in 1995, the first scientific publication about fractal antennas [11]. After that there has been a continuous work in this field to make antenna resonate at different resonant frequencies and to miniaturize using fractal geometry.

Cohen first implemented the fractal geometry on dipole antenna. There was a binding of wire in such a way that the length of the wire remains same but the size is reduced due to addition of consecutive fractal iterations.

1.9 Properties of Fractals:

1.9.1 .1 Space Filling Property:

As it is known that in order to use GSM band 900MHz frequency band is required. The wavelength corresponding to this band is roughly 33cm.in order to use $\lambda/4$ antenna, roughly 8.3 cm long antenna is needed. Antenna of this height is comparable to the size of Mobile. In order to encompass this length in small area, there is a need of Fractal antenna. Fractal uses self similarity and scale invariance to encompass large electrical length in small area .In this way electrical length of antenna increase to large extent. As the length of antenna based on wavelength increases, hence resonant frequency of antenna decreases [12].

$$\lambda = \frac{c}{f_r} \dots\dots\dots (1.6)$$

1.9.2 Multiband Requirement:

Antenna scaling factor is responsible for multiband characteristics of fractal antenna, which means that the different parameters (impedance, gain, pattern etc.) remain same if all the dimensions are scaled by same factor. Due to self similarity property geometry of fractal patch looks same at different scale and geometries at these different scales lead to different resonant frequencies without aberration in different parameters of antenna. These different frequencies are due to different path taken by current due to Indentations [12].

In modern scenario antenna is required to operate in different frequency bands in order to support different wireless technologies. for e.g. IEEE 802.11b/g in the band of 2.4GHz, IEEE 802.11a at 5.3GHz and 5.8GHz , Air traffic control radar .96 to 1.215GHz, GPS 1.227 to 1.575 GHz. The fractal antenna fulfill all above requirement due to its multiband characteristics. Multiband behavior comes from the fact that self similar design at different scales leads to patch antennas of different sizes thereby generating different resonant frequencies [11]. In order to generate multiple frequencies from a MSA, iteration function plays an important role.

1.10 Iterated Function System(IFS):

Fractals can be constructed using iterated function; this procedure is normally called Iterated Function Systems (IFS). Fractal geometry is created by repeating a certain set of

reference geometry at different scale. Instead of the word "repeat" mathematical synonym "iterate" is used and the process is called iteration. IFS (iterated function system) is another way of generating fractals. It is based on taking a reference figure and substituting it with several other identical ones.

These iterated function systems are based on the application of a series of affine transformations, w , defined by

$$W \begin{pmatrix} X \\ Y \end{pmatrix} = \begin{pmatrix} a & b \\ c & d \end{pmatrix} \begin{pmatrix} X \\ Y \end{pmatrix} + \begin{pmatrix} e \\ f \end{pmatrix} \dots\dots\dots (1.7)$$

Or equivalently, by

$$W(x, y) = (a*X + b*Y, c*X + d*Y + f) \dots\dots\dots (1.8)$$

Where a, b, c, d, e and f are real numbers. Hence, the affine transformation, w , is represented by six parameters

$$\begin{pmatrix} a & b \\ c & d \end{pmatrix} \text{ and } \begin{pmatrix} e \\ f \end{pmatrix} \dots\dots\dots (1.9)$$

Such that a, b, c and d control rotation and scaling, while e and f control linear translation. Now suppose we consider N as a set of affine linear transformations, and Let A be the initial geometry Then a new geometry, produced by applying the set of transformations to the original geometry, A , and collecting the results from can be represented by

$$W(A) = \bigcup_{n=1}^N W_n(A) \dots\dots\dots (1.10)$$

1.11 es of fractals:

Many types of fractal geometries are available but few are used more frequently for antenna designs are

1.11.1 Koch Curve:

The process of construction begins from the segment of single length, known as the zero generation of the Koch curve. In the next step generator is divided in three equal lengths. The center part is removed and is occupied by two tilted lines of same length as that of other two line segments. This process goes for an infinite number of times. It is clearly shown in figure that the width of Koch curve remains same but the perimeter increase leads to miniaturization of antenna. The same process implemented at different scale level depicts self similarity which leads to multi band characteristics of antenna [13].

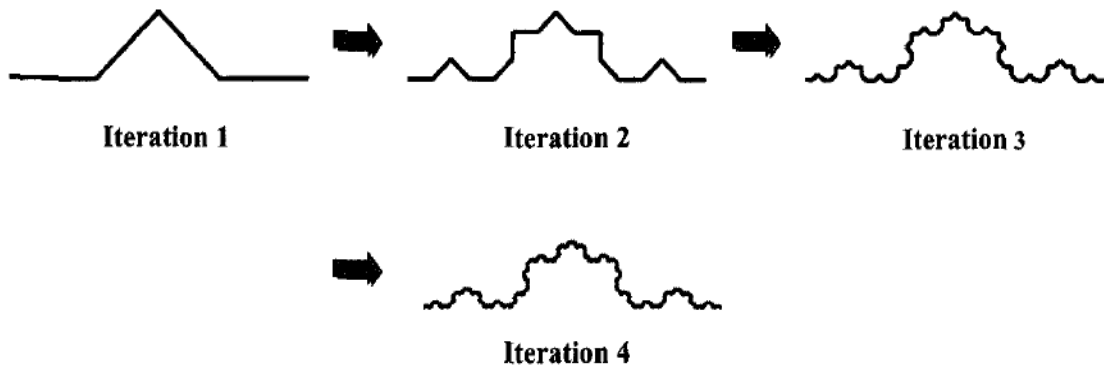


Fig 1.4 Basic Koch geometry [13]

1.11.2 Sierpinski Triangle:

In this type of Fractal geometry an equilateral triangle with area A is used as a generator. In first step triangle made by joining the midpoint of each side having area $A/4$ is removed. In second step three Triangles formed by joining the midpoint of three new formed triangle having area of each triangle $A/16$ i.e. total $3A/16$ area is removed. This similar process keeps on extracting more and more Number of Triangles thus increasing the perimeter at each stage [14]. It is clear from the figure that total area of triangle remains same but the perimeter increase leading to miniaturization of antenna. Self similar property is also self explanatory shown in figure 1.5.

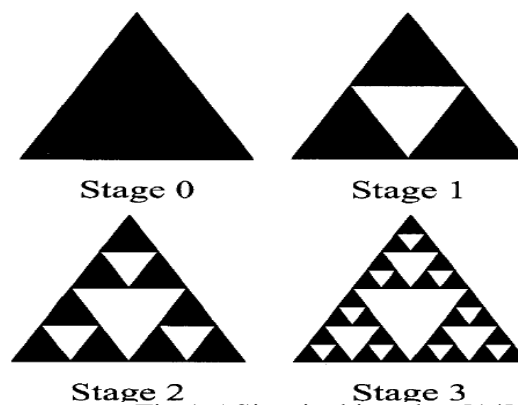


Fig 1.5 Sierpinski gasket [14]

1.11.3 Hilbert Curve:

These curves are plane filling curves, apart from being self-similar and simple. The geometries of the curve for first few fractal iterations are shown in fig 1.6. This indicates that for a given area, the total length of the line segment increase in near geometric progression, as the iteration order increases.

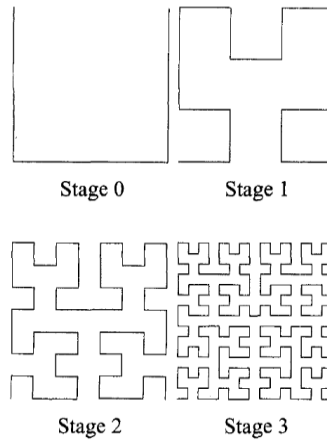


Fig 1.6 Hilbert Curve [13]

This can be interpreted as the cause for their relatively lower resonant frequency. It is clear that as the fractal iteration order increases, the total length of the line segment contributing the geometry increases in almost geometric progression, even as the area it encompasses remains same. Thus within a small area, a resonant antenna with the very large line length can be accommodated [15].

One of the major restraints of these multiband fractal antennas is their B.W. there are many ways to increase the B.W of Microstrip fractal antenna. Thick substrate and high electrical permittivity substrate can be used to increase the B.W of antenna. But these substrates lead to high surface waves which deteriorate the radiation efficiency of antenna, so stacking technique was used to fulfill this requirement. This technique is explained in next section.

1.12 Stacked Microstrip Antenna:

Fractal antenna provides multiband operation and space filling but B.W of fractal antenna is not of optimum value. Since B.W of antenna is directly proportional to volume of total substrate, so it has been observed that by placing a parasitic substrate over an active substrate, bandwidth can be increased. [16]

Stacked antenna consists of patch mounted on substrate. The ground plane is mounted on the back side of the patch. In case of stacked fractal antenna patch mounted on lower substrate is made up of any fractal geometry. On this antenna at some air gap one more substrate also known as superstrate is placed. The electrical permittivity of this substrate is less than as compared to lower substrate in order to enhance electromagnetic coupling.

The parasitic patch of same fractal geometry but of large dimensions as compared to lower patch is mounted on this superstrate. In this type of design lower patch is connected to feed line. This patch is known as active patch. Upper patch is excited by this lower patch. This geometry leads to high B.W dual band antenna. This geometry become more clear from figure

Figure 1.7 illustrates stacked fractal antenna based on sierpinsiki gasket fractal geometry. In this design lower patch is designed to resonate at 5.8 GHz (WLAN) and upper patch is designed to operate at 2.4 GHz (Bluetooth). In this design lower substrate has electrical permittivity of 4.4 and upper substrate has electrical permittivity of 2.4. The height of upper substrate is more as compared to lower substrate [17].

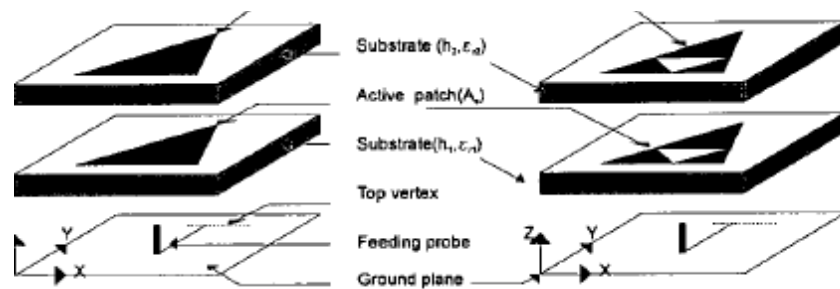


Fig 1.7 Stacking of micro strip antenna [17]

In literature survey it is found that most of the fractal antennas have low B.W. It is found that integration of stacking with fractal antennas leads to multiband high B.W antenna. The current research work mainly concentrate on design of fractal antenna and integration of stacking technique with fractal antenna to get desired antenna performance i.e. a multiband antenna with appreciable bandwidth at all the bands and a good gain for long distance applications.

1.13 Organisation of the Report:

Chapter 1 covers the Basics of WLAN, WiMAX and UWB, Microstrip antenna, Fractal geometry and its application to Microstrip antenna and Microstrip stacked antenna.

Chapter 2 presents the Literature survey based on basics of fractal geometry, sierpinsiki gasket fractal antenna, applications of microstrip fractal antenna and stacked microstrip

fractal antennas. Research gaps have been identified and objectives of the research work have been identified.

Chapter 3 gives the Design and simulation of Triangular fractal antenna embedded in a circle for UWB applications. The Gain of proposed antenna has been enhanced with gain cavity and superstrate technique.

Chapter 4 presents the Design and simulation of stacked fractal antenna for WLAN and INSAT/Super-extended C-band with a sierpinsiki fractal carpet structure.

Chapter 5 presents Design and simulation of Tree shaped fractal antenna for WLAN and WiMAX applications.

Chapter 6 covers the fabrication and testing of tree shaped fractal antenna for WLAN and WiMAX applications and comparison of results for validation

Chapter 7 presents the conclusion and future scope of the current research work.

Chapter 2

LITERATURE SURVEY

2.1 Basics of Fractal Geometry:

In 1992 Jampala presented a paper on classification of fractal geometries and its applications. This paper gave a general idea of this type of fractals, their generating techniques and applications. He explained that many examples of Fractals found in nature. Bends and branches in rivers, bursts of noise in transmission lines, clustering of stars, craters on the moon, shapes of snowflakes, mountain landscapes, eddies and turbulence. Lightning bolts, broken stars, Airport strips, spatial distribution of oil and other natural resources, price change and scaling In Economics, piano curves, Galaxy Clusters and many other phenomena could be expressed as Fractals [18].

In 1992 Liu et al presented a paper on formation and anomalous properties of fractal. In this paper author discussed three main research areas i.e. mathematical concept, examples of fractals and anomalous physical properties of fractal system [19].

In 1997 N. Cohen presented a paper on Fractal antenna application in wireless Telecommunication. Applying fractals to antenna elements allows for smaller, resonant antennas which are multiband/broadband and may be optimized for gain. No additional component was required in this antenna. These are simple and cost-effective to fabricate. Fractal Geometries also facilitate significant improvement in return loss and Gain of an antenna. These types of antennas could be mounted on small PCB board.[11]

In 2001 Best S.R presented the paper on the fractal loop: comparison of fractal and non fractal geometry was done. The purpose of this paper is to numerically model fractal and non fractal loop antenna occupying the same physical area in an effort to understand whether the fractal geometry of the loop is the significant parameter in determining the loop performance. This paper demonstrated that in case of loop antenna, fractal geometry does not give improved characteristics as compared to non fractal geometry [20].

In 2003 Douglas H.Werner et al presented a paper on overview of fractal Antenna Engineering Research. This paper gave overview of recent advances in development of

fractal antennas. In this paper application of fractal geometry to microstrip antenna was discussed [13].

2.2 Basics of sierpinski gasket fractal antenna:

In 2000 Baliarda et al proposed an iterative model of fractal antennas sierpinski gasket antenna. This model showed that fractal geometry of sierpinski gasket is responsible for its multi band characteristics. The model predicted the effects of variation of flare angle on multiband behavior of antenna. This model also showed that the log periodic nature of antenna is inherent to its fractal geometry. It had also been highlighted the self similar structure has by its very own nature a log periodic behavior [14].

In 2001 Junho Yeo Mitra R Presented a paper on Modified sierpinski gasket patch antenna for multiband applications. In this paper a multi band behavior of sierpinski fractal antenna had been studied, then to enhance the multi band behavior of antenna some modifications were introduced in geometry of sierpinski gasket antenna. It was observed that the height, the dielectric constant of substrate of the sierpinski patch, and the size of the upper triangular grid are function of resonant frequency of sierpinski patch. Novel technique for improving the multi-frequency characteristics of the sierpinski gasket patch antenna were studied [21].

2.3 Application of fractal antenna:

In 2001 Murad N.A et al presented a paper on Fractal patch antenna for GPS application. This paper presented the design of fractal patch antenna based on the basic structure of square antenna operate at 1.575 GHz for global positioning system application. In this paper, the fractal structure was intended to reduce the patch antenna size. As a part of the basic structure was removed at certain iteration factor, the electrical length of the antenna increase and this increased electrical length reduces the resonant frequency of an antenna [12].

In 2011 Suganthi.s et al proposed the Design of Miniature Fractal antenna. The numerical technique was used for the simulation of rectangular and fractal patch antenna of 0th, 1st and 2nd order iteration. The patches were designed on FR4 substrate of relative permittivity =4.3 and thickness h=1.53 mm. That showed resonant behavior at 2.4 GHz and 5.8 GHz with a gain of 3 dB and 5.8dB [22].

In 2011 A.kaka et al proposed a Multi-band and Miniaturized Monopole Antenna Design based on fractal geometry for UWB Wireless Applications. A new combined fractal geometry based Monopole antenna design for ultra wideband (UWB) applications was presented in this paper. Minkowski fractal technique was applied to the geometry of an antenna to have characteristics of multiband and miniaturization. Then sierpinski carpet geometry was applied to the first iteration of the minkowski fractal geometry. Gain of antenna varied from 4 dB to 6 dB. This antenna covered the whole UWB (i.e. 3.1 – 10.6 GHz) [23].

In 2007 Hyo-Won Song et al proposed Design of the Tree-Shaped UWB Antenna Using Fractal Concept. In this paper partial ground plane technique and fractal geometry was used to achieve a UWB. It was observed that with increase in number of stages of iteration, B.W and gain both increase due to increase in the impedance matching over the entire ultra wide band [24].

In 2012 Kailas K. Sawant et al proposed a novel CPW-fed circular square-corner fractal antenna with varying notch band for UWB applications. The design of this paper represented the novel CPW-fed circular square corner fractal antenna with varying notch-band frequency characteristics. This antenna exhibited ultra wide band characteristics from frequency ranges from 3.1 GHz to 15.0 GHz. The notch was created in operating frequency region in order to avoid interference with WLAN band. The gain of this antenna varied from 2.7 dB to 5 dB. This proposed antenna can be used for Ultra wide band (UWB) system, microwave imaging, precision position system, and radar tracking system [25].

In 2012 Ayachi Ajey et al presented a paper on Design and Analysis of Fractal Antenna for UWB applications. In this paper main factors contributing to the UWB characteristics were discussed. Fractal technique was adopted to improve radiation characteristics of the antenna. The impedance bandwidth of the proposed fractal antenna was 9.4 GHz ranging from 3.2GHz to 12.6 GHz with maximum gain of 6.2dB and efficiency of 98.66%. [26]

In 2014 M.A. Dorostkar et al proposed Design of a Novel Multi & Wideband Triangular-Circular Fractal Antenna for Mobile Communication and Upper UWB Applications. The antenna was designed using the triangular circular and elliptical ground with a partial ground plane. The antenna covered the frequency ranges from 0.9- 2.5 GHz, 5.4GHz-32GHz. The antenna was designed keeping in mind the requirement of low profile and UWB characteristics. This antenna covered the applications of RFID, DCS-

1800, PCS-1900, IMT-2000/UMTS, GPS, ISM (including WLAN), Wi-Fi, Bluetooth and upper UWB band.[27]

2.4 Stacked Fractal Microstrip Antenna:

In 2006 Mazlina Esa et al proposed Stacked Square Fractal Antenna with Improved Bandwidth for WLAN. This paper presented the design of stacked fractal microstrip antenna with a sandwich of air layer, operating between 5.15 GHz and 5.825 GHz. The square stacked microstrip antenna was found to perform well in terms of bandwidth, beamwidth and low cross polarization, despite its small size [28].

In 2006 Jaume Anguera et al, proposed Broadband Triple-Frequency Microstrip Patch Radiator Combining a Dual-Band Modified Sierpinski Fractal and a Monoband Antenna. A triple-frequency antenna combining a dual-band and a monoband antenna with broadside radiation patterns was designed. The dual-band antenna was formed by application of sierpinsiki fractal. This dual-band antenna was stacked over a monoband antenna. Due to stacking of dual band sierpinsiki gasket antenna over a monoband antenna, broadband characteristics were obtained [29].

In 2009 A.S.Elkorany et al presented a paper on ultra wideband stacked microstrip antenna. A novel ultra wideband stacked microstrip patch antenna (MPA) was proposed. In the new design the stacked patch is larger than the excited one. An impedance bandwidth of about 2.5:1 was achieved between 5.6 - 14.2 GHz when the excited patch and stacked one were co-centered [30].

In 2013 Vilenskiy Artem and Kletsov Andrey presented a paper on Ultra-Wideband Signals Radiation by Linear Arrays of Aperture Stacked Patch Antennas. A low-profile stacked ultra-wideband microstrip antenna was investigated as a radiator of ultra-wideband radio pulses with 50% relative bandwidth. Low permittivity materials such as Rogers RO 4003, Teflon and foam were used for antenna implementation. Linear antenna arrays designed on the basis of proposed stacked patch elements were investigated. Frequency-domain analysis demonstrated very good array elements matching and negligible mutual coupling. Transient radiated pulses were simulated for different observation angles in the antenna E-plane, energy patterns and fidelity factors were calculated. Time-domain results evidence small radiated pulse degradation and high fidelity factor values for broadside directions [31].

In 2014 Sumit Kumar et al proposed Miniaturized Inverted Multiband Stacked Triangular Fractal Patch Antenna for Wireless Communication. Geometry of this antenna was based on triangular shape inverted fractal patch which shows miniaturization and

multiband characteristics without degradation of its gain. Two shorting pins were used in the structure to make the antenna tunable as well as improve the value of return loss. This antenna resonates at 2.3367 GHz, 5.39 GHz, and 7.58 GHz with corresponding gain 8.68 dB, 7.30 dB and 6.33 dB [32].

2.5 Research Gaps:

Based on the literature survey following research gaps were found

- a) The use of parasitic elements and stacked patches has proved to improve the B.W of antenna. However, this technique results in high volume in spite of efficient results. Fractal technique can be integrated with stacked design to miniaturize the stacked antenna.
- b) In literature survey it was found that very complex defected ground structure like dumbbell shaped and T type slots were used. More work can be done in the field of defected ground structure shaping according to the resonant frequency of operation.
- c) It was found that shape of ground plane affect the UWB behavior of fractal antenna to large extent. So more work can be done in the field of ground plane shaping.
- d) There is no much work seen in the integration of UWB generator like circle, elliptical and triangular geometry with conventional fractal geometry like sierpinsiki and Koch. The integration of these two geometries leads to the improvement in radiation characteristics of antenna.
- e) It was found that improvement in gain was generally done at higher frequencies. So some technique must be applied to fractal antenna to increase the gain at low frequency.

2.6 Objectives of Research:

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

- a) To design and simulate Triangular fractal antenna embedded in circle for UWB application with a gain of around 5 dB.
- b) To apply Gain enhancement techniques i.e. High gain cavity and Superstrate technique to UWB Triangular fractal antenna embedded in circle for UWB to achieve a gain of 8 to 9 dB.
- c) To design a stacked fractal antenna for WLAN and extended C band application.

- d) To design a tree shaped fractal antenna for WLAN and WiMAX application having a gain of 2.2 dB and 3.6 dB.
- e) Fabrication and testing of antenna for tree shaped fractal geometry operating at WLAN and WiMAX band.

Chapter 3

Design of Triangular Fractal Antenna Embedded in a Circle for UWB Applications:

This chapter presents a novel circular triangular fractal microstrip feed antenna covering the band from 3.3GHz to 14 GHz. This design is simulated using the CST microwave studio. The gain of antenna varies from 2dB to 5.7 dB. The return loss of proposed antenna is less than 10 throughout the frequency band from 3.3 GHz to 14 GHz. This proposed microstrip fed circular triangular corner fractal antenna can be used for Ultra wide band (UWB) system, microwave imaging, precision position system, and radar tracking system.

3.1 Design of Circular Triangular Fractal UWB Antenna:

3.1.1 Dimensions of Circular Patch:

The current antenna is designed for resonant frequency of 3 GHz. Here circular patch is considered as an initial generator of UWB antenna. Then different perturbations are done on this basic geometry. Based on this resonant frequency, Diameter of circular patch is determined based on the following formula.

$$a_r = \frac{87.94}{f_r * \sqrt{\epsilon_r}} \dots\dots\dots (3.1)$$

Where a_r is diameter of circular patch,

f_r is resonant frequency of an antenna

ϵ_r is relative permittivity of substrate

The diameter of circle is found to be 13.9mm. An equilateral triangle of side length 11mm is cut from the circular patch forming first iteration of fractal geometry. This is followed by circle of diameter 6.8mm i.e. approx half of the diameter of initial generator, added to the patch. Then an equilateral triangle of side length 5mm is cut from the circle forming a second iteration of fractal geometry. A circle of diameter 3.4mm i.e. one fourth of the diameter of initial generator is added to the patch. Then again an equilateral triangle of side length 2.5mm is cut from the circle forming third iteration of fractal geometry. This process can be repeated up to infinite iteration. But practically infinite iterate structure is not possible due to fabrication constraints. Third iterative fractal antenna has been finalized to design on the

same substrate dielectric constant and thickness as conventional micro strip monopole antenna. Different stages of iterations are shown in figure3.1.

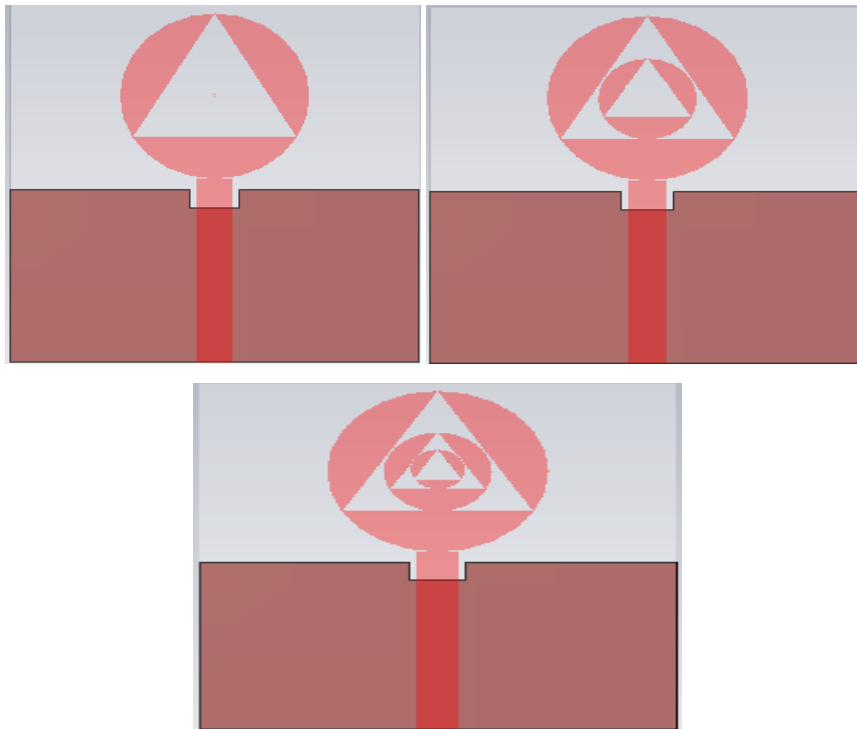


Fig 3.1 Proposed antenna design at different stages of iteration of fractal geometry

3.1.2 Dimensions of Substrate, Microstrip Feed Line and Partial Ground Plane

Dimensions of microstrip feed line are calculated using the transmission line model. The height of patch and microstrip feed line are taken as 0.07mm. Here partial ground plane act as an impedance matching circuit which insures that maximum current flow from feed line to circular patch. In this antenna design circular patch act as reactive Reactance. Partial ground plane act as capacitive Reactance. The capacitance of partial ground plane varies with the length of partial ground plane. The length, at which resonance occurs, is optimum length for simulation [49]. The width of ground plane is equal to that of substrate. The dimensions of substrate, microstrip feed line and ground plane are given in table 3.1.

	Substrate	Partial ground plane	Feed line
Length(mm)	30	14.5	15.4
Width(mm)	30	30	2.7
Height(mm)	1.6	0.07	0.07

Table 3.1 showing dimensions of proposed antenna

3.2 Simulation Results:

3.2.1 Return Loss:

3.2.1. a Return Loss of 1st Iterated Proposed Antenna:

It can be seen from fig 3.2 that proposed antenna does not radiate efficiently in UWB with application of first iteration of fractal geometry.

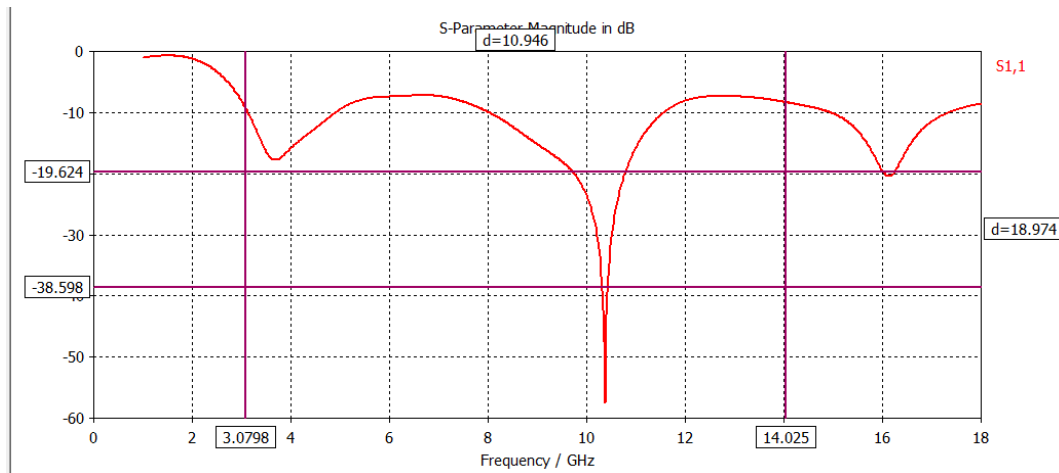


Figure 3.2 Return loss of proposed antenna after 1st iteration

3.2.1. b Return loss of 2nd iterated proposed antenna:

After application of second iteration of novel fractal geometry to the reference antenna there is a huge improvement in return loss of antenna. Now antenna radiates from 3.35 GHz to 12.923 GHz. But B.W of this antenna can further be increased and return loss can also be improved with application of 3rd iteration of fractal geometry.

The return loss of antenna is a measure of range of frequency over which antenna radiates properly. Return loss also gives information about how well proposed antenna impedance is matched. The proposed antenna operates in a band ranges from 3.3295 GHz to 13.984 GHz. This proposed antenna covers the WLAN band, satellite communication applications band and WiMAX band.

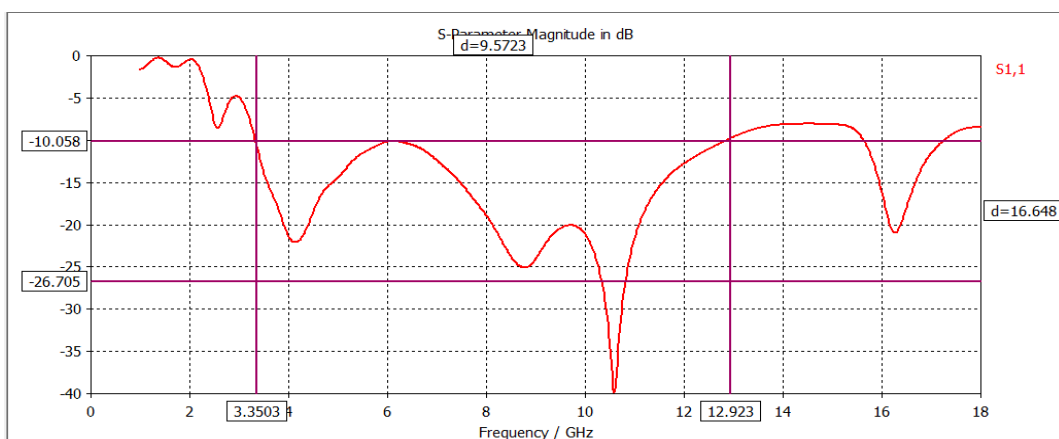


Fig 3.3 Return loss of proposed antenna after 2nd iteration

3.2.1. c Return Loss of Proposed Antenna after Final Stage of Iteration:

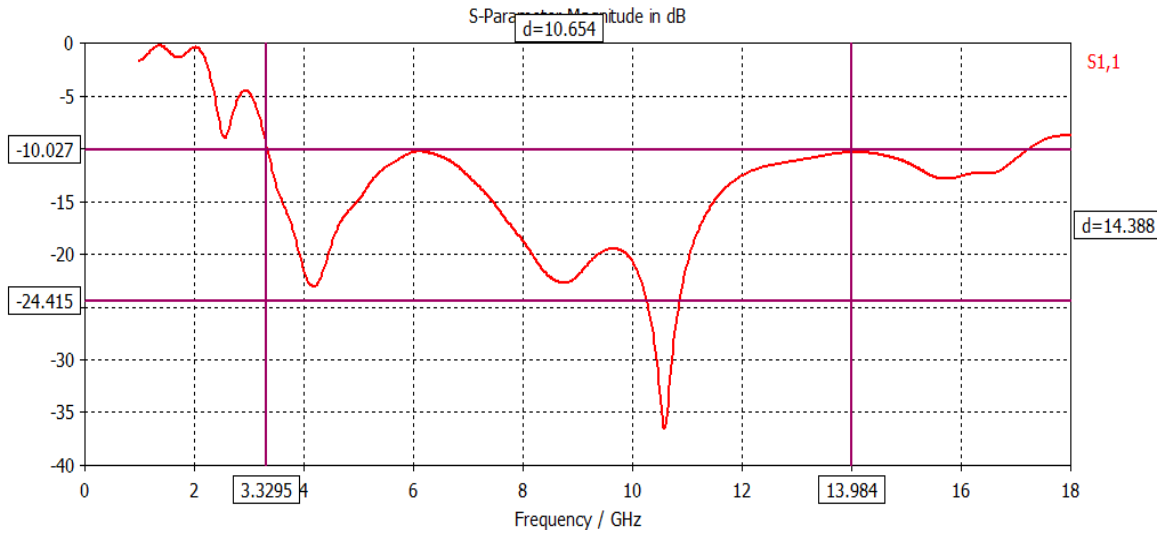
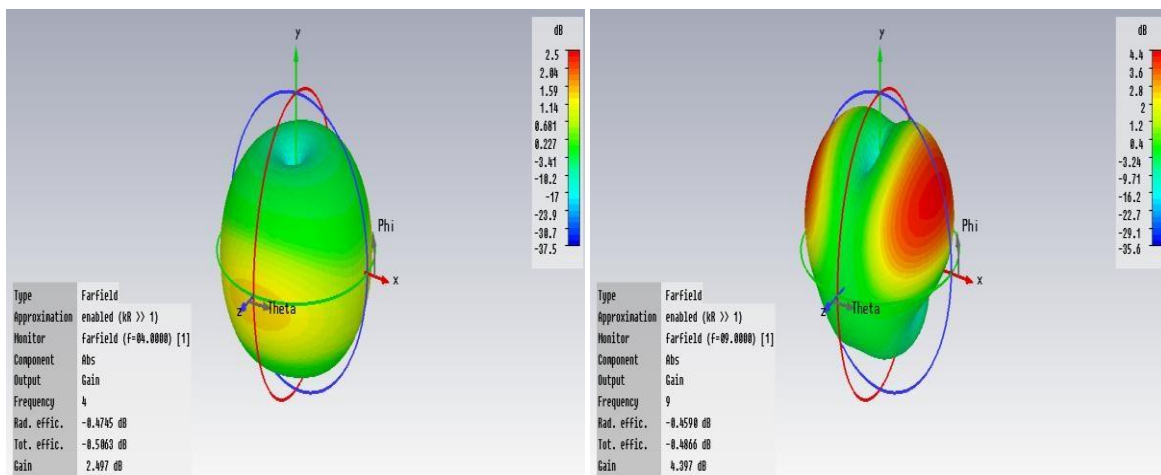


Fig 3.4 Return loss of proposed antenna after 3rd iteration

The bandwidth of proposed antenna is 10.65 GHz. The return loss characteristics of proposed antenna improve with the application of fractal geometry to the basic circular patch.

3.2.2 Gain:

The gain of proposed antenna varies from 2 dB to 5.9 dB. The 3D plot of gain of an antenna at 4 GHz, 9GHz and 11 GHz is shown in figure 3.5. As we know that Gain and Bandwidth product always remains constant, so as it is UWB antenna so it possesses low gain. But at high frequency Gain of this proposed antenna reaches a value of 5 dB.



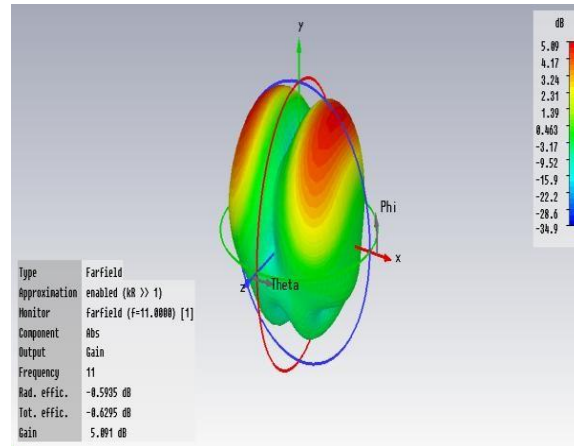


Fig 3.5 Gain of proposed antenna at 4 GHz, 9GHz and11 GHz

3.2.2. a Comparison of Gain of Proposed Antenna after 1st, 2nd and 3rd Iteration of Fractal Geometry:

Stag of iteration	Gain at 4 GHz	Gain at 9 GHz	Gain at 11 GHz
1 st	2.589 dB	3.778 dB	4.506 dB
2 nd	2.504 dB	4.382 dB	5.260 dB
3 rd	2.497 dB	4.397 dB	5.891 dB

Table 3.2 showing the comparison of Gain of proposed antenna at different stages of iteration. It is clear from the above table that except at lower frequencies gain of antenna increases with application of fractal geometry to the basic UWB generator i.e. circle. This is due to the more perturbations developed in the patch of antenna. Due to these perturbations radiation efficiency of antenna increases which increases the gain of antenna.

3.2.3 Surface Current:

Surface current is a very important factor in analyzing the behavior of an antenna. It gives information about current density on the different parts of the antenna. Accordingly, different techniques can be applied in order to supply maximum current to the patch. Fig 3.6(a) and 3.6(b) show the surface current on the patch and partial ground plane, respectively.

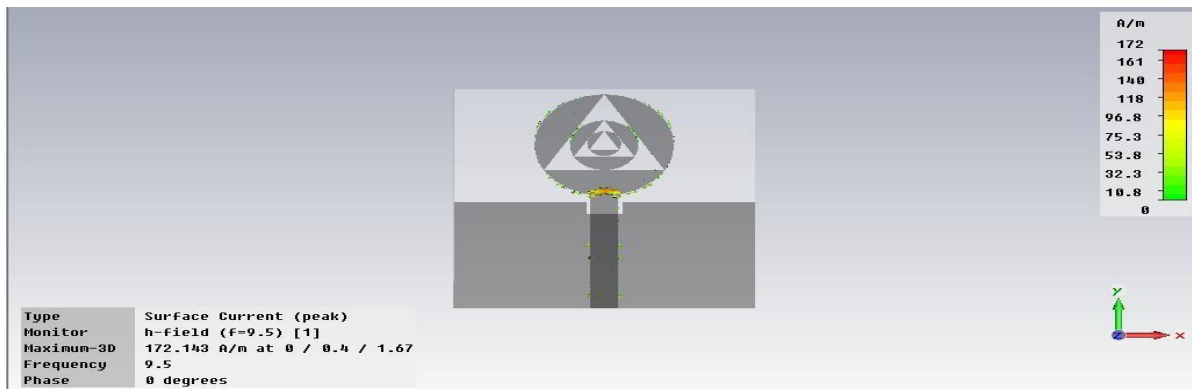


Fig 3.6(a) showing surface current distribution at patch

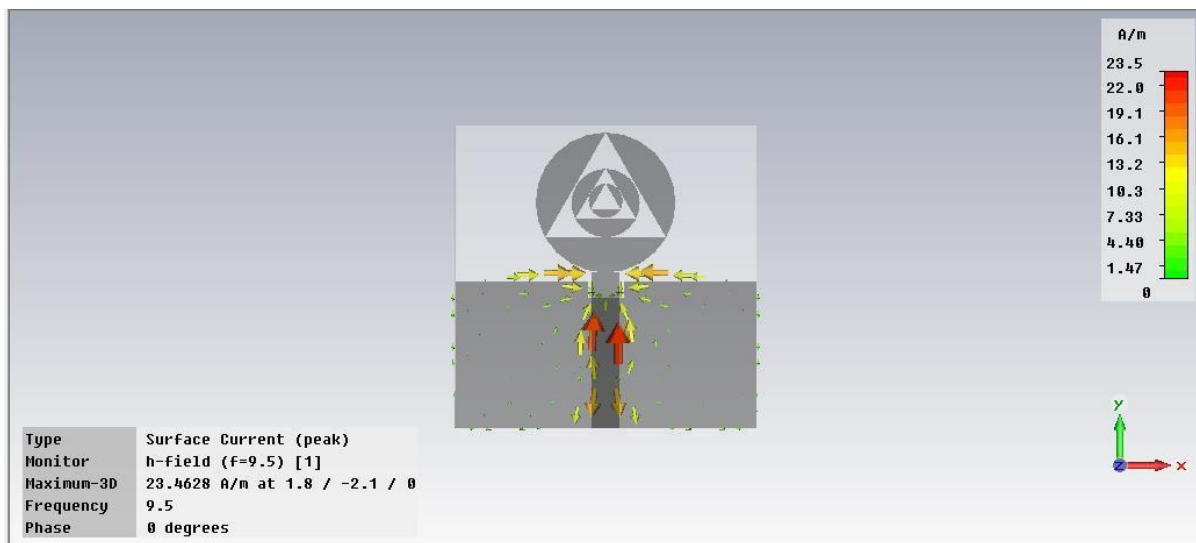


Fig 3.6(b) showing the surface current distribution at ground plane

The proposed antenna is based on novel triangular circular fractal geometry. This antenna operates efficiently throughout the frequency band from 3.3295GHz to 13.984GHz. Resonant frequencies of this antenna in its operating frequency range are 4GHz, 9GHz and 13 GHz. The gain of proposed antenna varies from 2 dB to 5.9 dB. In this chapter different stages of iteration of fractal geometries are also compared. It is found that with application of fractal geometry to the circularly polarized antenna, return loss, B.W and gain of antenna improves. In order to make the antenna suitable for long distances; high gain is required, for obtaining this, a superstrate technique is used, which is actually the stacked technique with fractal MSA.

3.3 Design of Circular Triangular Fractal Antenna with Increased Gain using Stacked Antenna with Air Gap.

In this technique, a substrate of thickness 1.58 and electrical permittivity of 2.48 is placed above the active patch in inverted manner. The circular triangular patch of same dimensions as that of active patch is placed on this substrate so called superstrate. This stacked structure enhances both gain and B.W of reference antenna.

3.3.1 Design of this Antenna:

In this technique Substrate having same dimensions, material and thickness is used as a substrate. On this substrate, Patch having the same structure as that of main patch is placed. This complete structure is placed on the main reference antenna at some air gap. The proposed antenna design is shown in figure below

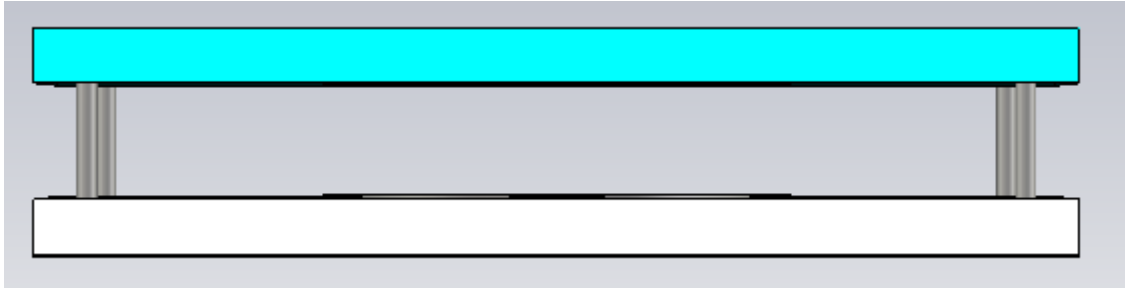


Fig 3.7 Design of proposed antenna

Here green color superstrate is of electrical permittivity 2.48 and height 1.58. The circular triangular corner patch of same dimensions and shape as that of reference antenna patch is mounted on this superstrate Making the structure a stacked patch antenna with two layers of antenna mounted on each other.

3.3.2 Simulation Results:

3.3.2. a Return Loss:The return loss graph shows that antenna radiates from 3.2462 GHz to 13.949 GHz. The B.W of this antenna is 10.7GHz. it remains unaltered with application of superstrate but the gain increases.

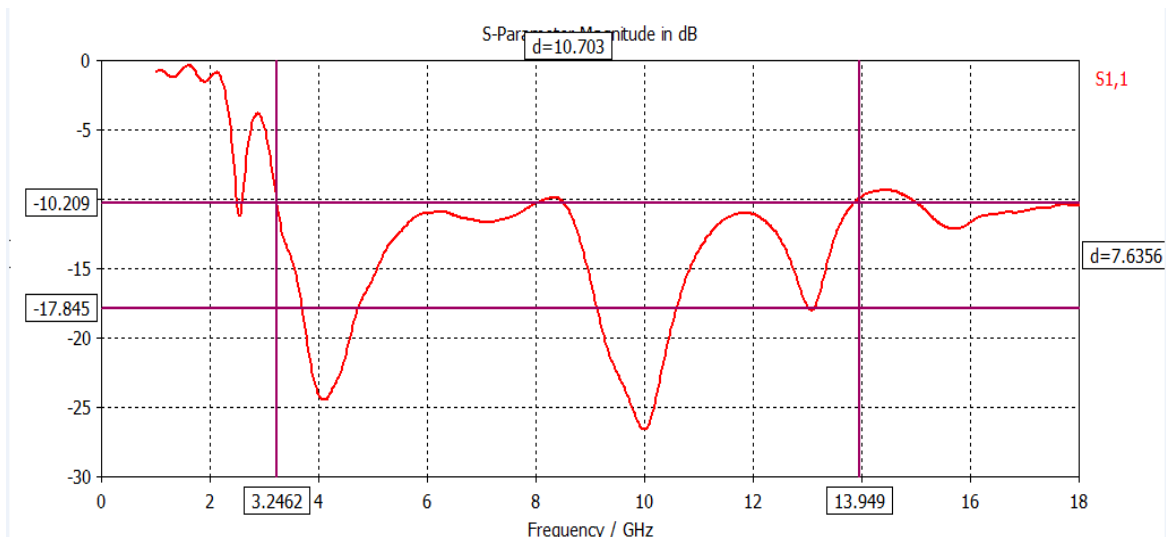
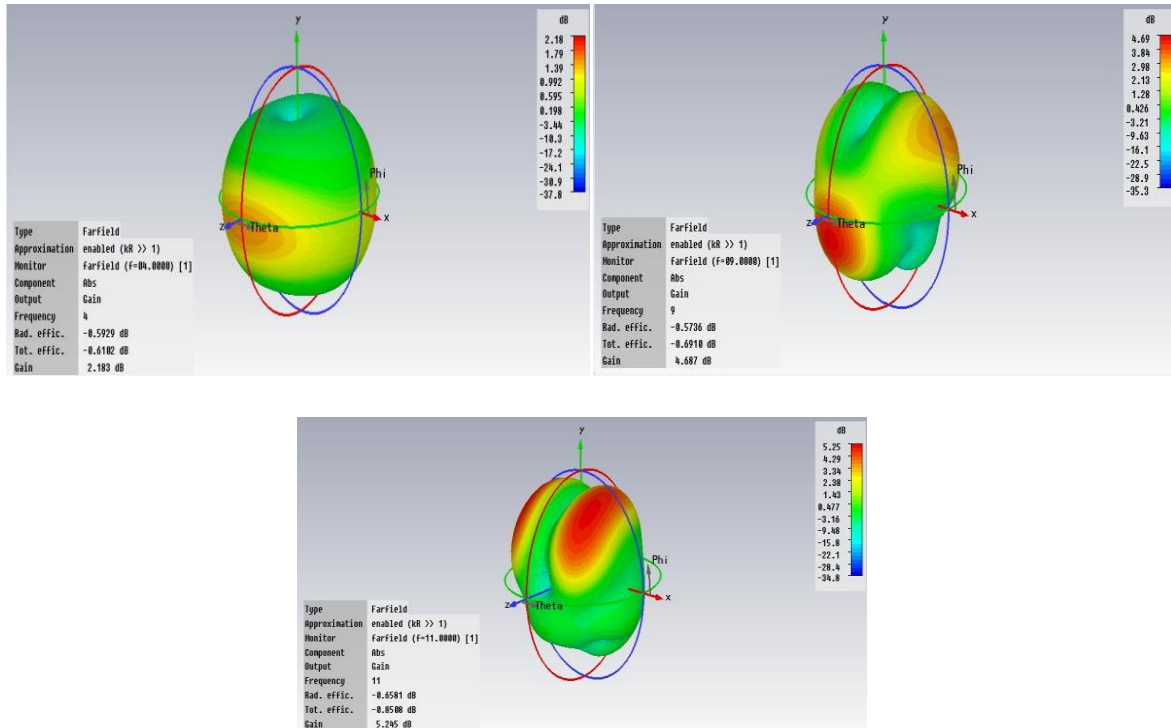


Fig 3.8 Return loss characteristics of proposed antenna

3.3.2.b Gain:

The 3D plot of gain of an antenna at 4 GHz, 9GHz and 11 GHz is shown in figure 3.9. The gain of this antenna increases as compared to the reference antenna except at lower frequency. Table 3.3 shows the comparison of gain of his antenna with reference antenna.



3.9 Gain of proposed antenna at 4 GHz, 9GHz and 11GHz

Gain	Reference antenna	Antenna with superstrate
At 4 GHz	2.497 dB	2.183 dB
At 9 GHz	4.397 dB	4.687 dB
At 11 GHz	5.091 dB	5.245 dB

Table 3.3 comparison of gain b/w reference antenna and antenna with superstrate

The gain of antenna can also be increased by placing the reference antenna in a cavity. This cavity suppresses the back lobes of antenna and reflecting more and more radiations in one direction leading to the high directive Gain antenna. This technique will be discussed in next chapter.

3.4 Design of circular triangular fractal UWB antenna for wireless communication using High gain cavity:

High gain cavity is another technique which suppresses the back radiations and thus reflects more and more radiations in forward directions.

3.4.1 Design of Proposed Antenna:

In this technique the reference antenna i.e. antenna without any gain enhancement technique is placed in a cavity. To increase the gain of an antenna; reflectors were placed on all the sides except the front side of an antenna. This arrangement formed a box shaped cavity around the antenna. This cavity is formed by placing substrate of 60 by 60 mm below the ground plane of antenna. Then four walls made up of FR4 material of height 6.4mm are placed on the four edges of antenna. The thickness of walls of the cavity and substrate is 1.6mm. The structure of this antenna is shown in figure3.10.

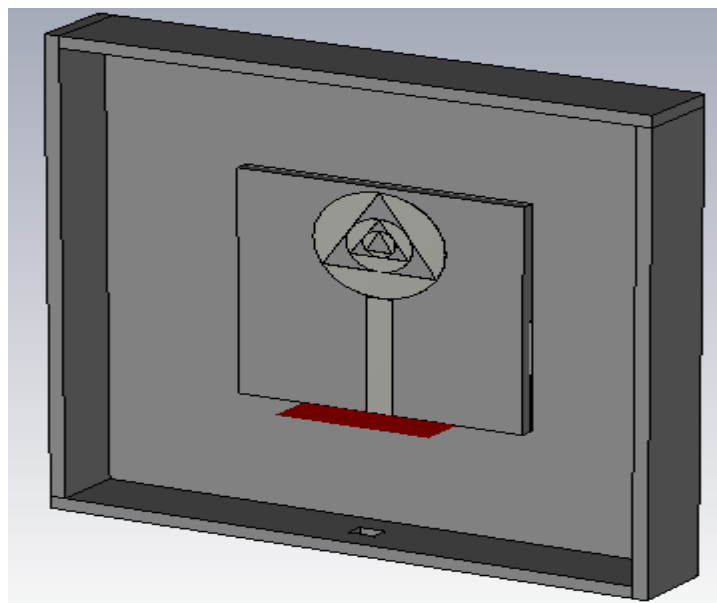


Fig 3.10 Design of high gain cavity back UWB fractal antenna

3.4.2 Simulation Results:

3.4.2. a Return Loss:

When circular fractal antenna is kept in resonator cavity then antenna operates over a frequency ranges from 3.0481GHz to 16.388GHz. The bandwidth of this design is 13.34GHz. The bandwidth in this case increases by approximately 2.69 GHz.

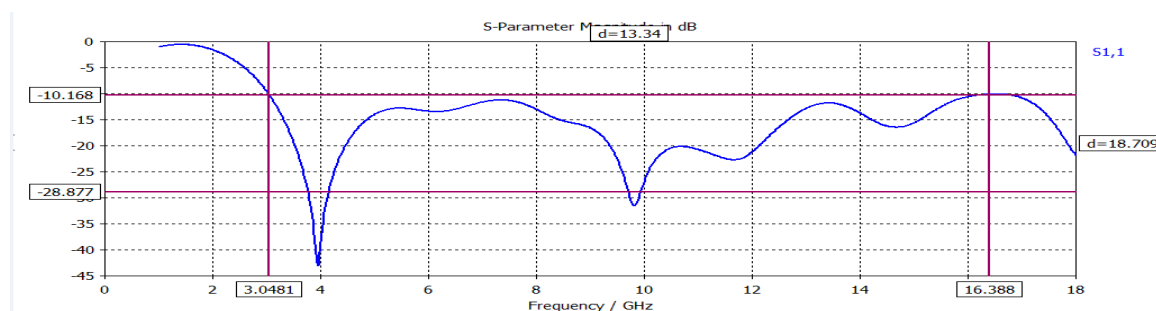


Fig 3.11 Return loss characteristics of high gain cavity antenna

3.4.2. b Gain:

The gain of proposed antenna varies from 2 dB to 7.805 dB. The gain of this antenna at 4 GHz, 9GHz and 11 GHz is shown in figure 3.12. Comparison of gain of this antenna with reference antenna is shown in table.

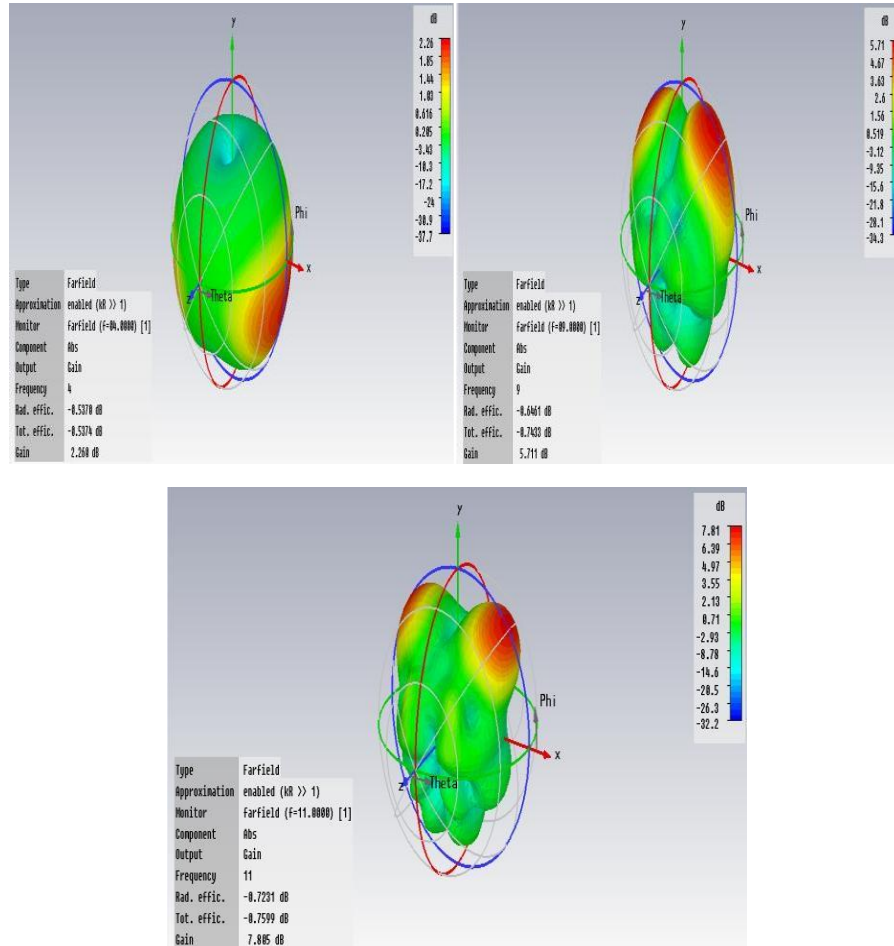


Fig 3.12 Gain of proposed antenna at 4 GHz, 9GHz and 11 GHz

3.5 Conclusion:

In this chapter Design of UWB antenna is discussed. The geometry of proposed antenna is based on a novel design. Return loss characteristics and gain of reference antenna is discussed. It is observed that antenna covers WLAN band (2.4 GHz, 3.6 GHz, 4.9GHz, 5GHz and 5.9 GHz) and WiMAX band (3.3 GHz, 5.8 GHz). Then in order to increase the gain different techniques are applied to the reference antenna. The return loss characteristics of modified antennas based on reference antenna geometry varies minutely. But the gain of reference antenna increase to almost 2 to 3 dB in some cases. Fig 3.13 shows the comparison of return loss characteristics of reference antenna with modified antennas.

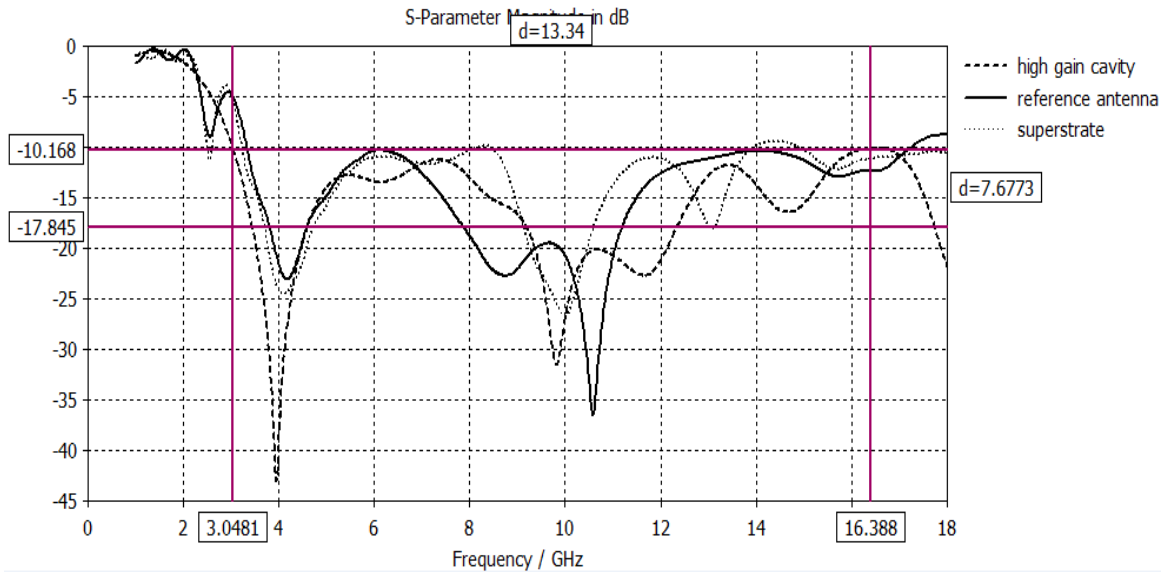


Fig 3.13 shows the comparison of return loss characteristics of reference antenna, high gain cavity and superstrate antenna

It is found that with application of gain enhancement technique to the reference antenna, Gain of antenna increases except at low frequency i.e. less than 5 GHz. Table 3.4 shows the comparison of gain of three proposed antenna at 4 GHz, 9 GHz and 11 GHz.

	Gain at 4 GHz(in dB)	Gain at 9 GHz(in dB)	Gain at 11 GHz(in dB)
Reference antenna	2.497	4.397	5.091
Superstrate technique	2.183	4.687	5.245
High gain cavity technique	2.260	5.711	7.805

Table 3.4 showing the comparison of different techniques applied to reference antenna From above comparison it is clear that High gain cavity antenna gives best result in terms of both gain and B.W.

Chapter 4

Stacked Fractal Antenna for WLAN and INSAT/Super-Extended C-band

4.1 Introduction:

In this chapter stacked fractal antenna based on sierpinsiki carpet fractal geometry is proposed. Proposed antenna resonates at 3.6 GHz and 4.5 GHz. Stacking technique is employed in this design to operate antenna at two different frequencies and for enhancement of gain and bandwidth. As B.W of antenna is directly related to its geometry. B.W of an antenna is directly proportional to the height occupied by an antenna [29]. Height of an antenna can also be increased by increasing the thickness of substrate. But it leads to the emergence of spurious radiations, which leads to the inefficiency of an antenna.

4.2 Sierpinsiki Carpet Fractal Geometry:

In this geometry generator is of square shape. The scale factor for this geometry is 1/3. So, 1/3 of the length of the generator is removed to form the 1st iteration stage of this fractal geometry[30]. This process is repeated to newly formed square in 1st iteration stage. This process becomes clear from the figure shown below

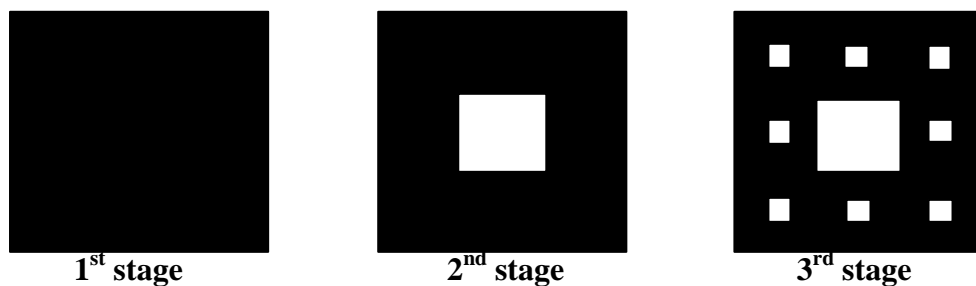


Fig 4.1 shows the different stages of iteration of sierpinsiki carpet fractal geometry

4.3 Design of Proposed Antenna:

In this design a patch whose length and width is calculated by using transmission line model, is mounted on the lower substrate, which is made up of FR4 material. This patch is responsible for 3.6 GHz resonant frequency. The ground plane is mounted on the back side of this substrate. Here DGS (defected ground structure) technique is employed to ground plane of lower substrate. Here DGS with addition to fractal geometry on the lower patch is used to miniaturize the antenna.

One superstrate having electrical permittivity 2.2 and thickness more as compared to substrate is placed at some air gap on the lower patch. Upper patch is mounted on this superstrate. Dimensions of upper patch are calculated using the transmission line model. This patch is responsible for 4.5 GHz resonant frequency. The lower patch, upper patch, ground plane and complete outer geometry of proposed antenna geometry is shown in fig 4.2 and fig 4.3. Dimensions of different components of proposed antenna are shown in table 4.1 and 4.2.

In the proposed design lower and upper patch are formed by 3rd iteration of sierpinsiki carpet fractal geometry. DGS technique [35, 36] applied to the ground plane in order to miniaturize the antenna to operate it at 4.5 GHz.



Fig 4.2 Figure showing geometry of Patch and DGS based ground plane

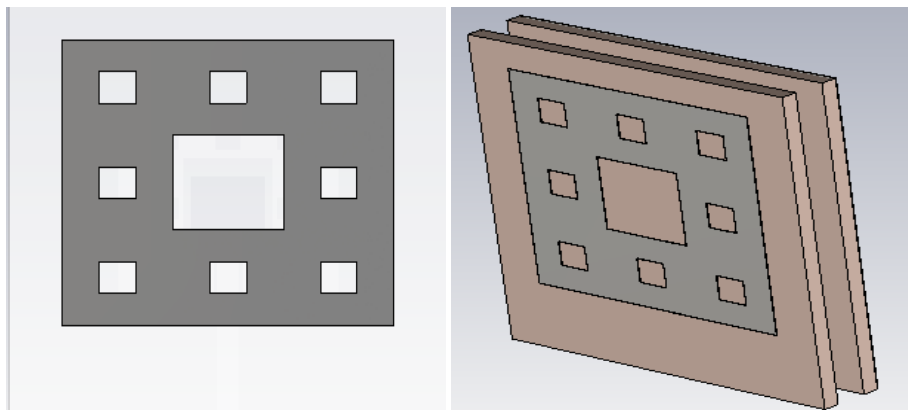


Fig 4.3 Fig showing geometry of upper patch and overall antenna

Stage of iteration of lower and upper patch	Lower patch's length(mm)	Lower patch's width(mm)	Upper patch's length(mm)	Upper patch's width(mm)
Zero iteration	15	20	22.5	30

First iteration	5	6.66	7.5	10
Second iteration	1.16	2.22	2.5	3.34

Table 4.1 shows the dimension of lower and upper patch at different stages of iteration

Component	Length(mm)	Width(mm)	Thickness(mm)
Substrate	32.1	39.6	1.6
Feed line	12.55	2	0.07

Table 4.2 shows dimensions of substrate and feed line

4.3.1 DGS (Defected Ground Structure):

For obtaining multiband and wideband characteristics, different techniques have been used like cutting slots in patch, fractal geometry and DGS. DGS may be realized by cutting slot from ground plane. Shapes of slot can be different. When DGS is applied to antenna equivalent inductive part gets increased leading to the high effective dielectric constant hence bandwidth increased. Different shapes in ground plane leads to different electrical path hence different resonant frequency and bandwidth can be achieved by varying the shape of slot in ground plane [35, 36].

4.4 Simulation results:

4.4.1 Return loss:

The proposed antenna resonates at 3.6867 GHz and 4.415 GHz. These two bands found applications in WLAN and C band respectively. The return loss at 3.6 GHz is found to be -15 dB and at 4.415 GHz, -25 dB. The B.W of proposed antenna at 3.6 GHz and 4.4 GHz is found to be 188 MHz and 204 MHz resp.

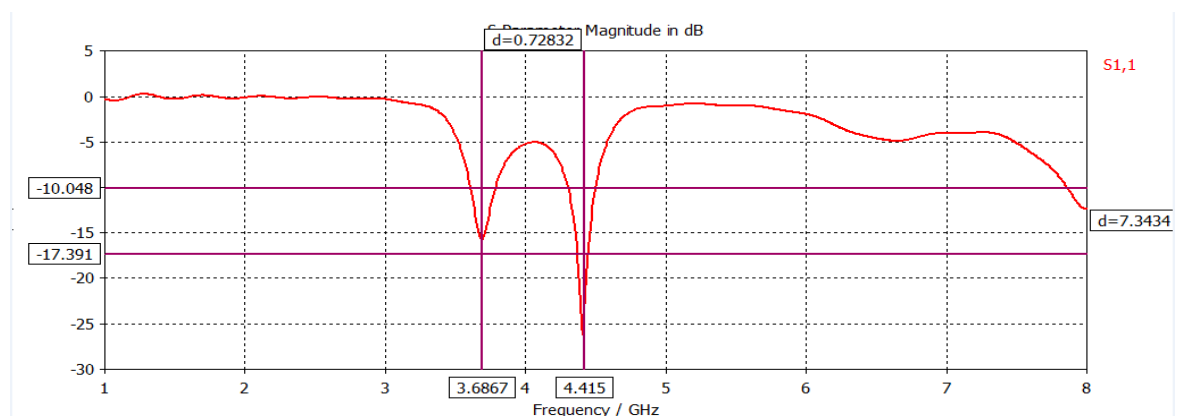


Fig 4.4 Showing the return loss graph of proposed antenna

4.4.2 Gain:

The gain of proposed antenna at 3.6 GHz and 4.415 GHz is 6.334 dB and 6.614 dB respectively. The gain plot of an antenna at 3.6 GHz and 4.4 GHz is shown in fig 4.5.

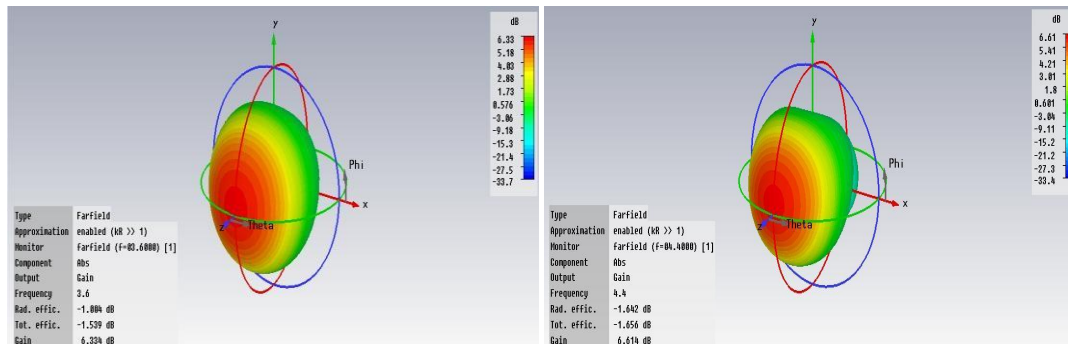


Fig 4.5 Gain of proposed antenna at 3.6 GHz and 4.4 GHz

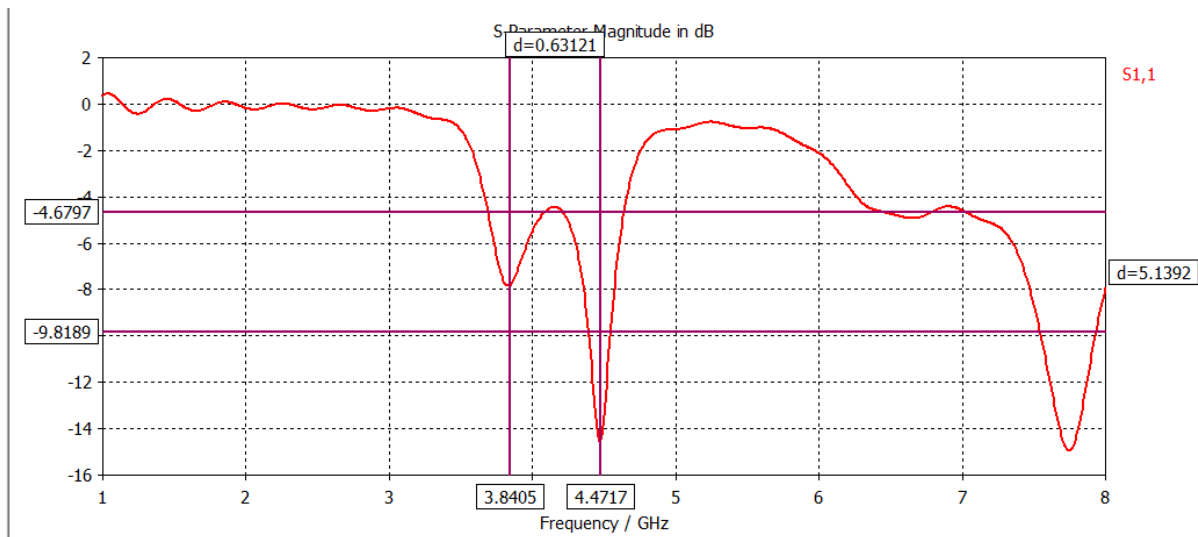


Fig 4.6 Return loss of proposed antenna without using DGS

4.4.4 Surface Current:

Fig 4.7, 4.8 and 4.9 show the surface current on lower patch, upper patch and ground plane. In ground plane maximum current is present around the slot which is quite helpful in increasing B.W. It is clear from the surface current diagram of upper patch that electromagnetic radiations are coupled to the upper patch efficiently.

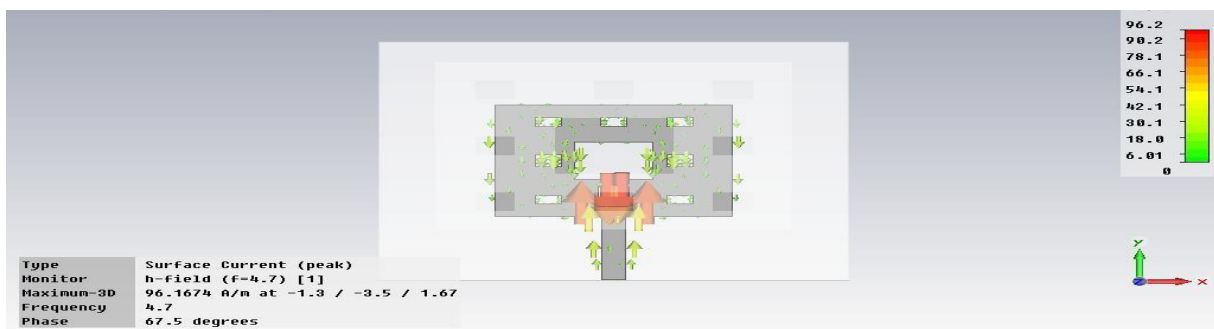


Fig 4.7 showing surface current on lower patch

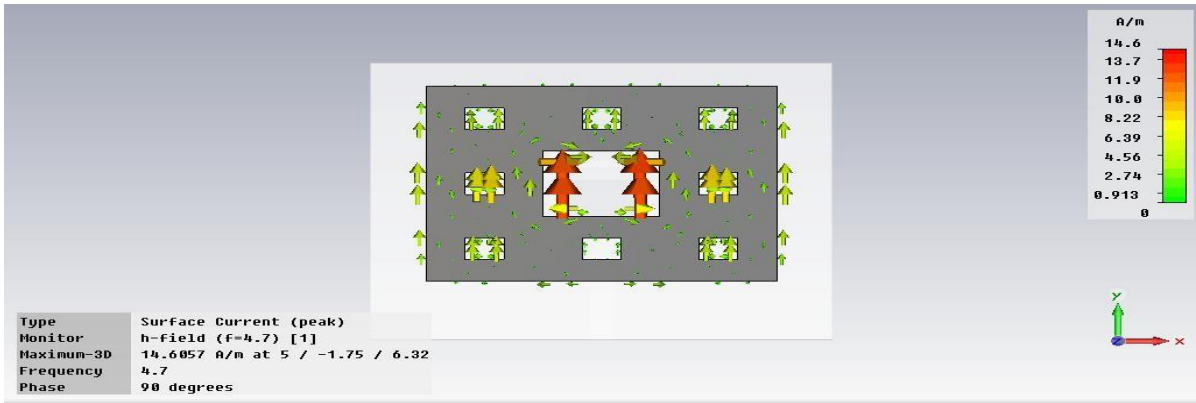


Fig 4.8 showing surface current on upper patch

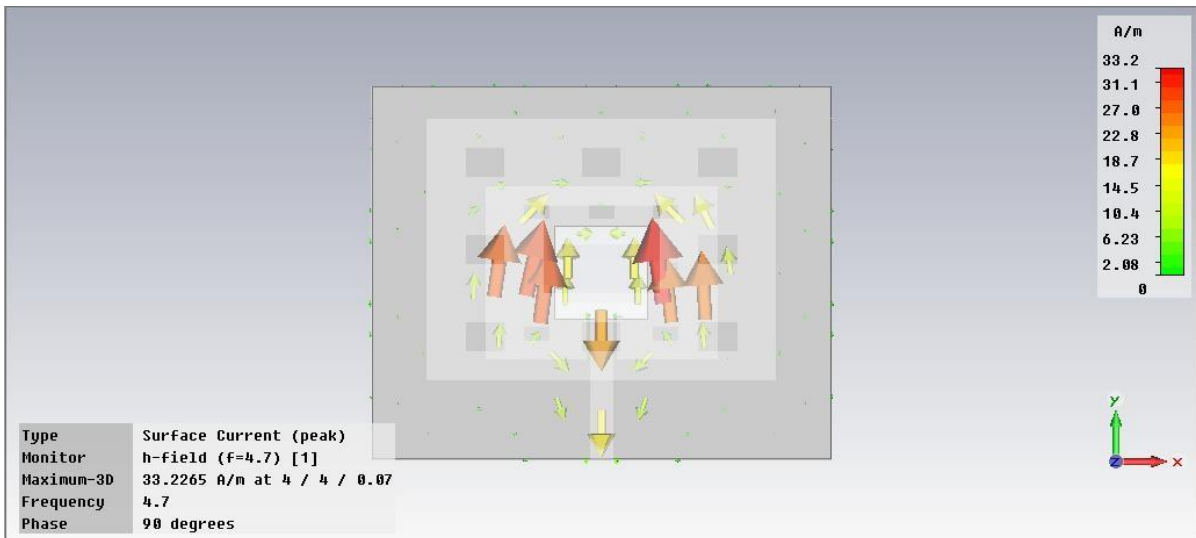


Fig 4.9 showing surface current on ground plane

4.5 Conclusion:

In this design DGS, fractal geometry and stacking technique is used to design a high gain, high B.W antenna. Proposed antenna operates at 3.6 GHz and 4.4 GHz with Gain of 6.334 dB and 6.614 dB and B.W of 189 MHz and 208 MHz. In this chapter return loss graph of proposed antenna without DGS and with DGS are also compared. This comparison shows how DGS technique is useful in this design in terms of enhancement of B.W and miniaturization.

Chapter 5

Tree shaped fractal antenna for WLAN and WiMAX

5.1 Introduction:

In this design novel modified tree shaped fractal geometry is applied to micro strip antenna. The partial ground plane and fractal geometry are responsible for ultra wide band characteristics of proposed antenna. Slots are introduced in partial ground plane of this antenna in order to provide more perturbation in the path of current which leads to broadband characteristics. The proposed antenna radiates efficiently from 3 to 6 GHz. The gain of this antenna varies from 2 dB to 4 dB. The proposed antenna covers WLAN and WiMAX band.

5.2 Design of Proposed Antenna:

Patch based on the tree shaped fractal geometry is mounted on the substrate made up of FR4 material. Tree shaped geometry involves integration of rectangles of different length and width. In this geometry Rectangle of dimensions calculated from the transmission line model is mounted on the substrate. This is followed by rectangle of reduced rectangle whose length and width are downscaled by a factor of $3/4$. This process is continuous up to the n th stage of iteration. In order to increase the B.W of proposed antenna slots are cut in each rectangle in order to provide the perturbation in the path of current which leads to the broadband characteristics. Slots in these rectangles also lead to the miniaturization of antenna. As path of current increases which leads to the increase in the electrical length of antenna, leads to the decrease in resonant frequency.

This patch is excited by the coplanar wave feed line. In this feed line, ground plane is divided into two parts and these are present on the same plane as that of patch. Length and width of this ground plane needs to be optimized. Dimensions of Patch and other components of proposed antenna are shown in table 5.1 and 5.2.

Then DGS technique is applied to this ground plane in order to enhance the B.W. as we know that more perturbation in the path of current leads to the broadband characteristics. This idea is implemented by cutting two slots symmetrical to each other. The proposed antenna design is shown in figure 5.1

Component	Length(mm)	Width(mm)
Zero iterated 1 st rectangle	8	16
Zero iterated second rectangle	6	12
Zero iterated third rectangle	4	8
First iterated 1 st rectangular slot	4	8
First iterated 2 nd rectangular slot	3	6
First iterated 3 rd rectangular slot	2	4

Table 5.1 showing dimensions of patch at different stages of iteration

Component	Length(mm)	Width(mm)	Thickness(mm)
Substrate	30	20	1.6
Feed line	9.5	3	0.07
Ground plane	7	8.2	0.07

Table 5.2 showing dimension of substrate, Ground plane and Feed line

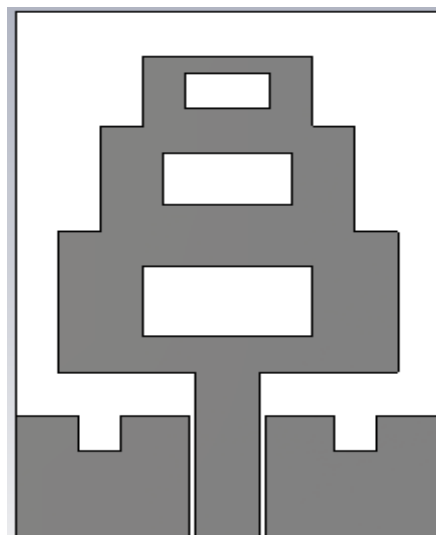


Fig 5.1 Design of proposed tree shaped antenna

5.3 Simulation Results:

5.3.1 Return Loss:

The proposed antenna covers the frequency band from 3.0908 GHz to 5.9825 GHz. The B.W of proposed antenna is 2.8917 GHz. The return loss of proposed antenna at 3.6 GHz (WLAN) is -24 dB and at 5.8 GHz (WiMAX) is -30 dB. Values of return loss shows impedance is matched throughout the operating frequency range of antenna. The return loss characteristics are shown in fig 5.2.

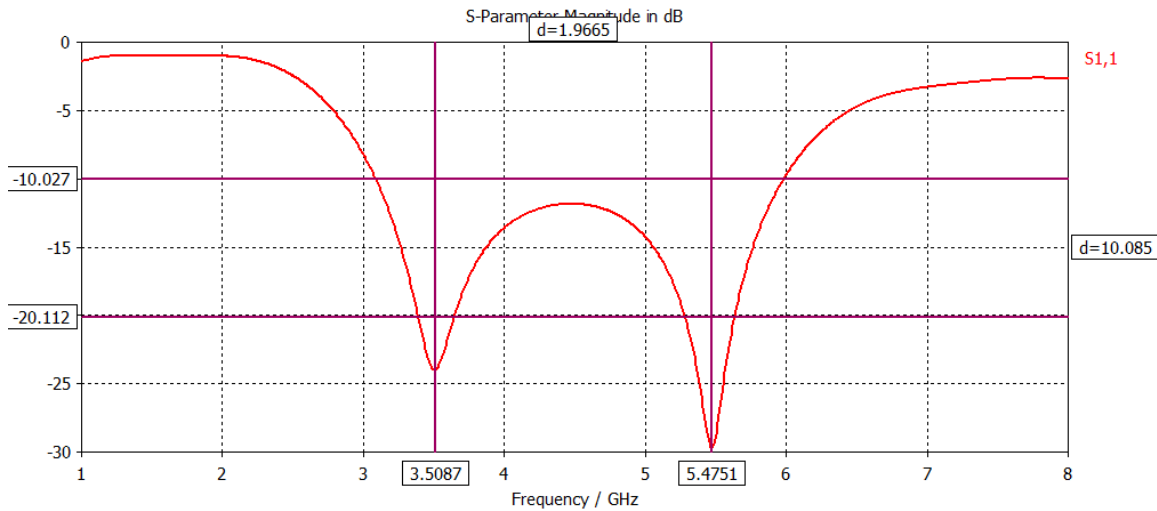


Fig 5.2 Return loss of proposed antenna showing resonant frequencies

5.3.2 Gain:

Gain of proposed antenna at 3.6 GHz and 5.6 GHz is 2.281 dB and 3.603 dB respectively. As B.W of this antenna is very high, according to Gain bandwidth product concept gain is low. The gain pattern of proposed antenna at 3.6 GHz and 5.6 GHz is shown in fig 5.3.

5.3.3 Surface Current:

Surface current distribution on tree shaped fractal antenna is shown in figure 5.4. It is quite clear from the distribution that surface current is propagating along the inner and outer boundaries of the patch which results in increase in the electric current path which further leads to the shifting of resonant frequency to lower side.

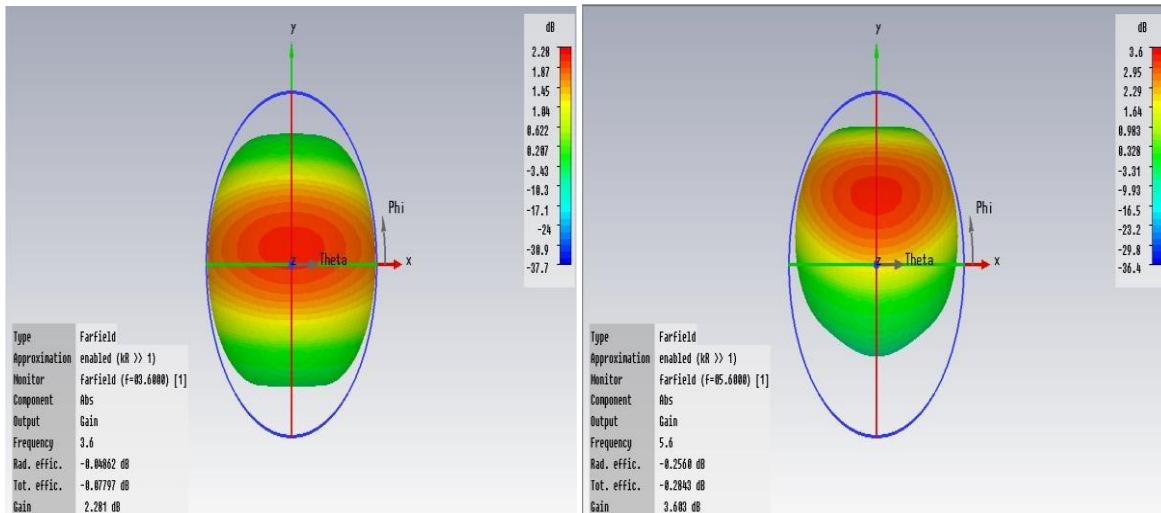


Fig 5.3 Gain of proposed antenna at 3.6 GHz and 5.6 GHz

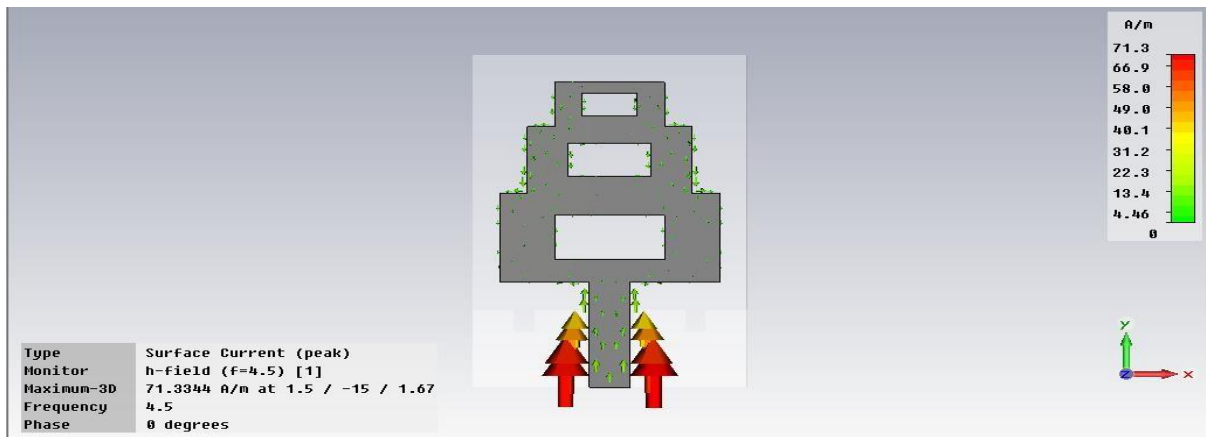


Fig 5.4 showing the surface current distribution of proposed tree fractal antenna

5.4 Conclusion:

Novel modified tree shaped fractal geometry is applied to microstrip antenna to form a UWB antenna. The bandwidth of proposed antenna is 2.89 GHz. It covers both WLAN and WiMAX band. Gain of proposed antenna at WLAN and WiMAX band is 2.281 dB and 3.603 dB respectively. Further work can be done in this design to increase the gain of proposed antenna to further extent.

Chapter 6

FABRICATION AND TESTING OF ANTENNA

6.1 Introduction:

The chapter presents fabrication of tree shaped fractal for validation of results for practical usage of the antenna.

6.2 Fabrication process steps:

The different steps incorporated in the fabrication process are shown in the fig 6.1.

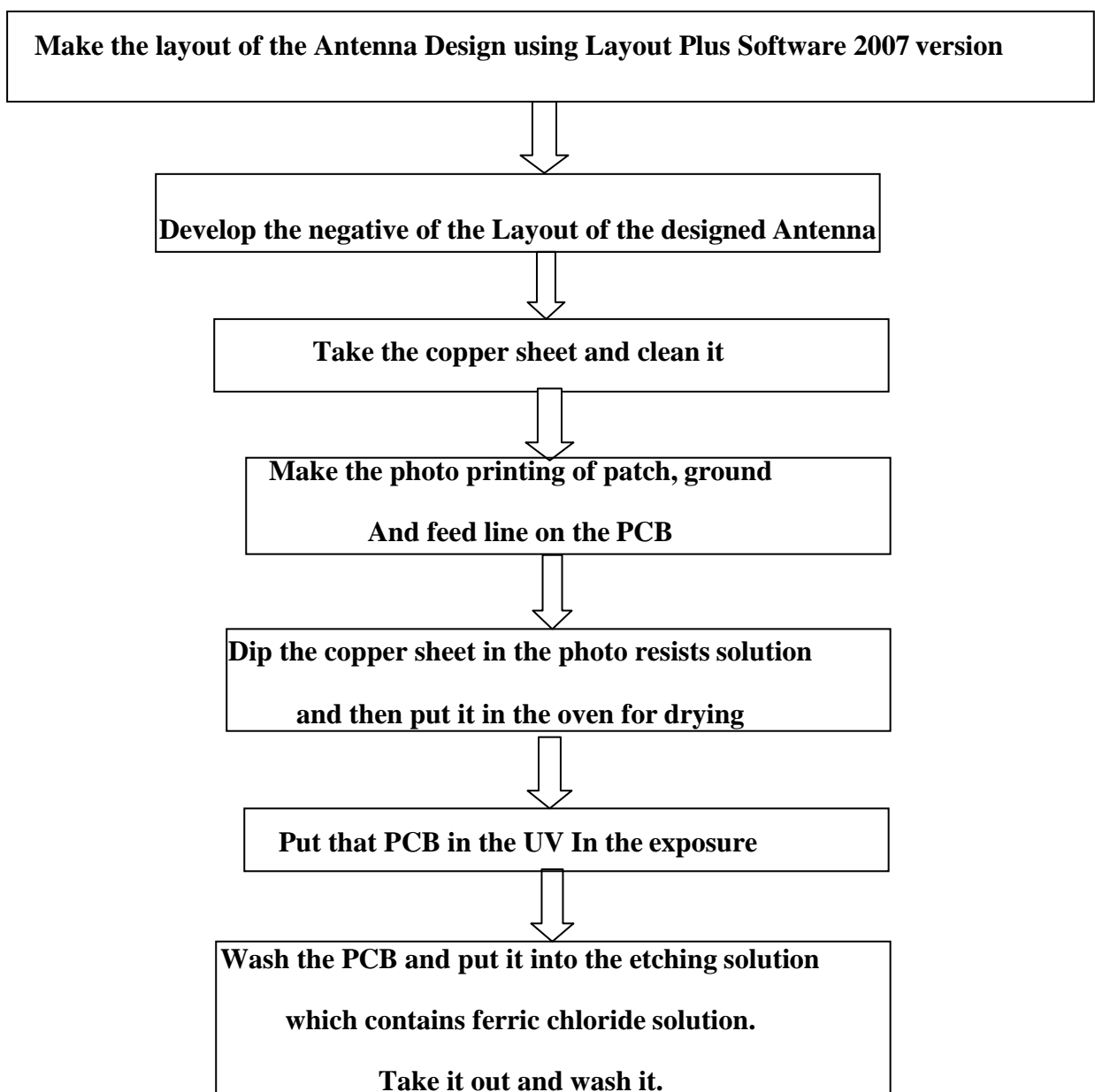


Fig 6.1 Flow chart of antenna fabrication process

Initially in Layout Plus software 2007 version, layout of proposed antenna is prepared. Negative of this layout is designed using the above software. In order to fabricate an antenna on copper sheet, copper sheet is cleaned. Photo printing of each component of antenna is made on PCB. Then PCB is dipped into a photo resist solution. This PCB is made dry in Oven. Then this PCB is placed in UV exposure. At last this PCB is placed in an etching solution containing ferric chloride.

6.3 Equipment Used

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



Fig 6.2 Network analyser for Testing

6.4 Fabricated Antenna Design

Fabricated tree shaped fractal antenna design is as shown in the figure below:

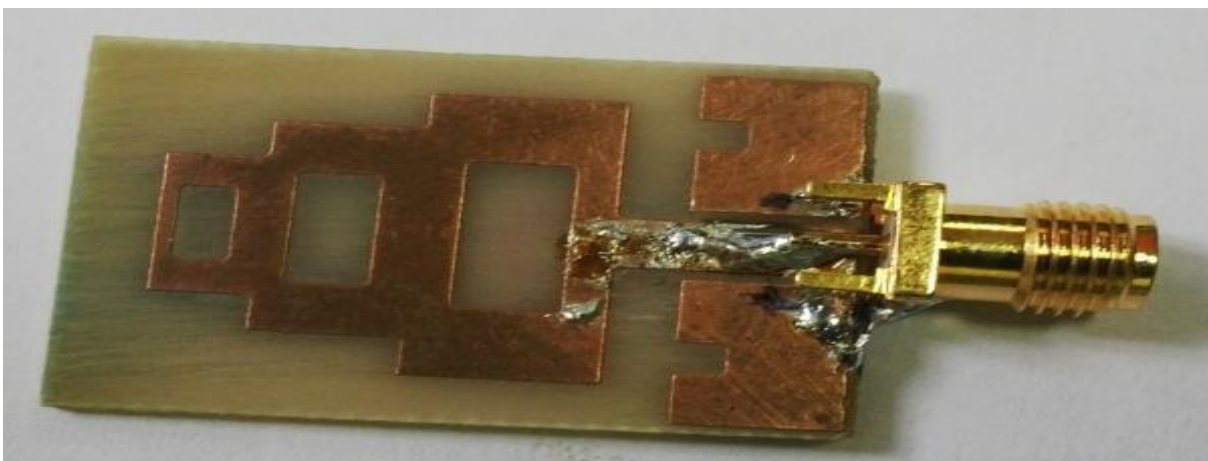
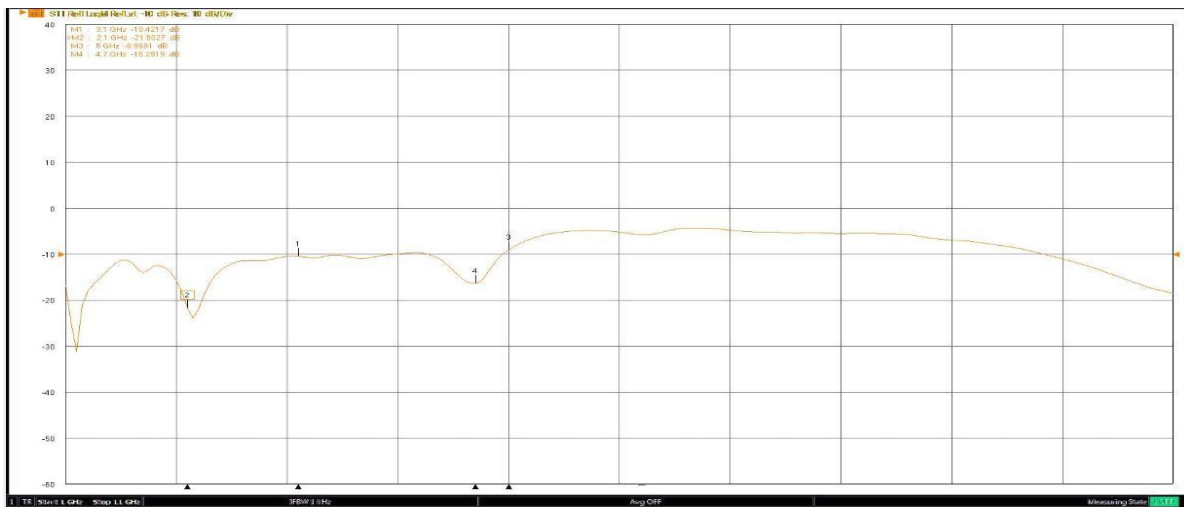


Fig 6.3 showing the fabricated tree shaped antenna

6.5 Testing Results



6.4 Measured return loss using Network Analyzer

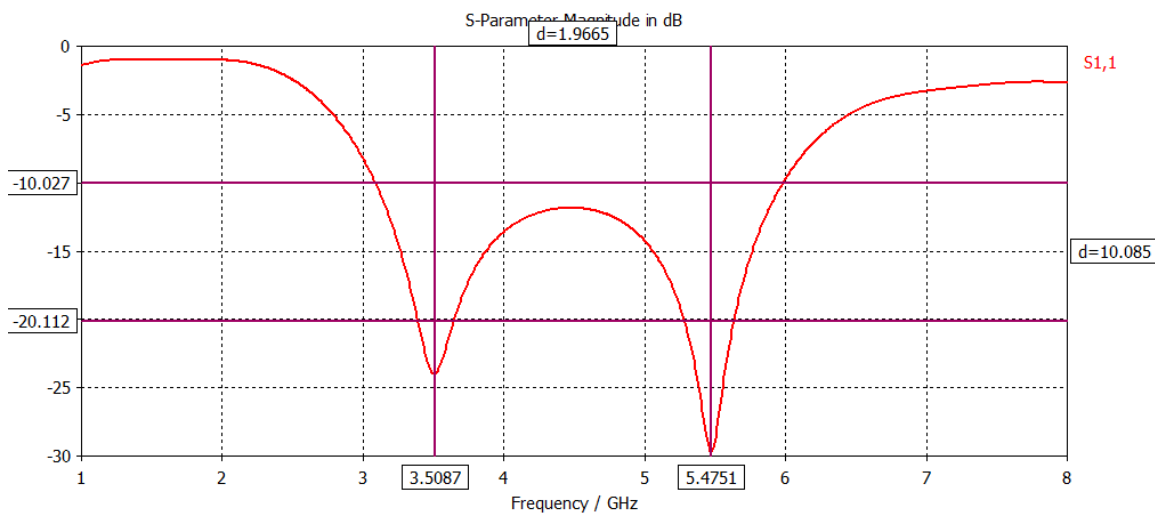


Fig 6.4 Simulated antenna return loss

6.6 Comparison of Simulated and Tested Antennas results:

Table 6.1 shows the comparison of simulated and tested results. The return loss of tested result deviated from simulated results due to fabrication losses. The return loss at 3.6 GHz in testing is found to be -10.42 dB in comparison to -24 dB in simulated results. The resonant frequency also deviates by 0.2 GHz. The return loss at 5.4 GHz in testing is found to be -16.26 dB in comparison to -30 dB in simulated results. The resonant frequency also deviates by 0.1 GHz.

Parameters	Tested result at 3.6 GHz	Simulated result at 3.6 GHz	Tested result at 5.4 GHz	Simulated result at 5.4 GHz
Return loss	-10.42 dB	-24 dB	-16.26 dB	-30 dB
Resonating frequency	3.4 GHz	3.6 GHz	5.3GHz	5.4 GHz

Table 6.1 Comparison of simulated and tested result

Conclusion:

The testing results are deviated from the simulated results mainly due to two main factors namely fabrication errors and testing errors.

Chapter 7

Conclusion and Future Scope

7.1 Conclusion:

The aim of the current research work was to design multiband, high gain fractal antenna for WLAN, WiMAX and UWB applications. Latest techniques like DGS, EBG could be easily applied to the microstrip antenna to achieve better results.

It was observed in literature survey that sierpinsiki gasket fractal geometry, circular shaped geometry and tree shaped geometry are very conducive structure for multi-band and UWB applications. Keeping in mind these structures, some modifications are done in these basic geometry to get desired results.

- In chapter 3 integration of circular patch is done with sierpinsiki gasket fractal geometry to form circular triangular fractal antenna. This geometry leads to improved Radiation characteristics, Gain and Return loss. Then Gain of this reference antenna is increased by maximum 3 dB with use of two techniques i.e. stacked fractal geometry and high gain cavity.
- In chapter 4 stacking technique is used to form a multiband antenna. In this antenna active and passive patches are designed to operate at two different resonant frequencies forming dual band antenna. DGS, stacking and fractal geometry techniques are applied to this proposed antenna to get desired results.
- In chapter 5 alteration in tree shaped geometry was done in order to improve the broadband characteristics of antenna. DGS technique coupled with coplanar wave guide is applied to this antenna to get high B.W antenna.
- In chapter 6 Fabrication process of tree shaped fractal antenna was explained. The comparison of tested and simulated results is done to validate the results

It was observed that DGS technique in addition with Fractal geometry can lead to high B.W and miniaturized antenna. Concept of partial ground is very helpful in order to obtain UWB. Circular, elliptical and triangular patches in addition to partial ground plane with optimized length lead to UWB. Above mentioned concepts are used in the proposed designs to get the required UWB operation. Microstrip stacked fractal antenna is another revolutionary technique in term of dual band high B.W antenna. This concept in addition with DGS is explored in one of the designs. The output obtained from all the three antennas is compared

in terms of the resonant frequencies , gain and return loss , gain and feeding technique used is summarized in the table 7.1.

Parameters	Circular triangular fractal antenna	Stacked fractal antenna	Tree shaped fractal antenna
Operating frequency	3.32 - 13.98 GHz	3.68 GHz and 4.415 GHz	3.09 – 5.98 GHz
Return loss	-20 dB at 4 GHz, -25 dB at 9 GHz and -35 dB at 11 GHz	-15 dB at 3.6 GHz and -25 dB at 4.415 GHz	-25 dB at 3.6 GHz and -30 db at 5.6 GHz
Impedance(Ω)	50	50	50
Bandwidth	10.65 GHz	188 MHz at 3.6 GHz and 204 MHz at 4.415 GHz	2.89 GHz
Gain	2.497dB at 4 GHz, 4.397 at 9 GHz and 5.091 at 11 Ghz	6.334 dB at 3.6 GHz And 6.614 dB at 4.415 GHz	2.2 dB at 3.6 GHz and 3.6 dB at 5.6 GHz
Feeding technique	Microstrip feed line	Insect microstrip feed line	CPW

Table 7.1 comparison of parameters of different proposed designs

7.2 Future Scope:

Since fractal antenna is still a modern trend in antenna research, so lot of open areas are present in this field. Different open areas in which work can be done in future are given below:

- **Different Feeding Techniques:**

In all designs proposed in this thesis, only microstrip feed line and CPW feed line is used. These feed lines do not contribute to the high gain and B.W of an antenna. So different feed line techniques like proximity coupling or aperture coupling can be used to enhance the gain and B.W of proposed antenna.

- **Mathematical Analysis to validate results:**

More work can be done in the field of mathematical analysis and modification of fractal geometries leads to the improvement in miniaturization, multiband

characteristics, Gain and return loss characteristics of proposed antenna. But this field is more related to the core mathematics.

- **Ground Plane Shaping:**

More work can be done in the field of ground plane shaping for improving the impedance matching. More impedance matching leads to the higher gain without affecting the B.W of proposed antenna. Partial elliptical ground plane with proper DGS techniques or any other shape can be more useful in further optimizing the different characteristics of antenna.

- **EBG:**

EBG (electromagnetic band gap) technique can also be applied to the microstrip fractal antenna to increase the B.W and for compactness of antenna.

- **Metamaterials:**

Little research has been done on applications of metamaterials in antenna systems. Emission in metamaterials using an antenna has been recently presented in 2002 by Enoch.

References

- [1] Theodore S. Rappaport, "Wireless Communication and Practice", Second Edition, 2002.
- [2] Andrea Goldsmith, "Wireless Communications", Cambridge University Press, 2005
- [3] Byron W. Putman. 802.11 WLAN Hands-On Analysis. Author House, 2005.
- [4] H. G. Schantz, The Art and Science of Ultrawideband Antennas. Boston, MA: Artech House, 2005.
- [5] "First report and order," Federal Communications Commission (FCC), Feb. 2002.
- [6] Balanis, c.A., Antenna Theory: Analysis and Design, John Wiley & Sons, Inc, 1997.
- [7] Garg, R., Bhartia, P., Bahl, I., Ittipiboon, A., Microstrip Antenna Design Handbook, Artech House, Inc, 2001.
- [8] Howell, J. Q., "Microstrip Antennas", IEEE AP-S int. Symp. Digest pp 177-180, 1972.
- [9] Munson, R.E., "Conformal Microstrip antennas and Microstrip phased arrays", IEEE transaction on antennas and propagation, vol-AP22, pp74- 78, 1974.
- [10] M. M. Nikolić and A. R. Djordjević, "Improving radiation pattern of microstrip antennas," IEEE First European Conference on Antennas and Propagation, Nov. 2006.
- [11] N. Cohen, "Fractal Antenna Applications in Wireless Telecommunications," Proceedings of the Electronics industries Forum of New England, 1997, pp. 43-49
- [12] Murad N.A Esa .M, Yusuf, S.K Fisal N "Fractal patch antenna for GPS application", Research and Development IEEE 2003.
- [13] Douglas H. Werner and Suman Ganguly, "An Overview of Fractal Antenna Engineering Research," IEEE Antennas and Propagation Magazine, vol.45, no.1, pp.38-57, February 2003.
- [14] Baliarda C.P Borau C.B Rodero M.N Robert J.R "An iterative model of fractal antennas Application to the sierpinsiki gasket antenna" Antennas and propagation, IEEE Transaction Vol 48 713-719, May 2000
- [15] Vinoy k.j , Jose k.a Varadan V.A varadan V.K "Hilbert curve fractal antenna with Reconfigurable characteristics" Microwave symposium Digest, 2011 IEEE MTT-S International, 381-384 2011.
- [16] Mohd Fairus Mohd Yusof, Ikhwan Peranggi Pohan, Mazlina Esa, Noor Asniza Murad and Yap Eng Chuan "Stacked Square Fractal Antenna with Improved Bandwidth for Wireless

Local Area Network Access Point “.International RF and microwave conference proceedings, Putrajaya, Malaysia, September 12-14, 2006

[17] Sumit Kumar, Deepak Gangwar, R. L. Yadava “Miniaturized Inverted Multiband Stacked Triangular Fractal Patch Antenna for Wireless Communication” Signal processing and integrated networks, 2014.

[18] Jampala s “Fractal classification and applications,” IEEE circuit and system, 1992

[19] Liu, S.H “Formation and Anomalous properties of fractal,” IEEE Engineering in Medicine and biology Magazine, vol. 11, June 1992

[20] Best S.R “The fractal loop: comparison of fractal and non fractal geometry,” Antenna and propagation society international symposium , IEEE 146-149,2001.

[21] Junho Yeo Mittra R “Modified sierpinski gasket patch antenna for multiband Application” Antennas and propagation, Transaction IEEE, 2001

[22] [17]Suganthi.s Raghavan s Kumar.D “Design of Miniature Fractal antenna” Antenna and propagation, Transaction IEEE, 2011.

[23] A.kaka, M Toycan, V.Bashiry, H.Admegil and S.D walker “A Multi-band and Miniaturized Monopole Antenna Design based on fractal geometry for UWB Wireless Applications” Antenna and propagation society international symposium, 2011.

[24] Hyo-Won Song, Hee-Soon An, Jung-Nam Lee, Jong-Kweon Park, and Jin-Suk Kim “Design of the Tree-Shaped UWB Antenna Using Fractal Concept” IEEE circuit and system, 2001

[25] Kailas K. Sawant, Dr. Raj Kumar Sc „E” and Dr. Arun N. Gaikwad “novel CPW-fed circular square-corner fractal antenna with varying notch band for UWB applications” International RF and microwave conference, 2012.

[26] Ayachi Ajey, Shambavi K. and Zachariah C Alex “Design and Analysis of Fractal Antenna for UWB applications” Electrical, electronics and computer science (SCEECS), 2012

[27] M.A. Dorostkar, Z.H.Firouzeh “Design of a Novel Multi & Wideband Triangular-Circular Fractal Antenna for Mobile Communication and Upper UWB Applications”.7th International Symposium on Telecommunications 2014.

- [28] Mazlina Esa, Noor Asniza Murad and Yap Eng Chuan “Stacked Square Fractal Antenna with Improved Bandwidth for Wireless Local Area Network Access Point” international RF and microwave conference proceedings, september 12-14, 2006.
- [29] Jaume Anguera, Enrique Martínez-Ortigosa, Carles Puente, Carmen Borja and Jordi Soler, “Broadband Triple-Frequency Microstrip Patch Radiator Combining a Dual-Band Modified Sierpinski Fractal and a Monoband Antenna” IEEE transactions on antenna and propagation 2006.
- [30] A.S.Elkorany, A.A Sharshar and S.M. Elhalafawy “ultra wideband stacked microstrip antenna” IET microwave and propagation, 2009.
- [31] Vilenskiy Artem and Kletsov Andrey “Ultra-Wideband Signals Radiation by Linear Arrays of Aperture Stacked Patch Antennas.” EURAD, 2013.
- [32] Ayachi Ajey, Shambavi K. and Zachariah C Alex “Design and Analysis of Fractal Antenna for UWB applications” Conference on Electrical, Electronics and Computer Science, 2012
- [33] S. Wong, B. L. Ooi, P. S. Kooi and M. S. Leong “an improved microstrip sierpinski carpet antenna” APMC, 2001.
- [34] Homayoon Oraizi and Shahram Hedayati “Miniaturized UWB Monopole Microstrip Antenna Design by the Combination of Giuseppe Peano and Sierpinski Carpet Fractals” IEEE antennas and wireless propagation letters, 2011.
- [35] Wen-Chung Liu, Senior Member, IEEE, Chao-Ming Wu, and Yang Dai “Design of Triple-Frequency Microstrip-Fed Monopole Antenna Using Defected Ground Structure” IEEE transaction on antennas and propagation, vol 59, july 2011.
- [36] Amit Singh Bhadouria, Mithilesh Kumar “Multiband DGS Based Microstrip Patch Antenna for Open Satellite Communication” IEEE International Conference on Advances in Engineering & Technology Research (ICAETR - 2014), August 01-02, 2014.
- [37] Yang Lu, Yi Huang, IEEE, Hassan Tariq Chattha, and Ping Cao “Reducing Ground-Plane effects on UWB Monopole Antennas” IEEE antenna and wireless propagation letters, vol. 10, 2011.
- [38] C. Borja and J. Romeu, “Fraction Vibration Modes in the Sierpinski Microstrip Patch Antenna,” IEEE International Symposium on Antennas and Propagation Digest, Volume 3, Boston, Massachusetts, July 2001, pp. 612-615.

- [39] Kim, T. Yoo, J. Yook, and H. Park, "The Koch Island Fractal Microstrip Patch Antenna," IEEE International Symposium on Antennas and Propagation Digest, Volume 2, Boston, Massachusetts, July 2001, pp. 736-739.
- [40] D. H. Werner, M. A. Gingrich, and P. L. Werner, "A Generalized Fractal Radiation Pattern Synthesis Technique for the Design of Multiband and Broadband Arrays," IEEE International Symposium on Antennas and Propagation and USNCAJRSI National Radio Science Meeting URSI Digest, Salt Lake City, Utah, July 2000, pp. 281
- [41] J. Romeu and Y. Rahmat-Samii, "A Fractal Based FSS with Dual Band Characteristics," IEEE International Symposium on Antennas and Propagation Digest. Volume 3, Orlando, Florida, July 1999, pp. 1734-1737.
- [42] J. Romeu, C. Borja, S. Blanch, and I. Girona, "High Directivity Modes in the Koch Island Fractal Patch Antenna," IEEE International Symposium on Antennas and Propagation Digest, Volume 3, Salt Lake City, Utah, July 2000, pp. 1696-1699.
- [43] Steven R Best, "The Effectiveness of space filling Fractal Geometry in lowering Resonant Frequency," IEEE Antennas and Propagation Letters, vol 1, 2002 p112-115.
- [40] Peitgen, H., H. Jürgens and D. Saupe., "Chaos and Fractals: New Frontiers of Science", Springer- Verlag. New York. 1992.
- [44] Y.J. Sung, M. Kin, and Y.S. Kin, "Harmonics Reduction with Defected Ground Structure for Microstrip Patch Antenna" ,IEEE Antenna and Wireless Propagation Letters, Vol. 2, 2003.
- [45] J. Gianvittorio and Y. Rahmat-Samii, "Fractal Patch Antennas: Miniaturizing Resonant Patches," IEEE International Symposium on Antennas and Propagation and USNCNRSI National Radio Science Meeting MRSI Digest, Boston, Massachusetts, July 2001
- [46] Himanshu Singh, Y.K. Awasthi, A.K. Verma , "Microstrip Patch Antenna with Defected Ground Structure and Defected Microstrip Structure", International conference on microwave, pp. 937-938, 2008.
- [47] D. H. Werner, M. A. Gingrich, and P. L. Werner, "A Generalized Fractal Radiation Pattern Synthesis Technique for the Design of Multiband and Broadband Arrays," IEEE International Symposium on Antennas and Propagation and USNCAJRSI National Radio Science Meeting URSI Digest, Salt Lake City, Utah, July 2000, pp. 281
- [48] M.Fernandez Pantoja, F.Garcia ruiz, A.Rubio Bretones, S.Gonzalez Garcia, R.Gomez Martin, J.M.Gonzalez Arbesu, J.Romeu, J.M.Rius, P.L.Werner and D.H. Werner, " Design of Small Thin-Wire Sierpinski-Type Pre-fractal Antennas," IEEE Transactions on Antennas and Propagation, vol.54, no.6, June 2006, pp.1879-1882.

- [49] Marek E. Bialkowski and Amin M. Abbosh “Design of UWB Planar Antenna with Improved Cut-Off at the Out-of-Band Frequencies” IEEE antenna and wireless propagation letters, vol 7, 2008.
- [50] Dawar Awam, Shahid Bashir, and William Whittow “High Gain Cavity Backed UWB Antenna with and Without Band Notch Feature” Antennas & Propagation Conference, 11-12 November 2013
- [51] Sayantan Dhar, Rowdra Ghatak, Bhaskar Gupta and Dipak Ranjan Poddar “A Wideband Minkowski Fractal Dielectric Resonator Antenna” IEEE transaction on antennas and propagation, vol 61, june 2013.
- [52] Piyush Dalsania, Brijesh Shah and Ved Vyas Dwivedi “Analysis of Multiband behaviour on Square Patch Fractal Antenna” International Conference on Communication Systems and Network Technologies, 2012.
- [53] WANG Li-na, LIN Shu, CAI Run-nan, HUANG Guan-long, ZHANG Wen-bin “Multiband Printed Monopole Antenna with Square-Nested Fractal” 6th International ICST Conference on Communications and Networking in China, 2011.

