MULTIBAND FRACTAL ANTENNA DESIGN AND CHARACTERISATION USING ANTENNA MINIATURIZATION TECHNIQUES

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DECLARATION

I hereby declare that the work, which is being presented in the report, entitled "**Multiband Fractal Antenna Design and Characterisation using Antenna Miniaturization Techniques**," in partial fulfilment of the requirements for the award of degree of Master of Engineering in Electronics and Communication Engineering at Electronics and Communication Engineering Department of Thapar University, Patiala, is an authentic record of my own work carried out under the guidance of **Dr. Amit Kumar Kohli.**

The matter presented in this report has not been submitted in any University/Institute for the award of Master of Engineering.

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

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ABSTRACT

Modern telecommunication system requires antennas with wider bandwidth and smaller dimensions than conventional antennas. Operators are looking for systems that can perform over several frequency bands. This has initiated antenna research in various directions, one of which is by using fractal shaped antenna elements. The types of functionality now being demanded includes multiband operation, in some cases different radiation patterns are needed in the different bands. For example, the handsets are being produced with terrestrial cellular capability coupled with satellite based communications along with Bluetooth, Wi-Fi, GPS and many other operations. Fractal plays a prominent role for these requirements. Fractal antenna uses a geometric shape that has the property of self-similarity. Fractal antennas have ability to add more electrical length in less volume. Fractal antennas have improved impedance, improved SWR (standing wave ratio) performance on a reduced physical area, when compared to non-fractal Euclidean geometries. Fractal antennas show compressed resonant behaviour. In many cases, the use of fractal element antennas can simplify circuit design. Often fractal antennas do not require any matching components to achieve multiband or broadband performance.

The aim of this thesis is to design multiband antennas with circular patch and triangular antennas for wireless communication systems and study the effect of iterations and changing shape of straight triangles to curved triangles. Here, coaxial feed method is used to excite the patch antennas.

This thesis presents a design of circular patch four triangles and five triangles antennas. The triangles shapes are changed to get new antennas like straight and curved antennas. The proposed design of antennas have been modelled, designed and simulated using Computer Simulation Technology (CST) Microwave Studio 2010. These designs include the base design on circular patch and 4 to 5 triangles. The triangles are straight and curved. Other antennas are obtained by iterating the base design to different values. The antennas are designed on the FR-4 substrate with ε= 4.3 and thickness 1.4 mm. The designed antennas are studied experimentally for return loss and resonant frequencies behaviour using CST Microwave Studio 2010.

The purposed antennas are multiband antennas and small in size. It is found that increase in number of fractal iterations, number of resonant frequencies also increases. Further, this thesis focuses on unique features of fractal geometries along with its applications is different fields. It will be shown that how to quantify the space-filling ability of fractal geometries, and how this correlates with miniaturization. Several examples of fractal antennas which are designed recently are discussed in this thesis.

Keywords: **Fractal antenna, multiband, iterations, microstrip antenna, return loss, resonant frequency, CST Microwave Studio 2010.**

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LIST OF ABBREVIATIONS

VSWR	voltage standing wave ratio
dB	decibel
$G(\theta,\varphi)$	gain
$U(\theta,\varphi)$	radiation intensity
P_{in}	input power
D	directivity
FBW	frequency bandwidth
FBR	front to back ratio
HPBW	half power beam width
Q	quality factor
UWB	ultra wide band
IFS	iterated function system
FEA	fractal element antenna
CST	computer simulation technology
FR-4	fire retardant 4
GHz	giga hertz
MHz	mega hertz
Z_A	input impedance
Z_o	output impedance
P_r	radiated power
ε	relative permittivity

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CHAPTER-1
INTRODUCTION

1.1 Overview

In modern wireless communication systems wider bandwidth, multiband and low profile antennas are in great demand for both commercial and military applications. This has initiated antenna research in various directions; one of them is using fractal shaped antenna elements. Traditionally, each antenna operates at a single or dual frequency bands, where different antenna is needed for different applications.

Wireless operations, such as long range communications, are impossible or impractical to implement with the use of wires. The term is commonly used in the telecommunications industry to refer to telecommunications systems (e.g., radio transmitters and receivers, remote controls, computer networks, network terminals, etc.) which use some form of energy (e.g. Radio frequency (RF), infrared light, laser light, visible light, acoustic energy, etc.) to transfer information without the use of wires. Information is transferred in this manner over both short and long distances. Applications may involve point-to-point communication, point-to-multipoint communication, broadcasting, cellular networks and other wireless networks.

Antenna is a very important component for the wireless communication systems using radio frequency and microwaves. By definition, an antenna is a device used to transform an RF signal, traveling on a conductor, into an electromagnetic wave in free space. The IEEE Standard Definitions of Terms for Antennas (IEEE Std 145-1983) defines the antenna or aerial as "a means for radiating or receiving radio waves". In other words it is a transitional structure between free space and a guiding device that is made to efficiently radiate and receive radiated electromagnetic waves. Antennas are commonly used in radio, television broadcasting, cell phones, radar and other systems involving the use of electromagnetic waves. Antennas demonstrate a property known as reciprocity, which means that an antenna will maintain the same characteristics regardless if it is transmitting or receiving.

Operators are looking for antennas that can perform over several frequency bands or are reconfigurable as the demands on the system changes. Furthermore, aesthetics in the design of the systems are always important some applications require the antenna to be as miniaturized as possible. An excellent solution for compact (i.e., miniature) antennas multi-band antennas have been found in Fractal antennas. In the study of antennas, fractal antenna theory is a relatively new area. Although fractal geometry has been known to mathematics for a century, fractal antenna engineering research is a relatively very recent development because considerable computing speed is required to complete their design.

Fractal is a geometric shape that has the property of self-similarity, that is, each part of the shape is a smaller version of the whole shape. The term fractal was originally coined by Mandelbrot to describe a family of complex shapes that possess an inherent self-similarity or self-affinity in their geometrical structure. Fractals also model many natural objects and processes. It is the nature's language [1].

Benoit Mandelbrot, the pioneer of classifying this geometry, first coined the term 'fractal' in 1975 from the Latin word fractus, which means broken. The field is quite extensive with many applications from statistical analyses, natural modelling, compression and of course, computer graphics. Soon after scientists discovered the practical aspect of fractal geometry, research began in the field of electrodynamics. To date most efforts have been concentrated in understanding the physical process and mathematical background of interaction between electromagnetic waves and fractal structures.

Fig. 1.1 Examples of fractals that can be found in nature

These geometries have been used to characterize structures in nature that were difficult to define with Euclidean geometries. Examples include the length of a coastline, the density of clouds, and the branching of trees. Just as nature is not confined to Euclidean geometries, antennas and antennas array designs should not be confined, as well. In addition to having non-integer dimension, fractals usually exhibit some form of self-similarity which means that they are composed only of multiple copies of themselves at several scales. These properties can be used to develop new configurations for antennas and antenna arrays. It might be possible to discover structures that give us better performance than any Euclidean geometry could provide. Fractals represent a class of geometry with very unique properties that can be enticing for antenna designers.

Fractals are space filling contours, meaning electrically large features can be efficiently packed into small areas. Since the electrical lengths play such an important role in antenna design, this efficient packing can be used as a viable miniaturization technique. Fractals are structures of infinite complexity with a self-similar nature. What this means, is that as the structure is zoomed in upon, the structure repeats itself. This property could be used to design antennas that can operate at several frequencies [2].

Fractal antenna theory uses a modern (fractal) geometry that is a natural extension of Euclidian geometry. A fractal can fill the space occupied by the antenna in a more effective manner than the traditional Euclidean antenna. This can lead to more effective coupling of energy from feeding transmission lines to free space in less volume. Therefore, Fractals can be used in two ways to enhance antenna designs. The first method is in the design of miniaturized antenna elements. These can lead to antenna elements which are more discrete for the end user. The second method is to use the self-similarity in the geometry to blueprint antennas which are multiband or resonant over several frequency bands. This would allow the operator to incorporate several aspects of their system into one antenna [3].

Such antennas could be used to improve the functionality of modern wireless communication receivers such as cellular handsets. Because fractal antennas are more compact, they would more easily in the receiver package. Currently, many cellular handsets use quarter wavelength monopoles which are essentially sections of radiating wires cut to a determined length. Although simple, they have excellent radiation properties. However, for systems operating at 900 MHz such as GSM, the length of these monopoles is often longer than the handset itself, posing a nuisance to the user. It would be highly beneficial to design an antenna with similar radiation properties as the quarter-wavelength monopole while retaining its radiation properties. Other prevailing trends in wireless communications technology could also benefit. More and more systems are introduced which integrate many technologies. They are often required to operate at multiple frequency bands and so they require antenna systems which accommodate that requirement.

Recently there has been much interest in microstrip patch antennas. Because of their simplicity and compatibility with printed-circuit technology microstrip antennas are widely used in the microwave frequency spectrum. Simply a microstrip antenna is a rectangular or other shape, patch of metal on top of a grounded dielectric substrate. Microstrip patch antennas are attractive in antenna applications for many reasons. They are easy and cheap to manufacture, lightweight, and planar to list just a few advantages.
Also they can be manufactured either as a stand-alone element or as part of an array. However, these advantages are offset by low efficiency and limited bandwidth. In recent years much research and testing has been done to increase both the bandwidth and radiation efficiency of microstrip antennas [4].

The main goals of this project are to overcome these disadvantages and to develop an antenna with the following characteristics:

• Operates in the X-band (8 to 12GHz) frequency range

• Has a bandwidth of 20 to 30%

• Lightweight

• Dual-Linear polarization and good polarization orthogonally at scan corners

• Low loss of input signal

Because the lower portion of the frequency spectrum (S and C bands) is becoming saturated there is a need to move to higher and higher frequency bands. Thus a microstrip patch antenna as described would be useful to utilize a higher portion of the frequency spectrum.

Additional characteristics that will be pursued if time permits include:

• Usable in an array with 30 degrees by 15 degrees scanning

• Antenna element that allows for sub-panel build up for use in building arrays: planar, ideally no pins to align at each element, etc.

• Appropriate interface/balun structure to impedance match the antenna to the transmit/receive layer

1.2 Thesis Objective and Problem Statement

The aim of this thesis is to design multiband antennas with circular patch 4 to 5 triangles antennas for wireless communication systems and study the effect of iterations and changing shapes of straight triangles to curved triangles. Here, coaxial feed method is used to excite the patch antennas. To design a microstrip patch antenna for wireless communication it becomes necessary to use simulation programs to test the performance of the patch before fabrication. For the modelling and simulation of patch antennas, here we are using Computer Simulation Technology (CST) Microwave Studio 2010.

This thesis also presents the following work:

- Understanding the antenna concept.
- Measurement of the antenna properties.

- To study and have deep insight into fractals, their basic concepts including their properties and generation.
- To analyse different fractal antenna systems on different structures.

- To design multiband antennas with circular patch and triangles.
- To find their resonant values and return loss.

1.3 Thesis Outline

This thesis consists of six chapters.

Chapter 1 presents the overall idea of the fractals including objective and organization of the report.

In **Chapter 2** we present the Literature Survey on antenna. We also present the properties of antenna. Microstrip patch antenna is also discussed in this chapter along with feeding techniques.

In **Chapter 3**, we review the theory of Fractal antenna and its background along with some Fractal Geometries.

In **Chapter 4**, the generation process of fractal antennas are discussed. In this chapter advantages, disadvantages and applications of fractals are discussed.

In **Chapter 5**, the simulation and results are presented to study and compare the presented antennas. All antennas are simulated using CST Microwave Studio 2010.

In **Chapter 6**, this last chapter highlights the overall conclusion of the thesis with future work suggestion to improve the design and results of the antennas.

CHAPTER-2
LITERATURE SURVEY ON ANTENNAS

2.1 Introduction

An antenna is defined by Webster's Dictionary as "a usually metallic device (as a rod or wire) for radiating or receiving radio waves". The IEEE Standard Definitions of Terms for Antennas (IEEE Std. 145–1983) defines the antenna or aerial as "a means for radiating or receiving radio waves" [5].

Many different structures can act as antennas. Generally, antennas are constructed out of conducting material of some nature and can be constructed in many shapes and sizes. The size is related to the wavelength of operation of the antenna. An antenna designed for operation at 10 kHz is almost always much larger than an antenna designed for operation at 10 GHz.

2.2 Antenna Properties

The antenna forms a critical component in a wireless communication system. A good design of the antenna can relax system requirements and improve its overall performance [5]. The performance of the antenna is determined by several factors that also called antenna properties as follows:

2.2.1 Input Impedance

Generally, input impedance is important to determine maximum power transfer between transmission line and the antenna. This transfer only happen when input impedance of antenna and input impedance of the transmission line are match. If not match, reflected wave will be generated at the antenna terminal and travel back towards the energy source. This reflection of energy results causes a reduction in the overall system efficiency.

It is also important that the input impedance of the antenna is mostly resistive, so that most of the power introduced to the antenna is radiated. Input impedance has real and complex parts and its general form is:

$$Z_{in} = R_{in} + jX_{in} \tag{2.1}$$

where, R_{in} represents the resistance or power radiating portion of the impedance. X_{in} represents the reactive portion or power storage component of the impedance.

2.2.2 VSWR

Voltage Standing Wave Ratio (VSWR) is the ratio between the maximum voltage and the minimum voltage along transmission line. The VSWR, which can derived from the level of reflected and incident waves, is also an indication of how closely or efficiently an antenna's terminal input impedance is matched to the characteristic impedance of the transmission line. Increasing in VSWR indicates an increase in the mismatch between the antenna and the transmission line. A decrease VSWR means good matching with minimum VSWR is one. Most wireless system operates at 50 Ohm impedance. Hence the antenna must be designed with an impedance as close to 50 ohm as possible. A VSWR of 1 indicate an antenna impedance of exactly 50 ohms. Mostly, the ratio of VSWR≥1.5:1 is needed for antenna functional.

2.2.3 Gain

The gain of an antenna is essentially a measure of the antenna's overall efficiency. If an antenna is 100% efficient, it would have a gain equal to its directivity. There are many factors that affect and reduce at the overall efficiency of an antenna. Some of the most significant factors that impact antenna gain include impedance, matching network losses, material losses and random losses. By considering of all factors, it would appear that the antenna must overcome a lot of adversity in order to achieve acceptable gain performance.

Gain is a directional function; it changes with position around the antenna and is defined as

$$G(\theta, \varphi) = \frac{4\pi U(\theta, \varphi)}{P_{in}} \tag{2.2}$$

where $U(\theta, \varphi)$ is the radiation intensity and P_{in} is the input power to the antenna.

Gain is usually measured in decibels with reference to another antenna either an isotropic radiator (dBi) or to a simple dipole (dBd).

2.2.4 Radiation Pattern

The radiation patterns of an antenna provide the information that describes how the antenna directs the energy it radiates. All antennas, if 100% efficient, will radiate the same total energy for equal input power regardless of pattern shape. Radiation patterns are generally presented on a relative power dB scale. It can be show in polar plot 360 degree. Example of radiation pattern is shown in Fig. 3.3. In many cases, the convention of an E-plane and H-plane pattern is used in the presentation of antenna pattern data. The E-plane is the plane that contains the antenna's radiated electric field potential while the H-plane is the plane that contains the antenna's radiated magnetic field potential. These planes are always orthogonal [5].

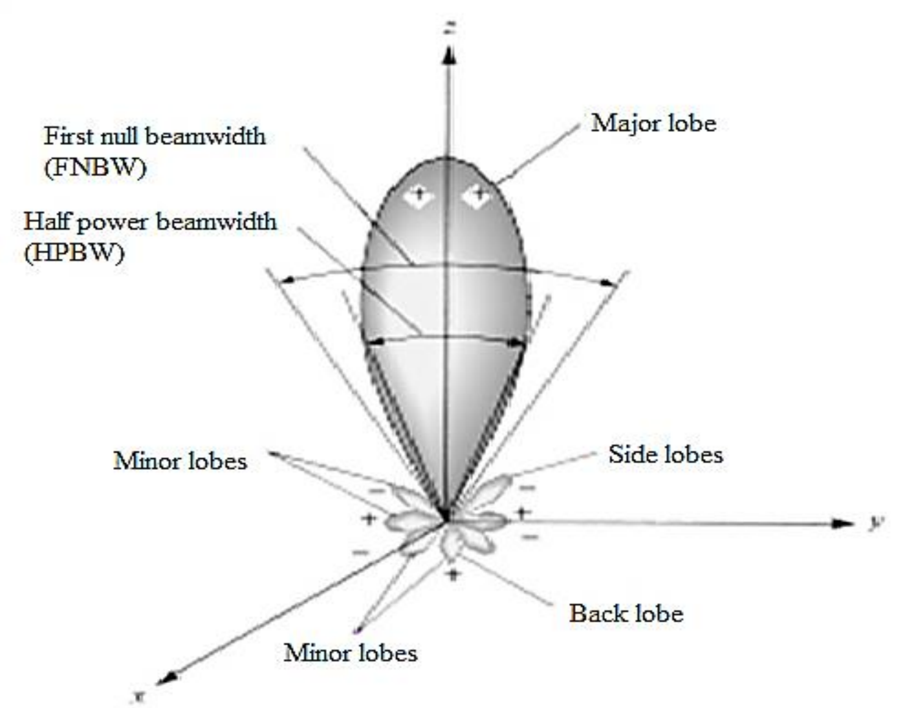

Fig. 2.1 Example of radiation pattern [5]

2.2.5 Directivity

Directivity, D, is important parameter that shows the ability of the antenna focusing radiated energy. Directivity is the ratio of maximum radiated to radiate reference antenna. Reference antenna usually is a isotropic radiator where the radiated energy are same in all direction and have directivity of 1. Directivity can be definition as

$$D = \frac{U_{max}}{U_o} \tag{2.3}$$

Where U_{max} = maximum radiated energy

U_o = isotropic radiator radiated energy

2.2.6 Polarization

The polarization of an antenna describes the orientation and sense of the radiated wave's electric field vector. There are three types of basic polarization:

- Linear polarization (linear)
- Elliptical polarization
- Circular polarization

Generally most antennas radiated with linear or circular polarization. Antennas with linear polarization radiated at the same plane with the direction of the wave propagate. For circular polarization, the antenna radiated in circular form.

2.2.7 Frequency Bandwidth (FBW)

The term bandwidth simply defines the frequency range over which an antenna meets a certain set of specification performance criteria. The important issue to consider regarding bandwidth is the performance trade-offs between all of the performance properties described above. Antennas form three classes in terms of frequency coverage:

• Narrow band – These antennas cover a small range of the order of few percent around the designed operating frequency.

$$FBW = \frac{f_{max} - f_{min}}{f_0} \times 100\% \quad (2.4)$$

where , f_{max}, f_{min} are the maximum and minimum frequencies
f_0 is the center frequency.

• Wideband or broadband – These antennas cover an octave or two range of frequencies.

$$FBW = \frac{f_{max}}{f_{min}} \quad (2.5)$$

• Frequency independent – these antennas cover a ten to one or greater range of frequencies.

2.2.8 Front to Back Ratio (FBR)

Front to back isolation ratio is defined as the difference in gain from the front of the antenna and the gain from the back of the antenna. FBR is of concern to communication engineers when the antenna is to be used in a crowded frequency band. Amateur radio operators frequenty use front-to-back isolation as a parameter when comparing Yagi-Uda antennas.

2.2.9 3 dB Beamwidth (half power beam width, HPBW)

Once the antenna pattern information is detailed in a polar plot, some quantitative aspects of the antenna pattern properties can be described. These quantitative aspects include the 3 dB beamwidth (1/2 power level), directivity, side lobe level and front to back ratio. To further understand these concepts, first consider the fundamental reference antenna, the point source. A point source is an imaginary antenna that radiates energy equally in all directions such that the antenna pattern is perfect sphere. These antennas is said to be an omnidirectional isotropic radiator and has 0 dB directivity. In practice when antenna is said to be an omnidirectional, it is inferred that this is referenced only to the horizontal or azimuth sweep plane. For any practical the 3 dB beamwidth of antenna is simply a measure of the angular width of the -3dB points on the antenna pattern relative to the pattern maximum. These -3dB points on the pattern represent the point on the pattern where the power level is down 3 dB of the value at the pattern maximum. Generally, the 3 dB beamwidth is expressed separately for each of the individual pattern sweep planes antenna, there will always be some specific direction of maximum radiated energy.

2.2.10 Return Loss

Return Loss is a measure of the reflected power from an impedance discontinuity, such as the input port of an antenna, and can be defined in terms of Z_A as:

$$Return\ Loss\ (dB) = -20\ log\ \frac{Z_A - Z_o}{Z_A + Z_o} \tag{2.6}$$

where Z_A is the antenna input impedance and Z_o is the measurement characteristic impedance. Since the reflected power from an antenna input port reduces the radiated powerP_r, it is a good practice to minimize return loss for maximizing antenna efficiency. Return loss can be measured accurately by using a calibrated network analyzer. A comparison of the measured results with the predicted data can then provide a guideline for how to proceed with the rest of the design process.

2.3 Fundamental Limits of Small Antennas

In today's world of communication there has an increasing need for more compact and portable antennas. Just as the size of circuitry has evolve to transceivers on a single chip, there is also a need to evolve small sized, high performance and low cost antenna designs which are capable of adjusting frequency of operation for integration fo multiple wireless technologies and decrease in overall size. However when the size of the antenna is made much smaller than the operating wavelength it becomes highly inefficient because radiation efficiency and impedance bandwidth decrease with the size of the antennas because these effects are accompanied by high currents in the conductors, high ohmic losses and large values of energy stored in the antenna near field.

Limits of an electrically small antenna can be analysed by assuming the antenna to be enclosed with a radian sphere of radius a [6]. The limit for the smallest possible quality factor, Q for any antenna within the radian sphere regardless of its shape can be described as [7]:

$$Q = \frac{1 + 2(ka)^2}{(ka)^3(1 + (ka)^2)} \tag{2.7}$$

An antenna is said to be small when it can be enclosed into a radian sphere, i.e. a sphere with radian a, where$a = \frac{\lambda}{2\pi}$. While there is no theoretical limit on the small antennas realized gain, there is a theoretical limit on the minimum achievable Q as a function of its size relative to the operating wavelength (*ka*). Since Q and bandwidth are inversely related (in a single resonance antenna), there is a corresponding upper limit on the maximum achievable bandwidth. For small antennas a fundamental limitation on the Q is established by Chu as [7]:

$$Q = \frac{1}{k^3a^3} + \frac{1}{ka} \tag{2.8}$$

This forms the lower fundamental limit of the Q factor that can be achieved by a linearly polarized antenna and is established regardless of the antenna current distribution inside the sphere. The current distribution inside the sphere is not uniquely determined by the field distribution outside the sphere so several current distributions can lead to the same Q factor. Here Q is described according to the stored electric energyW_e, magnetic energyW_m, frequency *w* and average radiated power P_r as:

$$Q = w\frac{2W_e}{P_r}, \;\; W_e \gg W_m \tag{2.9}$$

$$Q = w\frac{2W_m}{P_r}, \;\; W_e \gg W_m \tag{2.10}$$

An infinitesimally small antenna radiates only a TE_{01} or TM_{01} spherical mode that depends on the electric size of the antenna given by *ka*, where *k* is the wave number at resonance and *a* is the radius of the smallest sphere that encloses the antenna [8]. The real power is radiated because of propagating modes, while the reactive power is due to all modes and only less real power. Further the radiation resistance decreases while proportionally the reactive energy stored in the antenna neighbourhood increases rapidly which contributes to larger Q values. In general the Q of an antenna is inversely proportional to its bandwidth thus implying narrow bandwidth for the antennas with high values of Q. Narrow bandwidth antennas are not usually preferred because of the difficulty of matching. Achieving a low Q antenna basically depends on how efficiently it uses the available volume inside the radian sphere. Thus the high currents in the conductors, high ohmic losses, large values of the stored energy in the antenna near field and high Q values make the performance of small antennas inefficient.

2.4 Microstrip Antennas

Recently there has been much interest in microstrip patch antennas. Because of their simplicity and compatibility with printed-circuit technology microstrip antennas are widely used in the microwave frequency spectrum. Simply a microstrip antenna is a rectangular or other shape, patch of metal on top of a grounded dielectric substrate. Microstrip patch antennas are attractive in antenna applications for many reasons. They are easy and cheap to manufacture, lightweight, and planar to list just a few advantages. Also they can be manufactured either as a stand-alone element or as part of an array. However, these advantages are offset by low efficiency and limited bandwidth. In recent years much research and testing has been done to increase both the bandwidth and radiation efficiency of microstrip antennas.These antennas are low profile, conformable to planar and nonplanar surfaces, simple and inexpensive to manufacture using modern printed-circuit technology, mechanically robust when mounted on rigid surfaces, compatible with MMIC designs, and when the particular patch shape and mode are selected, they are very versatile in terms of resonant frequency, polarization, pattern, and impedance. In addition, by adding loads between the patch and the ground plane, such as pins and varactor diodes, adaptive elements with variable resonant frequency, impedance, polarization, and pattern can be designed [9].

Major operational disadvantages of microstrip antennas are their low efficiency, low power, high Q (sometimes in excess of 100), poor polarization purity, poor scan performance, spurious feed radiation and very narrow frequency bandwidth, which is typically only a fraction of a percent or at most a few percent. In some applications, such as in government security systems, narrow bandwidths are desirable. However, there are methods, such as increasing the height of the substrate that can be used to extend the efficiency (to as large as 90 percent if surface waves are not included) and bandwidth (up to about 35 percent) [10].

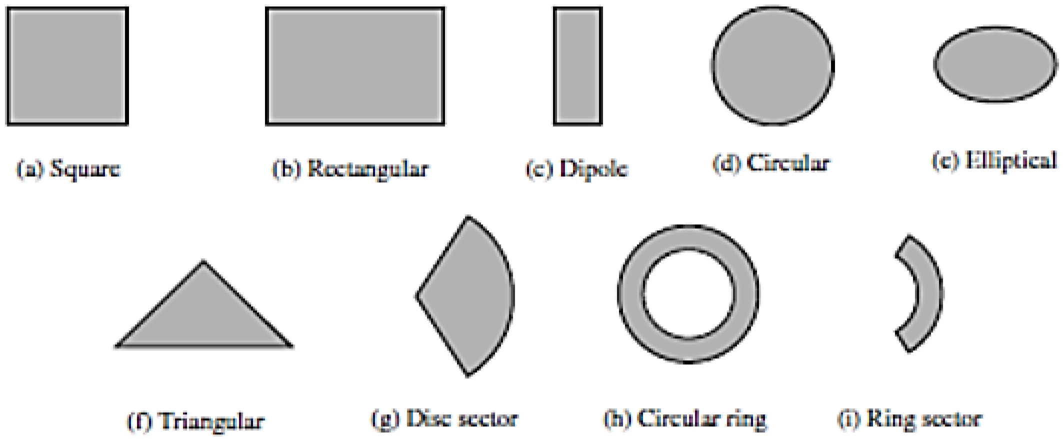

Fig. 2.2 Representative shapes of microstrip patch elements [5]

Often microstrip antennas are also referred to as *patch* antennas. The radiating elements and the feed lines are usually photoetched on the dielectric substrate. The radiating patch may be square, rectangular, thin strip (dipole), circular, elliptical, triangular, or any other configuration. These and others are illustrated in Figure 2.3. Square, rectangular, dipole (strip), and circular are the most common because of ease of analysis and fabrication, and their attractive radiation characteristics, especially low cross-polarization radiation. Microstrip dipoles are attractive because they inherently possess a large bandwidth and occupy less space, which makes them attractive for arrays [11], [12], [13], [14].

2.4.1 Circular Patch

One of the most popular configuration in microstrip patch antenna is the circular patch or disk, as shown in Figure 14.22. It also has received a lot of attention not only as a single element [15], [16], [17], [18], [19], [20], but also in arrays [21] and [22].

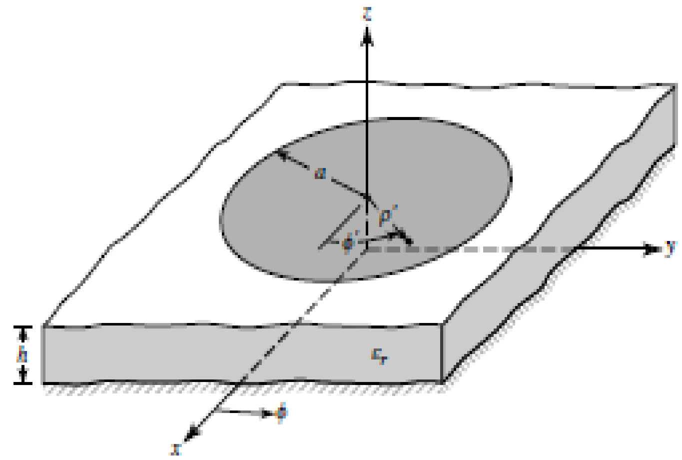

Fig 2.3 Geometry of circular microstrip patch antenna [5]

The modes supported by the circular patch antenna can be found by treating the patch, ground plane, and the material between the two as a circular cavity. As with the rectangular patch, the modes that are supported primarily by a circular microstrip antenna whose substrate height is small ($h\lambda$) are TMz where z is taken perpendicular to the patch. As far as the dimensions of the patch, there are two degrees of freedom to control (length and width) for the rectangular microstrip antenna. Therefore the order of the modes can be changed by changing the relative dimensions of the width and length of the patch (width-to-length ratio). However, for the circular patch there is only one degree of freedom to control (radius of the patch). Doing this does not change the order of the modes; however, it does change the absolute value of the resonant frequency of each [15]. Other than using full-wave analysis [20], [21], [72], the circular patch antenna can only be analyzed conveniently using the cavity model [62], [18], [19]. This can be accomplished using a procedure similar to that for the rectangular patch but now using cylindrical coordinates [15]. The cavity is composed of two perfect electric conductors at the top and bottom to represent the patch and the ground plane, and by a cylindrical perfect magnetic conductor around the circular periphery of the cavity. The dielectric material of the substrate is assumed to be truncated beyond the extent of the patch.

2.4.2 Feeding Methods

There are many configurations that can be used to feed microstrip antennas. The four most popular are the microstrip line, coaxial probe, aperture coupling, and proximity coupling [23], [24], [13], [25], [10], [26]–[28]. These are displayed in Figure 2.3. The microstrip feed line is also a conducting strip, usually of much smaller width compared to the patch. The microstrip-line feed is easy to fabricate, simple to match by controlling the inset position and rather simple to model. However as the substrate thickness increases, surface waves and spurious feed radiation increase, which for practical designs limit the bandwidth (typically 2–5%).

Coaxial-line feeds, where the inner conductor of the coax is attached to the radiation patch while the outer conductor is connected to the ground plane, are also widely used. The coaxial probe feed is also easy to fabricate and match, and it has low spurious radiation. In all our simulation we use coaxial feeding technique.

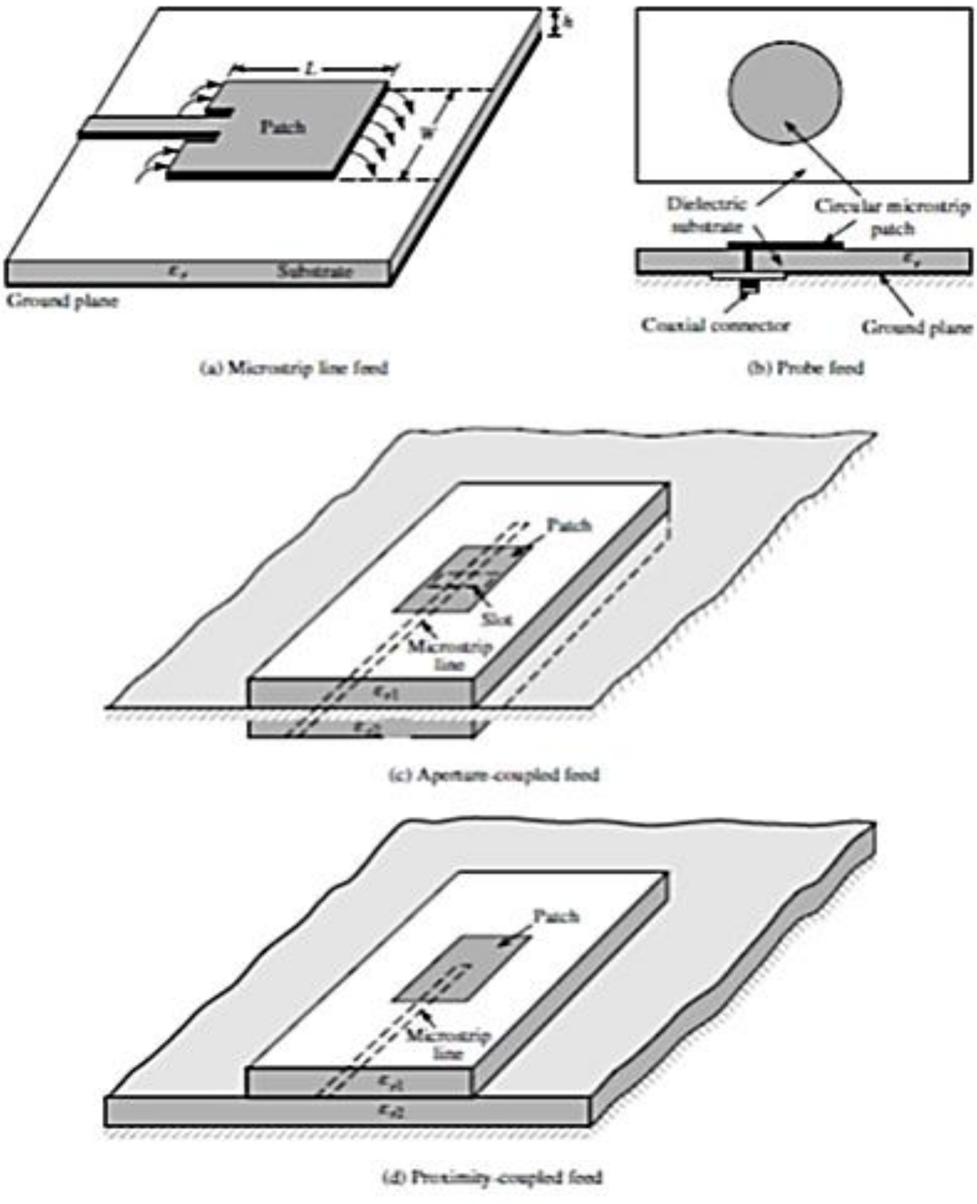

Fig 2.4 Typical feeds for microstrip antennas [5]

CHAPTER 3
LITERATURE SURVEY ON FRACTAL ANTENNA

3.1 Fractal's Definition

According to Webster's Dictionary a fractal is defined as being "derived from the Latin f*ractus* meaning broken, uneven: any of various extremely irregular curves or shape that repeat themselves at any scale on which they are examined."

Mandelbrot offered the following definition: "A fractal is a shape made of parts similar to the whole in some way" [29].

3.2 Background

A fractal is a rough or fragmented geometric shape that can be subdivided in parts, each of which is (at least approximately) a reduced-size copy of the whole. Fractals are generally self-similar and independent of scale. There are many mathematical structures that are fractals; e.g. Sierpinski's gasket, Cantor's comb, von Koch's curve. Fractals also describe many real-world objects, such as clouds, mountains, turbulence, and coastlines that do not correspond to simple geometric shapes.

As we see fractals have been studied for about a hundred years and antennas have been in use for as long. Fractal antennas are new on the scene. The geometry of the fractal antenna encourages its study both as a multiband solution and also as a small (physical size) antenna. First, because one should expect a self-similar antenna (which contains many copies of itself at several scales) to operate in a similar way at several wavelengths. That is, the antenna should keep similar radiation parameters through several bands. Second, because the space-filling properties of some fractal shapes (the fractal dimension) might allow fractal shaped small antennas to better take advantage of the small surrounding space.

3.3 Why Fractal as Antenna Elements?

Small antennas are of prime importance because of the available space limitation on devices and the oncoming deployment of diversity and multi-input multi-output (MIMO) systems. The basic antenna miniaturization techniques can be summarized into lumped element loading, material loading, use of ground planes, short circuits, the antenna environment and finally the antenna geometry. Among these techniques the antenna environment and finally the antenna geometry optimization and use of ground planes can achieve miniaturization or compactness of the antenna while maintaining the good antenna performance in terms of bandwidth and efficiency. However the classical small antennas suffer from inefficient performance. Fractal geometry provides the solution by designing compact and multiband antennas in a most efficient and sophisticated way. The general concepts of fractals can be applied to develop various antenna elements [30]. The properties of these fractal designed antennas allows for smaller, resonant antennas that are multiband and may be optimized for gain. When antenna elements or arrays are designed with the concept of self-similarity for most fractals, they can achieve multiple frequency bands because different parts of the antenna are similar to each other at different scales. Application of the fractional dimension of fractal structure leads to the gain optimization of wire antenna and the self-similarity makes it possible to design antennas with very wideband performance.

3.3.1 Fractals as Space-filling Geometries

A fractal is mathematically defined to be infinite in intricacy, this is not desirable if antennas are to be fabricated using these geometries. For example, the complexity and repetition of a cloud does not extend to infinitely small or large scales, but can be approximated as doing so for a certain band of scales. From the scale of human perception, a cloud does seem to be infinitely complex in larger and smaller scales. The resulting geometry after truncating the complexity is called a “prefractal”. A prefractal drop the intricacies that are not distinguishable in the particular applications. While Euclidean geometries are limited to points, lines, sheets, and volumes, fractals include the geometries that fall between these distinctions, a fractal can be a line that approaches a sheet. The line can meander in such a way as to effectively almost fill the entire sheet. These space-filling properties lead to curves that are electrically very long, but fit into a compact physical space and can lead to the miniaturization of antenna elements. As mentioned earlier and indicated by Gianviffwb (2002) that prefractals drop the complexity in the geometry of a fractal that is not distinguishable for a particular application. For antennas, this can mean that the intricacies that are much, much smaller than a wavelength in the band of useable frequencies can be dropped out. This now makes this infinitely complex structure, which could only be analysed mathematically, manufacturable [31].

The Hilbert curve is an example of a space-filling fractal curve that is self voiding (i.e., has no intersection points). The first four steps in the construction of the Hilbert curve are shown in Fig. 3.1.

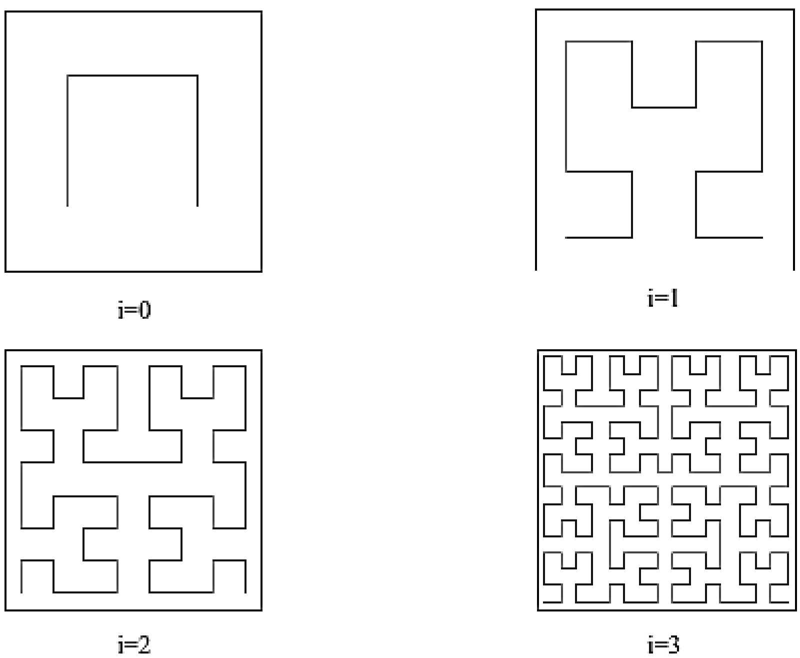

Fig. 3.1 Generation of four iterations of hilbert cuves [32]

3.3.2 Fractals as Miniaturized Antennas

A fractal can fill the space occupied by the antenna in a more effective manner than the traditional Euclidean antenna. This leads to more effective coupling of energy from feeding transmission lines to free space in less volume. Fractal loop and fractal dipole wire radiators are contrasted with linear loop and dipole antennas, fractals effectively fills the space and because of fractal dimensions allows antenna miniaturization.. Fractal antennas do not need to be limited to only wire antennas.

3.3.3 Fractals as Multiband Antennas

Fractal antennas show multiband or log periodic behavior that has been attributed to self similar scale factor of the antenna geometry. Fractal loop shows improved impedance and SWR performance on a reduced physical area when compared to non fractal Euclidean geometries. In order to enable more operating bands within lower spectrum , a higher scaling factor is required. Fractal antenna Represents a class of electromagnetic radiators where the overall structure is comprised of a series of repetition of a single geometry and where repetition is at different scale.

3.4 Fractal Geometry

There are many fractal geometries that have been found to be useful in developing new and innovative design for antennas. Fig. 3.2 shows some of these unique geometries[32].

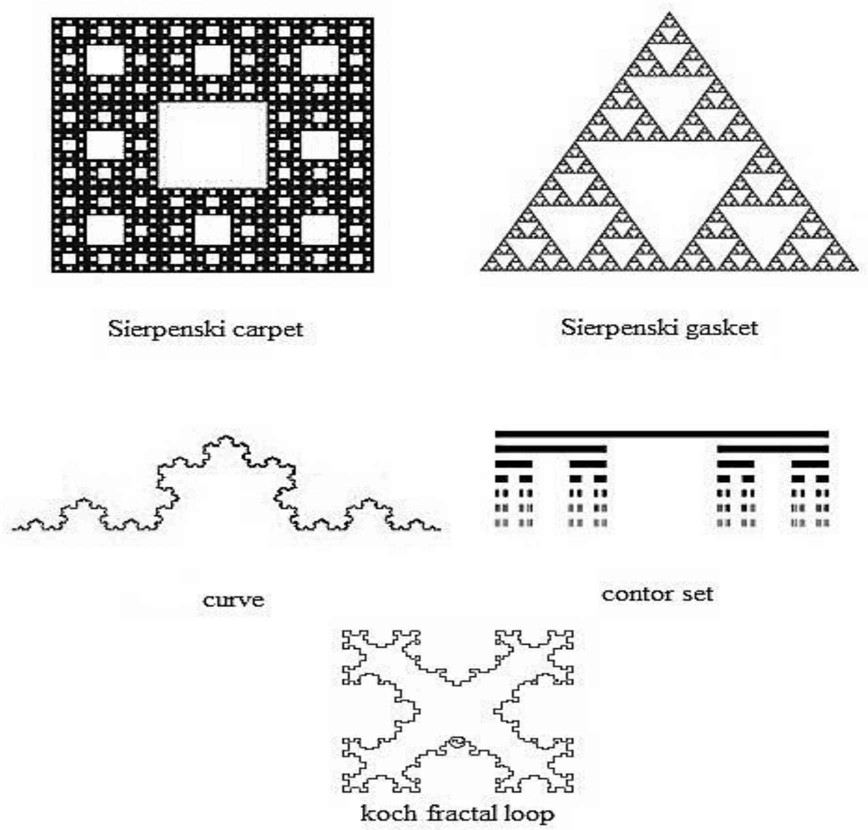

Fig. 3.2 Example of other fractal antennas [32]

3.4.1 Sierpinski Carpet

Sierpinski Carpet fractal antenna is realized by successive iterations applied on a simple square patch as shown in Fig. 3.3(a), which can be termed as the zeroth order iteration. A square of dimension equal to one third of the main patch is subtracted from the center of the patch to retrieve first order iteration, as shwn in Fig. 3.3(b). The next step is to etch squares which are nine times and twenty seven times smaller than the main patch as demonstrated in Fig. 3.3(c) and 3.3(d) respectively. The second and third order iterations are carried out eight times and sixty four times respectively on the main patch. This fractal can be termed as third order fractal as it is designed by carrying out three iterations. The pattern can be defined in such a way that each consequent etched square is one-third in dimension as compared to the previous one sharing the same centre point. This procedure of design carried out on a square shaped patch can be implemented on any of the four geometries named above [33].

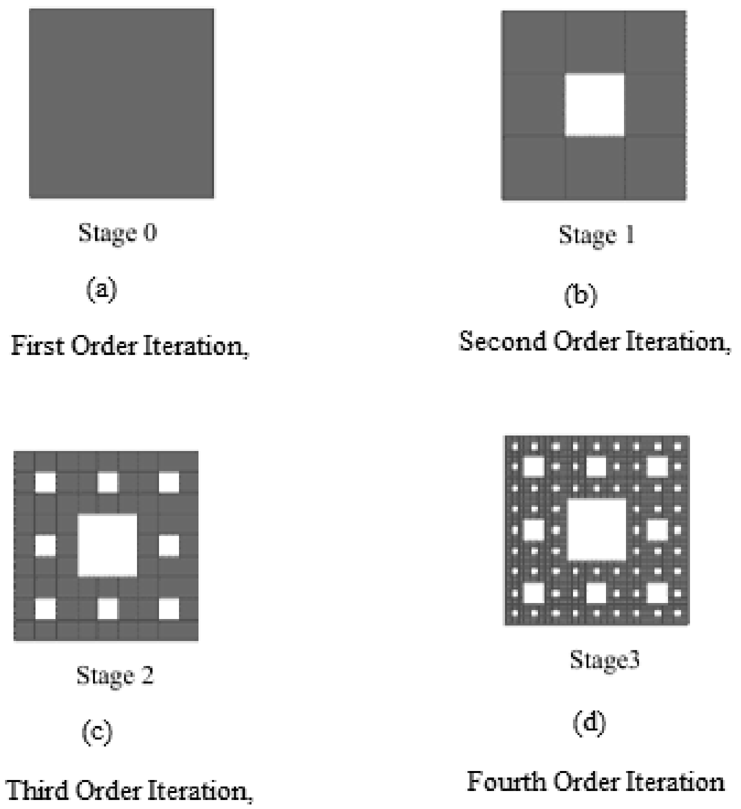

Fig. 3.3 Four stages in construction of sierpinski carpet [33]

3.4.2 Koch Curves

The geometric construction of the standard Koch curve is fairly simple. It starts with a straight line as an initiator. This is partitioned into three equal parts, and the segment at the middle is replaced with two others of the same length. This is the first iterated version of the geometry and is called the generator. The process is reused in the generation of higher iterations[34].

3.4.3 Hilbert Curves

Fig. 3.5 shows the first few iterations of Hilbert curves. It can be noticed that each successive stage consists of four copies of the previous, connected with additional line segments. This geometry is a space-Filling curve, since with a larger iteration, one may think of it as trying to fill the area it occupies. Additionally the geometry also has the following properties: self-Avoidance (as the line segments do not intersect each other), simplicity (since the curve can be drawn with a single stroke of a pen) and self-similarity[32].

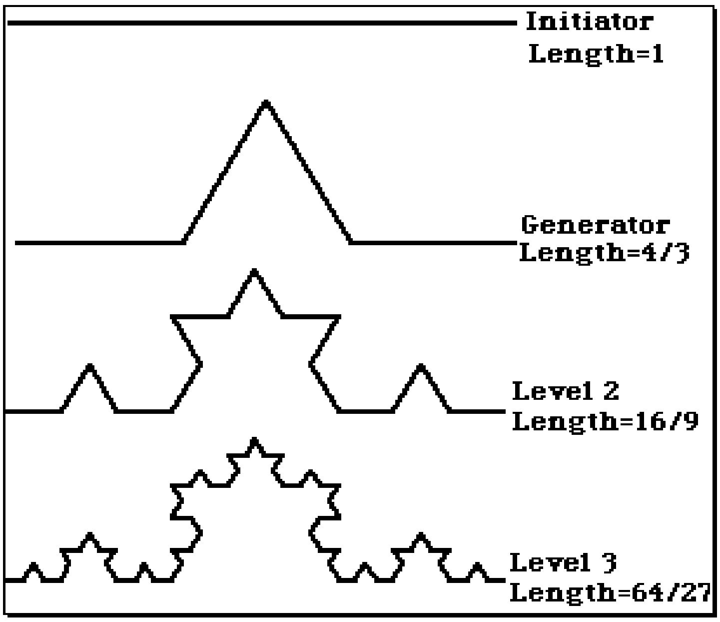

Fig. 3.4 Step of construction of koch curves geometries [32]

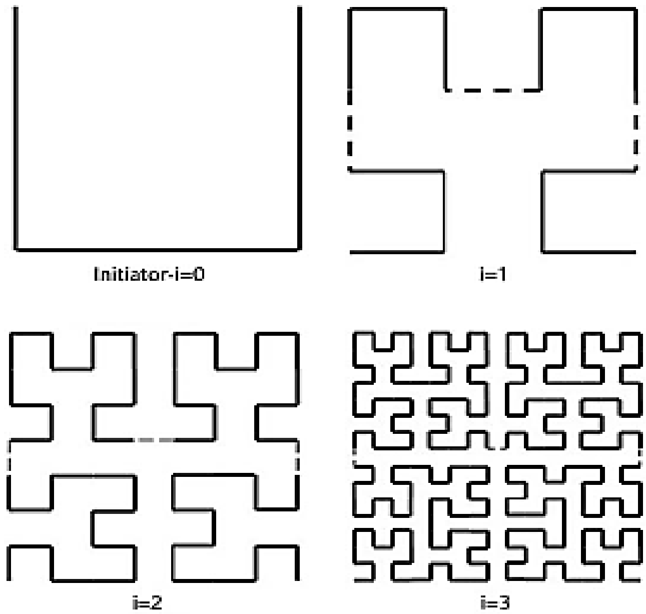

Fig. 3.5 Four stage in construction of hilbert curves [32]

3.4.4 Sierpinski Gasket Geometry

Sierpinski gasket geometry is the mostly widely studied fractal geometry for antenna applications. Sierpinski gaskets have been investigated extensively for monopole and dipole antenna configurations. The self-similar current distribution on these antennas is expected to cause its multi-band characteristics. It has been found that by perturbing the geometry the multi-band nature of these antennas can be controlled. Variations of the flare angle of these geometries have also been explored to change the band characteristics of antenna. Antennas using this geometry have their performance closely linked to conventional bow-tie antennas. However some minor differences can be noticed in their performance characteristics. It has been found that the multi-band nature of the antenna can be transformed into wideband characteristics by using a very high dielectric constant substrate and suitable absorbing materials [35].

3.4.5 Circular Microstrip Patch Antenna

First, a nearly circular metallic patch is designed. Then a point star shaped fractal geometry with some sharpness factor and dimension is subtracted from solid nearly circular patch as shown in Fig. 3.6 to expose substrate material to create first fractal iteration. Proper care has been taken to maintain electrical connectivity throughout the circular boundary. Such four electrically interactive iterations are included in the antenna geometry to design the final fractal geometry for the proposed antenna as shown in Fig. 3.6 [36].

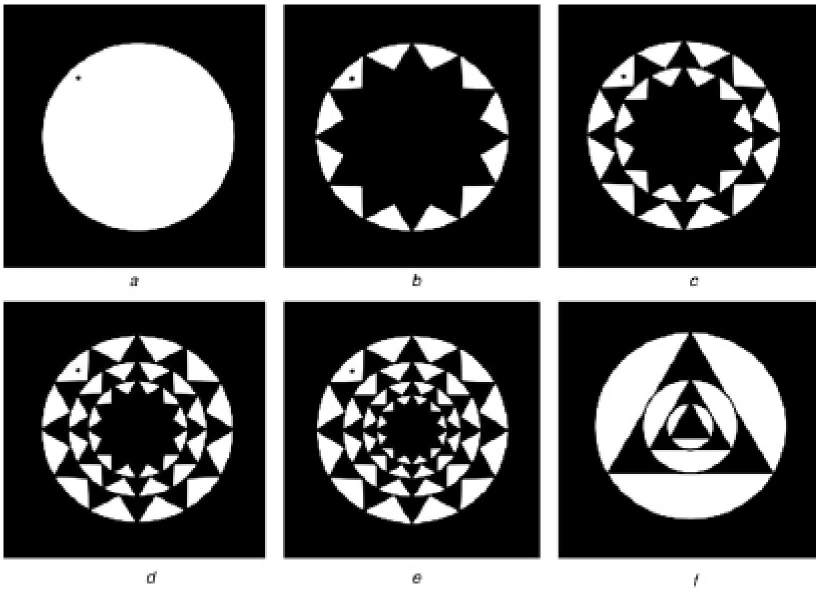

Fig. 3.6 Circular microstrip patch antenna [36]

3.4.6 Giusepe Peano fractal

The recursive procedure of the Giusepe Peano fractal is shown in Fig. 3.7, which is applied to the edges of the square patch up to the second iteration as depicted in Fig. 3.8. The iterations of Sierpinski carpet fractal are shown in Fig. 3.3. The proposed antenna applies the above two fractals to the square patch as shown in Fig. 3.9. The antenna feed is through a microstrip line with a matching section over a semi-elliptical ground plane. The ground plane is selected as a combination of the rectangular and semi-elliptical shapes in order to obtain an approximately linear phase variation for for the transmission and reception of narrow pulses in UWB systems. The group delay should be nearly constant across the frequency band [37]. As the iteration of fractal geometry increases, its resonance frequency decreases, this may lead to an effective antenna miniaturization. However, for iterations higher than the second iteration, the reduction of operating frequency is not achievable since the antenna design becomes quite complicated and its fabrication becomes difficult [38].

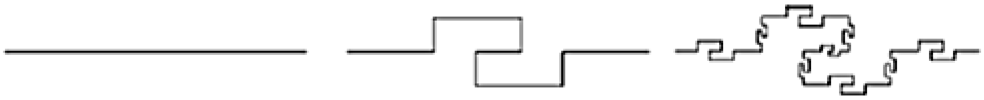

Fig. 3.7 Initiator and generator of the giusepe peano fractal [38]

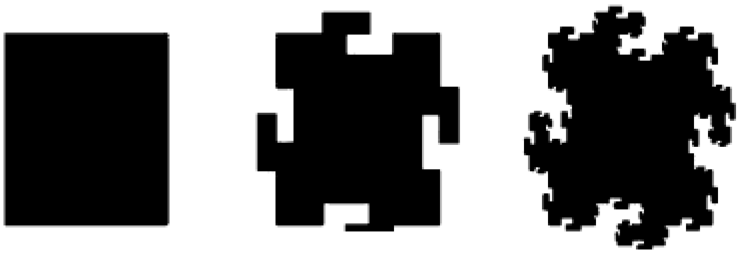

Fig. 3.8 Giusepe peano fractal as applied to the edges of the metallic patches [38]

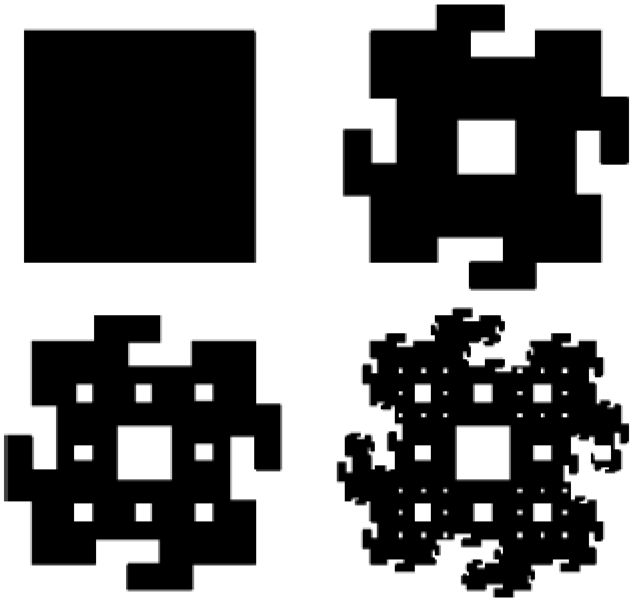

Fig. 3.9 Proposed geometry [38]

3.4.7 Pythagorean tree fractal

The construction of the Pythagoras tree begins with a square. Upon this square are constructed two other squares, each scaled down by a linear factor, such that the corners of the squares coincide pairwise. The same procedure is then applied recursively to the two smaller squares, ad infinitum [39]. Fig. 3.10 shows an illustration of the first five iterations in the construction process. Iteration in the construction adds squares of size, for a total area of 1. Thus, the area of the tree fractal might seem to grow without boundary [40]–[42]. However, starting at the fifth iteration, some of the squares overlap, and the tree fractal actually has a finite area because it snuggles into a box. we design an MPTF by eliminating the first iteration’s large side square and change the isosceles right-angled triangle to an isosceles triangle with steep angles to reduce the fractal height to design compact antennas. This triangle change is our fractal freedom degree that helps the antenna designer to make a novel fractal shape. Our purpose in designing an MPTF is to use this fractal to control impedance bandwidth and resonances [43].

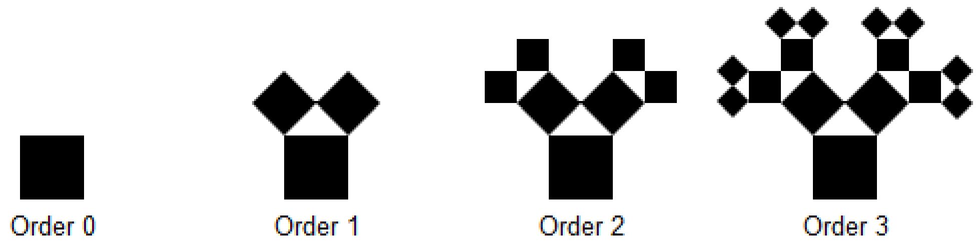

Fig. 3.10 Illustration of the first five iterations for pythagorean tree fractal [39]

3.4.8 Fractal Arrays

The idea of using fractal spacing for arrays has been investigated by several researches. In references [20, 21, 22], the spacing of the array was shaped using fractal geometrise, while the elements were standard Euclidean shapes. Arrays with the distribution of a cantor set has been the topic of these papers, [23,24]. A cantor set distribution is also implemented in [25,] for the spacing of an array .Similar features of the patterns of the arrays compare to similarities in the spacing geometry. Also, Cantor Sets of the different fractal dimension are simulated, showing a correlation between the maximum side lobe level and the fractal dimension. A derivation of the radiation patterns for cantor sets distributed currents is presented in [49]. In paper [50], the authors present an analysis of array elements in a Sierpinski carpet configuration to create sum and difference patterns.

Simple procedure for evaluating the impedance matrix of the Peano-Gosper fractal array has been presented in [51]. Phased array antennas can be focused by deploying proper phase excitations on the array elements. Fractal geometry has been applied to focused arrays. The binary tree fractal geometry was applied to element positions [52]. The performances of the arrays investigated show that fractal antennas can be similarly focused, while giving their favourable properties. The fractal technique was proved efficient for the design of a DRA of 920 elements which produce nineteen pencil beams for a satellite communication network. Sierpinski gasket fractal array antenna has been discussed in detail in [35].

CHAPTER-4

GENRATION PROCESS AND FRACTAL APPLICATIONS

4.1 Generation Process: Iterated Function Sysmtems (IFS)

Any fractal ha s some infinitely repeating pattern. When creating such fractal, you would suspect that the easiest way is to repeat a certain series of steps which create that pattern. Instead of the word "repeat" we use a mathematical synonym "iterate" and the process is called iteration. IFS (iterated function system) is another way of generating fractals. It is based on taking a point or a figure and substituting it with several other identical ones.

Iterated function systems (IFS) represent an extremely versatile method for conveniently generating a wide variety of useful fractal structures [53]. These iterated function systems are based on the application of a series of affine transformations, w, defined by [54]

$$w\begin{pmatrix} x \\ y \end{pmatrix} = \begin{pmatrix} a & b \\ c & d \end{pmatrix}\begin{pmatrix} x \\ y \end{pmatrix} + \begin{pmatrix} e \\ f \end{pmatrix} \qquad (4.1)$$

or, equivalently, by

$$w(x, y) = (ax + by + e, cx + dy + f) \qquad (4.2)$$

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

$$\left(\begin{matrix} a & b \\ c & d \end{matrix}\middle|\begin{matrix} e \\ f \end{matrix}\right) \qquad (4.3)$$

where a, b, c, and d control rotation and scaling, while e and f control linear translation (see Fig. 4.1).

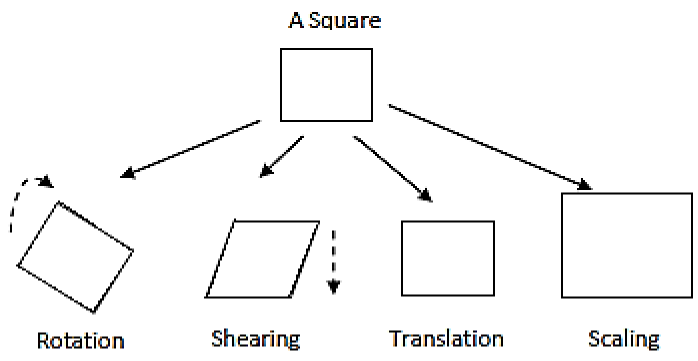

Fig. 4.1 The affine transforms [54]

Now suppose we consider $w1, w2, \ldots, wN$ as a set of affine linear transformations, and let A be the initial geometry. Then a new geometry, produced by applying the set of transformations to the original geometry, A, and collecting the results from $w1\ (A), w2\ (A), \ldots, wN(A)$, can be represented by

$$W(A) = \bigcup_{n=1}^{N} w_N(A) \tag{4.4}$$

where W is known as the Hutchinson operator. A fractal geometry can be obtained by repeatedly applying W to the previous geometry. For example, if the set A_0 represents the initial geometry, then we will have

$$A_1 = w(A_0),\ \ A_2 = w(A_1), \ldots\ldots,\ A_{K+1} = w(A_K) \tag{4.5}$$

An iterated function system generates a sequence that converges to a final image, A_∞, in such a way that

$$w_1(x,y)=(\tfrac{1}{3}x + (0)\,y + 0,\ (0) + \tfrac{1}{3}y + 0) \tag{4.6}$$

$$w_2(x,y)=(\tfrac{1}{6}x - \tfrac{1.732}{6}y + \tfrac{1}{3},\ \tfrac{1.732}{6}x + \tfrac{1}{6}y + 0) \tag{4.7}$$

$$w_3(x,y)=(\tfrac{1}{6}x + \tfrac{1.732}{6}y + \tfrac{1}{2},\ -\ \tfrac{1.732}{6}x + \tfrac{1}{6}y + \tfrac{1.732}{6}) \tag{4.8}$$

$$w_4(x,y)=(\tfrac{1}{3}x + (0)y + \tfrac{2}{3},\ (0)x + \tfrac{1}{3}y + 0) \tag{4.9}$$

$$W(A)=w_1(A) \cup w_2(A) \cup w_3(A) \cup w_4(A) \qquad (4.10)$$

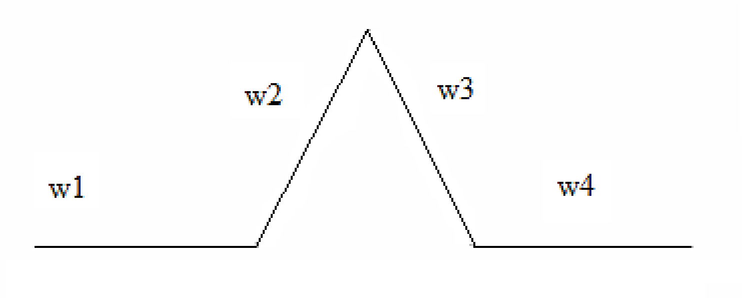

Fig. 4.2 The standard koch curve as an iterated function system [53]

The transformation is applied for each iteration to achieve higher levels of fractalizaltion.

$$w(A_\infty)= A_\infty \qquad (4.11)$$

This image is called the attractor of the iterated function system, and represents a "fixed point" of w.

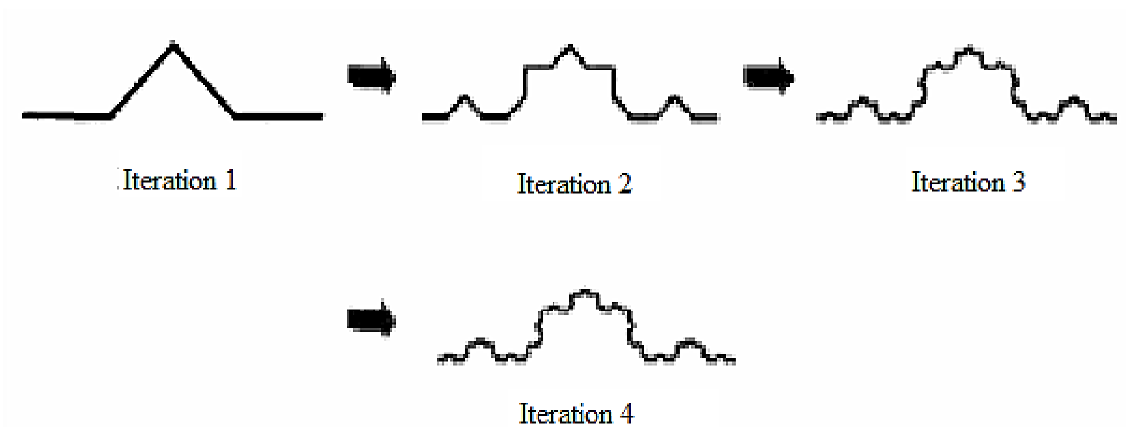

Fig. 4.3 The first four stages in the construction of the standard koch curve via iterated function system approach [53]

Fig. 4.3 illustrates the iterated function system procedure for generating the well-known Koch fractal curve. In this case, the initial set, A, is the line interval of unit length, i.e., A = { x : x ∈[0,1]). Four affine linear transformations are then applied to A, as indicated in Fig. 4.3. Next, the results of these four linear transformations are combined together to form the first iteration of the Koch curve, denoted by A_1. The second iteration of the

Koch curve, A_2 , may then be obtained by applying the same four affine transformations to A1,. Higher-order version:; of the Koch curve are generated by simply repeating the iterative process until the desired resolution is achieved. The first four iterations of the Koch curve are shown in Fig. 4.4 . We note that these curves would converge to the actual Koch fractal, represented by A_∞ , as the number of iterations approaches infinity[32]. Iterated function systems have proven to be a very powerful design tool for fractal antenna engineers. This is primarily because they provide a general framework for the description, classification, and manipulation of fractals [54]. In order to further illustrate this important point, the iterated function system code fix such diverse objects as a Sierpinski gasket and a fractal tree have been provided in Fig. 4.3 and Fig. 4.4 respectively [53].

The basic principle of construction of the triadic Koch curve consists of recursively replacing the edges of an arbitrary polygon (Initiator) by an open polygon (generator), reduced and displaced so as to have the same end points as those of interval being replaced. The amount of detail included in final display of curve depends on the number of iterations performed and

a	b	c	d	e	f
0.500	0.000	0.000	0.500	0.000	0.000
0.500	0.000	0.000	0.500	0.500	0.000
0.500	0.000	0.000	0.500	0.000	0.500

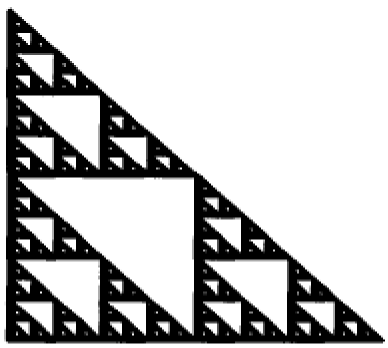

Fig 4.4 The iterated function system code for a sierpinski gasket [53]

the resolution of display system. Fig. 4.6 shows initiator polygon, generator polygon and the final curve after successive iterations[55]-[59].

4.2 Fractals in Nature and Applications:

Fractals are not just complex shapes and pretty pictures generated by computers. Anything that appears random and irregular can be a fractal. Fractals permeate our lives, appearing in places as tiny as the membrane of a cell and as majestic as the solar system. Fractals are the

a	b	c	d	e	f
0.195	-0.488	0.344	0.443	0.4431	0.2452
0.462	0.414	-0.252	0.361	0.2511	0.5692
-0.058	–0.07	0.453	-0.111	0.5976	0.0969
-0.035	0.07	-0.469	-0.022	0.4884	0.5069
-0.637	0.0	0.0	0.501	0.8562	0.2513

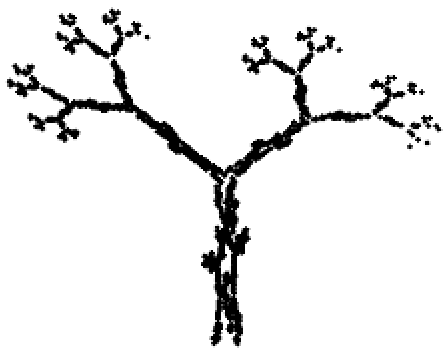

Fig. 4.5 The iterated function system code for a fractal tree [53]

Fig. 4.6(a) Initiator

Fig. 4.6(b) Generator

Fig. 4.6 (c) Final curve [53]

unique, irregular patterns left behind by the unpredictable movements of the chaotic world at work. In theory, one can argue that everything existent on this world is a fractal [60].

• The leaves in trees,
• The veins in a hand,
• Water swirling and twisting out of a tap,
• A puffy cumulus cloud,
• Tiny oxygen molecule, or the DNA molecule,
• The stock market

Fractals have more and more applications in science.

4.2.1 Astronomy

Fractals will maybe revolutionize the way that the universe is seen. Cosmologists usually assume that matter is spread uniformly across space. But observation shows that this is not true. Astronomers agree with that assumption on "small" scales, but most of them think that the universe is smooth at very large scales. However, a dissident group of scientists claims that the structure of the universe is fractal at all scales.

4.2.2 Nature

Take a tree, for example. Pick a particular branch and study it closely. Choose a bundle of leaves on that branch. All three of the objects described - the tree, the branch, and the leaves - are identical. To many, the word chaos suggests randomness, unpredictability and perhaps even messiness. Weather is a favorite example for many people. Forecasts are never totally accurate, and long-term forecasts, even for one week, can be totally wrong. This is due to minor disturbances in airflow, solar heating, etc. Each disturbance may be minor, but the change it create will increase geometrically with time. Soon, the weather will be far different than what was expected. With fractal geometry we can visually model much of what we witness in nature, the most recognized being coastlines and mountains. Fractals are used to model soil erosion and to analyze seismic patterns as well.

4.2.3 Computer Science

Actually, the most useful use of fractals in computer science is the fractal image compression.

This kind of compression uses the fact that the real world is well described by fractal geometry. By this way, images are compressed much more than by usual ways (e.g.: JPEG or GIF file formats). An other advantage of fractal compression is that when the picture is enlarged, there is no pixelisation. The picture seems very often better when its size is increased.

4.2.4 Fluid Mechanics

The study of turbulence in flows is very adapted to fractals. Turbulent flows are chaotic and very difficult to model correctly. A fractal representation of them helps engineers and physicists to better understand complex flows. Flames can also be simulated. Porous media have a very complex geometry and are well represented by fractal .This is actually used in petroleum science.

4.2.5 Surface Physics

Fractals used to describe the roughness of surfaces. A rough surface characterized by a combination of two different fractals.

4.2.6 Medicine

Biosensor interactions can be studied by using fractals.

4.2.7 Telecommunications

A new application is fractal-shaped antenna that reduce greatly the size and the weight of the antennas . The benefits depend on the fractal applied, frequency of interest, and so on. In general the fractal parts produces 'fractal loading' and makes the antenna smaller for a given frequency of use. Practical shrinkage of 2-4 times are realizable for acceptable performance. Surprisingly high performance is attained.

4.2.8 Wireless Communication

There are many applications that can benefit from fractal antennas. Discussed below are several ideas where fractal antennas can make an real impact. The sudden growing the wireless communication area has sprung a need for compact integrated antennas. The space saving abilities of fractals to efficiently fill a limited amount of space create distinct advantage of using integrated fractal antennas over Euclidean geometry. Examples of these types of application include personal hand-held wireless devices such as cell phones and other wireless mobile devices such as laptops on wireless LANs and networkable PDAs. Fractal antennas can also enrich applications that include multiband transmissions. This area has many possibilities arranging from dual-mode phones to devices integrating communication and location services such as GPS, the global positioning satellites. Fractal antennas also decrease the area of a resonant antenna, which could lower the radar cross-section (RCS). This benefit can be exploited in military applications where the RCS of the antenna is a very crucial parameter.

4.3 Fractal Antennas Offer Benefits

A fractal element antenna, or FEA, is one that has been shaped in a fractal fashion, either through bending or shaping a volume, or introducing holes. They are based on fractal shapes such as the Sierpinski triangle. Mandelbrot tree, Koch curve, and Koch island. The advantage of FEAs, when compared to conventional antenna designs, centred around size and bandwidth. Size can be shrunk from two to four times with surprising good performance. Multiband performance is at non-harmonic frequencies, and at higher frequencies the FEA is naturally broadband. Polarization and phasing of FEAs also are possible.

In order for an antenna to work equally well at all frequencies, it must satisfy two criteria: it must be symmetrical about a point, and it must be self-similar, having the same basic appearance at every scale: that is, it has to be fractal. In many cases, the use of fractal element antennas can simplify circuit design, reduce construction costs and improve reliability. Because FEAs are self-loading, no antenna tuning coils or capacitors are necessary. Often they do not require any matching components to achieve multiband or broadband performance [61].

Fractal antennas also provide many versatile capabilities. They can be extremely small for applications requiring an embedded antenna, or contained in transparent materials to achieve near-invisible larger-scale form factors. The following table highlights the features and benefits of Fractal Antenna Systems' technology [62]:

Feature	Advantage	Benefit
Wideband/multiband	Instantaneous spectrum access	Use one antenna instead of many
Compact	More design and use versatility	Lowers cost and enhances desirability
Fractal loading	Added inductance and capacitance without components	Enables small, efficient, reliable antennas
Fractal ground plane/counterpoise	Smaller, multiband	Greater versatility, new packaging options
Frequency independent	Consistent performance over huge frequency range	Fractal solutions open up previously unknown options
Low Mutual Coupling	Close packing of antennas	Small arrays with excellent steerability
Proven Products	Designed for harshest conditions	In use by military and commercial customers
New design space	Powerful solutions possible	Design to requirements, not pick from catalog

Table 4.1 Features and benefits of fractal antenna systems' technology [62]

4.4 Disadvantages of Fractal Antenna

Disadvantages of fractal antenna technologies are

- Gain loss
- Complexity
- Numerical limitations
- The benefits begin to diminish after first few iterations,

CHAPTER-5
SIMULATION RESULTS

The software used for simulation in this thesis is CST microwave studio. CST microwave studio is a specialized tool for the fast and accurate 3D EM simulation of high frequency problems.

The antenna design starts with specifying the materials used in designing antenna. We have designed four antennas, one with 4 triangle straight shape, 4 triangle curved shape, 5 triangle straight shape and 5 triangle curved shape. In all the antennas coaxial feeding technique is used.

To design this antenna we use copper as an antenna element and FR-4 (fire retardant-4) as a substrate element. Here we have considered and compared few cases.

Case I: Simple antenna with circular patch 4 triangle straight vs Simple antenna with circular patch 4 triangle curved

Simple antenna with circular patch 4 triangle straight

This antenna is constructed using FR-4 as substrate thickness of 1.4 mm. The dimension of the substrate is 140x140 mm. Its relative dielectric constant is ε=4.3. Antenna element used in this antenna is copper with thickness 0.02 mm. To simulate this antenna we require ground plane which is also made of copper with thickness thrice the thickness of substrate i.e. 4.2 mm. The structure of this antenna is shown in fig 5.1.

After designing antenna return loss graph is calculated between the frequency range of 0-10 GHz which is shown in fig 5.2 The graph shows that there are five resonant frequencies for this antenna. The table for frequency and return loss is given in table 5.1

Frequency (GHz)	3.63	4.7	5.0	5.95	8.2
Return loss (dB)	-17.8	-11.2	-13.2	-22.8	-13.5

Table 5.1 Return loss and frequencies of circular patch 4 triangle straight

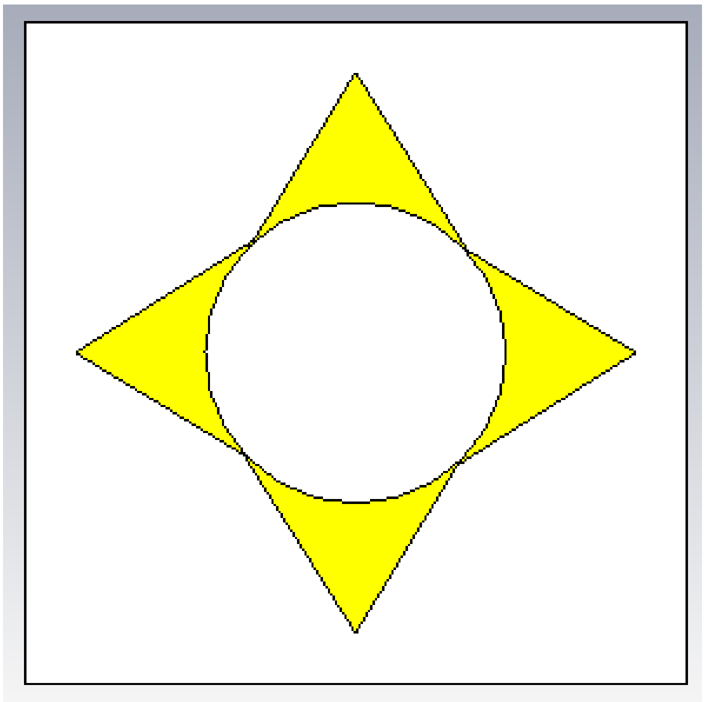

Fig 5.1 Circular patch 4 triangle fractal antenna

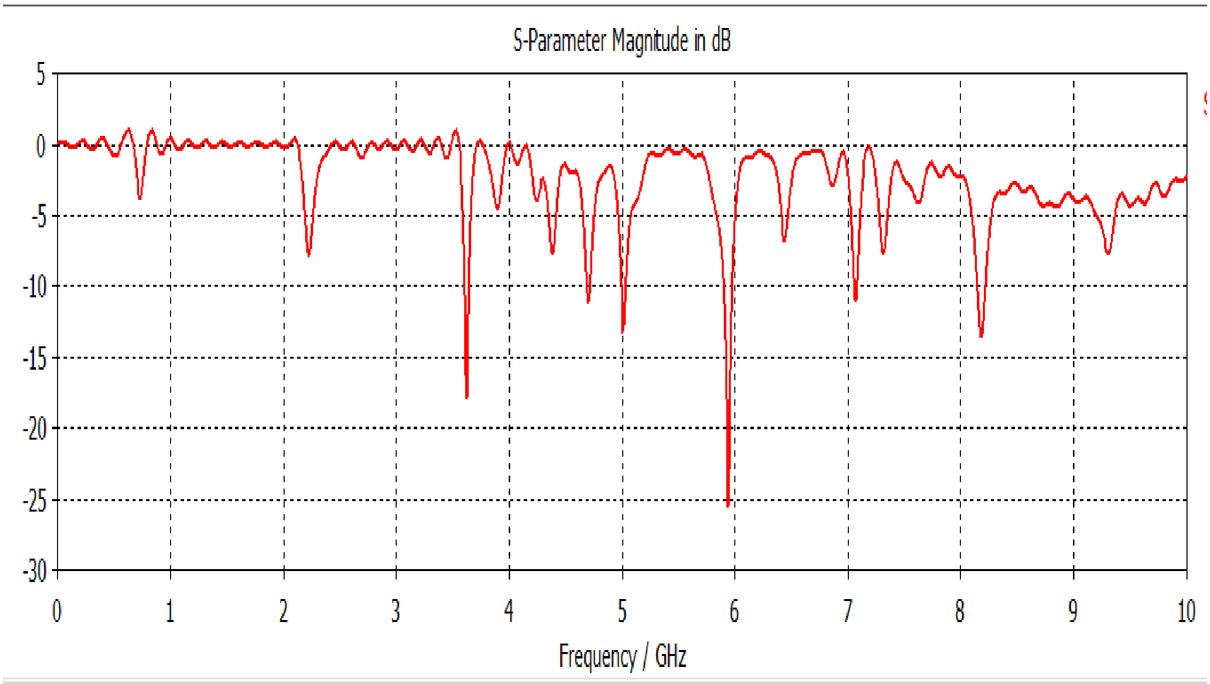

Fig 5.2 Return loss vs frequency graph for circular patch 4 triangle fractal antenna

So the best return loss is found at 5.95 GHz with -22.8 dB.

Simple antenna with circular patch 4 triangles curved

This antenna is constructed using FR-4 as substrate thickness of 1.4 mm. The dimension of the substrate is 140x140 mm. Its relative dielectric constant is ε=4.3. Antenna element used in this antenna is copper with thickness 0.02 mm. To simulate this antenna we require ground plane which is also made of copper with thickness thrice the thickness of substrate i.e. 4.2 mm. The difference between the previous and this antenna is that shape of this antenna is curved as shown fig 5.3. The antenna is designed using CST microwave studio 2010.

The antenna designed is simulated using the software as mentioned above. After simulating the resulted return loss graph is shown in fig. 5.4.

The graph shows that there are seven resonant frequencies for this antenna. The seven resonant frequencies which are founded are 2.25, 3.52, 4.9, 5.38, 6.38, 7.24, 9.0 GHz.

The table for the calculated value for frequency and return loss is given in the table 5.2. After seeing the table we can say that the best return loss -18.9 dB occurs at 4.9 GHz.

Frequency (GHz)	2.25	3.52	4.9	5.38	6.38	7.24	9.03
Return loss (dB)	-17.8	-13.5	-18.9	-11.96	-11.6	-12.8	-16.4

Table 5.2 Return loss and frequencies for circular patch 4 triangles curved antenna

There are more resonant frequencies in circular patch 4 curved triangles antenna than circular patch 4 straight triangles. So we can say that by changing the shape of antenna from straight to curve number of resonant frequencies increases.

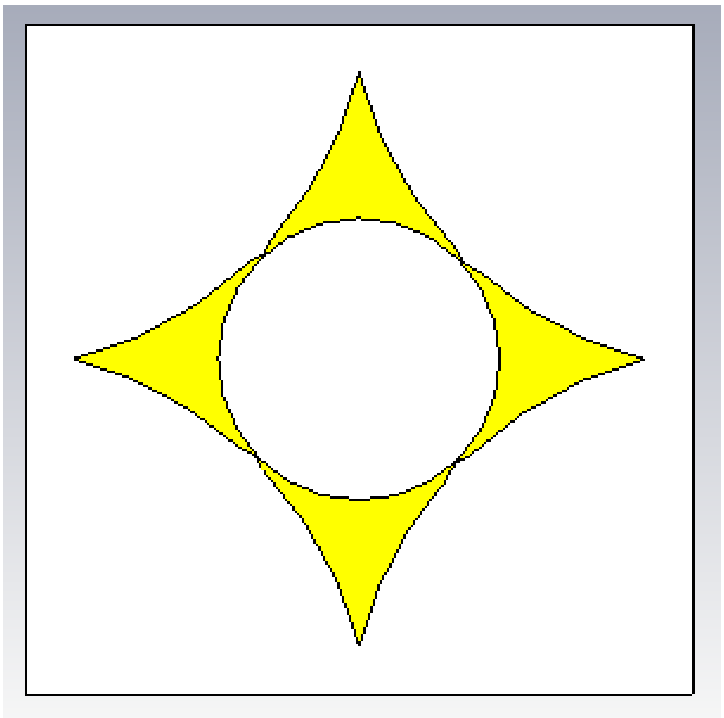

Fig 5.3 Circular patch 4 triangle curved fractal antenna

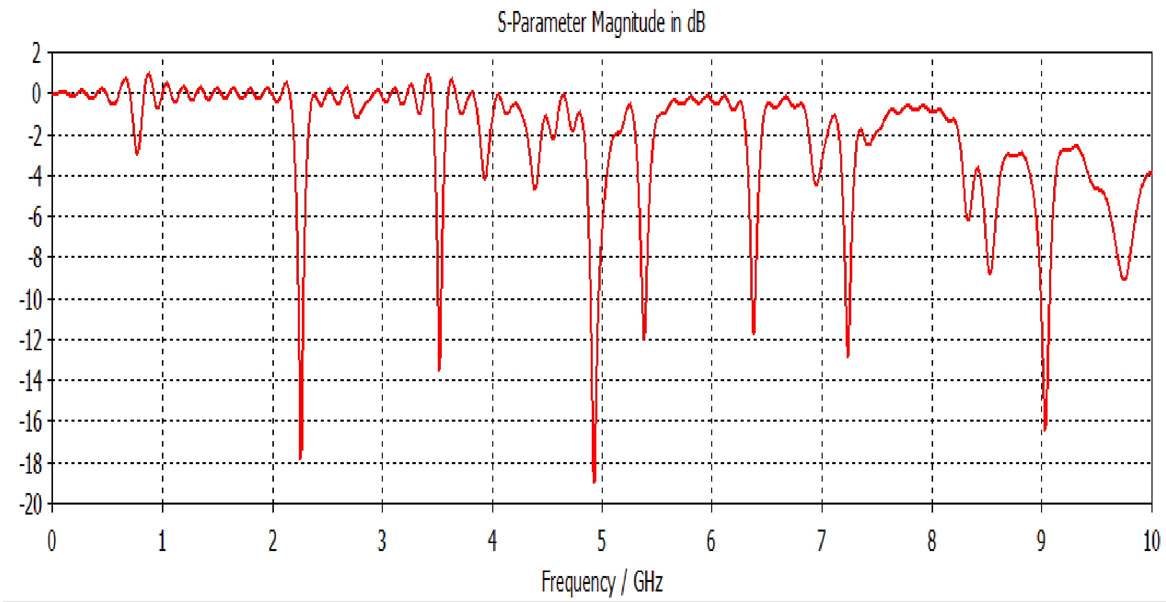

Fig 5.4 Return loss vs frequency for circular patch 4 triangle curved fractal antenna

CASE II: Simple antenna with circular patch 5 triangle single iteration vs curved antenna with circular patch 5 triangles

Simple antenna with circular patch 5 triangle single iteration

This antenna is constructed using FR-4 as substrate thickness of 1.4 mm. The dimension of the substrate is 140x140 mm. Its relative dielectric constant is ε=4.3. Antenna element used in this antenna is copper with thickness 0.02 mm. To simulate this antenna we require ground plane which is also made of copper with thickness thrice the thickness of substrate i.e. 4.2 mm. The antenna is shown in fig 5.5.

Now the results are simulated using CST Microwave Studio to calculate the retun losss graph. The graph is shown in fig 5.6.

The graph readings for this antenna are shown in the table. The table for frequency and return loss is given in table 5.3.

Frequency (GHz)	3.04	5.5	6.21	6.38	6.59
Return loss (dB)	-11.7	-23.8	-23.9	-11.6	-16.9

Table 5.3 Return loss and frequencies values for circular patch 5 triangles simple

The antenna has five resonant frequencies. The minimum return loss value occurs at -23.9 db with 6.21 GHz.

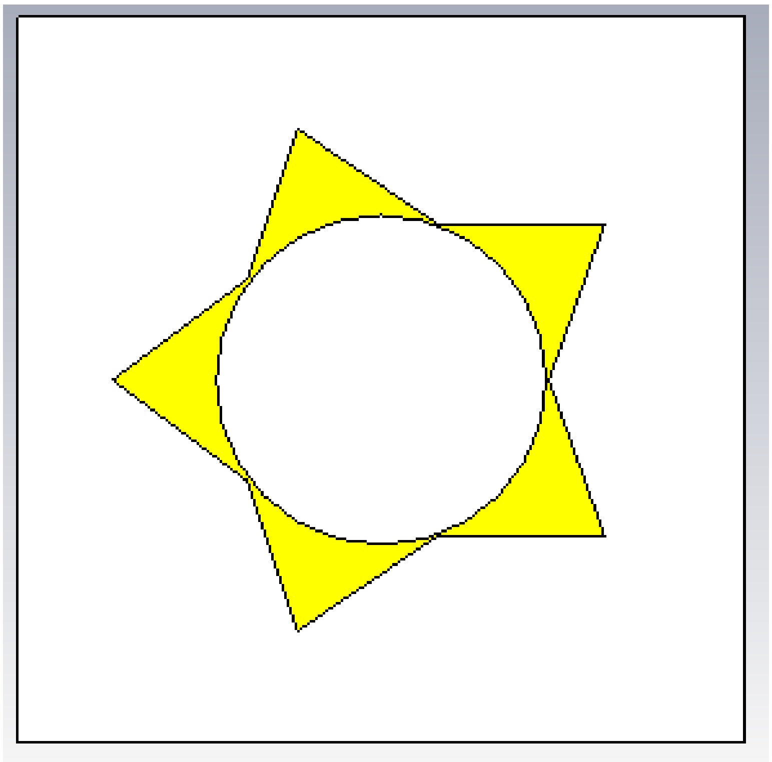

Fig 5.5 Circular patch 5 straight triangles antenna

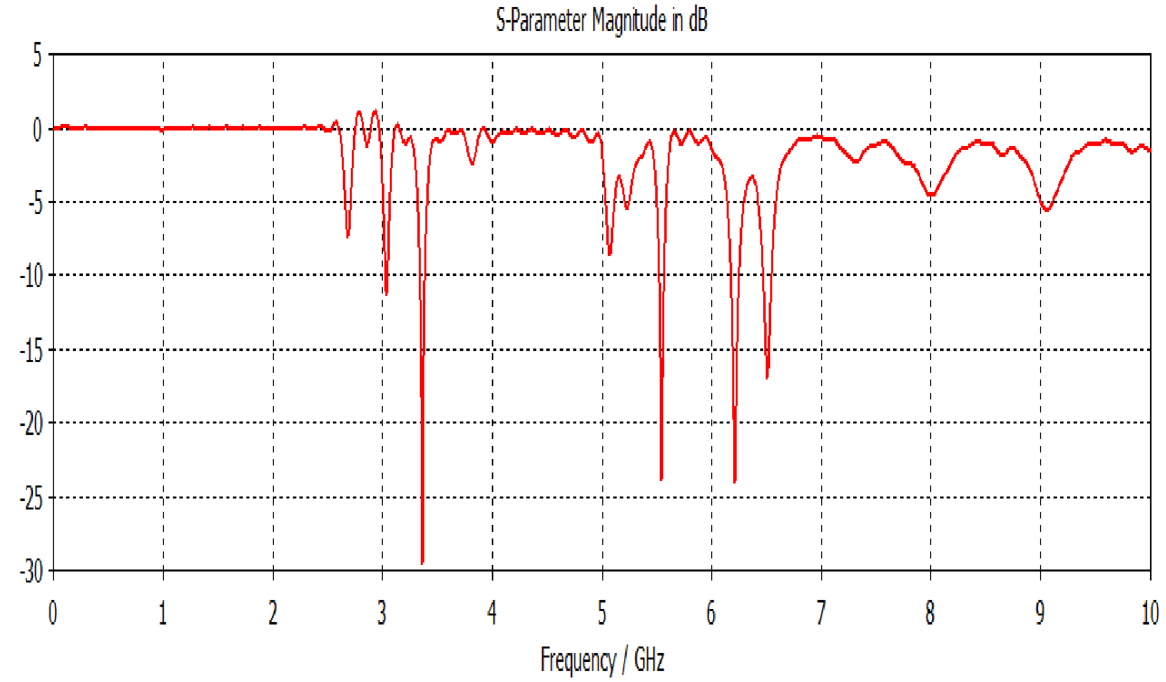

Fig 5.6 Return loss vs frequencies graph for circular patch 5 triangles simple

Curved antenna with circular patch 5 triangles

This antenna is constructed using FR-4 as substrate thickness of 1.4 mm. The dimension of the substrate is 140x140 mm. Its relative dielectric constant is ε=4.3. Antenna element used in this antenna is copper with thickness 0.02 mm. To simulate this antenna we require ground plane which is also made of copper with thickness thrice the thickness of substrate i.e. 4.2 mm. This antenna is constructed with curved shape. The antenna is as shown in fig 5.7.

The return loss graph is calculated using CST Microwave Studio 2010. The graph which is obtained after simulation is as shown in fig 5.8.

The values of resonant frequencies are 5.28, 5.69, 7.0, 8.4, 9.6 GHz. The table 5.4 shows the resonant frequencies and the return loss values for the above antenna.

Frequency (GHz)	5.28	5.69	7.0	8.4	9.6
Return loss (dB)	-13.6	-21.2	-15.0	-24.3	-13.0

Table 5.4 Return loss and frequencies for circular patch 5 curved triangles

This antenna with curved shape has five resonant frequency. The minimum return loss -24.3 dB occurs at 8.4 GHz.

By changing the shape of antenna from straight to curve in circular patch 5 triangles we see that return loss value decreases. So the antenna with -24.3 dB i.e. circular patch curved 5 triangles is better than circular patch simple 5 triangles.

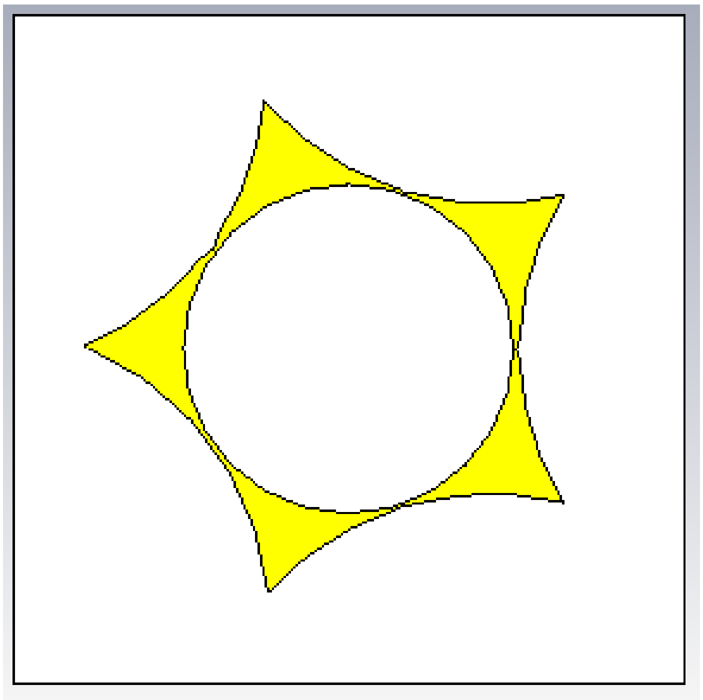

Fig 5.7 Curved antenna with circular patch 5 triangles

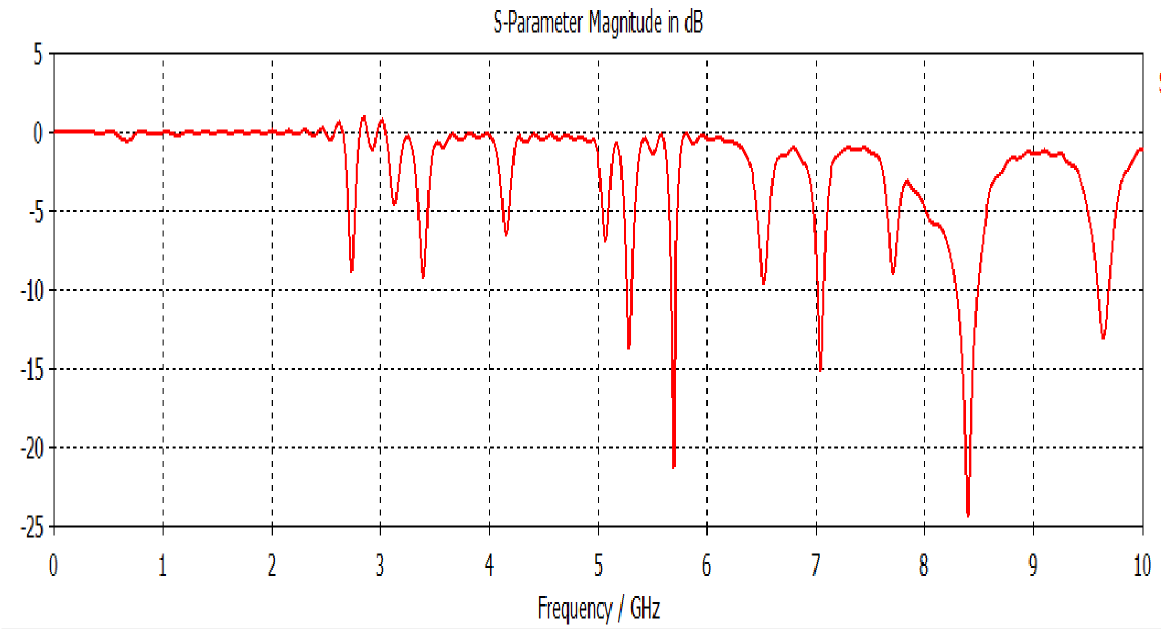

Fig 5.8 Return loss graph for curved antenna with circular patch 5 triangles

Case III: Circular patch 4 curved triangles with 3 iteration vs Circular patch 5 curved triangles with 3 iterations

Circular patch 4 curved triangles with 3 iterations

This antenna is constructed using FR-4 as substrate thickness of 1.4 mm. The dimension of the substrate is 140x140 mm. Its relative dielectric constant is ε=4.3. Antenna element used in this antenna is copper with thickness 0.02 mm. To simulate this antenna we require ground plane which is also made of copper with thickness thrice the thickness of substrate i.e. 4.2 mm. In this antenna the antenna element is curved and it is iterated three times. The design of this antenna is as shown in fig 5.9.

Then results are simulated using CST software which shows frequency vs s parameters in dB which is known as return loss graph. The graph is as shown in fig 5.10.

The graph values are given in the table 5.5

Frequency (GHz)	1.25	2.05	2.26	5.48	6.5	9.06	9.66
Return loss (dB)	-19.0	-17.5	-29.6	-20.3	-17.2	-21.0	-19.9

Table 5.5 Return loss values for circular patch 4 curved triangles with 3 iteration

There are seven resonant frequencies for this antenna they are 1.25, 2.05, 2.26, 5.48, 6.5, 9.06, 9.66 GHz. This antenna has seven resonant frequencies between the range 0 – 10 GHz with minimum return loss of -29.6 dB at 2.26 GHz.

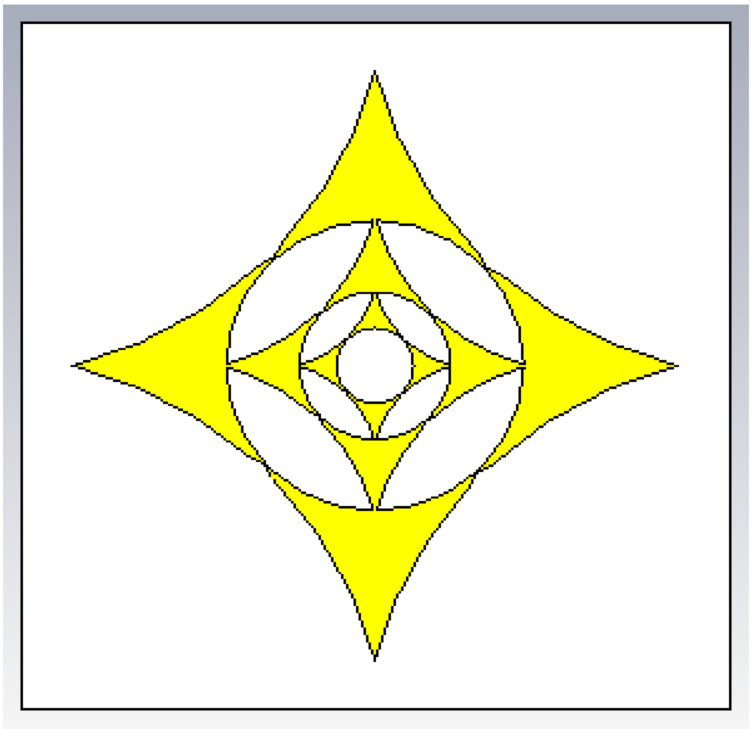

Fig 5.9 Circular patch 4 curved triangles with 3 iteration

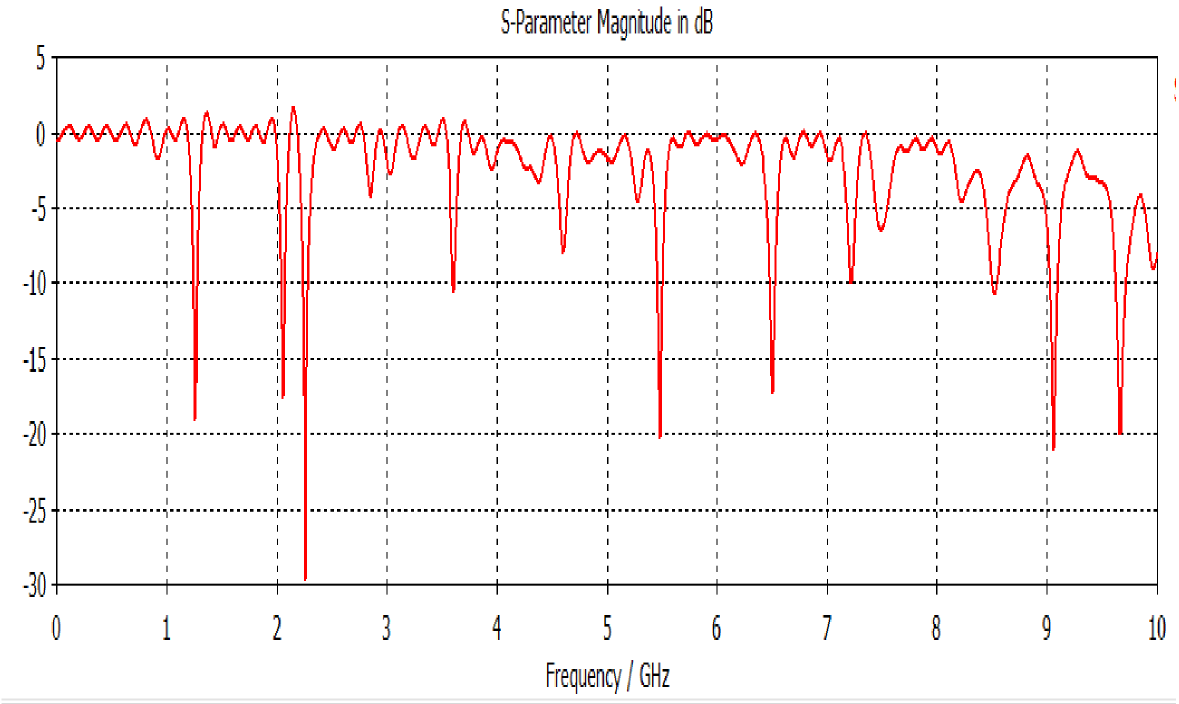

Fig 5.10 Return loss graph for circular patch 4 curved triangles with 3 iteration

Circular patch 5 curved triangles with 3 iterations

This antenna is constructed using FR-4 as substrate thickness of 1.4 mm. The dimension of the substrate is 140x140 mm. Its relative dielectric constant is ε=4.3. Antenna element used in this antenna is copper with thickness 0.02 mm. To simulate this antenna we require ground plane which is also made of copper with thickness thrice the thickness of substrate i.e. 4.2 mm. In this antenna the element is again curved but it has five triangles on it. The design is as shown in fig 5.11.

The designed antenna is simulated in CST microwave studio. The return loss graph for this antenna is as shown in table 5.6

The values of the graphs are

Frequency (GHz)	1.66	2.72	5.1	5.6	5.75	6.9	7.81	8.4	9.73
Return loss (dB)	-19.4	-15.2	-16.5	-13.4	-15.75	-16.4	-30.3	-12.7	-12.9

Table 5.6 Return loss values for circular patch 5 curved triangles with 3 iterations

There are 9 resonant frequencies for this antenna they are 1.66, 2.7, 5.1, 5.6, 5.75, 6.9, 7.81, 8.4, 9.73 GHz and minimum return loss is -30.3 dB at 7.81 GHz.

There are more resonant frequencies in circular patch 5 curved triangles 3 iterations than circular patch 4 curved triangles 3 iterations. So we can say that with increase in number of curved triangles more resonant frequencies are produced. The lesser return loss occurs in second antenna with value of -30.3 dB at 7.81 GHz.

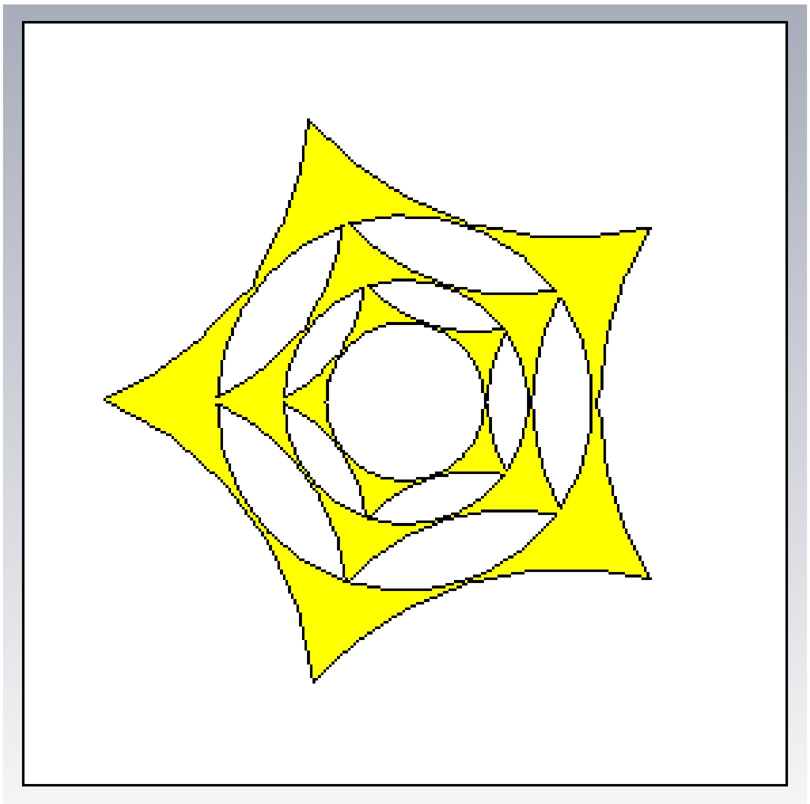

Fig 5.11 Circular patch 5 curved triangles with 3 iterations

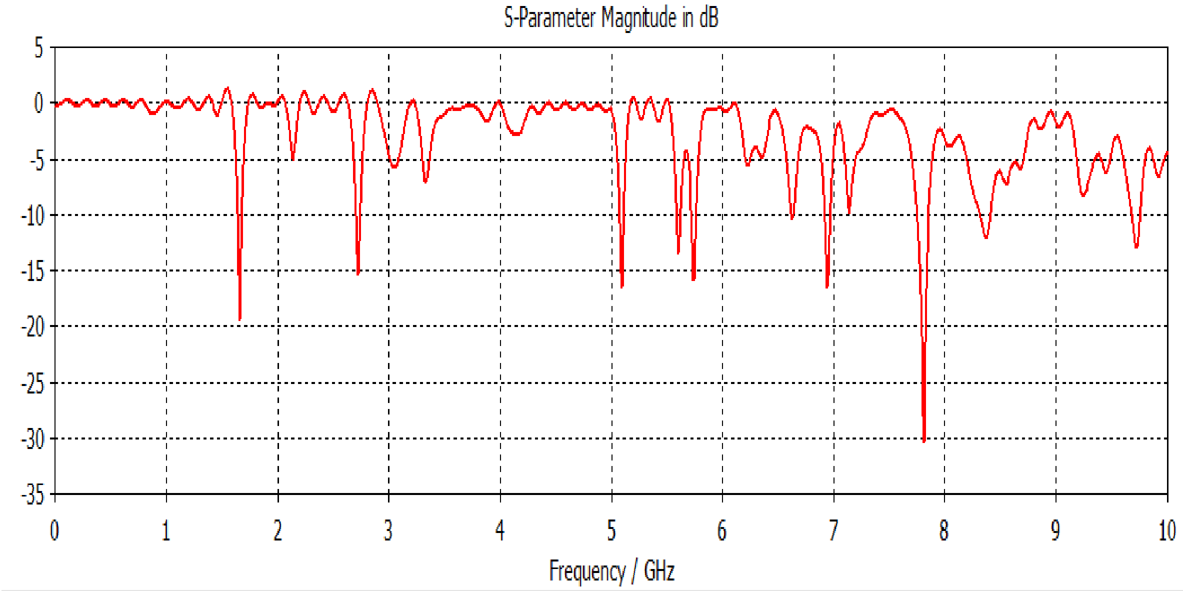

Fig 5.12 Return loss graph for circular patch 5 curved triangles with 3 iterations

Case IV: Simple circular patch 4 triangles 3 iterations vs circular patch 5 triangles curved antenna with 3 iterations.

Simple circular patch 4 triangles 3 iterations

This antenna is constructed using FR-4 as substrate thickness of 1.4 mm. The dimension of the substrate is 140x140 mm. Its relative dielectric constant is ε=4.3. Antenna element used in this antenna is copper with thickness 0.02 mm. To simulate this antenna we require ground plane which is also made of copper with thickness thrice the thickness of substrate i.e. 4.2 mm. The antenna is as shown in fig 5.13.

The return loss graph for this antenna is as shown below in fig. 5.14. The result are simulated using CST studio using coaxial feeding technique.

The values of return loss w.r.t frequency are shown in the table 5.7. The resonant frequencies are 1.28, 2.0, 3.71, 4.51, 4.88, 6.21, 6.71, 7.12, 9.32 GHz.

Frequency (GHz)	1.28	2.0	3.71	4.51	4.88	6.21	6.71	7.12	9.32
Return loss (dB)	-20.5	-13.3	-22.3	-18.5	-20.8	-12.27	-13.7	-14.2	-28.7

Table 5.7 Return loss and frequencies values simple circular patch 4 triangles 3 iterations

So, the minimum return loss occurs -28.7 dB at 9.32 GHz. There are 9 resonant frequency for this antenna.

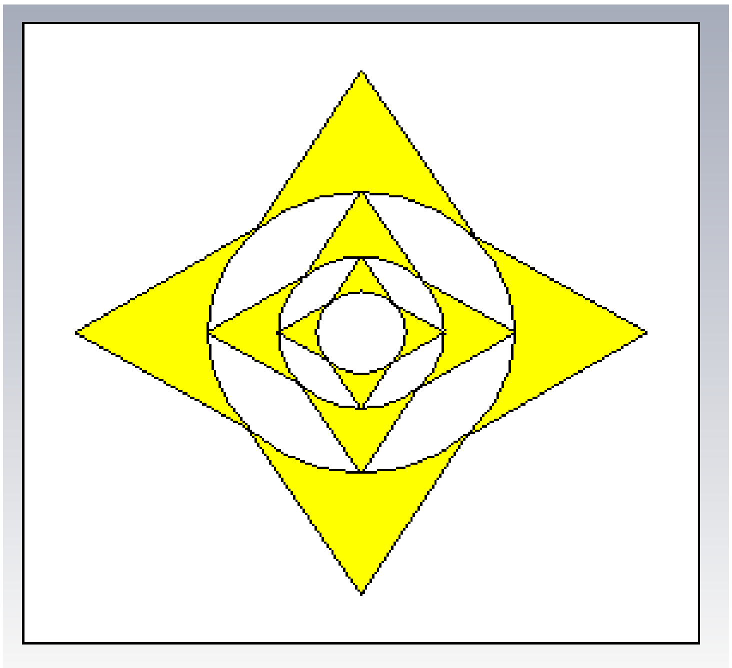

Fig 5.13 Simple circular patch 4 triangles 3 iterations

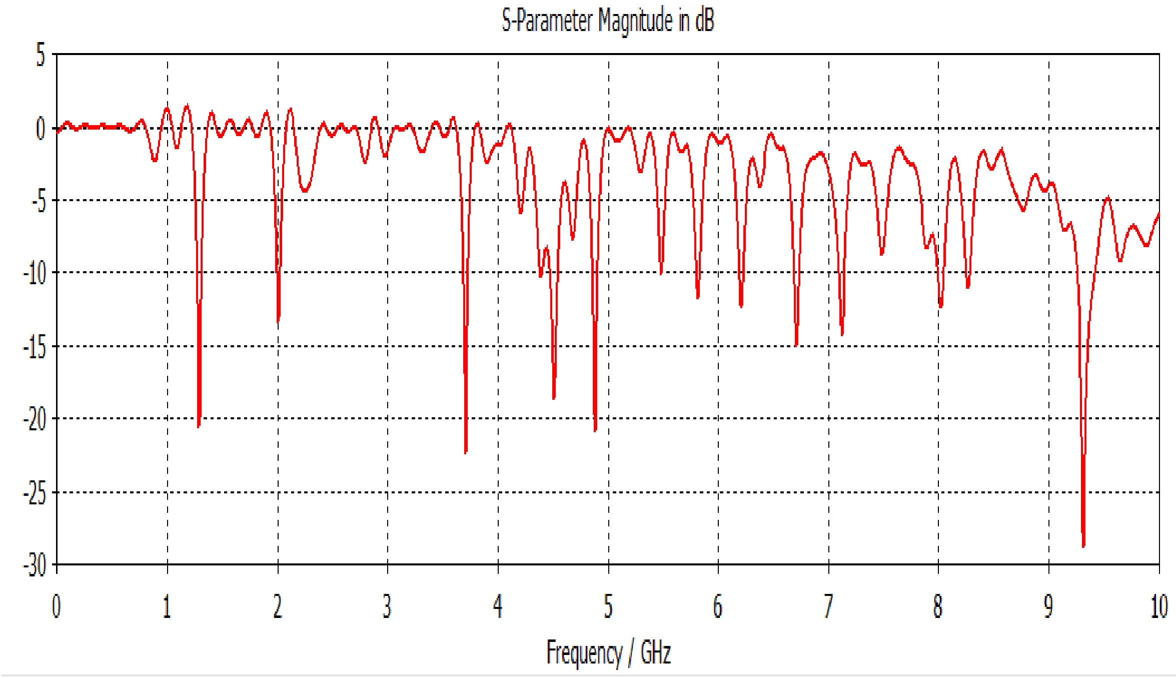

Fig 5.14 Return loss graph for simple circular patch 4 triangles 3 iterations

Circular patch 5 curved triangles with 3 iterations

This antenna is constructed using FR-4 as substrate thickness of 1.4 mm. The dimension of the substrate is 140x140 mm. Its relative dielectric constant is ε=4.3. Antenna element used in this antenna is copper with thickness 0.02 mm. To simulate this antenna we require ground plane which is also made of copper with thickness thrice the thickness of substrate i.e. 4.2 mm. This antenna is curved with five triangles and three iterations. The design is as shown in fig 5.15.

The return loss graph for this antenna is as shown in fig 5.16. There are 8 resonant frequencies in this antenna they are 1.66, 2.72, 5.1, 5.75, 6.9, 7.81, 9.73 GHz.

There are 8 resonant frequency for this antenna and minimum return loss is -30.3 dB at 7.81 GHz.

The values of the graphs are given in table 5.8

Frequency (GHz)	1.66	2.72	5.1	5.6	5.75	6.9	7.81	9.73
Return loss (dB)	-19.4	-15.2	-16.5	-13.4	-15.75	-16.4	-30.3	-12.9

Table 5.8 Return loss values for circular patch 5 curved triangles with 3 iterations

With the increase in number of triangles in circular patch 4 triangles 3 iterations and changing the shape to curve triangles we can say that there are more resonant frequencies in circular patch 5 triangles than circular patch 5 curved triangles. The lesser return loss occurs in Circular patch 5 curved triangles with 3 iterations antenna with value of -30.3 dB at 7.81 GHz.

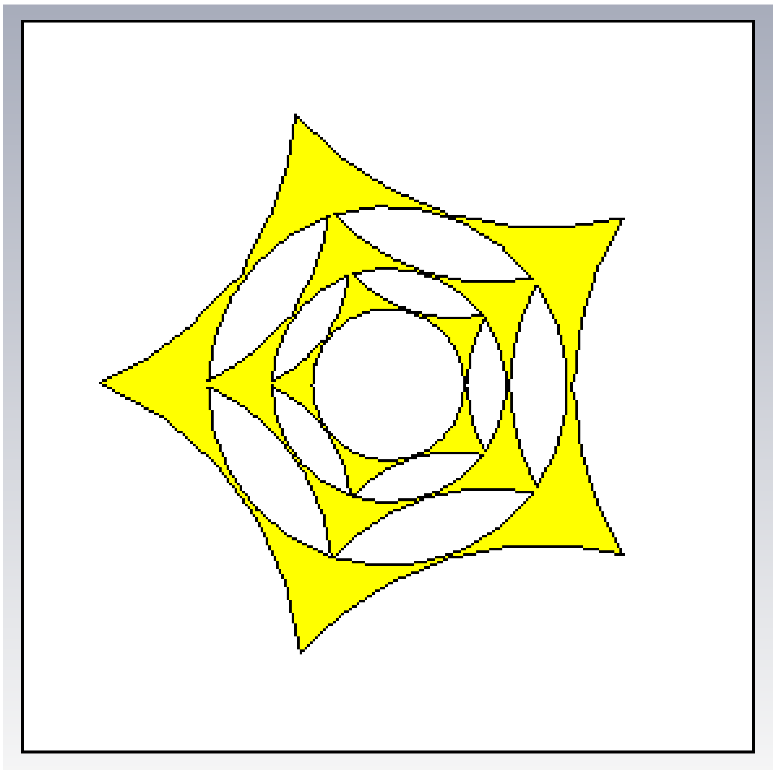

Fig 5.15 Circular patch 5 curved triangles with 3 iterations

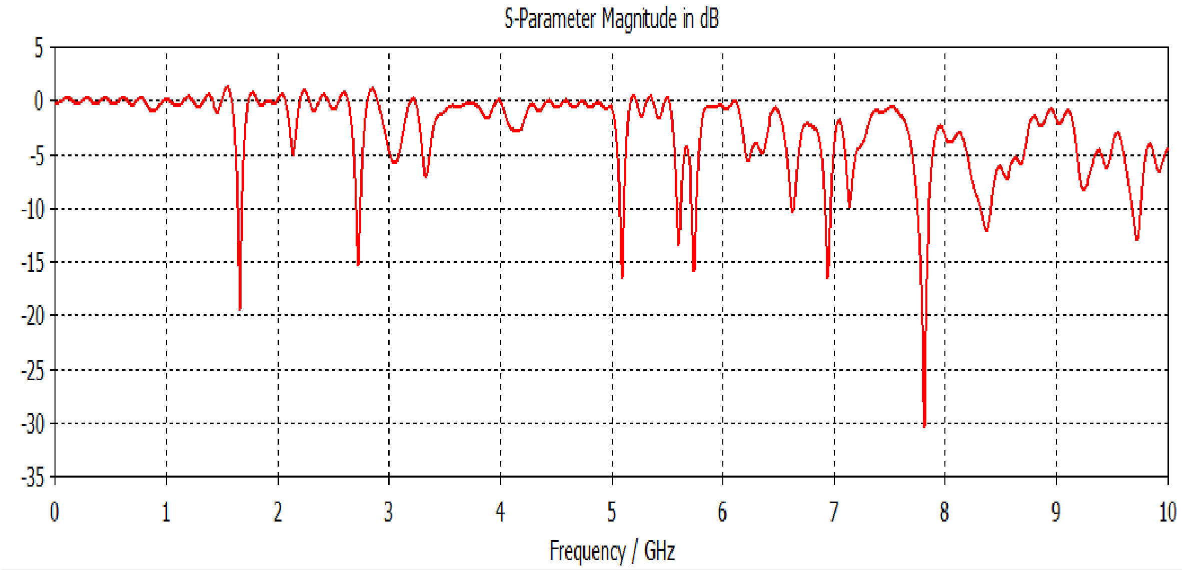

Fig 5.16 Return loss graph for circular patch 5 curved triangles with 3 iterations

Case V: Circular patch 4 curved triangles with 2 iterations vs Circular patch 4 curved triangles with 4 iterations

Circular patch 4 curved triangles with 2 iterations

This antenna is constructed using FR-4 as substrate thickness of 1.4 mm. The dimension of the substrate is 140x140 mm. Its relative dielectric constant is ε=4.3. Antenna element used in this antenna is copper with thickness 0.02 mm. To simulate this antenna we require ground plane which is also made of copper with thickness thrice the thickness of substrate i.e. 4.2 mm. The antenna is iterated with circular patch 4 curved triangles two times to get the desired antenna. The antenna is as shown fig 5.17.

The resulted antenna is simulated using CST Microwave Studio 2010. The obtained return loss graph for this antenna is as shown in fig 5.18.

The resonant frequencies are 1.45, 1.92, 2.25, 5.45, 5.75, 6.49, 8.51, 9.03, 9.62 GHz. The values for return loss graph are as given in the table 5.9.

Frequency (GHz)	1.45	1.92	2.25	5.45	5.75	6.49	8.51	9.03	9.62
Return loss (dB)	-14.8	-11.5	-30.3	-30.8	-15.75	-21.9	-14.1	-26.9	-22.6

Table 5.9 Return loss and frequencies for circular patch 4 curved triangles with 2 iterations

This antenna has 9 resonant frequencies with minimum return loss -30.8 dB at 5.45 GHz.

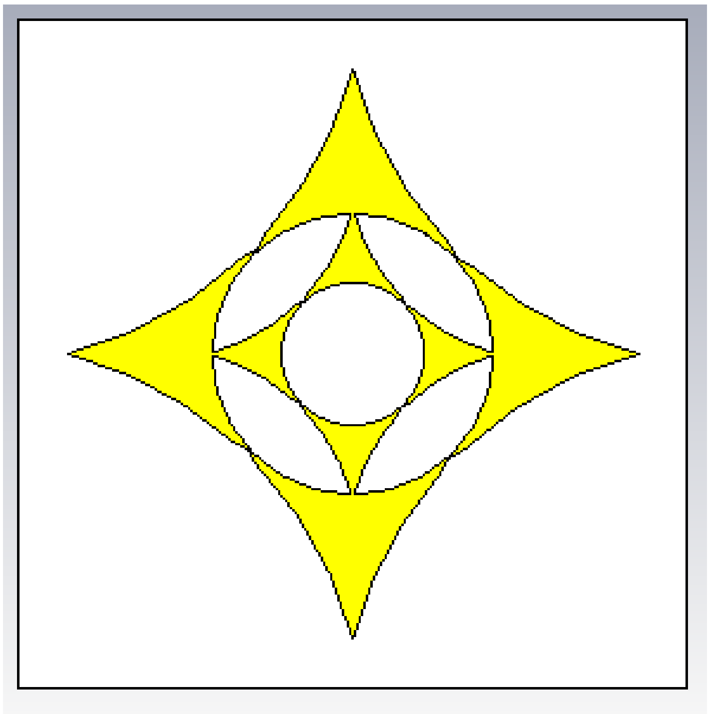

Fig 5.17 Circular patch 4 curved triangles with 2 iterations

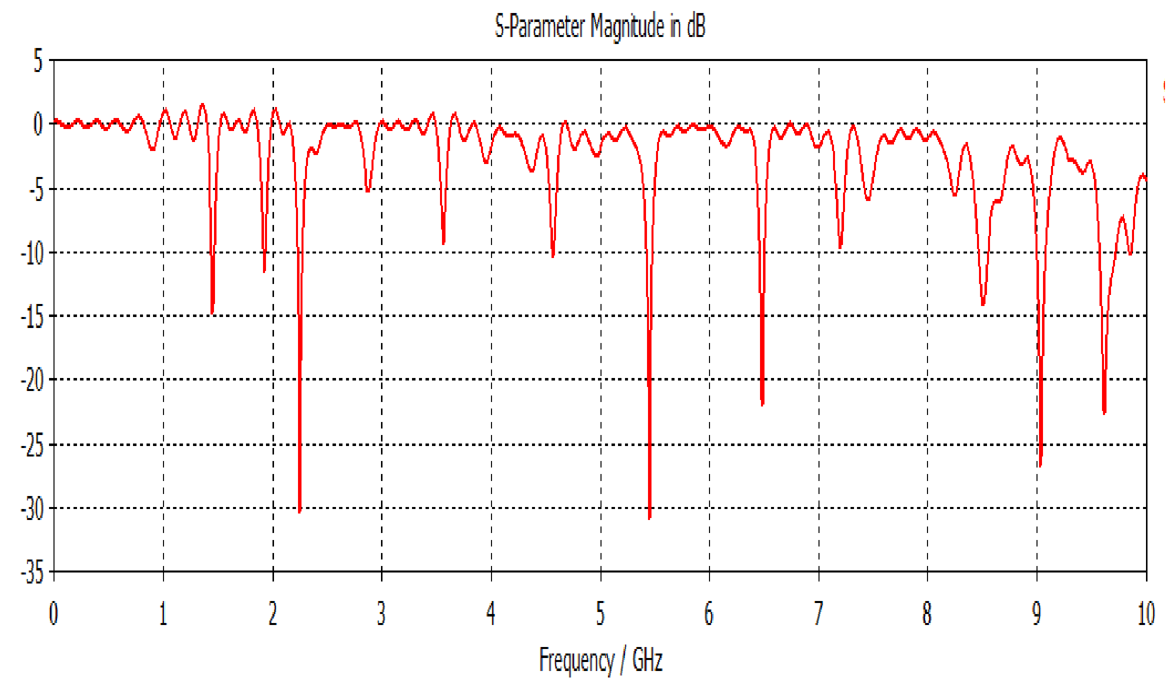

Fig 5.18 Return loss graph for circular patch 4 curved triangles with 2 iterations

Circular patch 4 curved triangles with 4 iterations

This antenna is constructed using FR-4 as substrate thickness of 1.4 mm. The dimension of the substrate is 140x140 mm. Its relative dielectric constant is ε=4.3. Antenna element used in this antenna is copper with thickness 0.02 mm. To simulate this antenna we require ground plane which is also made of copper with thickness thrice the thickness of substrate i.e. 4.2 mm. This antenna is same as the above antenna but it has 4 iterations in it. The substrate thickness is same as of the previous antenna along with ground plane thickness. The antenna is as shown in fig 5.19.

The resulted antenna is simulated using CST Microwave Studio 2010. The obtained return loss graph for this antenna is as shown in fig 5.20.

The resonant frequencies which are found after simulation are found to be 1.2, 2.12, 2.28, 5.49, 5.75, 8.53, 9.05, 9.67 GHz. The readings of this graph are given the table 5.10.

Frequency (GHz)	1.2	2.12	2.28	3.57	5.49	5.75	6.5	9.05	9.67
Return loss (dB)	-21.8	-13.2	-19.0	-10.2	-18.2	-15.75	-10.2	-14.8	-16.1

Table 5.10 Return loss and frequencies for circular patch 4 curved triangles with 4 iterations

This antenna has 10 resonant frequencies with lowest return loss at 1.2 GHz of -21.8 dB.

After comparing the above two antennas we have seen that with increase in number of iterations from 2 to 4 in circular patch curve antennas the number of resonant frequencies increases from 9 to 10.

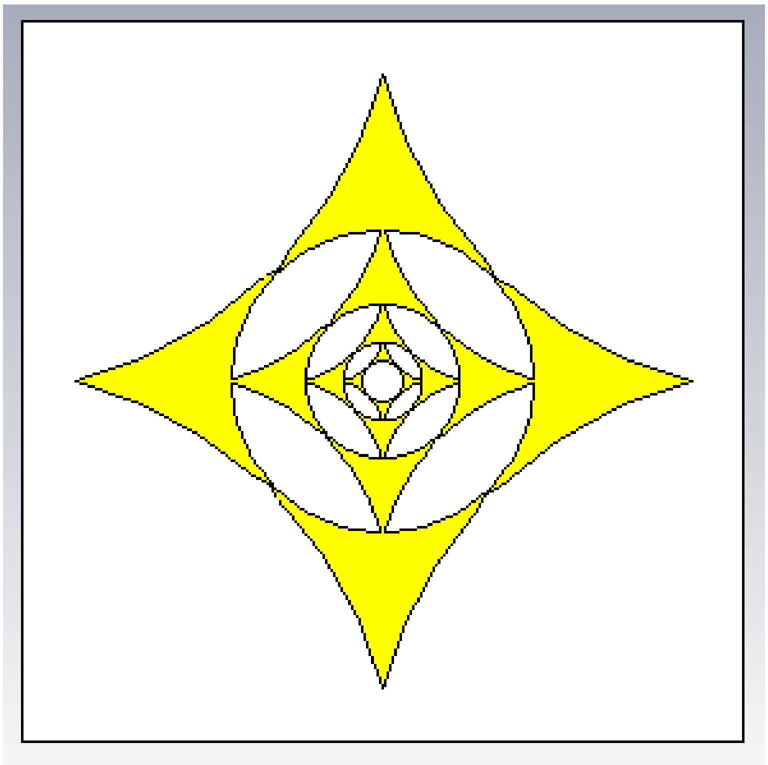

Fig 5.19 Circular patch 4 curved triangles with 4 iterations

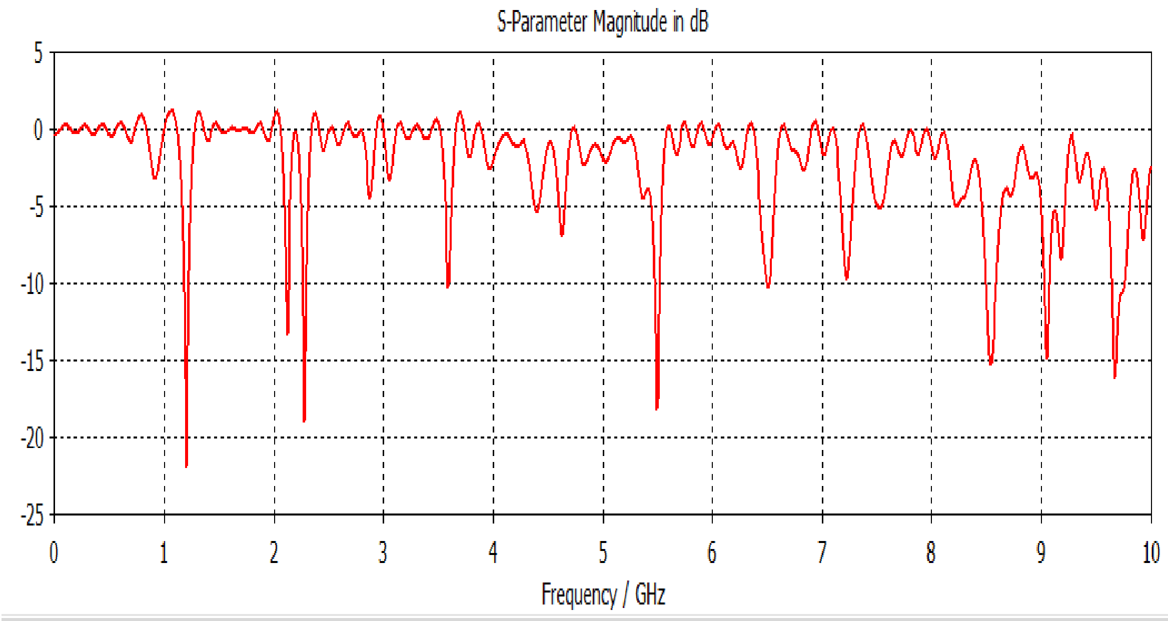

Fig 5.20 Return loss graph for circular patch 4 curved triangles with 4 iterations

Case VI: Circular patch 5 curved triangles with 2 iterations vs Circular patch 5 curved triangles with 4 iterations

Circular patch 5 curved triangles with 2 iterations

This antenna is constructed using FR-4 as substrate thickness of 1.4 mm. The dimension of the substrate is 140x140 mm. Its relative dielectric constant is ε=4.3. Antenna element used in this antenna is copper with thickness 0.02 mm. To simulate this antenna we require ground plane which is also made of copper with thickness thrice the thickness of substrate i.e. 4.2 mm. This antenna is obtained by performing one more iteration on circular patch 5 curved triangles. The antenna is as shown in fig 5.21.

The return loss of the above design is simulated using CST Microwave Studio 2010 and the return loss graph is as shown in fig 5.22.

The resonant frequencies are found at 2.96, 5.06, 5.72, 7.75, 8.36, 9.7 GHz. The values of resonant frequencies and return loss are given in table 5.11.

Frequency (GHz)	2.96	5.06	5.72	7.12	7.75	8.36	9.7
Return loss (dB)	-10.8	-12.1	-28.7	-12.8	-24.5	-17.54	-18.0

Table 5.11 Return loss and frequencies for circular patch 4 curved triangles with 4 iterations

There are 7 resonant frequencies in circular patch 4 curve triangles with 2 iterations with minimum return loss of -28.7 dB occurs at 5.72 GHz.

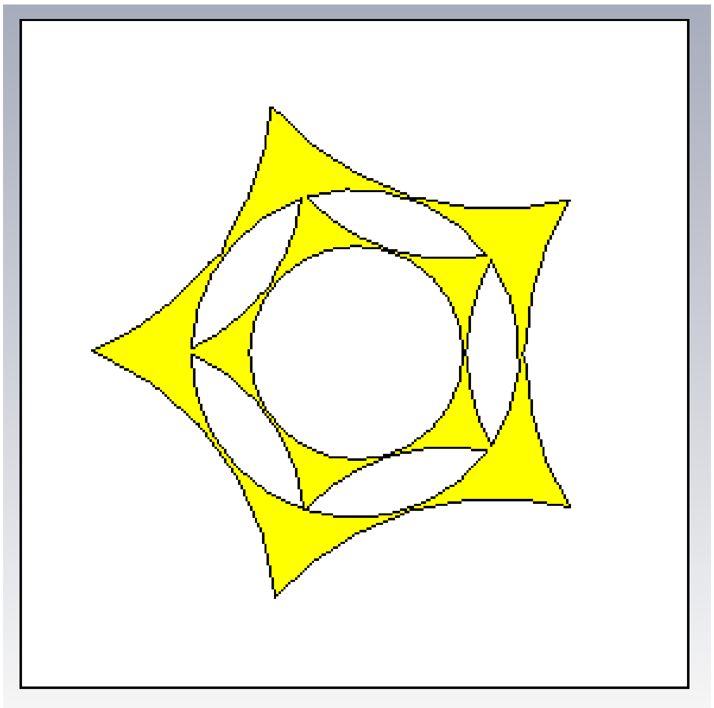

Fig 5.21 Circular patch 5 curved triangles with 2 iterations

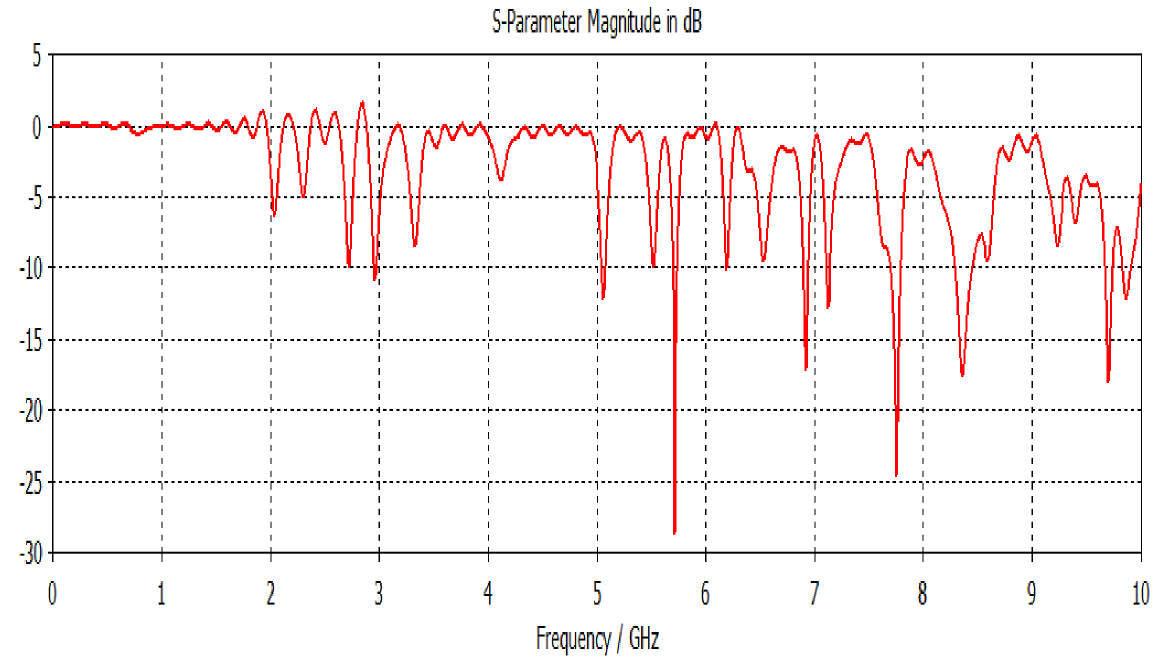

Fig 5.22 Return loss graph for circular patch 5 curved triangles with 2 iterations

Circular patch 5 curved triangles with 4 iterations

Circular patch 5 curved triangles with 4 iterations antenna is constructed using FR-4 as substrate thickness of 1.4 mm. The dimension of the substrate is 140x140 mm. Its relative dielectric constant is ε=4.3. Antenna element used in this antenna is copper with thickness 0.02 mm. To simulate this antenna we require ground plane which is also made of copper with thickness thrice the thickness of substrate i.e. 4.2 mm. This antenna is obtained using circular patch 5 curved triangles using four iterations in it. The desired antenna is as shown in fig 5.23.

The return loss of the above design is simulated using CST Microwave Studio 2010 and the return loss graph is as shown in fig 5.24.

The resonant frequencies which are found after simulation are 2.7, 5.1, 5.57, 6.94, 7.74, 7.92, 8.33, 9.7 GHz. The values of return loss vs frequencies are given in the table 5.12.

Frequency (GHz)	2.7	5.1	5.57	5.73	6.94	7.74	7.92	8.33	9.7	9.9
Return loss (dB)	-25.7	-20.4	-22.1	-18.7	-18.7	-17.3	-17.8	-12.5	-14.1	-17

Table 5.12 Return loss and frequencies for circular patch 5 curved triangles with 4 iterations

So there are 10 resonant frequencies in circular patch 5 curved triangles 4 iteration with minimum return loss of -22.1 dB occurs at 5.57 GHz.

Comparing the two antennas we can say that with the increase of number of iterations of circular patch 5 curved triangles from 2 to 4 the number of resonant frequency increases from 7 to 10 values.

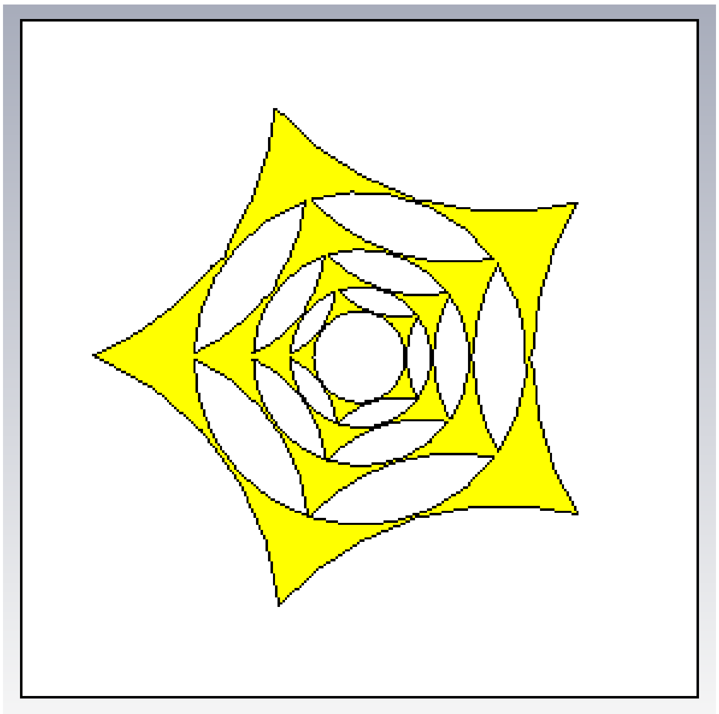

Fig 5.23 Circular patch 5 curved triangles with 4 iterations

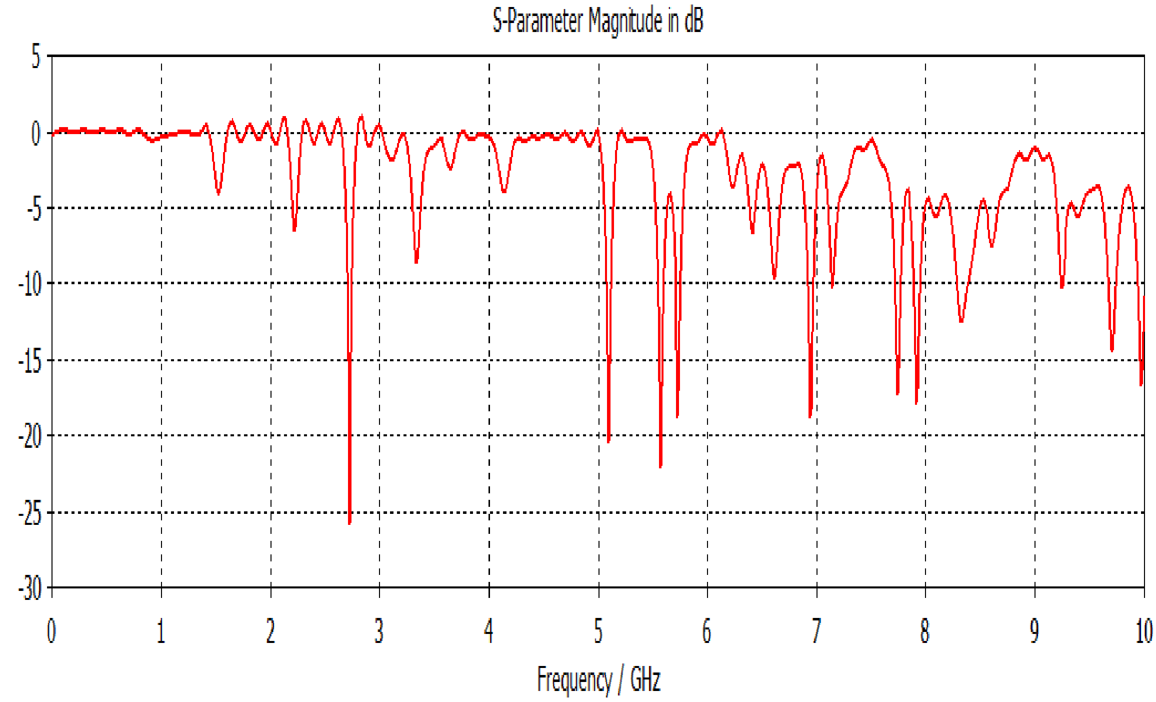

Fig 5.24 Return loss graph for circular patch 5 curved triangles with 4 iterations

CHAPTER-6

CONCLUDING REMARKS AND FUTURE SCOPE

Fractal antenna engineering represents a relatively new field of research that combines attributes of fractal geometry with antenna theory. Research in this area has recently yielded a rich class of new designs for antenna elements as well as arrays. Fractals are space-filling geometries that can be used as antennas to effectively fit long electrical lengths into small areas. This concept has been applied to wire and patch antennas. Through characterizing the fractal geometries and the performance of the antennas, it can be summarised that increasing the fractal dimension of the antenna leads to a higher degree of miniaturization. Also, it has been shown that a high degree of complexity in the structure of the antenna is not required for miniaturization. Truncating the fine structure of the fractal that is not discernable at the wavelengths of interest does not affect the performance of the antenna. Therefore, miniaturized antennas can be fabricated using only a few generating iterations of the generating procedure. Applications of fractal geometry are becoming increasingly widespread in the fields of science and engineering. This report presented a comprehensive overview of the research area we call fractal antenna engineering. Included among the topics considered were design methodologies for fractal antenna elements, application of fractals and advantages of fractal antennas. The field of fractal antenna engineering is still in the relatively early stages of development, with the anticipation of much more innovative advancement to come over the months and years ahead.

The aim of this thesis is to design multiband antennas with circular patch and triangles antennas for wireless communication systems and study the effect of iterations and changing shapes of straight triangles to curved triangles. Here, coaxial feed method is used to excite the patch antennas. After analysing all the results obtained after simulation of all purposed antennas it has been seen that with the increase in number of iterations the number of resonant frequencies increases. The same behaviour is seen when the shape of antenna is changed from straight shape to curved shape. When the shape of antenna is changed to curve shape the values of return losses also decreases and the best results are obtained. All the designed antennas are multiband antennas.

Fractal antenna is still a new topic in the field of research. So there is huge scope of work in this area. The antennas which are purposed in this thesis are made of copper element, the substrate is FR-4 of thickness 4.3 mm. The feeding method used in this thesis is coaxial feeding technique. For future work the fractal antenna element can be changed to silver, titanium etc. and thickness can also be varied to more or less values than 4.3 mm. The feeding method can also be changed. All these values can be changed the results can be calculated.

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