DESIGN OF AN IMPROVED X-SHAPED FRACTAL ANTENNA WITH DEFECTED GROUND STRUCTURE

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

the degree of

Master of Engineering

in

Electronics and Communication Engineering

Submitted by

Ramanjeet

Roll No. : 801461021

Under the guidance of

Mr. Sukhwinder Kumar

Lecturer, ECED Department

Thapar University, Patiala

ELECTRONICS AND COMMUNICATION ENGINEERING DEPARTMENT

THAPAR UNIVERSITY

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

PATIALA – 147004 (PUNJAB)

DECLARATION

I, Ramanjeet, hereby declare that the work which is being presented in the dissertation entitled **"Design of an Improved X-Shaped Fractal Antenna with Defected Ground Structure"** by me in partial fulfilment of the requirement for the award of degree of M.E. in Electronics and Communication submitted in Electronics and Communication Engineering Department of Thapar University, Patiala, is an authentic record of my own work carried out under the supervision of **Mr. Sukhwinder Kumar, Lecturer, Thapar University, Patiala.**

Ramanjeet

RAMANJEET

Date: 13/07/2016

Roll no. : 801461021

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

Date: 13/07/2016

Sukhwinder Kumar
Lecturer, ECED department
Thapar University, Patiala

Countersigned by:

Dr. Sanjay Sharma
Professor & Head
ECED, Thapar University

Dr. S.S. Bhatia
Dean of Academic Affairs
Thapar University

ACKNOWLEDGEMENT

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

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

Ramanjeet

RAMANJEET

Roll No. 801461021

ABSTRACT

Today's modern communication system is challenging the antenna designers to design compact and portable antennas that have ability to meet multi standards. Fractal geometries are widely used in antenna design because of their unique properties of self-similarity and space-filling. In this thesis, the fractal geometry has been applied to Microstrip patch to design the antenna for wireless applications. Effect of each parameter used in designing of the antenna on its performance is discussed by varying each parameter separately. Importance of fractal iterations in decreasing the fundamental frequency and increasing the number of resonating bands is illustrated by comparing the results of each stage including the initiator path also. Microstrip feed line is used for the excitation of antenna. Defected ground structure (DGS) is also applied on the conventional ground to improve the radiation characteristics which is depicted by the return loss plots with and without DGS. Antenna is designed and fabricated on the FR-4 substrate having dielectric constant of 4.4. All the simulations are performed on CST (Computer simulation technology) software.

Finally, a multiband antenna is formed that confirms its applications in many wireless standards of modern communication system. The operational resonating frequencies comes out to be 1.7 GHz , 2.5 GHz, 3.4 GHz, 4.6 GHz, and 5.5 GHz which can be satisfactorily used for GSM 1700, Bluetooth, IMT, WiMAX and WLAN standards. All the measured results are in agreement with the simulated ones.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

AMPS	Advanced Mobile Phone System
CPW	Coplanar Waveguide
CSRR	Complementary Split Ring Resonator
CST	Computer Simulation Technology
dB	Decibel
DGS	Defected Ground Structure
DCS	Digital Communication System
ECT	Electromagnet Coupling Theory
GHz	Giga Hertz
GPS	Global Positioning System
GSM	Global System for Mobile Communication
GCPW	Grounded Coplanar Waveguide
IEEE	Institute of Electrical and Electronics Engineering
IMT	International Mobile Telecommunication Band
MHz	Mega Hertz
MMIC	Monolithic Microwave Integrated Circuits
OFDM	Orthogonal Frequency Division Multiplexing
PCB	Printed Circuit Board
RF	Radio Frequency
RFID	Radio Frequency Identification

RL	Return Loss
SRR	Split Ring Resonator
SDM-B	Satellite-Digital Multimedia Broadcasting
UWB	Ultra-Wideband
GCPW	Grounded Coplanar Waveguide
UMTS	Universal Mobile Telecommunications System
VSWR	Voltage Standing Wave Ratio
Wi-Fi	Wireless Fidelity
WiMAX	Wireless Interoperability for Microwave Access
WLAN	Wireless Local Area Network

CHAPTER 1

INTRODUCTION

1.1 Overview of Wireless Systems

Wireless communication is today's booming segment in communication system. It provides us high speed with better quality information exchange between portable devices that are placed anywhere in this world. Basic applications that are commonly needed in daily use are automated highway systems, smart appliance, cellular phones, video teleconferencing etc. Wireless communication network have become spread throughout in the world than anyone could have imagined in 1960s and 1970s when this cellular idea was first developed. Mobile and cellular network that are in major role are mentioned below.

The Advanced Mobile Phone System (AMPS) was the first generation American cellular system. In 1983, the AMPS were released using frequency band of 800 MHz to 900MHz with 30 KHz bandwidth for each channel. Analog technology has been used by AMPS with frequency division multiple access (FDMA) technology and brings voice only. This Advanced Mobile Phone System (AMPS) lacks security and capacity and has been a commercial success. The Advanced Mobile Phone System was become in use later to Narrowband AMPS (NAMPS) and Digital AMPS (DAMPS). Global system for mobile communication (GSM) is a digital time division multiple access (TDMA) system that uses 8 time slots each of having 25 KHz frequency [1]. GSM is best-selling in Europe and Asia. In United States, GSM operates at 850MHz (Cell band) and 1900 MHz frequency band (PCS band) however 900MHz and 1900MHz band (DCS band) are used in other countries. GRPS is having 2.5G GSM, which is now involved into EDGE Enhanced data rate for GSM Evolution (EDGE), a 3G technology [2]. Some of the commonly used wireless standards are tabulated in the Table 1.1 [3].

Table 1.1 Commonly used wireless standards

Wireless standards	Frequency bands(GHz)	Bandwidth range(MHz)
Bluetooth	2.4-2.5	100

GSM	900	0.89-0.96	70
	1800	1.710-1.805	95
	1900	1.850-1.990	140
International mobile telecommunication(IMT)		2.3-2.4	100
		2.7-2.9	200
		3.4-4.2	800
		4.4-4.9	500
WLAN		2.4-2.484	84
		5.150-5.350	200
		5.725-5.825	100
WiMAX		2.5-2.690	190
		3.4-3.690	290
		5.250-5.850	600

1.2 Antenna Properties

There are several factors which are determined according to antenna performance. The main properties of those factors are [4]:

1.2.1 Return loss

Return is the power loss in transmission line from where the signal is reflected back by any discontinuity in a transmission line or optical fibre. This discontinuity occurs when there is a mismatching with the load. It is generally conveyed as a ratio in decibels (dB):

$$RL(dB) = 10log_{10}(P_i/P_r) \quad \ldots (1.1)$$

Where, $RL(dB)$ is the return loss in decibel, P_i termed as incident power, and P_r is the reflected power. Return loss of antenna is also correlated with reflection coefficient (Γ) and voltage standing wave ratio (VSWR). Standing wave ratio deceases as the return loss increases. Return loss measures the matching of devices. For high return loss there is proper matching of devices. Return loss should be high to overcome from insertion losses.

1.2.2 Bandwidth

Bandwidth defines the range of frequency through which an antenna meets certain set of specification performance standards. Bandwidth also defines the net bit rate or maximum throughput of physical or logical communication path in digital communication system. There are two methods of calculating antenna bandwidth: if antenna is broadband, then condition is:

$$f_H/f_L \geq 2 \qquad \dots (1.2)$$

Narrow band by %age

$$BW_P = (f_H - f_L)/f_c \times 100\% \qquad \dots (1.3)$$

$$BW_P = f_H/f_L \qquad \dots (1.4)$$

Where

f_c = Centre frequency

f_L = Lower cut off frequency

f_H = Higher cut off frequency

Antennas cover three types of classes in terms of frequency band:

a) Narrow band – Small range of frequency is covered by these antennas having order of few percent around the designed operating frequency.

b) Wide-band or broadband – An octave or two ranges of frequencies are covered by this antenna.

c) Frequency Independent- ten or more than ten frequency range is covered by this antenna.

1.2.3 Gain and Directivity

Antenna characteristics are defined by directivity and gain. Gain is recall to define an antenna's capability to make the apparent power more than the actual power transmitted in a given direction. The term directivity of antenna is stated as the ratio of the maximum radiation intensity to the average radiation intensity. Efficiency of antenna attains its 100% percent when directivity becomes equal to the gain of antenna. Gain has directional functional property due to which it changes with position around the antenna. Gain is commonly dignified in decibels with reference to another antenna like an isotropic antenna. An isotropic radiator is an antenna that radiate in all directions equally but practically this too difficult to obtain this characteristics of isotropic antenna.

1.2.4 Polarization

The antenna polarization defines the direction of radiated wave's electric field vector. Waves have polarization property which can oscillate with more than one orientation. Different type of polarization is:

- Linear polarization
- Circular polarization
- Elliptical polarization

The most common type of polarizations are circular or linear polarization in which antenna radiates. In linear polarization, antenna radiates with direction of the wave propagate at the same plane and circular form of antenna radiation is created in circular polarization.

1.3 Types of Antennas

Different types of antenna depending upon polarization, radiation and apertures are used. These are described in following below [5]:

- **Circularly polarized antennas** are used for electric field lines vectors to radiate in any direction. Circular polarized antennas describe the corkscrew-like pattern of electromagnetic waves that are generated. A complete rotation of waves in both vertical and horizontal planes corresponds to single wavelength. But linearly polarized antennas are better than Circular polarized antennas in term of loss of 3 Db per read, because of separation of power in two different planes. In this antenna type, there are two orthogonal components of E-field at 90 degree phase shift with equal magnitude. Axial ratio which is the difference of maximum peak angle and minimum peak angle should be 0 dB for this antenna.

- **Linearly polarized antenna** radiates EM wave in particular one direction i.e. either in horizontal plane or vertical plane which are direction of propagation. These antennas are used in daily applications because of their low cost and smaller in size. Manufacturing of linear polarization antennas are easier than all antennas. Electric fields produced are perpendicular to the plane that's why this antenna has a linear property. Orientation of radio frequency ratio tag measures the constant reading values which are fixed permanently in the plane. Some examples of these antenna types are broadcast tower for AM radio, the MTI MT-263003 Outdoor Antenna etc.
- **Omni-directional antennas** use 2D geometric plane. Waves are transmitting and receive in horizontal directions by this antenna. Application of Omni directional antenna is used in wireless routers and cellular phones because of their easy installation. They are easy to apply at homes and offices because of its adjustable shape. For cross polarization, Omni directional antennas are not in use to reduce interference because of its vertical polarization behaviour.
- **Directional antennas** define their specific direction where they transmit and receive the signal. RF energy is only focused by this antenna in specific direction. Radiation obtained by this antenna is attained at maximum level in a specific direction and also this type of antenna increases the gain to cover much distance. Beam antennas are also called as directional antennas. To cover corridors and long hallways uses this type of antennas which are near line of sight coverage. Requirement of common user it to cover larger area but there is drawback of this antenna that coverage areas will not be large as there is lesser angular coverage angle. Directional antenna is easy to mount because of particular direction of antenna where the coverage is required.
- **Aperture Antennas** are mounted on upper face of spacecraft or aircraft. Dielectric material is used to cover these antennas and protect these antennas from the unsafe environmental conditions.

- **Wire Antennas** are commonly used antennas in many applications like ships, buildings, spacecraft, automobiles etc. straight antenna, helix antenna and loop antenna are the common types of wire antennas. Many of the shapes like rectangular, ellipse, and square are formed by loop antennas.
- **Array antennas** come into use to get better radiation pattern unlike a single antenna which has not a desirable radiation pattern. A set of radiating patch antennas are arranged for better results of radiation pattern. Arrangement of these patches is in such a manner that we get maximum radiation pattern in chosen directions.
- **Microstrip Patch Antennas** are now days are very common antennas which are firstly come in 1970s. Microstrip Patch Antennas consist of a metallic patch with a substrate and ground. Rectangular and circular patches are commonly used for fabrication because they are easy to construct. Microstrip Patch Antennas have low cross-polarization radiations. These antennas are mechanically robust in nature. Radiation pattern, return loss, gain and all other parameters are good for various applications like radar, Bluetooth, WLAN, satellites, cars etc. these are low profile microstrip antennas with comfortable planar and non-planar surfaces. Fabrication of these antennas is very easy because of their non iterated behaviour.
- **Reflector Antennas** are very used for long distance transmission. Diameters used for parabolic reflector antenna are very large i.e. near about 305m which then attain very large gain for transmission to miles of distance.

1.4 Basic Microstrip Antenna

In antenna theory and design, microstrip antenna is the most popular topic in recent years. Microstrip antenna is used in many application of modern microwave system. Fabrication of these microwave devices were done on semiconductor chips having very lesser volume, fixed in appropriate designed packages. Microstrip antenna is constructed with a metallic layer printed on a thin, grounded dielectric substrate. Radiation of this antenna consists of broad beam broad side to the plane of substrate. Thus a very low profile antenna has created and fabricated by using printed circuit technique and has one more technique to fabricate is photolithography technique. The basic requirement for antennas is low cost, low weight [6]. Microwave integrated circuit that uses four basic forms are:

- Coplanar waveguide
- Slot line
- Strip line
- Microstrip line

The most common form that is used is microstrip line discussed below.

1.4.1 Micro-strip Line

Microstrip line is used for microwave integrated structure. This is the most ordinarily used transmission line for antenna design. This transmission line contains dielectric substrate having strip conductor and ground plane on other side. The characteristic impedance of the microstrip line is calculated by the strip width, dielectric constant, and substrate thickness.

1.4.2 Microstrip Structure

Structure of microstrip antenna shown in Fig. 1.1 consist of radiating metallic patch, microstrip feed line, substrate and ground**.**

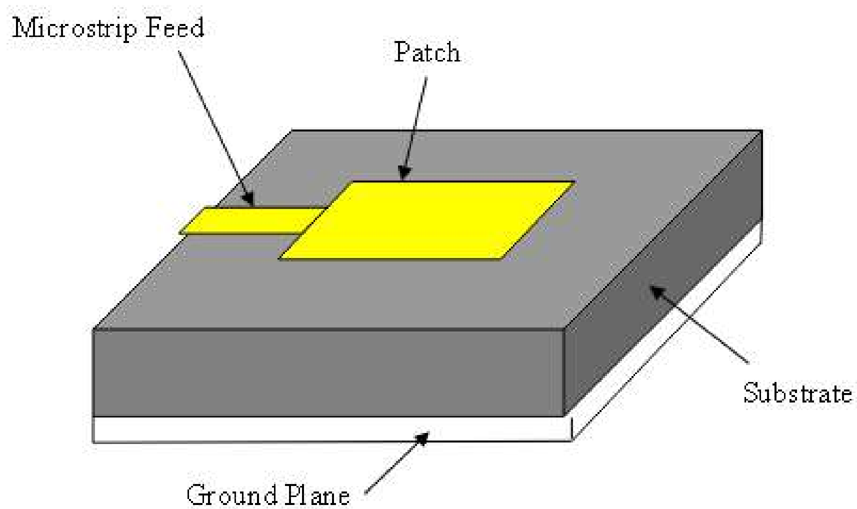


Fig. 1.1 Layout of microstrip patch antenna [6]

1.4.3 Basic Characteristics

The basic features of microstrip antenna is summarize in this section with rectangular structure with probe feed. The antenna is driven with a voltage between ground plane and feed probe when operating in the transmission mode. Electrically thin dielectric substrate is used in microstrip antenna. Due to this, current produces on ground and patch. When length of the patch element is near half, the patch resonates and indicating large field and current amplitudes. The approximate analysis based on magnetic pole of the cavity model and transmission line approximating becomes more practical when the thickness of the substrate is reduced. Bandwidth and the thickness of substrate are inversely proportional to each other. If the thickness is decreased i.e. the thin substrate is chosen then bandwidth will increase and similarly if thick substrate is chosen then bandwidth will decrease.

1.4.4 Principle of Operation

Electric field lines that are produced at the edge of the patch can be divided into two components i.e. normal and tangent components. A source of voltage is given between ground plane and feed probe. Microstrip antenna should operate in transmitting mode. Small electric field components are produced at thin electrically dielectric substrate. At resonance, there are large current and field components because length of the patch is nearly about zero. Magnetic current is radiate according to induced surface current density on patch and ground plane due to which resulting radiations created.

1.5 Feeding Techniques

To design an antenna, feeding techniques are important to know. An antenna should work on complete power of transmission so that there will be fewer losses. For very high frequencies, there will be more difficulty to design the feeding techniques because feeding input loss depends on frequency and thus overall design get effected. The techniques that can be used are [6]:

- Coaxial probe feeding
- Proximity coupled feeding
- CPW feeding
- Microstrip line feeding

1.5.1 Microstrip Line Feeding

Microstrip feeding is much easier technique than any other techniques to fabricate. Patch is connected to this microstrip feed which is a conducting strip. Impedance of feed should be 50 ohm which is matched to the input ports. Spurious feed radiation and surface wave increases which is disadvantage of this technique by bandwidth get limited.

1.5.2 Coaxial Probe Feeding

For narrow band and efficient radiation, the use of coaxial feed is come into contact. In coaxial feeding, middle conductor is linked to patch and external conductor is attached to the plane of ground. Fabrication of this coaxial probe is simple and also matches easily. There are also disadvantages of this probe, one of them is, for thick substrate coaxial probe feeding is difficult to use. Narrow band also appears by using this type of probe. Fig. 1.2 shows the structure of coaxial probe feed.

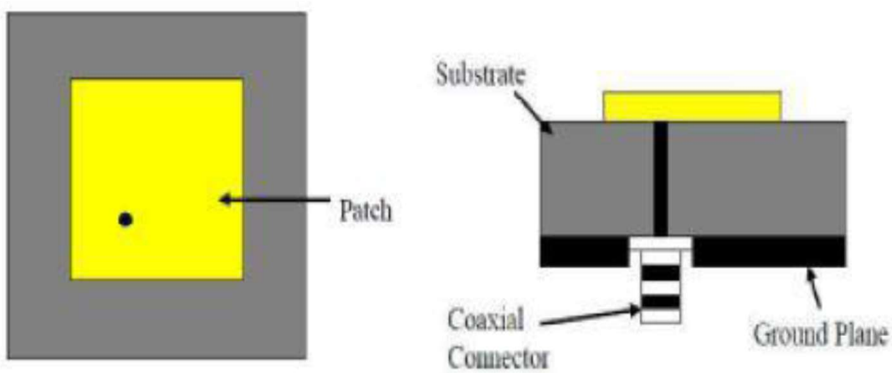


Fig. 1.2 Coaxial probe feed [6]

1.5.3 Aperture Coupled Feeding

The aperture coupling is the toughest to install among all of other feedings and consist of narrow bandwidth. However, this feeding has spurious radiations and easy to model. Aperture coupled feed have two substrate of different material which are divided around the ground plane. Microstrip line which is connected to patch is down to the lower substrate, energy obtained is coupled to patch through a slot that was cut from the ground plane which separates the two substrates. Dielectric constant of these two substrates is different to each other. Dielectric constant of upper substrate is thick, but for lower substrate dielectric permittivity is thick. The structure of these feeding techniques is shown in Fig. 1.3. Radiation elements separate from the feed by ground plane in order to protect from spurious radiations, which will gives the better polarization. The main advantage of this feeding is that it permits better optimization of feed mechanism element.

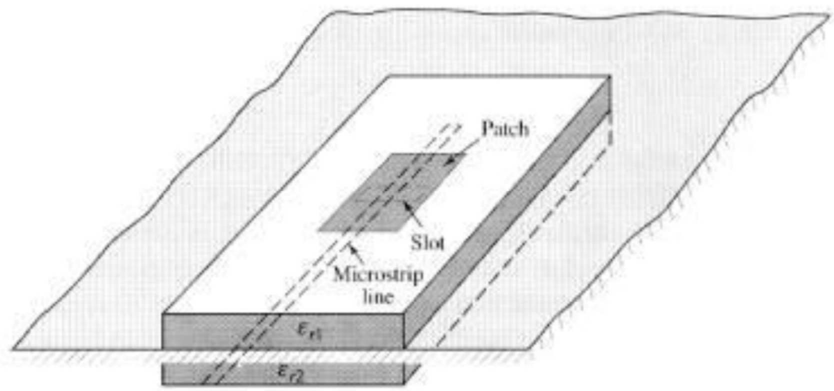


Fig.1.3 Aperture coupling feed [4]

1.5.4 Proximity Coupled Feed

Largest bandwidth requires only through proximity coupled feed and this is somewhat easy to model and radiations that are spurious for us are also less. But this feeding technique is difficult to fabricate. Matching for antenna is must which is then controlled by length of feed and width to length ratio. Basic structure of this technology is shown below in Fig. 1.4.

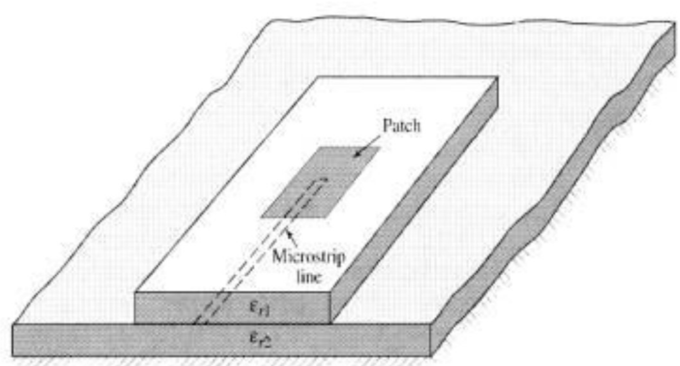


Fig. 1.4 Proximity coupling feed [4]

1.5.5 CPW Feed

Issues are come out in the arrangement of creation of two layers printed circuit antennas. Although when microstrip line is asymmetrical, off to the centre matching of the antenna is not too influenced. Also with higher cross polarization there is no effect on matching of antenna. The alignment is necessary for etching on both sides of the substrate. This alignment problem is terminated by etching the slot from the feed line from same side of substrate. All these achievements are found in coplanar waveguide feed (CPW). CPW feed is constructed with a metallic strip which is implant to surface of substrate of dielectric material. Two thin tight openings ground terminals running neighbouring and parallel to the strip on the same surface Losses which determined in microstrip feed are lesser in CPW feed shown in Fig. 1.5. One application of coplanar waveguide is that fibre optics system can form into whole with slotted antenna. For wide band applications, this type of feeding technique is used. Bidirectional radiation pattern can be formed by applying coplanar feed to the slot antenna. Many of the CPW feed antennas are attractively used for WiMAX and Wi-Fi. Basic structure of CPW feed is as shown in Fig. 1.5.

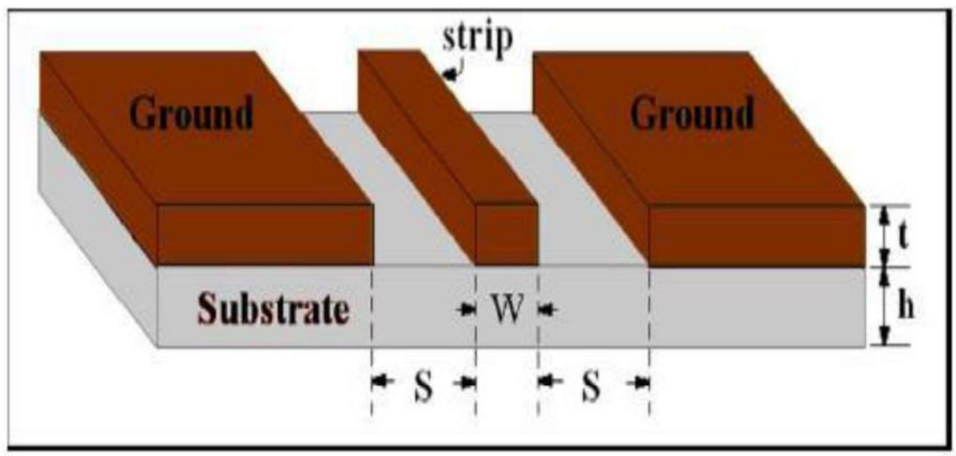


Fig. 1.5 CPW feed [5]

1.6 Fractal Overview

Fractal is defined from the word "fractus", which is a Latin word, was given by Mandelbrot in 1977. Fractal is a self-similar geometry which is very first designed by Nathan Cohen. As fractal has space filling property, that's why this property increases the electrical length of antenna. With the increasing electrical length of antenna, radiation pattern also becomes better. Self-similar property is the main aspect of fractal antenna. Properties of antenna that we yet discussed can improve by using this fractal geometry to a great extent. Fractal antenna is an advanced version of microstrip antenna because of self-similar property and space filling property. Because of space filing property, current in antenna increase to a great extent, which then give better results like return loss graph improves and gives wide bands which is our main focus area.

1.6.1 Fractal in Nature and Applications

Fractals in nature are found in various ways like trees, clouds, waves, mountain ranges, jaggedness of coastline etc. Anything which is random, irregular in shape and repeats itself can be called as fractal. Fractals are used in many of computer science applications such as fractal image compression. Fractal image compression is the best example showing usefulness of fractals in computers representing the fact that our real life world is also designated by fractal geometry. Using this way, images are compressed in much better and easy way, as in this technique no pixelisation is present, hence when image is again enlarged, it is much better than the usual ways. Fractal shaped antenna is the new practical application which is used to reduce the size of antenna and also helps in reduction of weight. Company that was firstly design these fractal shaped antenna is "Fractenna". Applications of fractal antenna depends on different factors such as type of fractal geometry applied, required frequency, number of iterations etc. Only upto two or five iterations can be realised practically. As already discussed, fractals have complex nature which is used for reducing size of antenna and developing low profile antennas. Self-similarity property helps in achieving multiple frequency bands as different parts have similar shape to each other at different scales. This combination of complex geometry and self-similarity produces an antenna with multiple and wide band performances.

From the above discussions it can be concluded that by including fractals into antennas we can have the following benefits:

- Antenna with wide and multiband applications can be designed.
- Size can be reduced by much extent when compare to conventional antennas.
- Antennas are mechanically simple and much robust.
- Specific stop and pass bands can be designed according to requirement due to which multi frequency characteristics.
- Properties of fractal antenna mainly depend upon the geometry; there are fewer effects on characteristics of antenna by applying discrete components.

1.6.2 Fractal Geometries

Fractal geometries are of many types. Commonly studied and investigated fractal geometries are listed below:

- Sierpinski Gasket Geometry

- Sierpinski Carpet Geometry
- Koch Curves
- Hilbert curve

1.6.2.1 Sierpinski Gasket Geometry

Sierpinski gasket geometry is also known as sierpinski triangle. The procedure of this sierpinski geometry is done by joining the midpoints of triangle from every side that will generate infinitely repeating triangles and triangle is cut-out from the centre. The way through which Sierpinski gasket geometry created is as shown below in four steps:

Let’s take an equilateral triangle as an example:

Start with an equilateral triangle.

a. Four separate triangles are formed by connecting midpoints of each side.

b. From the centre, cut out an equilateral triangle.

c. Cut out the triangles from the three black triangles that are left. The centre triangle of every black triangle at the corner was also cut out.

d. Screen resolution is further used to repeat the above process and this will give the following pattern as shown in Fig. 1.6.

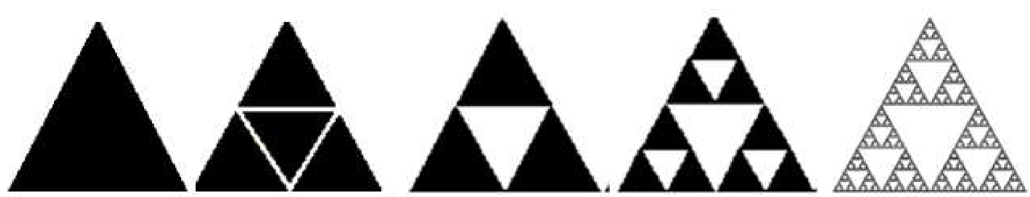


Fig. 1.6 Sierpinski triangles

After the first iteration of this triangle, only three quarters of area is left from the original triangle i.e. one quarter of triangle is removed after each iteration. The Sierpinski's triangle area is $(0.75)^n$ times the area of the novel triangle. Table 1.2 shows the number of iterations that are growing up after every iteration. According to observation of this table, a formula to analyse the number of triangles being removed for any iteration:

Table 1.2 Iterations of Sierpinski triangle

Iterations	No. of triangles in each iteration
1	1
2	4
3	13
4	40
5	121

At N^{th} iteration, number of triangles that are removed $N = \sum_{i=0}^{i=n-1} 3^i$

1.6.2.2 Sierpinski Carpet Geometry

Instead of triangles that are introduce in Sierpinski gasket geometry, Sierpinski carpet uses squares to define its geometry. In this geometry, we begin with square as an initiator, one middle square is taken out from the original square resulting into formation of nine squares similar to the original one and again the process continues for the nine squares formed for next iterations. Construction of this geometry is as shown below in Fig. 1.7.

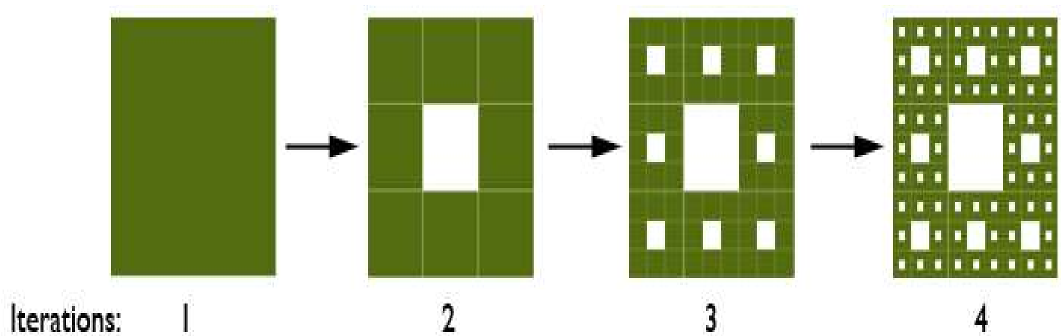


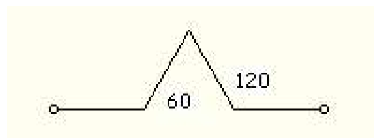
Fig. 1.7 Different iterations of Sierpinski carpet geometry.

1.6.2.3 Koch Curves

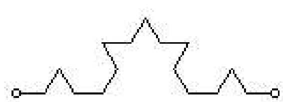
Koch curves are formed by dividing a straight line into three equal parts, which is iterated infinitely times. The intermediate part gets constituted into two parts of same length. Construction of Koch curve is very simple as illustrated below.

a. A straight line starts this process.

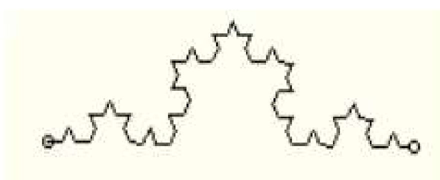
b. This straight line is then fragmented into three equal parts, but the central part of straight line has two parts at an angle of 60° and 120°.



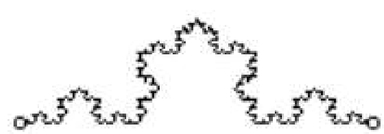
c. Repeat these 1 and 2 steps to the four line segments that are formed in above second step.



d. Next iteration curves are obtained as shown:



Three time iteration



Four time iteration

In each iteration, the length of size is multiply by 4/3 to maintain displacement between 2 point constants.

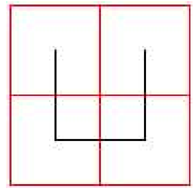
Total Koch length, $L = (4/3)^n$

After every n iteration, total number of Koch edge = 4^n

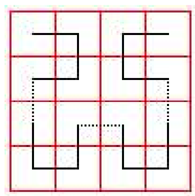
1.6.2.4 Hilbert Curve

David Hilbert was first discovered this Hilbert curve geometry. This curve will cover the whole plane after much iteration. So this curve named as space filling curve. Construction of Hilbert curve demonstrated as below:

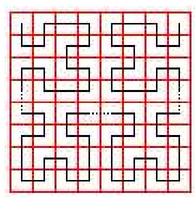
a. Begin with the essential staple-like shape as portrayed on the primary outline



b. The curve which is discussed in past get reduced to half of its size. All the while, diminished matrix size by factor of two. After this, four copies that are observed I curve are placed at the grid. The lower two curves must be put specifically as they may be. The upper two must be pivoted a quarter turn - one cleared out, another privilege. The later curve is obtained by connecting the short pieces along with short straight sections. The segments that are connecting to each other are vertical and other times horizontal.



c. All whatever is left of the curves are made successively one from another utilizing the same algorithm



Not at all like the Sierpinski Triangle and Von Koch Curve, during the time spent developing the Hilbert Curve, the same staple-like shape gets recoil and transform into different spots. Few of them are turned at an angle of 90 degree. This type algorithm is named as Lindenmayer System (L-system). L-system is a string revising system that is fundamentally applied to create fractal with measurement somewhere around 1 and 2. The curve must be joined by presenting some line sections after the transformation. Thus, the curve will shelter the entire plane after some iteration. Hilbert curve is shown in Fig. 1.8.

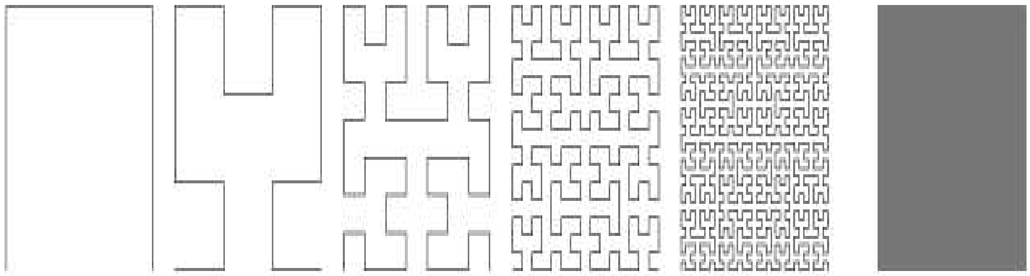


Fig. 1.8 Generation of Hilbert curve

After each iteration, the fractal gets to be 2 units longer. The length of the curve increased up to 2n units after n iterations.

1.7 Fractal as an Antenna

In antenna theory field, initial application of fractals was given by D.L. Jaggard and Kim. Fractal antenna was proposed as a radiating element for researching properties of multi frequency and also Sierpinski monopole antenna was introduced, which is presented by Carles Puente Baliarda. Low side lobe is formed by methodology based on randon fractal geometry. While Euclidean geometries are restricted to focuses, lines, sheets, and volumes, fractals incorporate the geometries that fall among these qualifications. That is why fractal can be considered as a line which is approaching towards a sheet. This line can fill the whole sheet. The curves are fit within a compact size due to space filling properties. Miniaturization of these antenna elements are due to this property. The monopole antenna was capable to work at five frequency bands. These multiband occur due the self-similar pattern of fractal antenna. The resonant frequency became lower from its initial value as iterations in the antenna are increased.

Conducting elements are placed into flat surface; elements are so arranged that it will form fractal geometry. Design is printed on copper surface and conducting surface is used where design is laminated. A few of iterations are taken to get fractal geometry that is required. A circuit board type design is created which is used in cell phones. Antennas with fractal type geometry are efficiently used to transmit or receive signals.

In fractal geometry, each of the iteration of antenna represents a certain range of frequencies. So these fractal antennas are widely used in much variety of products and these fractals are used in different circumstances. To bring down the size of antenna, small fractal loops are used. Input resistance of antenna can be increased by using these loops. Fractals are come into use to miniaturize the patch or wire elements. Radiation efficiency mainly depends upon the corners and sharp edges. Fractals have infinite iterations in which smaller are replica of first larger shape.

1.8 Advantages and Disadvantages of Fractal Antenna:

Several advantages and disadvantages of fractals over microstrip antennas are:

Advantages:

1. Compact in size, therefore less cost is required to construct.
2. Reliability is improved.
3. As compare to microstrip, size of antenna reduces to 4-5 times.
4. There is no requirement of extra components in antenna to obtained multiband applications.

Disadvantages:

1. Gain obtained in fractal antennas is lower than microstrip antenna.
2. Geometry of fractal antenna is tougher than microstrip antenna.
3. Particular mathematical analysis is not applied to fractals.

1.9 Thesis Organisation

Organisation of thesis report consists of these following chapters as below:

Chapter 1: Discussion of various parameters of antenna is done in first chapter. These parameters are radiation pattern, return loss, gain, directivity, VSWR, bandwidth, beam width. Different types of feeding techniques used to excite antenna are characterized. Further, many fractal geometries are discussed in this chapter.

Chapter 2: Authors are presented Microstrip antennas and Fractal antennas on the basis of requirements of frequency bandwidth for applications like GSM, WLAN, Bluetooth, Wi-Fi, radar system etc.

Chapter 3: Different design guidelines for designing the proposed antenna are discussed. Formation of each iteration used in fractal geometry is illustrated in detail. DGS technique is used in conventional ground plane. Dimensions of the slots etched out from the ground plane are also depicted.

Chapter 4: Parametric study is carried out in chapter 4. Optimization of parameters and effect of each parameter on radiation characteristics is depicted in the form of return loss plot.

Chapter 5: Final simulated and fabricated results are shown and discussed. Final simulated return loss plot and radiation patterns are shown. Fabrication technique is mentioned. Simulated and measured results are also compared.

Chapter 6: Conclusions based on the thesis research work is discussed and ways to extend this work for further improvement is also illustrated in the topic ‘future scope’.

CHAPTER 2

LITERATURE REVIEW

2.1 Earlier Research on the Fractal and Microstrip Patch Antenna

Many researchers have investigated about the microstrip and fractal antennas till now. Some of the researches are discussed below:

Shrivishal Tripathi et al. proposed a compact octagonal shaped fractal with multiple-input–multiple-output working for ultra-wide band. Self-similar property is applied to this proposed antenna to attain wideband applications. Also Koch fractal geometry with space filling property is used for miniaturization phenomena. Orthogonal fractal monopoles and grounded stubs are applied for better resolution results. C-shaped slot is etched from monopole antenna to attain band rejection phenomenon. Dimensions of proposed antenna are 45×45 mm. Radiation pattern that was obtained by this antenna is quasi-omnidirectional. Impedance bandwidth obtained by this antenna is 2 to 10.6 GHz. Simulated results of this antenna are common with the measured results [7].

Wei-Chung Weng et al. proposed the H- fractal planar antenna on FR4 substrate having thickness of 1.6mm. It was seen that designed prototype shows multiband behaviour i.e. antenna could be excited at multiple resonance. Many antenna parameters like reflection coefficient, radiation pattern, gain, return loss were measured and found out to be good and satisfactory for the wireless applications. The designed antenna confirms its working on the WLAN 5.5 GHz bands. Simulated results were in agreement with the measured ones [8].

Yasser Ojaroudi, Sajjad Ojaroudi and Nasser Ojaroudi presented a novel design and analysis of ultra-wideband (UWB) monopole antenna. This antenna has dual band-notched (5.5/7.5 GHz) parameters and extended bandwidth (3-15.7 GHz). Size of this designed antenna is $12\times18\times1.6\ mm^3$. A pair of I-shaped slot was etched from the ground plane to make the defected ground plane and also a pair of rotated T-shaped slots in the centre of I-shaped slots is connected to attain dual band-notched characteristics. Requirement of radiation pattern and return loss is attained by using this type of antenna. Results that are come out after simulation offered bandwidth of (3 - 15.7 GHz) and also gave rejection bands which prevent from interference with X-band satellite bandwidth range and WLAN [9].

Peshal B. Nayak, Sudhanshu Verma and Preetam Kumar proposed a fractal antenna that works for cognitive radio system which covered the spectrum sensing application because of multiband performance. This represented antenna designed for frequency band of 900-4000 MHz having four bands. Radiation pattern and gain of antenna are become better for cognitive radio system. Microstrip antenna uses E-shaped fractal antenna. Frequency band covered by fractal antenna are 945 MHz, 1945 MHz, 2470 MHz. Change in iteration levels is also discussed in this paper along with substrate and ground air gap [10].

M. Naser-Moghadasi et al. proposed a compact monopole antenna with coplanar waveguide feed. A folded T-shaped element (FTSE) is implanted in fractal patch antenna design. Fractal unit cells are used to match the impedance of antenna. Band notch behaviour is also described by folded T-shaped. Length of folded T-shaped element is used to tune filtering property. Ground plane have rectangular notches that will increase the impedance bandwidth of proposed antenna for UWB performance. The effect of antenna parameters is observed in this paper. Simulation results show the desired radiation pattern and voltage standing wave ratio. Frequency bands which are covered by proposed antenna are 2.94 to 11.17 GHz. Dimensions of antenna are chosen as $14 \times 18 \times 1$ mm^3 [11].

Kamariah Ismail and Siti Hasyimah Ishak represented a fractal antenna having defected ground structure with a geometry related to Sierpinski, occupied central frequency of 5.8 GHz. Design and simulation is done on computer simulation technique (CST). Fabrication of antenna is completed by using loss tangent of 0.025 and by using FR4 thickness of 1.6 mm. Radiation pattern is improved by using defected ground plane. The proposed antenna is used for RFID application [12].

S. Chaimool et al. investigated a fractal loop antenna that can have multiband behaviour. Short monopole is used to design this antenna which is full of fractal loops. The Minkowski fractal model is in use to optimise the parameters of loaded fractal loops. Dimensions of miniaturized antenna are $10 \times 45 \times 0.8$ mm^3. This proposed antenna is also designed for USB dongle applications. Simulated results of proposed antenna attain many of the frequency applications like WiMAX, WLAN, Wi-Fi etc [13].

R. Kumar et al. proposed pentagonal-cut fractal antenna based on coplanar waveguide feed. According to the requirement of antenna parameters, fabrication of this antenna is optimised with dimensions. Frequency bands of 2.5 to 15 GHz are covered by this design which is an ultra-wide bandwidth. A three-dimensional electromagnetic simulator is used to simulate the results of presented antenna. Radiation pattern and return loss are improved by using this antenna design. In this paper we studied that Impedance bandwidth is enhanced by affecting the design parameters. Only Omni-directional pattern is obtained in H-plane and in E-plane bidirectional radiation pattern is obtained. Throughout the band, a constant group delay is measured in this proposed antenna and backscattering is also good. For greater data transmission rate, this type of antenna can be used in wireless communication and microwave imaging [14].

Shufeng Zheng et al. presented fractal antenna–filter–antenna array (AFA) which is used for miniaturization of bandpass frequency selective surfaces**.** Frequency selective surface depends on antenna–filter–antenna array shows lower profile as compare to conventional frequency selective surfaces. But they are commonly large in sizes. The unit cell of antenna–filter–antenna array is decreased due to the use of fractal geometry. In this paper, cross-shaped fractal coupling aperture along with Minkowski island-shaped transmit/receive patches are introduced with its iteration factors and orders. The presented frequency selective surfaces which are used at C-band are fabricated with the help of waveguide measurement setup [15].

A. Valizade, Ch. Ghobadi, J. Nourinia, and M. Ojaroudi projected a compact square slot antenna which described the switchable band-notched characteristics, also having reconfigurable property. This proposed antenna also shows many reconfigurable properties for UWB frequency operations. A ∏-shaped slot is come into use for attaining single band notch performances. This type of slot is cut from the centre of the square metallic radiating stub. A p-i-n diode is implanted from the ∏-shape of slot that was etched from the stub, this will produce multi resonance functions and helps to obtain reconfigurable characteristics. C-shaped slots is obtained from ∏–shaped slot if the p-i-n diode is forwardly biased which generate a shorting path to the higher segment of ∏–shaped slot. Therefore by converting ∏–shaped slot into a couple of C-shaped slots, more number of resonances are observed and also impedance bandwidth becomes better. A metal strip biased the p-i-n diode inside ∏–

shaped slot. The dc biasing voltage cannot interfered the RF signal when blocking capacitor of 100-pF is used inside ∏–shaped slot. Theory of electromagnet coupling is applied in this paper to obtain wideband applications. In this theory, two L-shaped slots are injected to the microstrip feed line which will excite the resonances, this happened due to coupling effect occurred between ground plane and patch. Hence broader impedance is developed for higher bands without any increase of size. This proposed 20×20 mm^2 antenna is fabricated on FR4 material with thickness of 0.8 mm. It covered the frequency range from 3.04 to 11.17 GHz and also have good radiation pattern [16].

Yazi Cao, et al. investigated on a miniaturized multiband antenna which is designed by two open ended slots. The first slot is in the shape of T and second one is of E-shaped. Both the slots are etched out from the ground plane. The antenna responds to five resonating frequencies and can be used in GSM900/DCS1800/ PCS1900/UMTS and 2.4-GHz-based WLAN bands. The five bands occurred are controlled by the five monopole slots etched having different lengths. It is also seen that the antennas with E and inverted T shape slots always occupy less volume [17].

Wei Hu, Ying-Zeng Yin, Peng Fei and Xi Yang presented novel triband rectangular patch antenna having compact size. WLAN and WiMAX frequency applications are obtained by etched square and L slots from the patch antenna. A monopole radiator set of symmetrical L strips and square slots are main contents of this proposed antenna. This resonant type structure helps to achieve WLAN/WiMAX bands which are having three resonant frequencies. Antenna with 28×32 mm^2 dimension overall dimension was designed to cover triband applications on FR4 substrate and relative permittivity of 4.4. Coplanar waveguide feed is given to this proposed antenna having width of 3.5 mm. Bandwidths of 0.480 GHz (2340–2820 MHz) and 0.9 GHz (3160–4060 MHz) and 0.680 GHz (4.69–5.37 GHz) are covered by this triband antenna. A good range of antenna is also observed in this antenna design which lies in 2.77–3.06 dBi (2.3-2.7 GHZ) range for the lower operating band, 2.98–3.13 dBi (3.3-3.7 GHz) range for the middle operating band and 3.10-2.78 dBi (5.0-5.3 GHz) range for the upper operating band. This shows that stable gain is obtained by square slot antenna used for wireless communication [18].

Mehdi Veysi, Manouchehr Kamyab, and Amir Jafargholi proposed a microstrip patch antenna that was applied by proximity coupling feed. This antenna have proposal two novel single-feed dual-band and dual-polarized characteristics. The first technique to obtain dual-band and dual-polarized functions is by connecting open circuit stub at the open end of the feed line of patch antenna. By applying this technique two resonant frequencies are attained. The initial resonant frequency has same value of 5.8 GHz but the second is changed. This all depends on stub's location, the stub's length and feed point location. Same broadside radiation patterns are obtained but polarization is different at these two frequencies. Microstrip-gap proximity-coupled feed is the second technique to get dual-band and dual-polarized properties. Radiation pattern, gain and cross polarization are obtained at good levels by computer simulation technique [19].

Mahdi Naghshvarian Jahromi et al. proposed fractal monopole antenna for impedance-Matching Enhancement by using compact grounded coplanar waveguide. Sierpinski- Carpet antenna which is a printed fractal monopole is used to compare coaxial fed system with GCPW fed antenna. Frequency range of 6.25–8.4 GHz used for conventional Sierpinski- Carpet antenna and frequency range of 4.65–10.5 GHz matches for modified Sierpinski- Carpet antenna. This antenna design clearly shows that Multiband behaviour of antenna is converted into wideband with the helping of this new technique. Lower crosspolar field is obtained by using grounded CPW and also gave good radiation pattern. Designing of this antenna is used for FCC ultrawideband radio system. Proposed antenna used for ultrawideband is done in time domain analysis [20].

Javad Pourahmadazar et al. investigated a novel modified Pythagorean tree fractal monopole antenna for ultra-wideband. In this design, a conventional T-patch is used where modified Pythagorean tree fractal is incorporated. By applying this type of technique, impedance bandwidth is increased and produced more resonances. Resonances are also formed by increasing the number of levels of trees. Dimension of proposed antenna is $25 \times 25 \times 1$ mm^3 and frequency of operation for this antenna is between 2.6 and 11.12GHz having VSWR<2. Resonance and bandwidth obtained in this antenna is controlled in manner by using modified Pythagorean tree fractal antenna. Author discussed the impedance bandwidth in this antenna design [21].

Nima Bayatmaku et al. proposed an E-shaped fractal antenna for mobile communication and also for multiband behaviour. Many of the iteration levels are done to design this type of multiband antenna and compare each iteration results.

Resonance and bandwidth are improved as the number of iterations is increased. Many of the parameters including radiation pattern, gain, current distribution are observed in this E-shaped design in detail. Requirement of multiband antenna is overcome by this proposed design [22].

Alireza Pourghorban Saghati et al. investigated a novel reconfigurable slot antenna which shows three different switchable frequencies. Three electronic switches are given by this design which is a different type of feature. These three electronic switches selects different resonant frequencies. There is possibility of occurrence of different resonances at the same time. The antenna has sickle-shaped slots in the ground plane with three pairs of p-i-n diodes. The pin diodes are connected between three metal strips inside the slots and the ground plane. Different type of resonant frequencies are obtained by this type of antenna i.e. 2.4-GHz Bluetooth, 3.5-GHz WiMAX and 5.8-GHz WLAN are covered by proposed antenna. The problem of serving one frequency band at a time is is overcome by designing this antenna [23].

Qin Wang, Jinquan Huang presented Bowtie Sierpinski Fractal Patch Antenna which is used for RFID. Mom model was introduced for this antenna that was prepared by RWG vector basis function which is compatible for transmission lines. Radiation pattern is developed at different angles like 30°, 60° and 90°. Author noticed that current produced only on the surface of triangle. Conclusion of this paper shows that resonant frequency decrease as the flare angle is wider. Also radiation pattern came into better position for higher frequency as the flare angle wider, also bandwidth improved [24].

Abolfazl Azari presented about the specific property of self-similarity and space-filling in the fractal antennas. That is why in multi-band and broad-band antennas are commonly used by antenna designers. New fractal geometry is discussed in this study that has attained an ultra-wideband antenna. This can be achieved by square loop antenna of a wire and by choosing proper size and feed location. Dual bandwidths is covered by this suggested antenna design which include the range 7.5 - 14.5 GHz and 17.5 – 37 GHz. Study of this antenna shows better results in radiation pattern. Dimensions of this antenna were $6.2 \times 6.2\ cm^2$ [25].

Y.B. Thakare et al. proposed a star shaped fractal antenna which is used for back scattering radar cross-section reduction. This proposed fractal antenna size is half of the conventional circular microstrip patch antenna. Vector network analyser is used for measuring the behaviour of return loss. It can also cover a frequency band of 0.85 to 4 GHz. Back scattering radar cross-section is reduced by this type of antenna which then compares results with conventional circular microstrip patch antenna. Reduction of back scattering radar cross-section at multiband is done by increasing the number of iterations in the fractal antenna. Backscattering will also lowered by varying dielectric constant of substrate and thickness. Adjustment of substrate thickness provides maximum radar cross-section reduction by the antenna. Frequency effect and aspect angle are also discussed for variation on Back scattering radar cross-section reduction [26].

Chih-Chiang Chen et al. presented a microstrip antenna which shows better return loss graph by etching the slots from it. Bands of antenna that are useful for many applications were increased to a great extent. This research shows the multiband antenna can design by etching slots from the radiating patch. GSM, DCS, and WLAN 2.4 GHz covers triple band which is the best application of proposed antenna. Radiation pattern of proposed antenna achieved to an excellent for every band by properly implementation of proposed antenna. Many of the linear slits are used with meandered patch having a bending techniques was described in this paper which shows that slots antenna is very useful to get characteristics for GSM (global system for mobile communication, 890–960 MHz) and DCS (digital communication system, 1710–1880 MHz) [27].

Yi-Fang Lin et al. designed an independent dual-band hybrid dielectric resonator antenna (DRA). A coplanar waveguide (CPW) with inductive slot is applied to this proposed antenna as a feed. In this configuration, the CPW inductive slot executes the purposes of an operational radiator and the feeding arrangement of the DRA. The hybrid arrangement resonates at two different frequencies independently by enhancing the structure factors. One of them is obtained from the DRA with the broadside shapes and second from the inductive slot with patterns similar to dipole patterns. Parametric study is also experienced to determine the performance of parameters like resonance frequency and bandwidth [28].

Rashid Ahmad Bhatti, Yun-Taek Im, and Seong-Ook Park presented a multiband planer inverted-F antenna. This antenna obtained ten frequency bands for wireless communication. A shorted parasitic patch is used in this antenna design. a quarter-wave resonator attached to feed line which is in parallel with patch the main resonator is connected with four slits to initiate several current modes in the design. The proposed antenna for wireless communication systems like Global System for Mobile Communications (GSM-900), Digital Communications System (DCS), WiBro at 2.35 GHz, Bluetooth Personal Communication Service (PCS), Universal Mobile Telecommunications System (UMTS), Satellite-Digital Multimedia Broadcasting (SDM-B) at 2.65 GHz, WiMAX at 3.5 GHz an also there are two frequency bands for WLAN [29].

Zhang Hu, et al. designed a multiband application antenna named as modified Sierpinski fractal antenna. At resonance frequencies, broader bandwidth is attained by using improved ground plane and perturbed fractal antenna. Omnidirectional radiation pattern of an antenna is obtained when dimensions of antenna are taken as $50.8\times69\times1.6mm^{3}$. Lower resonating frequencies and return loss having bandwidth under -10db are 0.75-1.03GHz and 1.42-2.15GHz is observed after simulation results. This proposed antenna is used as CDMA2000, TD-SCDMA, GSM and WCDMA bands [30].

K.H. Chiang et al. investigated a defected ground antenna. The slots are etched from the ground to made it defected. Author in this paper discussed that by taking proper size and shape of slots, impedance bandwidth can be improved to a great extent. The proposed antenna consists of two U-shaped slots that are cut out from the ground plane. Front of the antenna is trapezoidal shape as a radiating element. Simulated results of proposed antenna increase the bandwidth of antenna by 112.4% which is incomparable with the plane ground [31].

Jin-Sen Chen presented the design analysis of triangular-ring slot coupled patch antennas. Coplanar waveguide feed is given to the antenna with a tuning stub applied to the feed. Length of tuning stub is so adjusted that impedance matching of resonant frequency is obtained in proper manner. Author analysed the behaviour of triangular-ring slot antenna having tuning stub of CPW feed and back patch. The initial resonant frequency with tuning stub obtained when slot ring parameter is having one guided wavelength. Bi-directional radiation patterns characteristics are achieved when slot –ring size is nearly equal to back patch [32].

X. Yang et al. represented a reconfigurable patch antenna based on Hilbert fractal curve. Third iteration of antenna design is also come into use by the author to obtain multiband behaviour of antenna. Different radiation patterns are also observed by including slots in the proposed antenna. These slots gave better radiation characteristics. The proposed antenna could be efficiently used in radar or telecommunication systems [33].

S. Petko represented 3-D fractal tree antenna having new compact designing. The parameters that were influenced by this design of antenna are due to elevation angles and also parameters are affected by the iteration levels used for this antenna design. In this paper, author concluded that reflection coefficient and return loss are improved by designing by fractal tree antennas. RF switches are also used by many other fractal tree antennas at the branches of antenna. By applying this type of technique, size of antenna is reduced by 60% and also helps to raise the bandwidth up to 70% [34].

Steven R. Best proposed the resonant behaviour of fractals and non-Euclidean wire antennas. Fractal wire antennas are deigned to get proper resonance and better radiation patterns which are done by space filling property that a fractal have. Size of fractal antenna is smaller than Euclidean antenna i.e. they can resonant at same frequency. Koch fractal antennas are come in discussion in comparison with Euclidean antenna for their resonant behaviours. Author discussed that physical properties of antenna also matters to understand physical significance of a fractal antenna. Loop area, total wire length and wire diameter are the physical properties for wire loop antenna, monopole height also include for wire monopole antenna [35].

Douglas H. Werner proposed the discussion of fractal geometry with electromagnetic theory that how to combine both, which then design new type of antenna that will give new bands of applications. Fractal antenna research discussed about the design of antenna and antenna arrays design. Fractals have no proper size and have many of iteration levels. This property of iteration levels is a unique property which will creates the antenna for multiband applications. Fractal arrays have highly desirable properties that will include multiband behaviour [36].

J. anguera et al. proposed a compact sized antenna by using Hilbert fractal curve theory. By using Hilbert fractal curve, author analgised and mentioned that by increasing iteration levels of antenna, the size of antenna is reduced and also length of curve become small. There are number of fractal antennas that were observed by the author which shows that by using of different configurations of Hilbert curves which will compare with standard λ/4 monopole antenna observe that Hilbert monopole wire length was increased as the iterations level were increased [37].

Ricky Chair, Kwai-Man Luk, and Kai-Fong projected a multilayer microstrip patch antenna with compact in design. Feed given to this multilayer patch antenna is coaxial feed technique. This antenna is highly advantageous for their low cost and light weight but used for low microwave frequencies. Two layer rectangular patch antenna is the first layer of antenna design, larger in physical dimensions. Area of projection of other two layers is kept similar. Resonant frequency of the two-layer rectangular patch antenna is lowered by 50% and has attained bandwidth of 5%, which is broader than the single-layer antenna. Topmost patch was cut into a bow-tie shape in the second structure of antenna which decreased the resonant frequency by 60% and bandwidth of 12% is attained. Better radiation pattern and lower cross-polarization level achieved by these two small size antennas when compared to co-polarization level by more than 20dB [38].

K. J. Vinoy et al. viewed the Hilbert's curve geometry which helps the author to design antennas by using this type of geometry. At that time Hilbert geometry was newly researched and also very easy to project. By use of Hilbert's curve geometry, antennas were designed with greater miniaturised level. Radiation patterns are varied only by presenting segments to the proposed antenna. RF switches connected as the additional segments make the radiation pattern configurable in same way as we are connecting switches along the length of antenna. This technique results in formation of antennas which possess the frequency tuning characteristics [39].

Zhengwei du et al. represented the fractal patch antenna and created the square fractal patch antenna and analysed the results according to antenna performance. Author obtained the multiband behaviour of fractal antenna and it was concluded that results are due to the driven element and not due to the parasitic fractal elements [40].

Jaume anguera et al. proposed the fractal patch antenna and observed improved antenna parameters like gain, radiation pattern, return loss, input reflection coefficient etc. Fractal iterations are done by author to observe the multiband behaviour of this antenna [41].

Carles Puente-Baliarda et al. represented multiband behaviour of proposed fractal antenna based on gasket geometry of Sierpinski. In this paper discussion, antenna is related to bow tie antenna having single band. Results of this antenna are obtained by simulation technique. Radiation pattern, gain and return loss graphs are experimentally discussed in this paper [42].

C. Puente et al. investigated multiband behaviour of fractal antenna by using new techniques. This antenna is designed in two different ways; spatial arrangement was the first approach of author and second was fractal with array factors. Lower side lobes array are formed by using this type of design. Self-repeating structure is created for fractal array factors. With the help of this structure, multi resonant frequencies are obtained [43].

2.2 Thesis Objectives

The main of the thesis project is to design and fabricate a multiband antenna which can satisfactorily work on various bands of wireless communications like GSM, Bluetooth, IMT, WiMAX, WLAN etc. and also to study the effect of fractal geometry and DGS (Defected Ground Structure) on the Microstrip patch antenna. Some of the main objectives are listed below:

- To design and fabricated X-fractal patch antenna with defected ground structure.
- To compare the measured and simulated results.
- To study the effect of fractal iterations on the performance of antenna.
- To analyse the effect of width of strip on the radiation characteristics of antenna.
- To study the radiation pattern obtained by the CST software.
- To discuss the effect of applying DGS (defected ground structure) in comparison to the conventional ground on the antenna return loss plot.

CHAPTER 3

ANTENNA DESIGN

3.1 Introduction

In this chapter the detailed discussion about the design parameters of the antennas are described. The complete structure is designed by using number of iterations and each iteration along with its effect on the antenna parameters is discussed deeply. As it discussed in chapter 'I' that fractals are very advantageous and have compact size when compared to conventional microstrip patch antennas. Fractal geometry is responsible for obtaining multiple resonances that is why fractal geometry is applied to form the antenna shown in order to obtain multiband behaviour. A simple rectangular strip line is taken as an initiator and some special spatial arrangement is used to form X- shaped antenna and these X shapes are again iterated at more levels, corresponding to the formation of the prototype antenna. Effect of various parameters used in the design of antenna on the antenna performance is explained and shown graphically in the form of return loss and radiation pattern. The Antenna designed is very much effective in covering many bands of wireless communications which are discussed in subsequent chapters. Further sections of this chapter are based on parametric design of antenna.

3.2 Antenna Design

X shaped fractal antenna is designed for multiband applications. This antenna design is shown in Fig. 3.2**.** For this antenna, computer simulation technique is used to determine the return loss graph which is main focusing part of antenna; other parameters like radiation parameter, VSWR, gain are also observed by this latest technique. The material of substrate is FR4 over which antenna design is placed; design is at the top surface of FR-4. Thickness of FR-4 substrate is 1.6 mm and of conducting strip of 0.1 mm. Grounding is very much important for antenna design, that's why ground is connected to the lower portion of substrate. The presented antenna has 3 stages which is perfect for multiband applications. Starting with first stage, a horizontal metal strip on FR-4 substrate is designed having length of L_1. Strips width at the upper face of substrate is 3 mm (W_0). Length and width of substrate is ($2*L_0+W_g$) and L_g. The strip L_1 is then rotated by 45 degree. The X-shaped antenna is formed by taking mirror images of strip L_1 along four sides. A strip of length G from the centre of design is created. This will complete the first iteration of X- shaped fractal antenna. Similarly, second iterations can also be formed by taking appropriate length of strips. The idea of creating a strip of length G came into mind was only because of interference. Because of this strip, there is no interference of final iteration strips with the feed line that is applied to the antenna. In the absence of this strip, losses in the return loss graph are come to great extent which is the huge disadvantage. After the completion of iterations of antenna design on the upper surface of substrate, ground plane is adjusted on the bottom of substrate. Fig. 3.3 shows the ground plane of proposed antenna. The effect of ground plane is greatly enhanced the radiating far field and the reactive near field. The Reactive far field exist near to the antenna. In this field, antenna acts as a large lumped constant inductor and capacitor. In this region, energy is stored but radiating portion is less. Mutual impedance is developed between antenna and its environment because of ground interaction with this area. The feed point impedance of antenna is changed but with this losses are increased. In case of radiating far field, radiation pattern are highly influenced i.e. much increase to an extent due to the presence of ground.

Slots are etched from the ground that will give better results of return loss graph. Slots will increase the frequency bands of desired antenna. Slots radiate EM waves in similar way that a dipole does. Slot antennas are also used at UHF and microwave frequencies instead of line antennas when greater control of the radiation pattern is required. Slot antennas are mostly used in radar antennas. Slots are etched from the ground of the antenna that will give the desired frequency bands. In this antenna, slots are cut in such a fashion that some parts of ground are not connected to each other. The part of ground which is not connected to the input port of antenna or to any other grounded copper are comes in contact with EM waves. Width of slots that are etched from the ground is very narrow. Three iteration levels of X – shaped fractal antenna is shown in Fig. 3.1.

3.2.1 Geometry of Final Proposed Antenna

Front view of fractal antenna is as shown below in Fig. 3.2 with proper defined dimensions. To avoid overlapping between feed line and strips of final stage, we can introduce a strip with length G. By taking appropriate length of this factor, overlapping is restricted. This typical design is applied on the substrate of material FR4 having length (L_f+L_0) and width of 1.6 mm. Length of the strips in this proposed antenna is centre to centre. Ground which is a conducting material of copper serves as a return path for current to different components on the design also shows a major role in the reflection coefficient graph. According to this ground plane, return loss graph varies. Ground does not necessarily have to be connected with the port from where input is transmitted. Ground plane is adjusted according the fractal design. Plane of ground which is so adjusted to get desired antenna frequencies is as shown in Fig. 3.3**.** Dimensions of antenna that are preferred in this X- shaped are shown in Table 3.1.

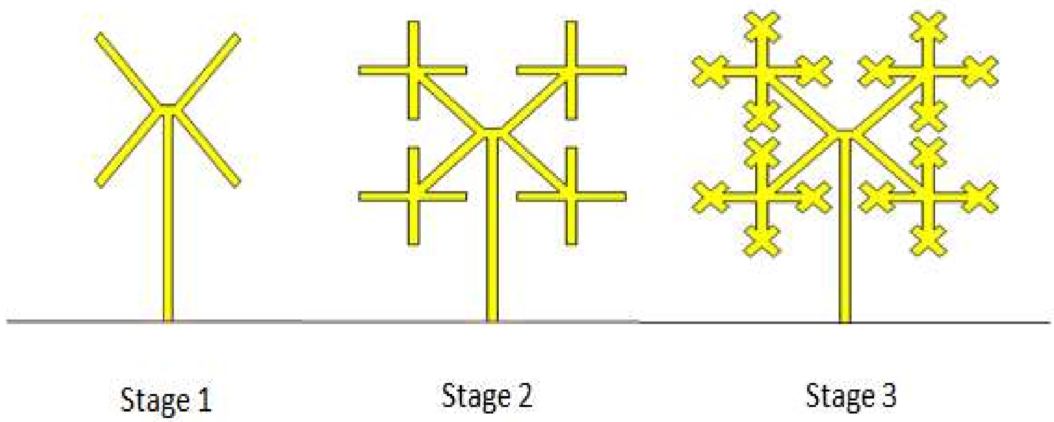


Fig. 3.1 Three stages of fractal antenna

Slots S1and S2 that is etched from the ground has width of 0.5 each. Lower dimension of slot s1 from where it is etched is (L_f -10.5) and S2 has lower dimension is (L_f -10). Slots with width of 12 and length of (L_f+L_0-0.3) also cut from the ground having length of (L_f+L_0) and width of k from both side. Results of antenna are mainly depends on slots of antenna. Main advantage of slot is that, it increases the electrical length of antenna due to which more EM wave are come in contact and thus enhance the various parameters of antenna.

Fig. 3.4 given below is without etching slot S1 from the ground. This clearly shows that there is a lot of difference between the etching slot and without slots. Many of the frequency bands are decreases their gain, bandwidth and also effect on side lobes.

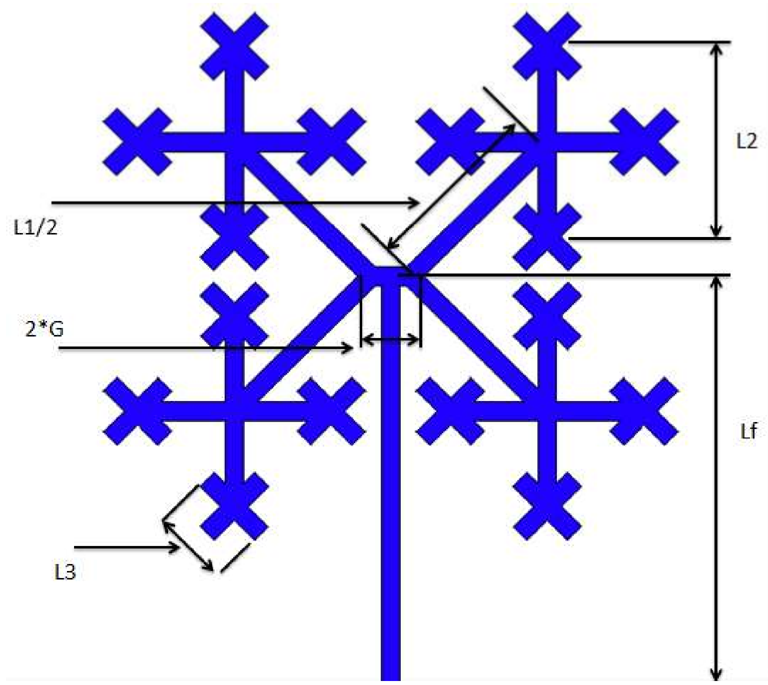


Fig. 3.2 Front fractal patch of the designed antenna

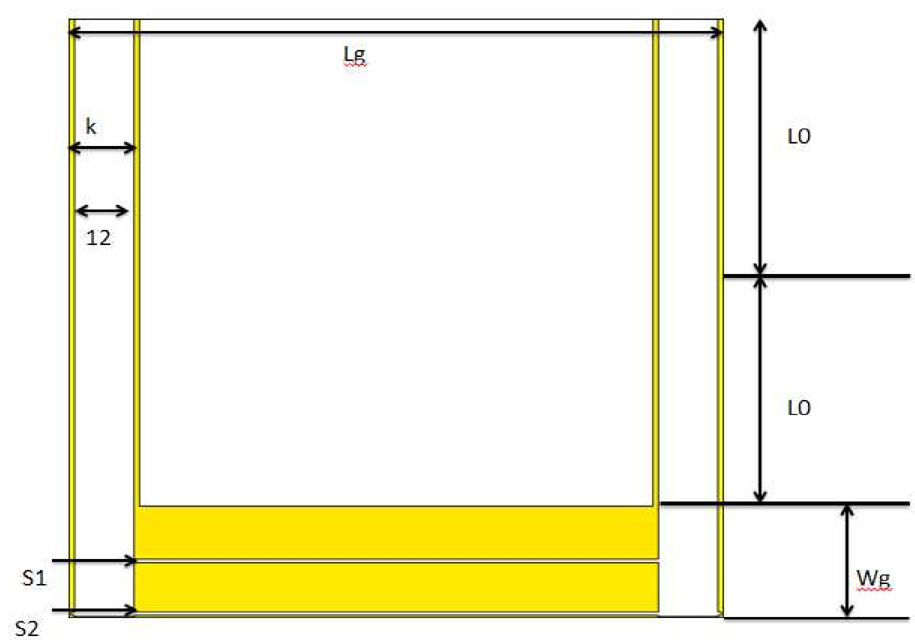


Fig. 3.3 Back view of the DGS formed

Table no. 3.1 Dimensions of optimized X-shaped fractal antenna

Parameter	L_1	L_2	L_3	W_0	H	L_g
Size(mm)	60	30	9	3	1.6	120
Parameter	G	K	L_f	W_g	L_0	
Size(mm)	3	12	63.71	20	43.71	

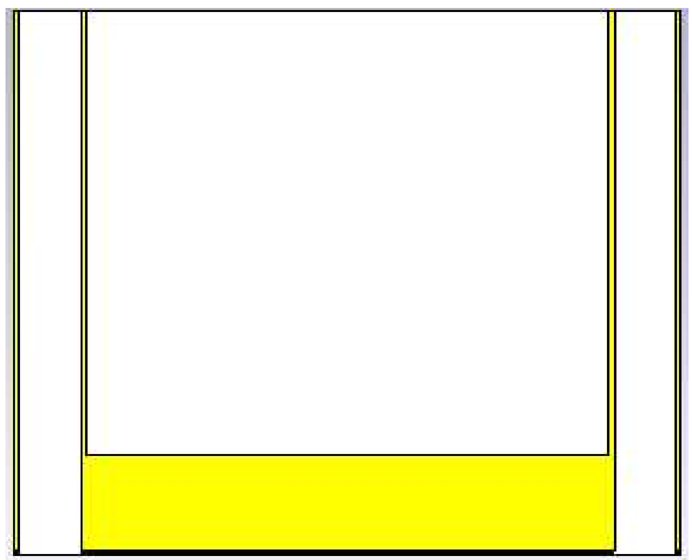


Fig. 3.4 Ground without slot

Results of these 3 stages are different to each other. From the simulation results of these three stages, we are looking of three basic parameters like return loss, Voltage Standing Wave Ratio, Gain, Directivity.

Return loss is defined as -20log$|r|$. Return loss graph of stage 1 is shown below in Fig. 3.5. In this stage, it covers the frequency range of 3.7-3.85, 4.4-4.9 which is used as international mobile telecommunication, frequency bandwidths of this stage is not too wide. For this reason fractals are introduced in antenna designs. This stage also covers a range of 5.1-5.9, 6.3-6.8.

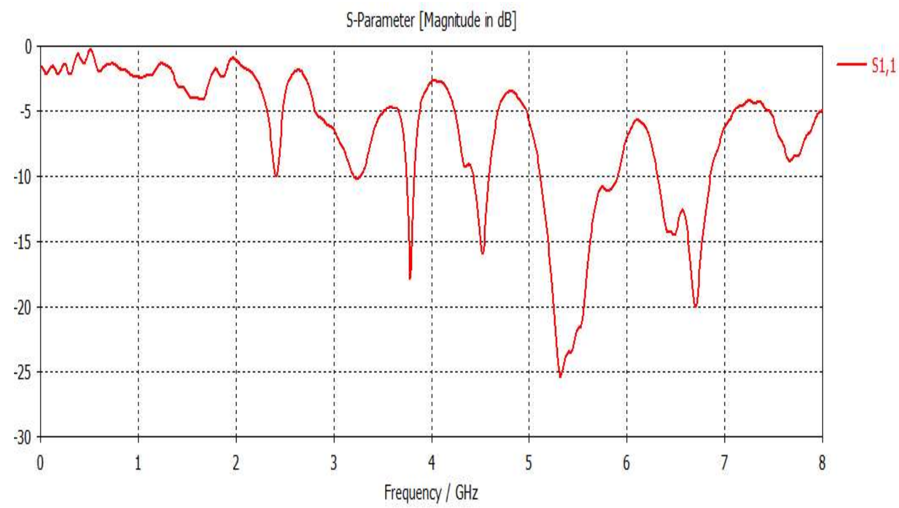


Fig. 3.5 Return loss plot for the 1st stage

Now, Results in the next iteration improves further in gain and also we found new frequency bands. Reflection coefficient graph of stage 2 is shown below in Fig. 3.6. As in stage 2 frequency band of 2.20 -2.39 are not extending to -10 dB but after second iteration this band increases reflection coefficient parameter and become in use for IMT band.

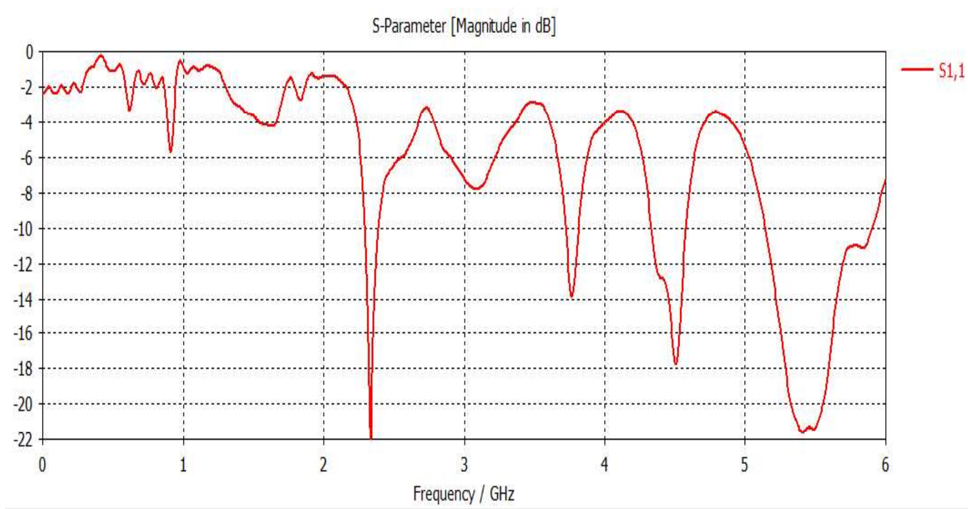


Fig. 3.6 Return loss plot for the stage 2

There is huge importance of slot S1 which is etched from the ground. In this particular antenna, without separating ground from each other doesn't give better results. After we separate ground with the help of slots, bandwidth of frequencies increased. The geometry of this fractal is symmetrical about 50 ohm microstrip feed line with width of W_0. Return loss graph of X- shaped antenna without slot S1 is as shown in Fig. 3.7.

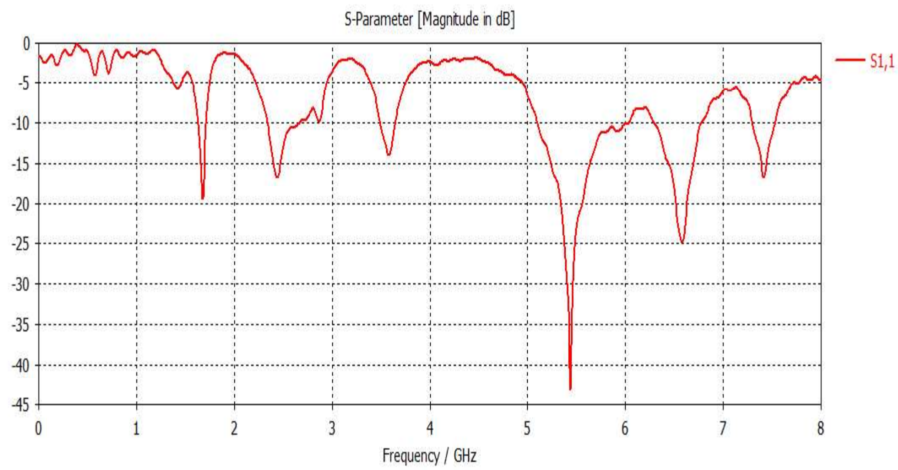


Figure 3.7 Return loss plot without slot

CHAPTER 4

OPTIMIZATION OF PARAMETERS

4.1 Introduction

In chapter 3, we studied the X- shaped antenna design in which various parameters are determined as like radiation parameter, return loss, gain etc. These parameters are discussed deeply with proper dimensions of antenna. In this chapter, we will determine the results by varying various parameters of antenna which will change the behaviour of antenna; also many of the frequency bands get changed. Parameters that will affect the antenna design, return loss graph, radiation pattern are the followings:

1. Number of iterations used.
2. Variation in width of radiating patch strips except feed line width.
3. Incorporation of Defected ground plane.
4. Length of the central conductor from where the feed is attached.

4.2 Effect of Iteration Levels

Various effects are examined in behaviour of antenna design by doing this procedure. Results of different iterations are discussed below:

Stage 1

It is the initiator stage for the X-shaped fractal formed shown in Fig. 4.1

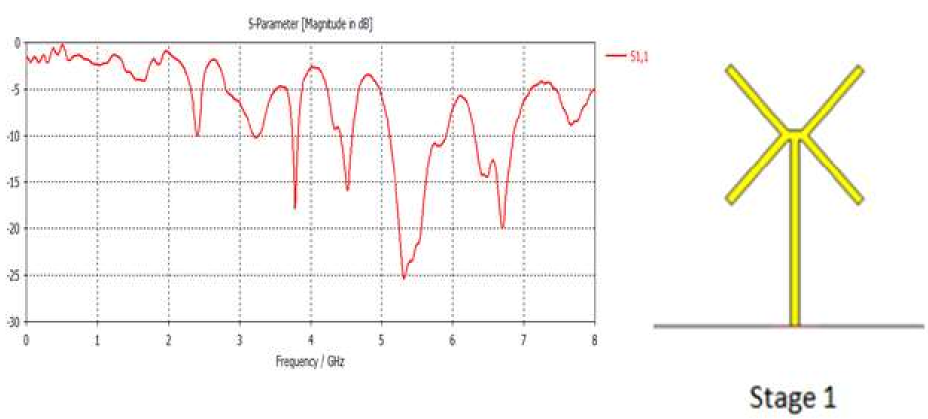


Fig. 4.1 S_{11} (dB) Simulated for the first stage

In this first iteration mode, the fundamental frequency has low gain which is around 2.4 GHz. All the frequency bands in this iteration are not that much useful for different applications because of their less gain. Now to decrease the resonant frequency and to broaden the bandwidth of this antenna, second iteration is come in use.

Stage 2

Design of second iteration and its return loss graph of second iteration are shown in Fig. 4.2**.**

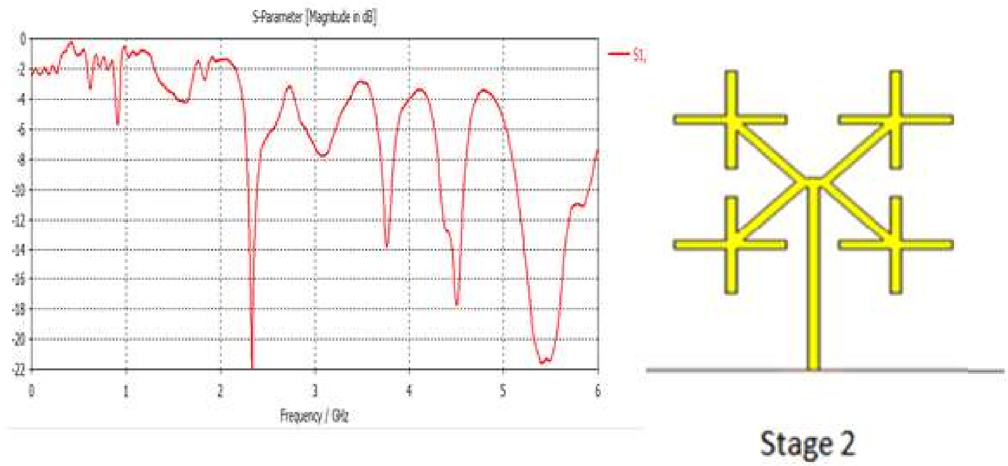


Fig. 4.2 S_{11} (dB) Simulated for the second stage

Results shown in second iteration are better than the first iteration level. Gain of the fundamental frequency at near about 24 GHz is increased and also gave clear results in 5 to 6 GHz frequency band. in this stage, bandwidth covered with this iteration is less. Therefore, to increase the number of bands, third iteration is needed. Design of third iteration and its simulation results are shown in Fig. 4.3.

Stage 3

Stage 3 is the final stage of the proposed antenna. It comes out after the second iteration of the initial X-Shape patch. Simulated return loss plot along with the stage 3 X-Shaped fractal patch is shown in Fig. 4.3.

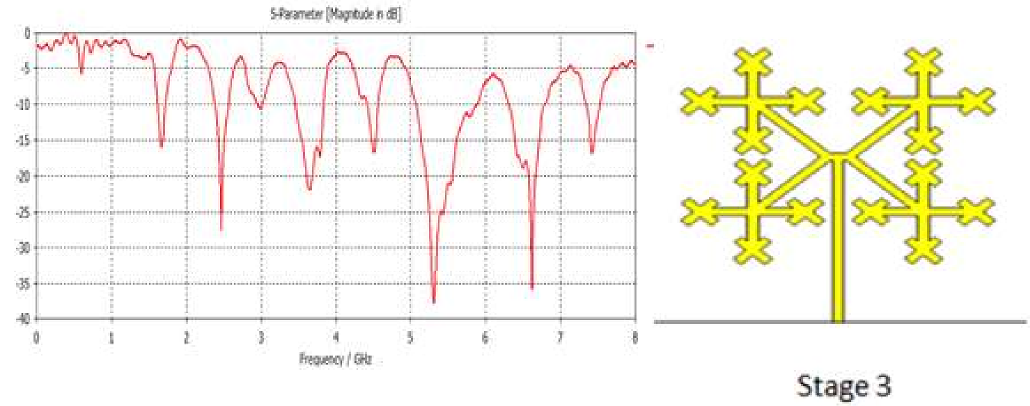


Fig. 4.3 S_{11} (dB) Simulated for the third stage

In this last iteration level, the resonant frequency decreases further with moderate gain. Number of bands used for various applications are also come out with this iteration. Frequency range from 5-6 GHz and 6-7 GHz is almost covered by this design and also cover Bluetooth band. Other applications of this design that are in use are IMT, radar, WLAN. These effects show that with increasing the iteration levels, improvement in antenna parameters like return loss, radiation pattern also seen.

4.3 Effect of Variations in Width of Patch Strips

Variation in the width of the strip 'w' in return loss plot of the designed antenna is shown in fig.--. From the plot it is clearly seen that the best results are obtained at 'w = 3 mm'. It is concluded that as the radiating surface increases, the antenna's performance is increased but we cannot increase it to certain limit as spurious radiations due to surface current density also starts increasing which limits the performance of the micro-strip antenna. Hence, we optimize our strip width to the value of 3 mm. Return loss of the antenna by taking varying width is given in Fig. 4.4.

4.4 Effect of Applying DGS Concept to the Ground

DGS stands for defected ground structure. Conventionally, microstrip antennas were formed with the whole conducting sheet below the substrate acting as a ground, but the researches show that by etching slots out of ground i.e. what means making it 'defected ground structure', will improve the performance of the antenna. Resonating bands will be increase as slots corresponds to increase resonating frequencies of antenna. Hence, efficiency of antenna will increase. Fig. 4.7 shows the slots etched out from the ground plane which corresponds to multiple bands. Fig. 4.4 shows the return loss plot with the conventional ground i.e. complete sheet below the substrate dielectric material whereas Fig. 4.5 shows the simulated return loss plot for the Defected Ground Structure (DGS). Fully ground plane structure of antenna is also shown in Fig. 4.6.

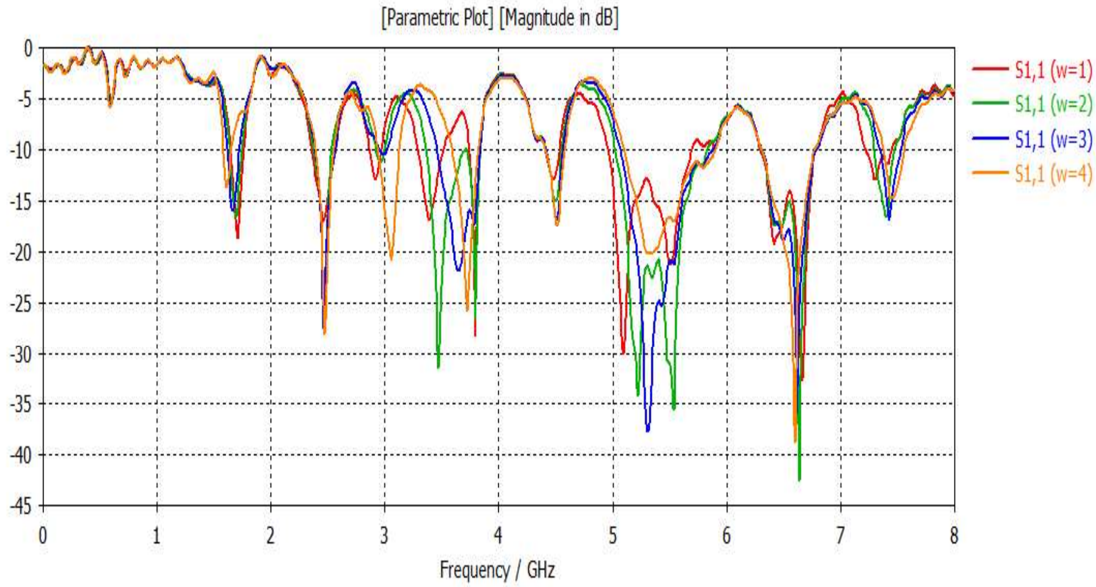


Fig. 4.4 S_{11} (dB) Simulated showing the effect of strip width

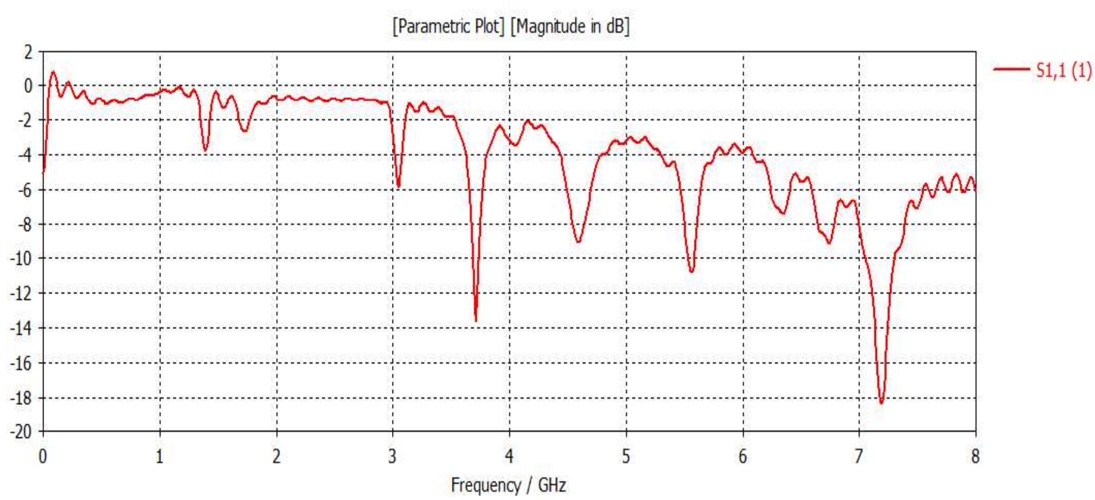


Fig. 4.5 S_{11} (dB) Simulated for the conventional ground (complete sheet)

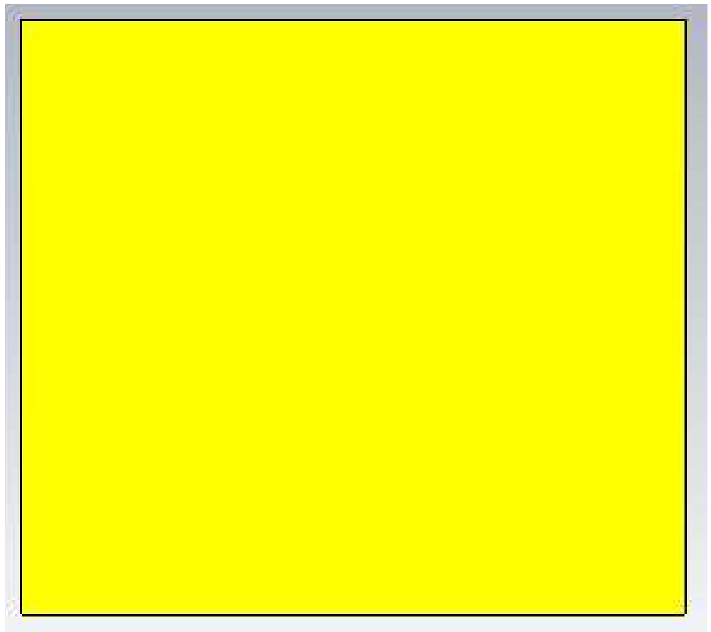


Fig. 4.6 Conventional ground

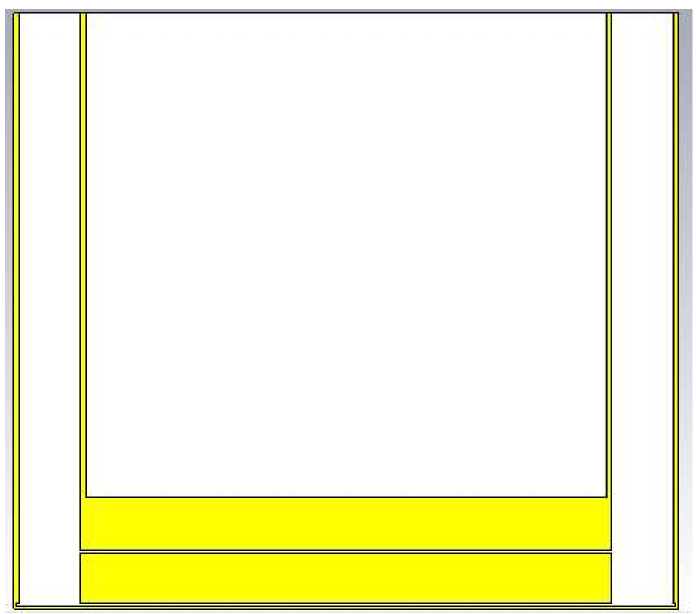


Fig. 4.7 Defected ground structure

Fig. 4.4 shows the return loss graph in which we found only few number of frequency bands. There is no frequency band between 1 to 2 GHz and 2 to 3 GHz. Also, the bands which are used for WLAN and between 4 to 5GHz having very less gain which are of no use. Determination from this graph come to the point that, before etching the slots from the ground plane, frequency bands are disappear from the return loss graph which is the greatest disadvantage of fully grounded plane for this specific type of antenna. The graph shown in Fig. 4.8 shows the return loss graph with etched slots from the ground plane.

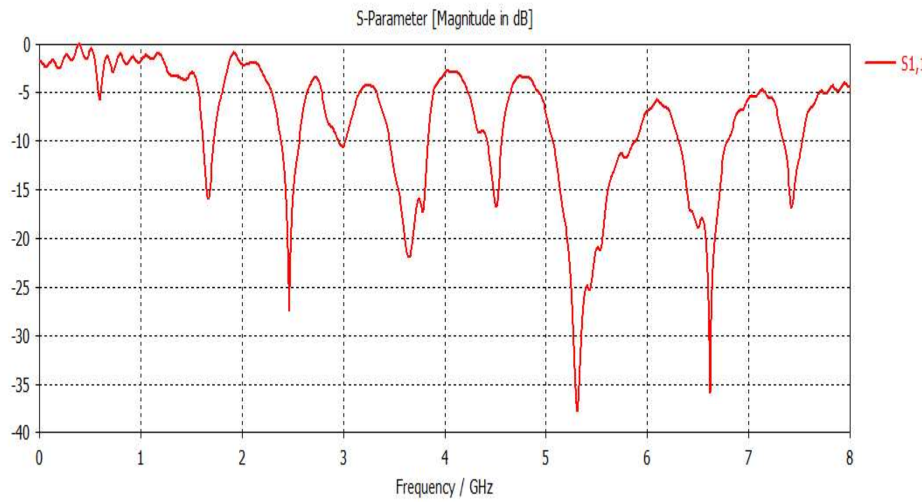


Fig. 4.8 S_{11} (dB) Simulated for the DGS

More number of frequency bands are attained by etching slots from the ground. That's why defected ground plane is much better technique for antennas to design with multiband behaviour which is further use in different applications of IMT, WLAN, radar system, Bluetooth etc.

4.5 Effect of Length of the Central Conductor (g)

Central conductor is the strip line present in the centre of the patch which is directly attached to the microstrip fed line. This conductor strip helps in providing efficient feed to the whole of the patch. Length of this strip is optimized experimentally by simulating different value and the results are shown in Fig. 4.9.

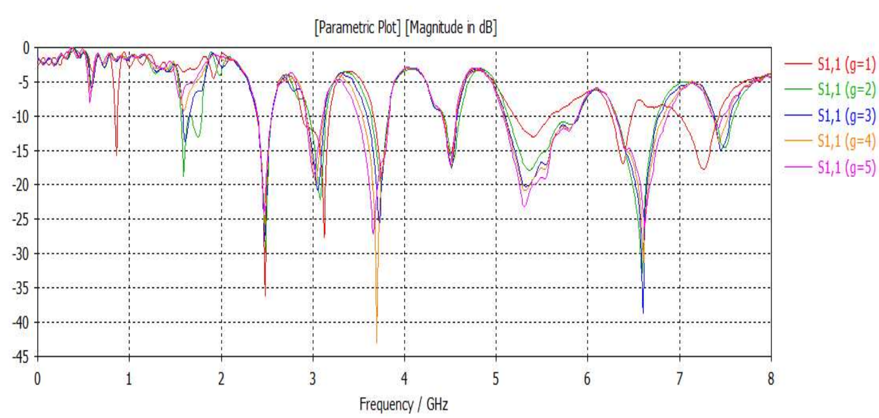


Fig. 4.9 S_{11} (dB) Simulated for optimizing length of central conductor

The optimised length for the central conductor is 3 mm as it is clearly shown from the graph that best results are obtained at 3 mm.

CHAPTER 5

RESULTS AND DISCUSSIONS

5.1 Introduction

In the previous chapter, the designing parameter for antenna design is given and also the effect of each parameter on the characteristics of antenna is given. This chapter illustrates the final results (simulated and fabricated both) which are obtained by the designed prototype. Simulations are done in CST software and testing of the fabricated antenna is performed in antenna research lab Thapar University, Patiala.

5.2 Simulated Return Loss Plot

Reflection coefficient graph of the desired antenna is as shown below in Fig. 5.1**.** This result is with slot S1 which will increase the gain of antenna and gives better return loss graph. This is the final results of third iteration, which shows that by increasing the number of paths of current, there will be increasing number of frequency bands occurs with good gain i.e. there are low radiation losses and dispersion. Resonant frequency increases as the number of iterations increases.

The impedance bandwidths at the lower and upper bands (dB) are 6.9% (2.39–2.56 GHz) and 14.5% (5.10–5.90 GHz), respectively. This proposed antenna works for international mobile telecommunication having band of 2.3-2.59 GHz. This frequency range also covers the Bluetooth band that is used in mobile communication, having frequency range from 2400-2500 MHz. The main aim of using this X- shaped antenna is to work on WLAN having range 5.1-5.9GHz and 2.4GHz. This designed antenna covers almost complete 5-6 GHz frequency i.e. having huge bandwidth range. This antenna has application in next 5th generation technique which will work in frequency range between 6-7GHz.

5.3 Simulated radiation pattern

Radiation pattern of X-shaped antenna is as shown in Fig. 5.2. By giving the proper feed to the antenna, radiation pattern will improve also. Displacement of feed may give improper results of radiation pattern. Therefore, Position of feed for a fractal antenna is exactly placed at the centre of the fractal width direction (y axis) and somewhere along the fractal resonant length direction (x axis). The exact position of feed along the resonant length is determined by the electromagnetic field distribution in the fractal. Looking at the current (magnetic field) and voltage (electric field) variation along the fractal, the current has a maximum at the centre and a minimum near the left and right edges, while the E-field is zero in the centre and maximum near the left and minimum near the right edges. Radiation pattern obtained shows the directivity of antenna in following figures. Measured results are shown in Fig. 5.5 and they are in agreement with the simulated results. Some of the minor deviations are due to fabrication errors.

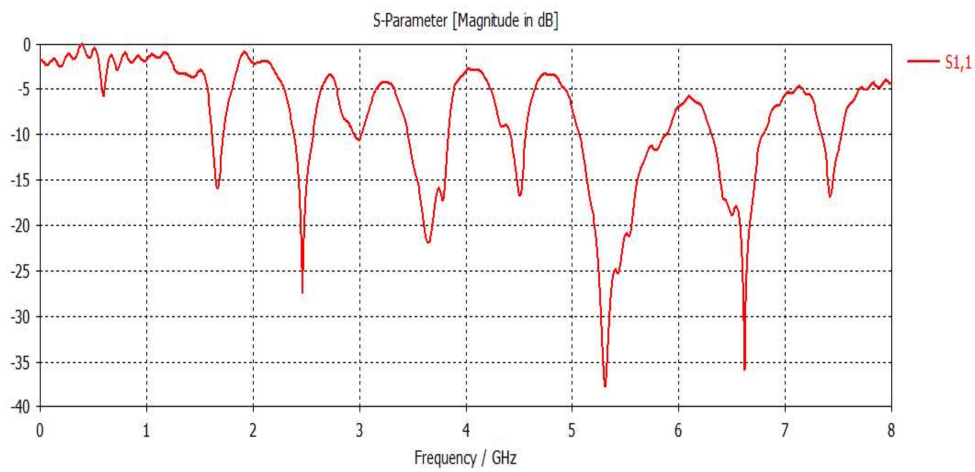
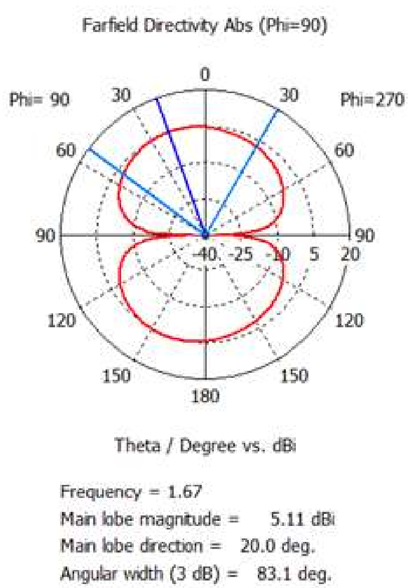
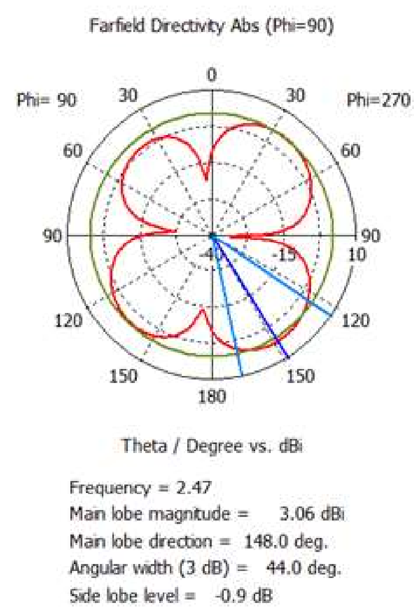


Fig. 5.1 S11 (dB) Simulated for the proposed antenna





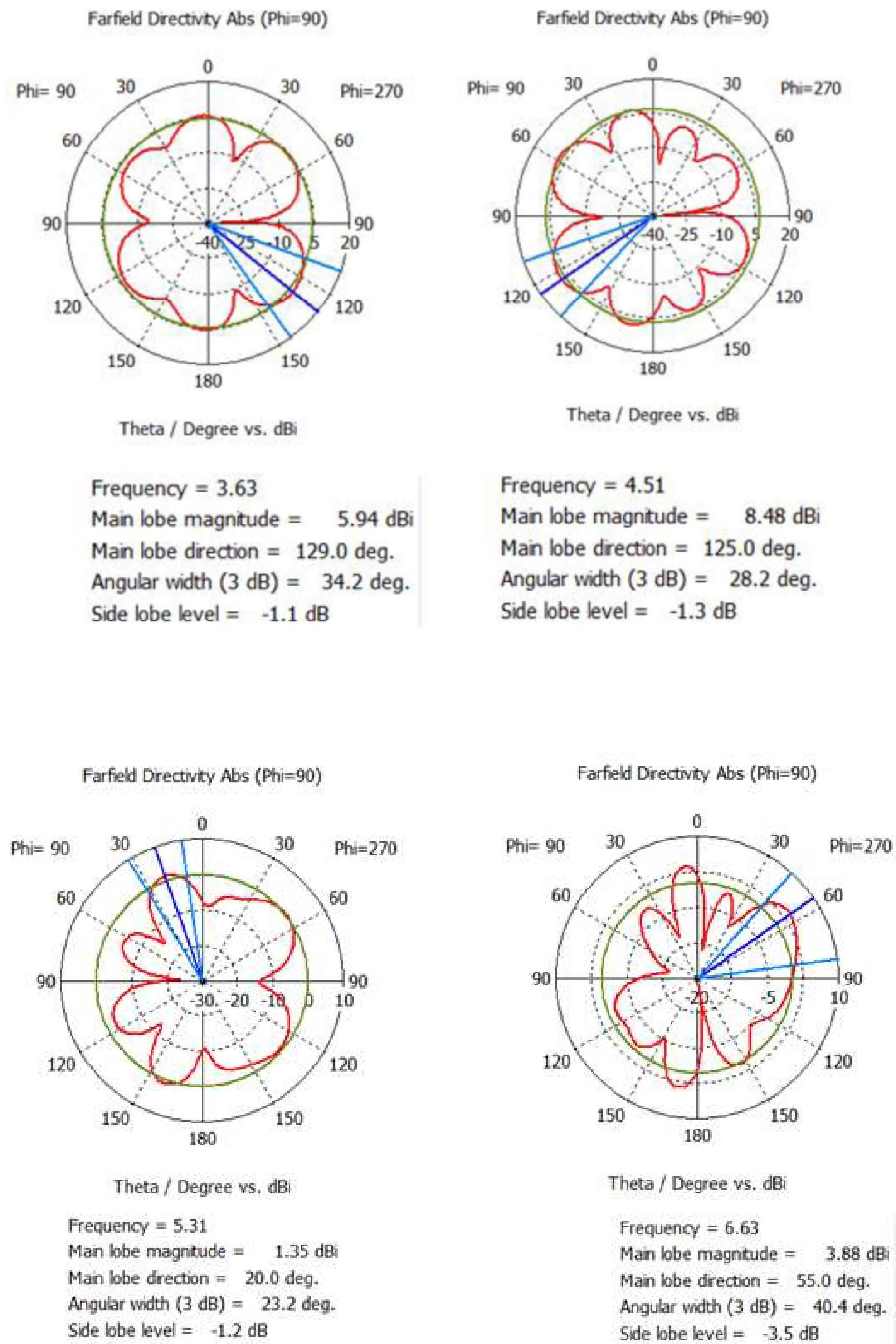


Fig. 5.2 Radiation patterns at different frequencies

5.4 Fabrication and Measured Results

After optimizing the design parameters for the proposed prototype and simulating its results in CST (computer simulation technology) software, the antenna is now fabricated and tested analytically. For the fabrication FR4 substrate is used whose height and dielectric constant are 1.6 mm and 4.4 respectively. Technique used for the fabrication is photolithography and wet etching technique for the etching of slots. Fabricated antenna is shown in Fig. 5.3 and its tested results are shown in Fig. 5.5. The fabricated antenna is tested by Agilent E5071C vector network analyser in the antenna research lab Thapar University, Patiala.

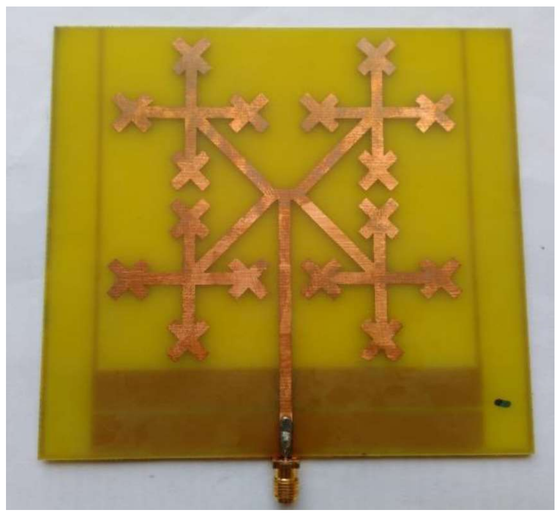


Fig. 5.3 Front view of fabricated antenna

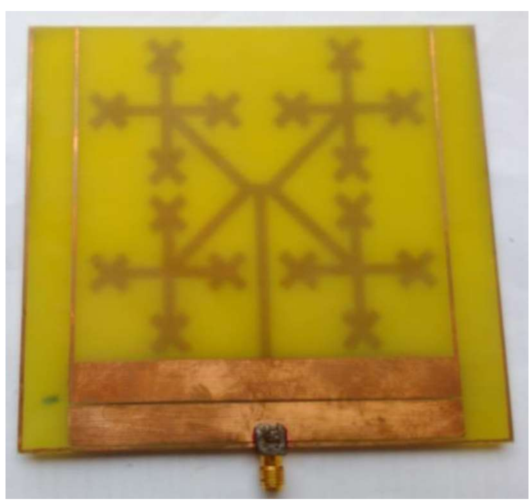


Fig. 5.4 Back view of fabricated antenna

Fig. 5.3 represents the front patch fabricated whereas the defected ground structure (DGS) fabricated is shown in Fig. 5.4**.** It can be clearly seen from the measured result plot; the antenna radiates and confirms its applications in wireless communication system practically as the measured result are in agreement with the simulated one. The slight variation in the simulated and measured result could be due to the fabrication error.

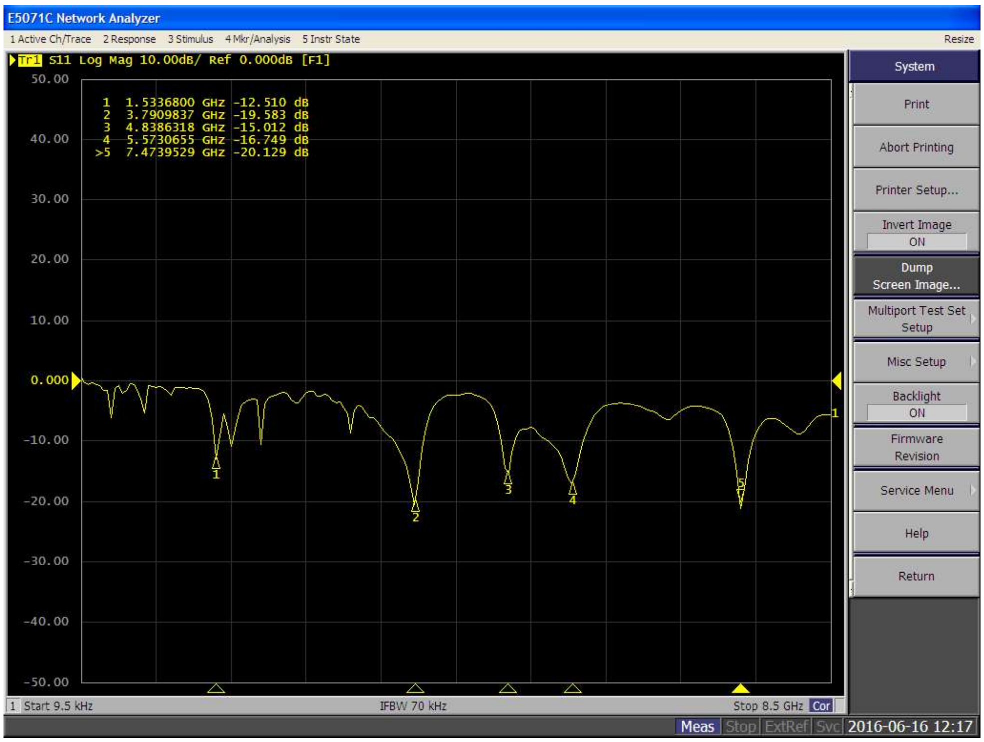


Fig. 5.5 Measured return loss plot for the fabricated antenna

CHAPTER 6

CONCLUSIONS AND FUTURE SCOPE

6.1 Conclusion

The previous chapters include all the theory, literature survey and design parameters of antenna. This chapter is the conclusion of the whole thesis report written previously. As described in the abstract and thesis objective the main aim of the thesis project was to design a multiband antenna, having compact size and improved radiation pattern. Introduction to each concept used in designing of antenna is discussed deeply in chapter 1. Chapter 2 is based on the research work that has been carried out by the researchers in this field till now. The research works proves helpful in any project and so as in this thesis also. With the help of the references from the previous year done, a new design of antenna is presented in Chapter 3. It illustrates all the parameters, used in designing of antenna in detail. Each iteration of fractal geometry is discussed separately and their effect on the antenna performance is depicted with the help of return loss plot vs frequency. In the chapter 4 parametric studies is carried out. Optimization of parameter is carried out by varying each parameter separately. Effect of the variation of parameters in the return loss plot is depicted. Chapter 5 is detailed discussions about the simulated and fabricated antenna. Comparison between the results is done and it was concluded that measured results were in agreement with the simulated results. Minute errors could be due to fabrication process. Radiation pattern are also depicted.

- The operational resonating frequencies comes out to be 1.7 GHz , 2.5 GHz, 3.4 GHz, 4.6 GHz, and 5.5 GHz which can be satisfactorily used for GSM 1700, Bluetooth, IMT, WiMAX and WLAN standards.
- It is concluded from the parametric study that as the fractal iterations are increased, the fundamental frequency is decreased and resonating bands are increased.
- Due to incorporation of DGS (defected ground structure) on the conventional ground, the antenna performance i.e. return loss, radiation pattern etc. is improved to a great extent.
- Antenna is fabricated as per design guidelines and it is concluded that measured results are in agreement with the simulated ones.

6.2 Future Scope

In this thesis work, antenna is designed which can operate at several frequencies or various applications and effect of the parameters used in designing of antenna on the antenna performance is also studied. This work can be extended in future for the improvement of various factors including results and physical dimensions of antenna. Below are points listed which can enhance the antenna performance in future:

- Size of the antenna is still large i.e. 12*12 cm, it can be further reduced by using more
- Work is done up to three iteration, more iterations can be performed to improve the radiation characteristics of antenna.
- 6-7 GHz frequency band covered by this antenna can be used for mobile communication in future.
- X-shaped fractal patch is used as a radiating element other alphabets like A-shaped, S-shaped etc. geometrical fractal patches can be designed and results can be compared.
- Work can be extended up to ultra-wideband frequency by using multiple inputs multiple output (MIMO) systems.
- Microstrip feed line is used in this research work, some other feeding techniques can be used and results can be compared.

References

[1] Andrea Goldsmith, "Wireless Communications", Cambridge University Press, 2005.

[2] Theodore S. Rappaport, “Wireless Communications and Practice,” Pearson Education India, second edition, 2009.

[3] “Different IEEE standards”

[4] C. A. Balanis, Antenna Theory, 3rd ed., John Wiley & Sons Inc., 2005.

[5] www.antrnnatheory.com

[6] Ramesh Garg, Prakash Bharti and Inder Bahl, “Microstrip antenna design handbook,” *Artech House*, Boston London.

[7] Shrivishal Tripathi, Akhilesh Mohan, Sandeep Yadav, “A Compact Koch Fractal UWB MIMO Antenna With WLAN Band-Rejection,” IEEE antennas and wireless propagation letters, vol. 14, 2015.

[8] Wei-Chung Weng and Chia-Liang Hung, “An H-Fractal Antenna for Multiband Applications”, IEEE antennas and wireless propagation letters, vol. 13, 2014.

[9] Yasser Ojaroudi Sajjad Ojaroudi Nasser Ojaroudi, “A novel 5.5/7.5GHz dual band-stop antenna with modified ground plane for UWB communications,” Wireless Personal Communication, Vol. 81, No. 1, pp. 319–332, 2014.

[10] Peshal B. Nayak, Sudhanshu Verma and Preetam Kumar, “Multiband fractal antenna design for Cognitive Radio Applications”, International conference on Signal Processing and Communication (ICSC), 2013 , pp. 115-120, 12-14 Dec. 2013.

[11] M. Naser-Moghadasi, R. A. Sadeghzadeh, T. Sedghi, T. Aribi, and B. S. Virdee, “UWB CPW-Fed Fractal Patch Antenna With Band-Notched Function Employing Folded T-Shaped Element’’, IEEE antennas and wireless propagation letters, vol. 12, 2013.

[12] Kamariah Ismail and Siti Hasyimah Ishak, “ Sierpinski Gasket Fractal Antenna with Defected Ground Structure (DGS)”, International Conference on ICT Convergence (ICTC), pp. 441-446, 15-17 oct, 2012.

[13] S. Chaimool, C. Chokchai and P. Akkaraekthalin, “ multiband loaded fractal loop monopole antenna for USB dongle application”, Electronics Letters, 8th Vol. 48 No. 23, Nov.2012.

[14] R. Kumar P.N., Chaubey, “Design of coplanar waveguide-feed pentagonal-cut Ultra-wide bandwidth fractal antenna and its backscattering”, IET Microw. Antennas Propag, Vol. 6, Iss. 13, pp. 1407–1414,2012.

[15] Shufeng Zheng, Yingzeng Yin, Jun Fan, Xi Yang, Biao Li, “Analysis of Miniature Frequency Selective Surfaces Based on Fractal Antenna–Filter–Antenna Arrays”, IEEE antennas and wireless propagation letters, vol. 11, 2012.

[16] A.Valizade, Ch. Ghobadi, J. Nourinia, and M. Ojaroudi, “A novel design of reconfigurable slot antenna with switchable band-notch and multiresonance functions for UWB applications,” IEEE Antennas and Wireless Propagation Letters, Vol. 10, pp. 1166-1169, 2012.

[17] Y.Cao, B. Yuan, and G. Wang, “A compact multiband open- ended slot antenna for mobile handsets,” IEEE Antennas Wireless Propag. Lett., vol. 10, pp. 911–914, Sep. 2011.

[18] Wei Hu, Ying-Zeng Yin, Peng Fei, and Xi Yang, “Compact triband square-slot antenna with symmetrical L-strips for WLAN/WiMAX applications,” IEEE Antennas and Wireless Propagation Letters, Vol. 10, pp. 462-465, 2011.

[19] Mehdi Veysi, Manouchehr Kamyab, and Amir Jafargholi, “Single-feed dual-band dual-linearly polarized proximity-coupled patch antenna,” IEEE Antennas and Propagation Magazine, Vol. 53, No.1, pp. 90-96, 2011.

[20] Mahdi Naghshvarian Jahromi, Abolfazl Falahati, and Rob. M. Edwards, “Bandwidth And Impedance Matching Enhancement Of Monopole Antenns Using Compact Grounded Coplanar Waveguide,” IEEE transactions on antennas and propagation, vol. 59, no. 7, July 2011.

[21] Javad Pourahmadazar, Changiz Ghobadi and Javad Nourinia,Novel Modified Pythagorean Tree Fractal Monopole Antennas for UWB Applications’’, IEEE antennas and wireless propagation letters, vol. 10, 2011.

[22] Nima Bayatmaku, Parisa Lotfi, Mohammadnaghi Azarmanesh, “Design of Simple Multiband Patch Antenna for Mobile Commuication Applications Using New E-Shape Fractal,”IEEE Antennas and Wireless Propagation Letters, VOL. 10, 2011.

[23] Alireza Pourghorban Saghati, Mohammadnaghi Azarmanesh and Reza Zaker , “A novel switchable single and multi frequency triple-slot antenna for 2.4-

GHz Bluetooth, 3.5-GHz WiMAX, and 5.8-GHz WLAN, " IEEE Antennas and Wireless Propagation Letters, vol. 9, pp. 534-537, 2010.

[24] Qin Wang, Jinquan Huang, "Numerical Research of Bowtie Sierpinski Fractal Patch Antenna in RFID,"International Conference on Microwave and Millimeter Wave Technology, 2010.

[25] Abolfazl Azari, "A New Ultra-Wideband Fractal Antenna," Symposium on Electromagnetic Theory, pp. 424-427 , Aug. 2010.

[26] Y.B. Thakare, Rajkumar, "Design of fractal patch antenna for size and radar cross-section reduction", IET Microw. Antennas Propag, Vol. 4, Iss. 2, pp. 175–181, 2010.

[27] C. C. Chen, C. Y. D. Sim, and F. S. Chen, "A novel compact quad-band narrow strip-loaded printed monopole antenna," IEEE Antennas Wireless Propag. Lett., vol. 8, pp. 974–976, Aug. 2009.

[28] Y. F. Lin, H. M. Chen, and C. H. Lin, "Compact dual-band hybrid dielectric resonator antenna with radiating slot," IEEE Antennas Wireless Propag. Lett., vol. 8, pp. 6–9, Mar. 2009.

[29] R. A. Bhatti, Y. T. Im, and S. O. Park, "Compact PIFA for mobile terminals supporting multiple cellular and non-cellular standards," IEEE Trans. Antennas Propag., vol. 57, no. 9, pp. 2534–2540, Sep. 2009.

[30] Zhang Hu, Guobin Wan, Changjie Sun and Huiling Zhao, "Design of Modified Sierpinski Fractal Antenna for Multiband application,''Symposium on Microwave, Antenna, Propagation and EMC Technologies for Wireless Communications,pp. 655-658, Oct. 2009.

[31] Ka Hing Chiang and Kam Weng Tam, "Microstrip monopole antenna with enhanced bandwidth using defected ground structure" IEEE Antennas And Wireless Propagation Letters, Vol. 7, pp. 532-535, 2008.

[32] Jin-Sen Chen, "Studies of CPW-fed equilateral triangular-ring slot antennas and triangular-ring slot coupled patch antennas" IEEE Transactions on Antennas and Propagation, Vol. 53, no. 7, pp. 2208-2211, 2005.

[33] X. Yang, B. Wang and Y. Zhang, "Reconfigurable Hilbert curve patch antenna," IEEE International Workshop on Antenna Technology, Small Antennas and Novel Metamaterial, vol. 6, pp. 521-524, March 2005.

[34] J. S. Petko, D. H. Werner, “Progressive evolution of fractal random arrays by generator mitosis,” IEEE Antennas and Propagation Society International Symposium, vol.3, pp. 2305-2308, June 2004.

[35] Steven R. Best, “A Discussion on the Significance of Geometry in Determining the Resonant Behavior of Fractal and Other Non-Euclidean Wire Antennas”, IEEE antennas and propagation magazine, vol. 45, no. 3, june 2003.

[36] Douglas H. Werner and Suman Ganguly, “An Overview' of Fractal Antenna Engineering Research”, IEEE Anlennasand Propagation Magazine. Vol. 45**,** NO. I , February 2003.

[37] J. Anguera, C. Puente, J. Soler, “Miniature monopole antenna based on the fractal Hilbert curve,” IEEE Society International Symposium Antennas and Propagation, vol.4, pp. 546-549, 2002.

[38] Ricky Chair, Kwai-Man Luk, and Kai-Fong Lee, “Measurement and analysis of miniature multilayer patch antenna,” IEEE Antennas and Propagation, Vol. 50, no. 2, pp. 244-250, 2002.

[39] K. J. Vinoy, K. A. Jose and V. K. Varadan, “Hilbert curve fractal antennas with reconfigurable characteristics,” IEEE MTT-S International Microwave Symposium Digest,” vol.1, pp. 381-384, May 2001.

[40] Zhengwei Du; Ke Gong; Fu, J.S.; Baoxin Gao, “Analysis of microstrip fractal patch antenna for multi-band communication [by FDTD]," Electronics Letters, vol.37, no.13, pp.805-806, 21 Jun 2001.

[41] J. Anguera, C. Puente, C. Borja and R. Montero, “Bowtie microstrip patch antenna based on the Sierpinski fractal, “IEEE Society International Symposium Antennas and Propagation,” vol.3, pp. 162-165, July 2001.

[42] C. Puente, M. Navarro, J. Romeu, and R. Pous, “Variations on the Fractal Sierpinski Antenna Flare Angle,” IEEE International Symposium on Antennas and Propagation Digest,” Vol. 4, Atlanta, Georgia, pp. 2340-2343, June 1998.

LIST OF PUBLICATIONS

1. Ramanjeet, Sukhwinder Kumar and Navjot Singh, "An X-Fractal Patch Antenna with DGS for Multiband Applications," *International Journal of Latest Technology in Engineering, Management & Applied Science (IJLTEMAS)*, Volume V, Issue VI, pp 81-85, June 2016.
2. Sahil Gupta, Sukhwinder Kumar and Ramanjeet, "octagonal shaped fractal slot loop antenna loaded with dielectric resonator," *International Journal of Latest Technology in Engineering, Management & Applied Science (IJLTEMAS)*, Volume V, Issue VI, pp 59-66, June 2016.
3. Ramanjeet and Sukhwinder Kumar, "A-Shaped fractal antenna with defected ground structure for wireless applications," **communicated** to *IEEE Wireless and Propagation Letters.*

raman.801461021.pdf

ORIGINALITY REPORT

12%	6%	9%	2%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	Submitted to Higher Education Commission Pakistan Student Paper	1%
2	Bhatti, R.A., Yun-Taek Im, and Seong-Ook Park. "Compact PIFA for Mobile Terminals Supporting Multiple Cellular and Non-Cellular Standards", IEEE Transactions on Antennas and Propagation, 2009. Publication	1%
3	Yi-Fang Lin. "Compact Dual-Band Hybrid Dielectric Resonator Antenna With Radiating Slot", IEEE Antennas and Wireless Propagation Letters, 2009 Publication	1%
4	dyuthi.cusat.ac.in Internet Source	1%
5	etd.fcla.edu Internet Source	<1%
6	R. Chair. "Measurement and analysis of miniature multilayer patch antenna", IEEE Transactions on Antennas and Propagation, 2002	<1%