

**MINKOWSKI ALGORITHM T-SHAPED FRACTAL PATCH
ANTENNA DESIGN WITH IMPROVED RETURN**

LOSS

*Thesis submitted in partial fulfilment of the requirement for the
award of the degree of*

MASTER OF ENGINEERING

In

ELECTRONICS AND COMMUNICATION

Submitted by

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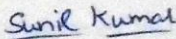
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DECLARATION

I hereby declare that the work, which is being presented in the dissertation, entitled "Minkowski Algorithm T-Shaped Fractal Patch Antenna Design with Improved Return Loss" in partial fulfilment of the requirements for the award of degree of Master of Engineering in Electronics and Communication Engineering submitted at the Department of Electronics and Communication Engineering of Thapar University, Patiala, is an authentic record of my own work carried out under the guidance of **Sukhwinder Kumar, Lecturer**, Department of Electronics and Communication Engineering and refers other research's work which are duly listed in reference section.

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

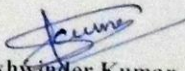
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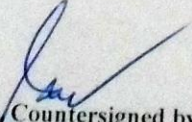

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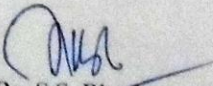
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ABSTRACT

Antenna is one of the largest components of the low profile wireless communication. In order to transmit and receive antenna information; modulation is done in which carrier wave is superimposed over modulating signal. At the required destination, the modulated signal was then received and the original information signal can be recovered by demodulation. Over the years, techniques have been developed for this process using electromagnetic carrier waves operating at radio frequencies as well as microwave frequencies. In the current scenario small, compatible and affordable microstrip patch antennas are developed in wireless communication industries keep on improving antenna performance. One of important concept to design antenna is that antenna have small size. For mobile applications, one may want that antenna must have small size and must be capable to resonate at multiple frequency bands. There are number of techniques that can be useful for designing of antenna which include making use of fractal geometry, use of slot and DGS. In this paper, T-shaped Patch antenna has been designed and fractal geometry has been applied to it in order to obtain self-similar characteristics. Square Patch length has been taken as square of length 36mm. Dimension of ground has been taken as been taken as 50 mm. The substrate used in this paper is FR-4. Parametric analysis has been applied in terms of changing microstrip line, feed point, thickness and geometry. Antenna resonates at three bands with return loss of 3.9 GHz, 4.5 GHz and 6.1 GHz. This antenna had return loss of -14.34 dB, -14.40 dB and -25.85 dB with bandwidth of 100 MHz, 110 MHz and 200 MHz at resonant frequencies. Further this antenna has good gain of 3.5dBi, 3.6 dBi and 6.1 dBi at corresponding frequencies and also compared with E shaped fractal geometry. This antenna can be useful for Wi-Max and WLAN applications. In this dissertation, fractal geometry and effect of changing thickness and feed are observed to select that configuration that will give best results used to improve characteristics of microstrip antenna, Fractal geometry has been applied on patch to obtain multiband characteristics to obtain wideband characteristics. The designed antennas in this dissertation report can be used in different applications like WLAN, WiMAX, satellite communications, RADAR applications and defence and secure communication application

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LIST OF ABBREVIATIONS

CDMA	Code Division Multiple Access
CP	Circular Polarization
FDMA	Frequency Division Multiple Access
FDTD	Finite-Difference Time-Domain
GPS	Global Positioning System
GSM	Global System for Mobile
GPRS	General Packet Radio Service
HFSS	High Frequency Structure Simulator
IFS	Iterative Function System
ISM	Industrial Scientific and Medical
LAN	Local Area Network
MIMO	Multiple Input Multiple Output
RF	Radio Frequency
RFID	Radio Frequency Identification
UMTS	Universal Mobile Telecommunications System
UWB	Ultra Wide Band
VSWR	Voltage Standing Wave Ratio
WLAN	Wireless Local Area Network
WiMAX	Worldwide Interoperability for Microwave Access
WPT	Wireless Power Transmission

Chapter 1

INTRODUCTION

This chapter gives a brief introduction about basics of antenna, importance of a microstrip patch antenna and multiband fractal antenna. Antenna is one of the largest components of the low profile wireless communication. In order to transmit and receive antenna information, modulation is done in which carrier wave is superimposed over modulating signal. At the required destination, the modulated signal was then received and the original information signal can be recovered by demodulation. Over the years, techniques have been developed for this process using electromagnetic carrier waves operating at radio frequencies as well as microwave frequencies. In the current scenario small, compatible and affordable microstrip patch antennas are developed in wireless communication industries keep on improving antenna performance. A patch antenna is a narrowband antenna with large beam width. It is fabricated by etching the antenna element pattern in metal trace which is bonded to an insulating dielectric substrate such as a printed circuit board with a continuous metal layer bonded to the opposite side of the substrate known as a ground plane. Fractal geometry is used to reduce the size of patch antenna. Fractal geometries are different from Euclidean geometries which have two common properties: space-filling and self-similarity. It is found that by applying fractal geometry, self-repeating structures are obtained. Fractal geometries that are used in this dissertation are Koch curve, Minkowski fractal geometry and many other self-similar shapes. By applying fractal geometry on patch, area of patch decreases, resonant length increases and number of frequency bands of antenna increases. Also it is good to achieve wideband characteristics apart from multiband characteristics; hence defected ground structure has been applied to antenna. There are different DGS that can be applied to antenna which include H shaped, plus shaped DGS. It is found that by applying DGS to antenna, characteristics of antenna improved.

1.1 Microwave Frequency Bands

Radio waves and microwaves play an important role in daily life. Television signals are transmitted by satellite using microwaves, military uses microwave for surveillance and navigation purposes. Telephone and data signals are transmitted by microwaves. Also in today's scenario, technology demands such an antenna that can operate on different wireless band and must have different features like low cost, less weight, low profile antenna which are capable of maintaining high performance over a chromatic spectrum of frequencies. Microwave spectrum is usually called as electromagnetic spectrum, since it ranges from 1GHz to 100 GHz. There are different microwave bands which are classified into many frequency bands. Applications most commonly used are of range 1 to 40 GHz. Hence different bands within this range are L band (1-2 GHz), S band (2-4 GHz), C band (4-8 GHz), X band (8-12 GHz), Ku band (12 -18 GHz), K band (18-26.5 GHz) and Ka band (26.5-40 GHz). Different bands together with their applications are mentioned in table 1.1. Microstrip antenna finds applications from 1 GHz to 12 GHz. Hence microstrip antenna can be designed for L band, S band, C band and X band applications. Standard band designations for microwave frequencies listed as per Institute of Electrical and Electronics Engineering (IEEE) is the industry standards.

Table 1.1: Various Microwave Bands with their Applications in Wireless Communication [35]

Microwave Band	Frequency Range	Applications
L Band	1 to 2 GHz	Military telemetry, GPS, Mobile phones (GSM), Amateur radio
S Band	2 to 4 GHz	GPS, WLAN, Bluetooth, Cellular phones, Wi-Fi
C Band	4 to 8 GHz	Long distance radio telecommunications, Microwave relay, Satellite communications
X Band	8 to 12 GHz	RADAR
Ku Band	12 to 18 GHz	Satellite television, RADAR

K Band	18 to 26.5 GHz	Astronomical observations, RADAR, Satellite communications
Ka Band	26.5 to 40 GHz	Satellite communications

1.2 Description and Working of Antenna

Antenna technology has been an important part of the communications revolution. The antenna is the transitional structure between free- space and a guiding device. It is an electric device which converts electric power into radio waves, and vice -versa. According to IEEE, antenna is defined as that part of a transmitting or receiving system that is designed to radiate or receive electromagnetic waves. Antennas are three-dimensional and live in a world of beam area, Ste radians, square degree, and solid angle. It has self and mutual impedance. It has three polarizations: linear, elliptical, and circular. It can be divided into two groups which are wire antennas and aperture antennas. There are demands technologies which have been completed in the 1970s through the early 1990s; signals of future discoveries and breakthroughs were captured in a special issue of proceeding of the IEEE (Vol. 80, No.1, January 1992) devoted to antennas. Figure 1.1 represents wireless communication link with transmitting and receiving antenna. The transmitting antenna in figure 1.1 is a region of transition from a guided wave on a transmission line to a free-space wave. The receiving antenna is a region of transition from a space wave to a guided wave on a transmission line. Thus, an antenna is a transducer, or transition device between a guided wave and a free space wave, or vice- versa [31].

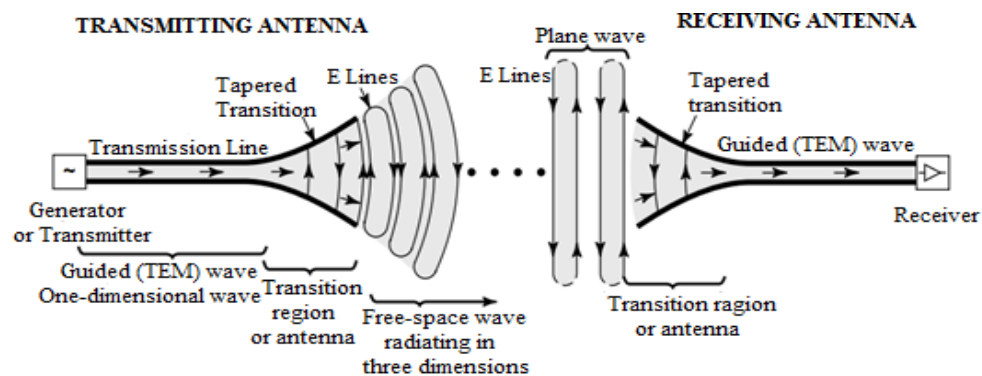


Figure 1.1: Wireless Communication Link with Transmitting Antenna and Receiving Antenna [31]

1.3 Parameters of Antenna

The parameters of antennas are the key factor for designing an efficiently radiating antenna. There are various parameters of antenna that must be calculated in order to check the efficient working of antenna. The few antenna parameters are:

- **Return Loss:** The return loss (R_L) is the logarithmic ratio measured in dB that compares the power reflected by antenna to the power that is fed into the antenna from transmission line. It is another way of expressing the mismatch. The R_L is defined as equation 1.1.

$$RL = -10 \log_{10} | p_r / p_i | \quad (1.1) \quad \text{Where } p_r = \text{reflected power, } p_i = \text{incident power.}$$

For the practical applications, $VSWR = 2$ is acceptable as the return loss would be -9.54 dB [12].

- **Gain:** The gain of the antenna is one of the most parameter as every research work on antenna is done to increase the gain. The gain of antenna is closely related to the directivity, it is a measure that takes in to account the efficiency of the antenna as well as its directional capabilities. Gain of antenna is defined as the ratio of the radiation intensity in a given direction to that of radiation intensity that would be obtained if the power accepted by the antenna were radiated isotropically [28]. Gain can also be defined as the product of directivity and efficiency given by equation 1.2.

$$\text{Gain} = 4 \times \pi \times U (\Theta, \varphi) / P_{in} \quad (1.2)$$

Where U = radiation intensity.

- **Directivity:** Directivity, D , is an important parameter that shows the ability of the antenna focusing radiated energy. The directivity of an antenna has been defined as “the ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged over all direction. In other words, if antennas do not have any losses then both directivity and gain are having same value. Directivity can be defined as equation 1.3.

$$D = \frac{U}{U_i} = \frac{4\pi U}{P_r} \quad (1.3)$$

Where D = Directivity of the antenna; U = Radiation Intensity of the antenna; U_i = Radiation Intensity of an isotropic source, and P_r = Total power radiated. Directivity is measured in dBi [31].

- **Voltage Standing Wave Ratio:** It describes how well antenna impedance matched to transmission line to which antenna is connected. It is the function of reflection coefficient and tells amount of power that gets reflected from antenna because of improper matching between transmission lines and receiving antenna. It is ratio of maximum voltage to minimum voltage in transmission line and it is defined by equation 1.4.

$$VSWR = \frac{(1+K)}{(1-K)} \quad (1.4)$$

Here K is the magnitude of reflection coefficient. VSWR is always a real and positive number but cannot be zero but it is having value unity for fully matched system. Return loss is related to VSWR as by equation 1.5.

$$\text{Return loss}(dB) = 20 \log \left[\frac{VSWR - 1}{VSWR + 1} \right] \quad (1.5)$$

- **Bandwidth:** Bandwidth of antenna is defined as the range of frequencies over which antenna can operate correctly. In other words bandwidth defines the frequency range over which an antenna meets a certain set of specification performance criteria. There are two methods for computing the bandwidth of antenna which are narrowband and broadband.

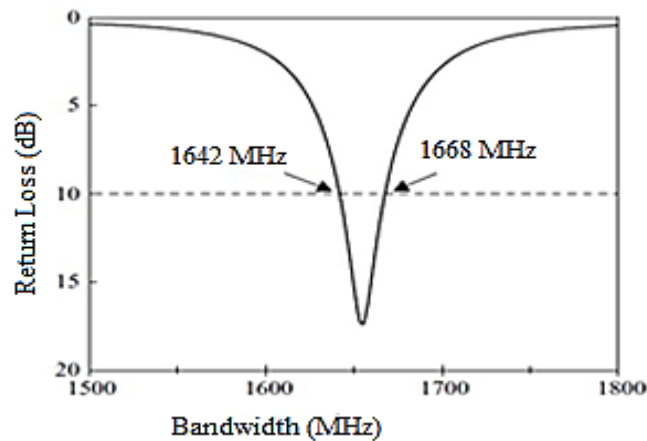


Figure 1.2: Bandwidth of Antenna

- Radiation Pattern:** Radiation pattern is a graphical representation of antenna radiation properties as a function of space coordinates. There are different shapes that radiation pattern can have like pencil beam and fan beam pattern. The radiation pattern is a graphical description of the relative field strength transmitted from or received by the antenna. There are different antenna patterns. Isotropic Pattern, Directional Pattern, Omni Directional Pattern, Principal Plane Patterns, E Plane Pattern, H Plane Pattern: The plane containing magnetic field vector and the direction of maximum radiation forms H plane pattern. Radiation pattern of antenna is shown in figure 1.2. It has different lobes which include major lobe, minor lobe, side lobe and back lobe.
 - Major Lobe- A clear peak in radiation intensity surrounded by regions of weaker radiation intensity is called as main lobe.
 - Minor Lobe- Any radiation lobe other than main lobe is called minor lobe. This lobe radiates power in undesired direction.
 - Side Lobe- A radiation lobe in any direction other than direction of intended radiation is said to form side lobe.
 - Back Lobe- Any radiation lobe opposite to that of main lobe forms back lobe. Hence to increase gain of antenna back lobes have to be minimized in order to increase directional properties [30].

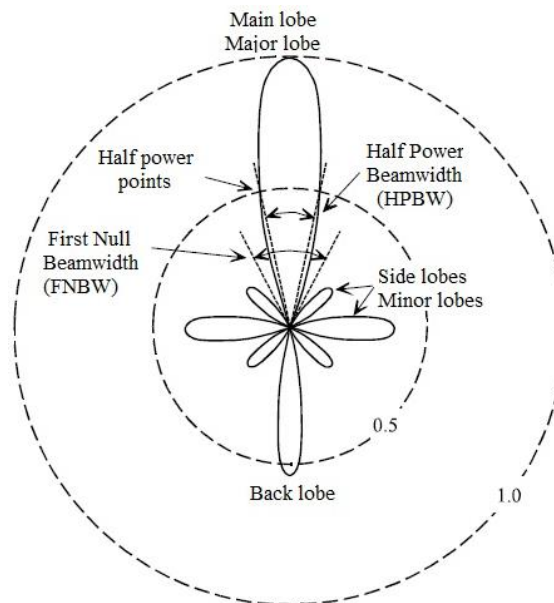


Figure 1.3: Radiation Pattern of Antenna with Different Radiation Lobes [30]

- **Front to Back Ratio:** It is defined as ratio of power gain between front and rear direction of directional antenna. In other words it is ratio of directivity of antenna in forward direction to that in rearward direction. When principle plane is plotted on relative dB scale, it is difference in dB level of maximum radiation and dB level of radiation in direction of 180 degrees.

From curve shown in figure 1.3, bandwidth values are obtained between points where -10 dB return loss line cuts the return loss and frequency curve. In curve shown in figure 1.3, it is clear that this antenna has return loss of -17dB and -10dB return loss curve cuts curve at two frequencies which are 1642 MHz and 1668 MHz. Difference between two frequencies gives measure of bandwidth. It is found that bandwidth not only depend on one factor but it depends on all characteristics of antenna.

1.4 Microstrip Antenna Design Theory

The idea of the microstrip antenna was introduced in 1950's but it became popular and took place in various applications 1970's. In its most basic form, a Microstrip patch antenna consists of a conducting patch of any planar or non-planar geometry on one side of a dielectric substrate with a ground plane on the other side and is shown in Figure 1.4. The patch is made of a conducting material such as copper or gold and can take any possible shape. It radiate because of fringing field between patch and ground of antenna. This phenomenon has been accelerated due to its advantages over antennas structures. This seems almost like the perfect antenna, but there is one main drawback, the bandwidth which typically is from a fraction of a per cent to a few percent depending on the substrate dielectric constant and thickness. The centre conductor of a coaxial cable serves as the feed probe to couple electromagnetic energy in or out of the patch. MPA are low-cost, low-profile and easy to fabricate.

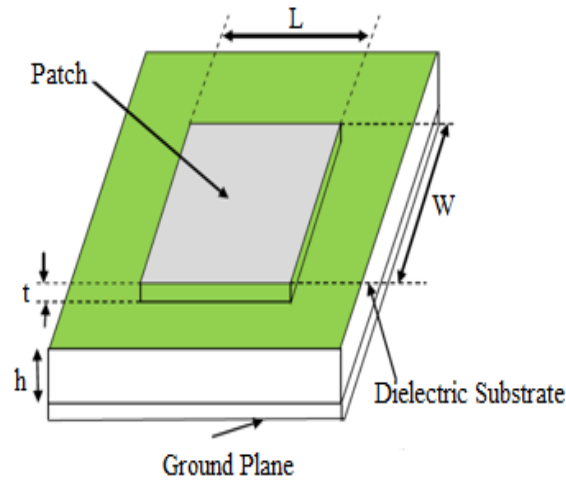


Figure 1.4: Structure of a Microstrip Patch Antenna

Microstrip patch may be of different shapes like rectangular, circular, square, disk sector and elliptical or some other common patch shapes as shown in Figure 1.5. For a rectangular patch it is found that the length L of patch is usually $0.3333 \lambda_0 < L > 0.5 \lambda_0$, where λ_0 is the free-space wavelength of antenna. Antenna patch is selected to be very thin such that $t \ll \lambda_0$ where t is the thickness of the patch. The height of the dielectric substrate is usually $0.003 \lambda_0 < h > 0.05 \lambda_0$. Dielectric constant of substrate is typically in range $2.2 < \epsilon_r < 12$ [28]. Microstrip patch antenna radiate because of fringing field which exists between the patch edge and the ground plane.

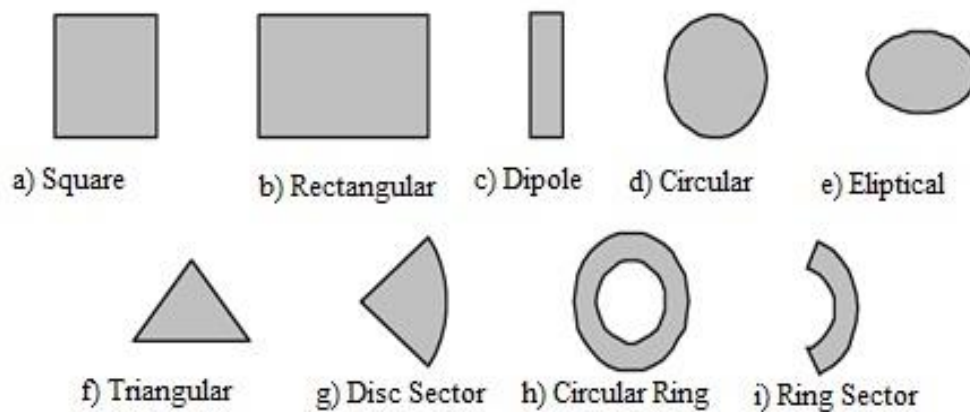


Figure 1.5: Common Shapes of Microstrip Patch Elements [28]

In order to have good antenna performance, a thick dielectric substrate with a low dielectric constant is desirable since it help in achieving larger bandwidth, better efficiency

and better radiation. However, such a configuration causes increase in antenna size. If one want to make a patch microstrip antenna, higher dielectric constants are required which make antenna not only less efficient but also result in narrow bandwidth. As the result compromise is made between these two configurations.

1.5 Feeding Techniques

Microstrip patch antennas can be fed by a variety of methods. These methods can be classified in to two categories contacting and non-contacting feeding technique. In the contacting type, the RF power is fed directly to radiating patch using a connecting element like microstrip line whereas in non-contacting scheme electromagnetic coupling is done to transfer power between microstrip lines and radiating patch. There are four most popular feed techniques out of which microstrip line and coaxial probe feeding technique are contacting techniques but aperture coupling and proximity coupling are non-contacting feeding technique [27].

1.5.1 Microstrip Line Feeding Technique

In this feed technique, a conducting strip is connected directly to the edge of the microstrip patch as shown in figure 1.6. The conducting strip width is less than the patch. Purpose of the insert cut in the patch is to match the impedance of the feed line to the patch without any additional matching combination. This is achieved by properly controlling the insert position. Hence this is an easy feeding scheme, since it provides area of the dielectric substrate being used, surface waves and spurious feed radiation also increases, as the result antenna bandwidth increases. However as the thickness of substrate increases, surface and superior wave generation occur, which decreases the bandwidth of antenna. There are different results obtained by using such different techniques

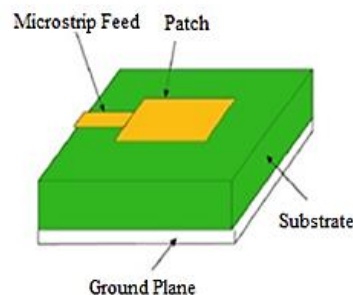


Figure 1.6: Microstrip Feed line with Rectangular Patch

1.5.2 Coaxial Probe Feeding Technique

It is common way to fed antenna. This method is called as probe fed to patch as shown in figure 1.7. The inner conductor of the coaxial connector extends through the dielectric and is soldered to radiating patch, and outer conductor of coaxial probe is connected to the ground plane. Coaxial feed is having advantage that feed point can be move all over the patch but is having disadvantage that it is difficult to drill a hole as the thickness of substrate increases [33].

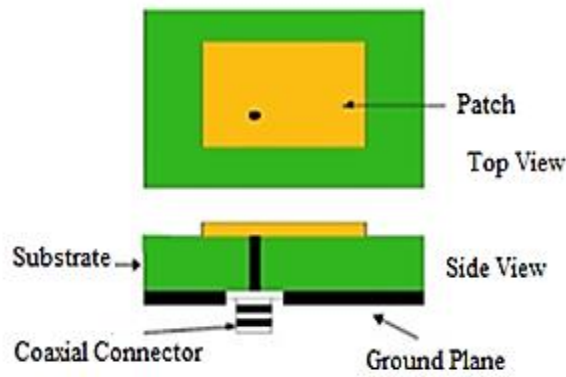


Figure 1.7: Coaxial Feed Line

1.5.3 Aperture Coupled Feed

In this technique two substrates are separated by common ground plane as shown in figure 1.8. A microstrip line on lower substrate is electromagnetically coupled to patch through slot aperture in common ground plane and its dimensions can be change to adjust bandwidth. This method has advantages like wide bandwidth and shielding of radiating patch from radiations emitting from feed structure. The major disadvantage of this feeding technique is that it is difficult to fabricate antenna due to formation of multiple layers.

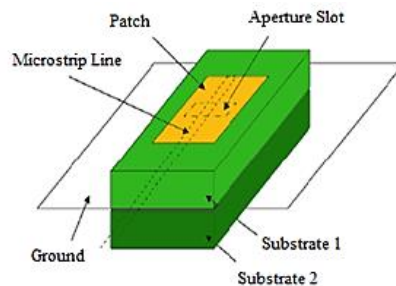


Figure 1.8: Aperture Coupling Feed

1.5.4 Proximity Coupled Feed

A configuration of proximity coupled feed is shown in figure 1.9. In this technique double layer substrate is formed with microstrip line on lower layer and patch on upper layer of substrate. This feed is called as electromagnetically coupled microstrip line. The coupling between patch and microstrip is capacitive in nature. The main advantage of this feed technique is that it eliminates spurious feeding radiation and provides high bandwidth but it is difficult to fabricate. Complexity of fabrication is due to double substrate structure.

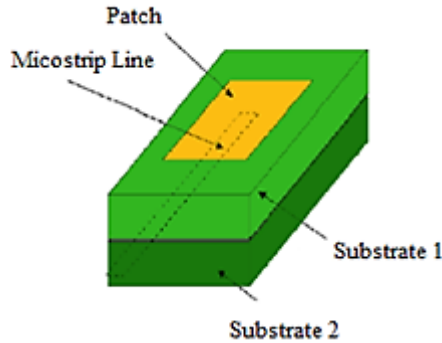


Figure 1.9: Proximity Feed line

Matching can be achieved by controlling the feed line length and width-to-line ratio of the patch. The major disadvantage of this feeding technique is that it is difficult to fabricate because of the two dielectric layers which need proper alignment. Also by using this technique there occurs an increase in the overall thickness of antenna. Table 1.2 below summarizes the characteristics of different feed techniques.

Table 1.2: Comparing the Different Feed Techniques

Characteristics	Microstrip Line Feed	Coaxial feed	Aperture coupled Feed	Proximity Coupled Feed
Spurious feed radiation	More	More	Less	Minimum
Reliability	Better	Poor due to soldering	Good	Good

Ease of fabrication	Easy	Soldering and drilling needed	Alignment required	Alignment required
Impedance Matching	Easy	Easy	Easy	Easy
Bandwidth	2-5%	2-5%	2-5%	13%

1.6 Analysis of Microstrip Patch Antenna

For the analysis of microstrip antenna there are different methods which are cavity model and transmission line model. It was found that transmission line model is easiest of all models. Using cavity model, a rectangular microstrip antenna can be represented as an array of two radiating slots with each slot having width W , a height of h and slots separated by a distance L . Basically transmission line model represents microstrip antenna by two slots which are separated by a low impedance Z_c and transmission line having length L . The microstrip is essentially non homogeneous line of two dielectrics, typically the substrate and air. For a microstrip line as shown in figure 1.10(a), electric field lines corresponding to it are shown as in figure 1.10(b)

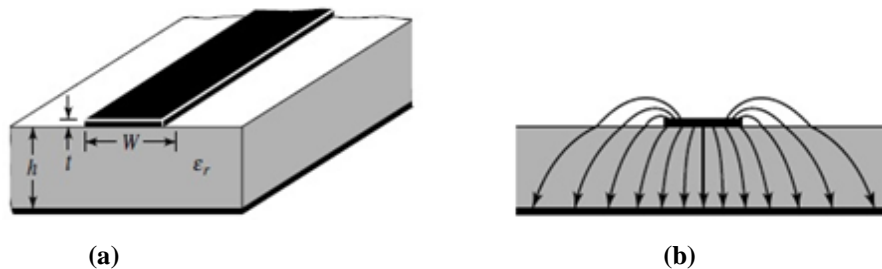


Figure 1.10: Transmission Line Model (a) Microstrip Line and (b) Electric Field Lines [30]

Since ratio W/h is much greater than unity and also value of ϵ_r is much greater than unity hence fringing in this case makes microstrip line look wider electrically as compare to physical dimensions. Because some of waves travel in air and some in substrate, as the result effective dielectric constant ϵ_{reff} is introduced to account for fringing and wave propagation. This effective dielectric constant produced has been due to fringing field. For

low frequencies, effective dielectric constant doesn't change but begin to increase but approach value of dielectric constant of substrate and is given by equation 1.6.

$$\epsilon_{\text{reff}} = \left(\frac{\epsilon_r + 1}{2} \right) + \left(\frac{\epsilon_r - 1}{2} \right) \left[1 + 12 \left(\frac{h}{w} \right) \right]^{-1/2} \quad (1.6)$$

Here ϵ_{reff} is the effective dielectric constant to account for fringing effect, ϵ_r is the dielectric constant of substrate, h is thickness of substrate and W is width of substrate. Figure 1.11 shows a rectangular microstrip patch antenna. The co-ordinates axis are selected in such a way that length is along x axis, width is along y axis and height is around z direction. Due to fringing effects patch of microstrip antenna looks greater in dimensions. Here dimensions of patch have been extended on each end by a distance of $3L$. Normalized extension of length is given by equation 1.7.

$$\Delta L = 0.412h \frac{(\epsilon_{\text{reff}} + 0.3) \left(\frac{w}{h} + 0.264 \right)}{(\epsilon_{\text{reff}} - 0.258) \left(\frac{w}{h} + 0.8 \right)} \quad (1.7)$$

The effective length of the patch is given by equation 1.8.

$$L_{\text{eff}} = L + 2\Delta L \quad (1.8)$$

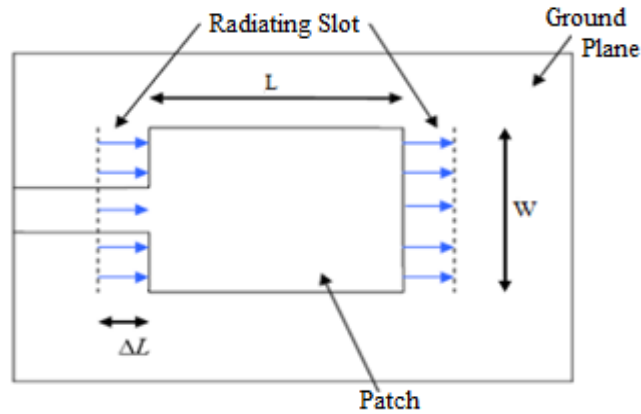


Figure 1.11: Physical and Effective Length of Microstrip Antenna [30]

For given resonance frequency f_0 , effective length is given by equation 1.9. This length is obtained by subtracting length due to fringing field.

$$L_{eff} = \left[\frac{c}{2f_0 \sqrt{\epsilon_{reff}}} \right]$$

(1.9)

For a rectangular microstrip patch antenna, the resonance frequency for TM_{mn} mode is given by equation 1.10.

$$f_0 = \frac{c}{2\sqrt{\epsilon_{reff}}} \left[\left(\frac{m}{l} \right)^2 + \left(\frac{n}{w} \right)^2 \right]^{1/2}$$

(1.10)

Here m and n are modes along L and W length respectively. For efficient radiation, the width of patch is given as by equation 1.11.

$$W = \frac{c}{2\sqrt{(\epsilon_r + 1)}} \quad (1.11)$$

In order to design any antenna, first of all resonance frequency is to be selected. Depending on that value dimensions are decided. There are two other parameters that are required which are dielectric constant of substrate and its thickness.

1.7 Advantages and Disadvantages of Microstrip Patch Antenna

Today's era Microstrip Patch Antennas are widely used. It is used in satellite communication, military purpose, GPS, missile system etc. Microstrip patch antennas suffer from a number of disadvantages as compared to conventional antennas. Some of its advantages and disadvantages are given below.

- **Advantages:** Microstrip antennas are useful over conventional antenna due to their small size and light weight. These antennas are having following advantages:
 - Low fabrication cost.
 - No cavity backing is required.
 - Light weight and low volume.
 - Low-profile planar configuration.
 - Dual Polarization can be easily made.
 - These antennas can be easily integrating with microwave circuits.

- Dual or triple frequency operations can be easily made.
- **Disadvantages:** In spite of several advantages of microstrip antenna, there also occur several disadvantages of these antennas which are as follows:
 - These antennas are having narrow bandwidth.
 - Gain of these antennas is small nearly 6 dBi.
 - Low efficiency.
 - Low power handling capacity.
 - Surface wave excitation.
 - Complex feed structure required for high performance arrays.

1.8 Applications of Microstrip Patch Antenna

With continuing research and development and increased usage of microstrip antenna it is expected that they will ultimately replace conventional antenna for most applications. There are many applications for microstrip antenna [31] which are:

- Satellite communication.
- Missile telemetry
- Man pack equipment
- Doppler and other radar

1.9 Outline of the Dissertation

In chapter 2 different types of fractal geometries along with their mathematical equations are described. IFS are discussed in this chapter for mathematical representation. Further this chapter also discusses advantages, disadvantages and applications of fractal antennas.

In chapter 3 brief literature study of microstrip antenna is given in order to obtain its basic fundamentals. The main aspects of fractal antenna are covered in this chapter like different fractal geometries.

In chapter 4 problem formulation has been discussed. In which we find the gaps of literature survey.

In chapter 5 design and implementation of antenna has been discussed. The fractal microstrip patch antenna is designed using HFSS. E-shaped fractal antenna with DGS has

been proposed for different wireless applications. Effect of change in substrate and geometry has been analysed.

In chapter 6 results and discussions of antenna are presented. As the antenna has been simulated using HFSS, all simulation results as well as all the data obtained from simulations is discussed in this chapter.

In chapter 7 conclusions to dissertation has been given and future work continued antenna design by using different fractal geometry, using different feeding techniques to feed microstrip antenna.

Chapter 2

TYPES OF FRACTAL GEOMETRIES

In this chapter, an introduction to the fractal geometry is given. Different types of fractal geometries with their mathematical expressions as well as their explanation are discussed. There are several advantages, disadvantages and applications of fractal geometry which are discussed in this chapter.

2.1 Introduction to Fractal Geometry

The term fractal is defined as recursively generated object. Fractal geometry can be available easily in nature but by using recursive nature of fractals, many antennas and resonators can be designed. The term fractal was coined by Mandelbrot to describe the family of complex shapes that have property of self-similarity in geometrical structure. Fractal means broken or irregular fragments. Fractal electrodynamics is the new area in which fractal geometry is combined with electromagnetic theory for solving new class problems of radiation, scattering and propagation. A fractal is a chunk geometric shape that may be subdivided in parts; each is a reduced size copy of the whole. By increasing number of fractal iteration, perimeter of patch increases and effective area of antenna decreases. The fractal is quite extensive with many applications from nature modelling, statistical analyses, and computer graphics. Fractal geometries are different from Euclidean geometries which have two common properties: space-filling and self-similarity. When different iterations of fractal geometries are applied on antenna or resonators, as the result self-similar structures with scale factor are obtained. Certain fractal may be constructed using iterative procedure of fractal geometry using Iterative Function System (IFS) Procedure. IFS procedure is applied to an initial structure called as generator which repeats itself many times at different scales. Fractal antennas have the advantages such as small size, lightweight, and suitable to integrate with devices.

2.2 Different Fractal Geometries

Fractal geometry is advantageous since by applying fractal geometry size of antenna decreases, resonant frequency reduces and number of bands increases. There are different fractal geometries that can be applied to antenna so as to obtain better results but

any self-similar structure can be made using these fractal geometries. Different fractal geometries are discussed follow.

- Minkowski Fractal Geometry
- Koch Curve
- Giuseppe Peano fractal geometry
- Hilbert curve fractal geometry

2.2.1 Minkowski Fractal Geometry

Application of fractal geometry on antenna optimizes shape of antenna so as to increase electrical length and reduce size of geometry. Geometric construction of fractal Minkowski curve is shown in figure 2.1 in which each side of basic patch is divided into three equal parts and middle part of each side is replaced by a projection inwards with two vertical and two horizontal segments of equal length. Process is repeated for successive iterations while maintaining basic shape. Minkowski geometry plays an important role in improving efficiency of antenna by filling entire volume with electrical length. By applying Minkowski fractal geometry, self-similar dimension D with a value of 1.46 is obtained.

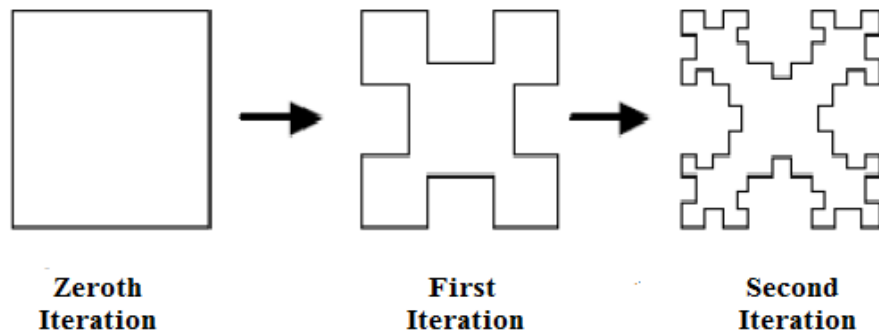


Figure 2.1: Minkowski Fractal Geometry

From figure 2.1, it is clear that by applying fractal geometry, area of antenna decreases but number of bands at which antenna resonates increases. In this dissertation for making double E-Shaped fractal microstrip patch antenna Minkowski fractal geometry algorithm has been used. By applying Minkowski fractal geometry, self-repeating structures are formed.

2.2.2 Koch Curve

The geometric construction of Koch curve is very simple. It starts with a straight line. In this length is divided into equal three parts, and middle is replaced with two others of the same length which joined at angle of 60 degree. This is the first iteration version of the geometry and is called generator. Similarly next iterations can be applied to form structures with scale factor of one third.

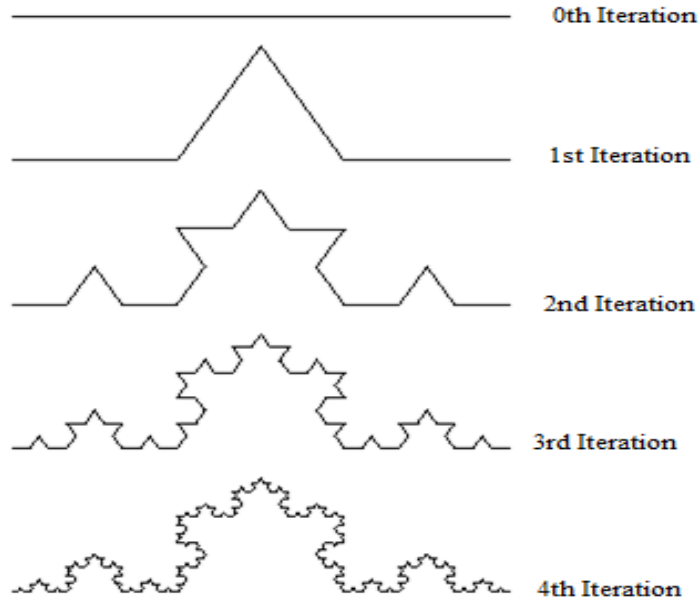


Figure 2.2: Koch Curve Fractal Geometry

By applying different iterations, self-similar structures represented as shown in figure 2.2. The process is reused in the generation of n^{th} iteration as shows in figure 2.2.

$$L = h \cdot \left(\frac{4}{3}\right)^n \quad (2.1)$$

Where n is the number of iterations and h is the height of monopole.

2.2.3 Giuseppe Peano Fractal Geometry

The procedure of Giuseppe Peano fractal geometry is shown in figure 2.3, which applied on the edges of square patch. In this geometry as increase in iterations, the resonance frequency decreases. It is little similar with the Minkowski fractal geometry. For higher iteration than the second, the reduction of operating frequency is not achievable since antenna design becomes quit complicated and its fabrication becomes difficult as

shown in figure 2.3 below. The use of Giuseppe Peano fractal geometry to microstrip antennas had revealed interesting characteristics and might be pursued in further investigations.

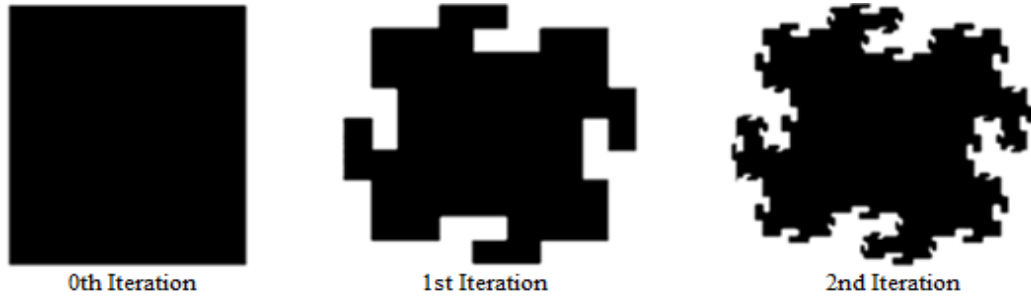


Figure 2.3: Giuseppe Peano Fractal Geometry

2.2.4 Hilbert Curve Fractal Geometry

This geometry is a space-filling curve. In this geometry as increase in iterations, the resonant length increases. Hilbert curve fractal geometry shown in figure 2.4. It may be noticed that each successive stage consists of four copies of the previous, iteration lines. The geometry has following properties: self-avoidance, simplicity and self-similarity.

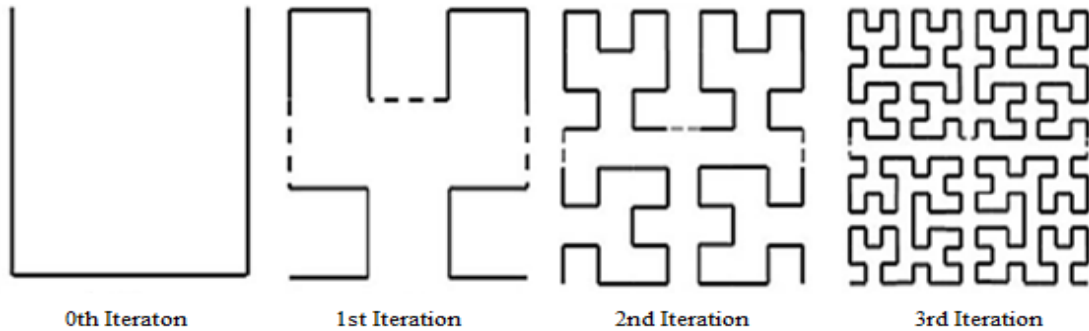


Figure 2.4: Hilbert Curve Fractal Geometry

2.3 Advantages and Disadvantages of Fractal Antennas

Fractal geometry is composed of self-similar structure. By applying fractal geometry to microstrip patch antenna, area of patch decreases and characteristics of antenna in terms of bandwidth, return loss and gain show improvement.

2.3.1 Advantages of Fractal Antennas.

In order to overcome limitations of microstrip antenna and fractal geometries are applied on microstrip antenna. Fractal antennas have following advantages.

- Fractal geometry causes reduction in size of antenna. By applying fractal geometry, area of metal portion decreases and hence size of antenna decreases.
- Fractal geometry helps in better impedance matching of antenna.
- By applying fractal geometry, bandwidth of antenna can be improved. Hence fractal geometry is helpful in achieving large bandwidth.
- It allows antenna to operate over large range of frequency thus making antenna independent of frequency.

2.3.2 Disadvantages of Fractal Antennas

In spite of several advantages of Fractal Antennas like multiband characteristics, good bandwidth and gain there are several disadvantages of fractal geometry as follows

- When different iterations of fractal geometry are applied, number of bands increases but complexity increases with increase in number of iterations.
- As number of iteration increases, complexity increase which may cause difficulty in fabrication.
- Benefits of antenna begin to decrease after few fractal iterations.
- By applying fractal geometry sometimes area of patch decrease by large amount which may causes gain of antenna to decrease.

2.4 Applications of Fractal Antennas

By using fractal patch antenna size of antenna decreases and number of bands increases. Sudden growth in wireless communications arise need of fractal geometry. Examples of fractal antenna include handheld cell phones and mobile devices like laptops on wireless LAN. Following are applications of fractal geometry.

- Miniature Broadband Ring like Microstrip patch antenna- A miniaturize broadband stacked fractal microstrip patch antenna is formed by using two fractal antenna

elements. One patch is active and second patch is parasitic. Further this helps in size reduction and achieving good gain [6].

- Radio Frequency Identification- Fractal antenna can be used for RFID applications. Fractal antenna plays an important role in RFID reader and tag antenna. These antennas can be used for logistics management, traffic toll collection and tagometry [1].
- Wideband Applications- By applying different iterations of fractal geometry antenna with wideband characteristics is obtained. Fractal antenna found can be useful for super wideband and ultra wideband applications [2].
- Mobile Applications-Since for mobile communication, it is necessary to use fractal antenna as single antenna can be design to resonate for Wi-Max, WLAN, UMTS, GSM and GPS applications. Hence fractal antennas are suitable for mobile applications [7].

Chapter 3

LITERATURE REVIEW

This chapter gives a literature survey on design of microstrip patch antenna, application of fractal geometry on the patch of antenna and defected ground structure on ground plane of the antenna. A brief review of these three sub sections is given in this chapter.

3.1 Related Work

Nagpal et al. [1] proposed E-shaped fractal microstrip patch antenna with defected ground structure for wireless applications. Different iterations of fractal geometry caused self-similar E shape structures. For obtaining good bandwidth, Different DGS configurations had been applied. This antenna was designed using FR-4 as substrate and operated at 3.7GHz, 6.7 GHz, 7.9 GHz and 8.7 GHz with bandwidth of 120 MHz, 500 MHz, 225 MHz and 315 MHz. This antenna found its application for Wi-Max, C Band and X band applications. This antenna is having small dimensions of 20X25 mm². Results have been compared first making E-shaped patch which modified to form wang shape followed by fractal antenna.

Khidre et al. [2] presented U slot microstrip antenna for higher mode applications. This antenna resonated in a band from 5.17 GHz to 5.81 GHz hence useful for number of applications. This antenna was having dual radiation beams with both beams were directed at centre frequency. This antenna was having a gain of 7.92 dBi. This antenna found its applications for different wireless applications. This antenna exhibit impedance bandwidth of 11 % at VSWR less than two. This antenna was having dimensions of 64X 74 mm². Substrate was having a dielectric constant of 2.2 and thickness of 3.1 mm. Design and simulation had been carried out using HFSS.

Gupta et al. [3] designed multiple band microstrip patch antenna. This antenna had been useful for c band and x band applications. This microstrip antenna was having a patch with different slots so as to have good antenna characteristics. These slots were four U slots, two small and two large and one I shaped slots. This antenna was having compact size of 25 X 23 mm². Feed to this antenna is given by coaxial feeding technique and feed

point is chosen properly. Design and simulation had been carried out using HFSS simulation software. This antenna was having bandwidth of 140 MHz from 5.85 GHz to 6 GHz and 1.21 GHz from 7.87 to 9 GHz. This antenna can be used for WLAN, C band and X band applications.

Janani.A et al. [4] designed E-shaped fractal patch antenna for multiband applications. For obtaining multiple bands, fractal geometry had been used. First of all, entire length was divided to form E shape patch by cutting two slots. On each section, fractal geometry was applied so as to make fractal antenna. . The proposed antenna had dimensions of 150 mm by 130 mm using two FR-4 having thickness of $h=0.8$ mm and $h=1.6$ mm and an air gap having thickness $h=4$ mm between two FR-4 as substrate. The design and simulation had been carried out using HFSS simulation software. The main parameters at operating bands such as return loss, impedance, gain had been studied. This antenna found its application for different applications for mobile communication.

Waladi et al. [5] designed fractal microstrip patch antenna using star triangular shape. Fractal geometry had been applied on triangle to obtain star shape antenna. This antenna was fed by microstrip feeding technique which was having width of 4.8 mm and length of 1.9mm. This antenna was having large bandwidth of 30 GHz from one to 30 GHz at VSWR less than two. This antenna had been used for ultra wideband and short wideband applications. This antenna had wideband characteristics because of presence of notch with dimensions of 4.8×1.9 mm².

Ghorpade et al. [6] made a comparison between E-shape antenna and E-shaped fractal microstrip patch antenna. From this analysis it was found that fractal antenna gave multiband characteristics. This antenna had large size of order of 150×130 mm². The design and simulation has been carried out using a software HFSS. Characteristics of antenna were compared in terms of VSWR, return loss, gain and bandwidth. Because of fractal geometry, E-shaped fractal antenna resonated at 1.93 GHz, 2.4 GHz, and 3.52 GHz to cover GSM frequency bands, UMTS, Bluetooth and Wi-Max applications. By increasing number of iterations beyond limit, results began to degrade.

Kumar Raj et al. [7] proposed an ultra-wideband inscribed triangle circular fractal antenna. This antenna had a circular patch with dimensions of 30 mm. In order to design

such antenna, substrate used was FR-4. This antenna had ultra wideband characteristics from 2.25 GHz to 15 GHz at VSWR less than two. The antenna was fed by coplanar waveguide. By applying fractal geometry CPW, wideband characteristics were obtained. The results of simulated antenna were compared with that of tested antenna and both offered same characteristics. Because of such a large bandwidth, these antennas were useful for UWB applications.

Oraizi et al. [8] applied fractal geometry on square patch to improve antenna parameters. The proposed fractal geometry was Giuseppe peano fractal geometry. By applying this fractal geometry on square patch, characteristics got improved. By applying this geometry, resonant length of antenna got increased while area will decrease. The proposed antenna had circular polarization at one of its resonance frequencies, which was realized by producing a repetition on its initial structure and its broad banding might be achieved by placing an air gap. This antenna is square of 30 mm. FR-4 epoxy was used as substrate with thickness of 1.6 mm and dielectric constant value of 4.4. This antenna found application for WLAN applications.

Behera et al. [9] had designed dual band fractal ring antenna by applying Minkowski fractal geometry. One side of ring of square patch was replaced by fractal Minkowski curve. The geometry was chosen in such a way that ratio of resonance frequencies was controlled with design parameters. Behaviour of different fractal geometries had been modelled with multiport network approach and results were analysed using full wave software. It was observed that change in indentation factor caused increase in gain and bandwidth followed by change in resonance frequency. By varying width of other 2 sides of ring, resonance characteristics were changed.

Chauhan et al. [10] designed crown fractal patch antenna with small size of square of 20 mm. FR-4 epoxy had been used as substrate with thickness 1.6 mm and dielectric constant of 4.4 mm. The antenna was fed by coaxial feed. This antenna had been resonated at four different frequency bands which are 8.4 GHz, 10.6 GHz, 10.1 GHz and 11.3 GHz with small return loss. This antenna had been designed to operate X band and C band applications. The design and simulations had been carried out using a software HFSS. Main application of this antenna is for X band with percentage bandwidth of 9% at 8.68 GHz,

5% at 9.44 GHz to 10.35 GHz. From different iterations results it was found that crown shape patch caused size to decrease and characteristics of antenna to improve.

Dalsania et al. [11] designed microstrip antenna using fractal geometry and got multiband behaviour of resonator antenna. By applying fractal geometry, increase in number of resonant frequencies with increase in number of iterations takes place. This antenna found its application. The presented multiband antenna was designed for Aeronautical radio navigation at 2.7 GHz – 2.9 GHz and Aeronautical/Maritime radio navigation 9.0 GHz – 9.3 GHz with captured downlink data of fixed/mobile satellite in S band and C band. The geometry used was Minkowski fractal geometry and three iterations of fractal geometry were applied. The design and simulation were carried out using HFSS.

Babu et al. [12] a symmetric four slot patch antenna was proposed and a two element MIMO array was developed by using it. The developed antenna array operated at three frequency bands. Hence tri-band antenna of frequencies 3.8 GHz, 6.6 GHz and 7.6 GHz was obtained with an improved impedance bandwidth of 20% and an average reduced mutual coupling of -40 dB. As the proposed antenna exhibits excellent return loss and isolation characteristics compared to the present widely used E-shaped patch antenna and it was a good choice for MIMO systems operating for UWB applications.

Arya et al. [13] analysed effects of using different defected ground structures configurations. Effect of using different DGS shapes like dumb bell, T shape, plus shape, comb shape was analysed. Substrate which was chosen was having dielectric constant of 3.39, loss tangent of 0.0025 and thickness of 2.4 mm. It was found that by increasing slots on ground, directions of current changes and bandwidth increases. Further by applying different DGS configurations, different resonance frequencies with different bandwidth were obtained. Out of different DGS configurations, skew F shaped DGS had been used to obtain dual band characteristics.

Bayatmaku et al. [14] proposed E shape fractal patch antenna for LTE, WWAN and heptads band. Three different iterations of fractal geometry were applied on patch of 130 mm X 110 mm by using substrate FR-4 with thickness of 1 mm and dielectric constant of 4.4. This fractal E-Shape fractal antenna resonated at 945, 1945 and 2470 MHz with wide band widths of 250 MHz, 400MHz and 260 MHz to cover GSM850/900,

GSM1800/1900/UMTS, LTE2300/2500, respectively. Hence, the proposed antenna had satisfactory characteristics for use as a multiband communication antenna. Design and simulations have been carried out using HFSS. By applying fractal geometry, different parameters like return loss, gain and bandwidth have been analysed.

Moraes et al. [15] presented a comparison between two different fractal geometries. Comparison was made between performance analysis of microstrip fractal antenna one based on Minkowski Island and other based on triangular Koch loop. From analysis it was found that at low resonance frequency, Antenna formed using Minkowski fractal geometry produced small resonance frequency as compare to Koch curve and at high frequencies Koch curve produced small resonance frequency and better results.

Choukiker et al. [16] proposed antenna for wide band applications. This antenna was designed to have wide band applications. The antenna was made of cantor shape fractal geometry and Koch fractal geometry. Koch fractal geometry is used at 40 degree angle. Lengths of Koch and cantor shape are set up so as to have large bandwidth. Measured -10 dB bandwidth for frequency range was 72.37% with impedance bandwidth of 72%.

Chung et al. [17] presented novel Wang shaped patch antenna with stable radiation pattern and cross polarization of -20 dB. This antenna was having bandwidth of 1.7GHz to 2.5 GHz, gain of 6.25 dBi to 15 dBi. It featured a small patch of $0.25 \lambda_0 \times 0.33 \lambda_0$ with large air-substrate height of $0.2 \lambda_0$, whereas the ground plane size used for this prototype was about $1 \lambda_0 \times 1.5 \lambda_0$. In the present design, the anti-phased currents were provoked by a dual L-probe fed by a wideband balloon.

Hong et al. [18] designed and simulated trapezoidal patch radiator and quasi fractal ground plane. Monopole antenna was designed for dual frequency applications with quasi fractal slot structure were applied to ground plane. FR-4 epoxy was used as substrate. Design and simulation were carried out using HFSS. The prototype for WLAN application was designed and then tested. The results showed that the prototype had good dual-band performance and the proposed technique was valid.

S. Yadav et al. [19] “A Dual Band Star Fractal Antenna with Slot for Wireless Applications”. In this paper a Dual Band Star fractal antenna with slot was proposed for

wireless applications, with a semi-elliptical ground plane. The proposed antenna was designed to operate at two different bands having bandwidth 1 GHz and 1.2 GHz at resonant frequencies 2.8 GHz and 5.7 GHz respectively for wireless applications with good return loss and radiation pattern characteristics, in the frequency band. The proposed antenna was fed by a 500 microstrip line and fabricated on a low-cost FR-4 substrate having dimensions 33.5(L) x 28.5(W) x 1.6(h) mm³ with $\epsilon_r=4.4$ and $\tan\theta=0.025$. The antenna shows acceptable gain with nearly Omni-directional radiation patterns in the frequency band for wireless applications as Wi-MAX and WLAN.

U. Soni et al. [20] “Koch Curve Fractal Antenna for Wi-MAX and C Band Wireless Applications”. In this paper, Koch curve fractal antenna is proposed for wireless applications. The antenna has been designed by increasing the perimeters of triangular shape patch by using self-similarity property. Number of iterations by the designing Koch snow flake for different resonant frequency, were given. The proposed antenna is designed to operate at Wi-MAX frequency from 3.4 GHz -3.69 GHz and C-Band applications in 2.8 GHz-6.4GHz frequency range. The proposed antenna is fed by a 50 Ω micro strip line and fabricated on a low-cost FR4 substrate having dimensions 33.5(L) \times 28.5(W) \times 1.6(h) mm³ with $\epsilon_r=4.4$ and $\tan\theta= 0.025$. The antenna shows acceptable gain with nearly Omni-directional radiation patterns in the frequency band for wireless applications.

Pushpanjali J. et al. [21] “Full Composite Fractal Antenna with Dual Band used for Wireless Applications” In this paper a full composite fractal antenna, having a modified Sierpinski fractal antenna with 50 Ω micro strip line, used for dual band wireless applications. The S₁₁ parameter and radiation characteristics of the antenna design indicate that a Sierpinski fractal antenna with circular slot having Dual Band frequency bandwidth from 3.8 GHz to 4.4 GHz and 4.8 GHz to 5.4 GHz to covering 5.2 GHz for C-Band and X-Band wireless applications in 3.8 GHz- 14 GHz frequency range. The proposed antenna is fed by a 50 Ω micro strip line and designed on a low cost FR4 substrate having dimensions 96(L) \times 72(W) \times 1.5(t) mm³ with $\epsilon_r=4.9$ and $\tan\theta = 0.025$. The antenna shows acceptable gain with nearly Omni-directional radiation patterns in the frequency band.

R. Choudhary et al. [22] “A Dual Band Compact Circularly Polarized Asymmetrical Fractal Antenna for Bluetooth and Wireless Applications”. In this paper, a dual band Compact fractal antenna is proposed for circular polarization (CP). The proposed antenna was designed to operate at dual bands having bandwidth 1 GHz and 8 GHz at resonant frequencies 2.4 GHz and 12.9 GHz respectively for Bluetooth and wireless applications with good return loss and radiation pattern characteristics. It consist asymmetrical antenna by truncating the sides of a square patch. The proposed antenna was fed by a 50- micro strip line and fabricated on a low-cost Rogers-RT 5880 substrate having dimensions 50(L) \times 50(W) \times 3.2(h) mm³ with $\epsilon_r = 2.2$ and $\tan\theta = 0.0009$. The antenna shows acceptable gain with Omni-directional radiation patterns in the proposed frequency range.

A. Rajshree et al. [23] “A modified sierpinski gasket triangular multiband fractal antenna for cognitive radio”. This piece of writing describes about a modified sierpinski gasket fractal multiband antenna for cognitive radio applications. This proposed new micro strip modified triangular fractal antenna having multiband behaviour in five different resonant frequencies 11.58GHz, 14.15GHz, 20GHz, 30GHz and 35GHz respectively that covers the frequency bands such as X band(8-12GHz), Ku band(12-18GHz), K band(18 -26.5GHz), Ka band(26.5-40GHz). This antenna had certain advantages like compact (30 \times 30mm), high directivity (8.15 -11.86dBi) and gain (3.2-8.6dBi). And also the analysis was carried out for five different resonant frequencies to synthesize the antenna parameters such as radiation pattern, gain and directivity. The output results prove that this one was well suitable for spectrum sensing in cognitive radio.

B. Taoufik, et al. [24] “Fractal Multiband Planar Antenna for Wireless Power Transmission”. In this paper we have developed and designed a low cost fractal Multi band micro strip antenna structure. This antenna was validated in the ISM (Industrial Scientific and Medical) band at 2.45 GHz and 5.8 GHz. The aim of this work is to develop an antenna which can be associated with an RF-DC rectifier to design a rectenna system for wireless power transmission "WPT". The technique used to have a multiband structure is the fractal geometry. The final circuit was a fractal multiband antenna with 65 x 30mm as dimensions.

Chapter 4

PROBLEM FORMULATION

In order to transmit or receive data in communication system, it is necessary to have compact system, Transmission and reception system requires transmitting or receiving antenna to transmit/receive information. There are different factors which govern antenna selection. These are size, weight, complexity, bandwidth, gain and applications. One of best antenna that can optimize all parameters is microstrip antenna. This antenna is having small size and less weight but suffers from disadvantages like low bandwidth, high return loss and less gain and efficiency. In order to use microstrip antenna for different wireless applications, different techniques have to be applied which are slot antenna, fractal antenna, use of met materials, electron band gap structures, use of DGS. U slot antenna for WLAN applications have been designed [2]. Microstrip antenna with wide bandwidth in C Band has been obtained by making U slot and I shape slot in patch [3]. Four slots had been cut out from patch antenna to form E shape patch [12] for MIMO array. Different configurations of defected ground structures had been made by different shapes [13, 18]. Advantage of using slot configuration is that characteristics of antenna improved in terms of gain and return loss. By applying DGS, only bandwidth of antenna increases, hence in order to increase bandwidth of antenna and multiband characteristics, fractal antenna would be required. There are different fractal geometries that are used. Minkowski fractal geometry had been used to make ring shape patch antenna for dual band applications. Width of antenna [9] is varied so as to improve characteristics. There are different fractal shapes that can be generated using fractal geometries algorithms. These are crown shape [5], Giuseppe Peano fractal for circular polarization [8]. Koch fractal geometry has been applied [4, 6] on triangular patch to have multiband characteristics. An ultra-wideband inscribed triangle circular fractal antenna [7] has been designed for different wireless applications. Antennas can also be designed using combination of fractal geometries like cantor shape and Koch shape [15] and Koch and Minkowski fractal geometry [16]. E shape fractal patch antenna is obtained [1, 4, and 14]. Further fractal geometry has been applied to each section to form self-similar E shaped antenna. Slots have been cut out on both sides to form Wang shape patch [17]. Fractal geometry has been applied on both sides of Wang

to produce modified E shaped antenna [1]. Fractal antenna had large size of 150 X 110 mm² and hence useful for GSM and mobile applications but suffered from disadvantage of large size. Antenna had small size but is having small bandwidth and less gain and more return loss, so it is necessary to make antenna for WLAN and other wireless applications. This geometry is modified by making parallel E-shaped fractal patch antenna of slight large than that of but less than [14] for different wireless applications. Effect of applying DGS has also been analysed. In this dissertation plus shaped DGS has been used.

4.1 Objectives

- On the basis of various literature studied, following objective has been proposed.
- Design and simulation of T shaped fractal Microstrip patch antenna with coaxial feeding technique using HFSS for the minimization of return losses.
- Optimization of antenna parameters for bandwidth, gain and return loss by the use of fractal configurations and its testing through HFSS.
- Effect of changing feed point of coaxial feed
- Effect of changing substrate
- Effect of Changing Feed
- Effect of changing substrate thickness

4.2 Methodology

There are different steps that have been followed in order to achieve the objective of dissertation:

- Fractal antenna dimensions calculated before design using HFSS software.
- Design, simulation and analysis are carried out using HFSS software.
- Application of different iterations of fractal geometry so as to obtain wideband characteristics

Chapter 5

DESIGN AND IMPLEMENTATION

In this chapter, design of various antenna structures has been discussed. Initially on basis of calculations, rectangular antenna dimension has been selected and results are analyzed. It is found that antenna resonated at fewer bands with less return loss and gain. In order to improve antenna characteristics, different techniques have been applied. These include slot cutting, use of fractal geometry or making use of defected ground structure. Further antenna characteristics can be compared by having parametric analysis in terms of antenna substrate and feed point.

5.1 Fractal Geometries Used in Designing Proposed Antenna

Fractal geometries composed of self-similar structures, there are different fractal geometries which include Minkowski fractal geometry, Sierpinski fractal geometry, cantor and many other self-similar structures. Minkowski fractal geometry is obtained by taking a square and dividing that square into three equal parts. Middle section is removed from each side. This means if square is taken, nine squares can be made from it hence, four different squares can be removed out from central point. In this dissertation, T-shaped fractal patch antenna has been designed. In this design, instead of removing squares from Central Square, one may remove squares from two sides to form, T shaped fractal. Another fractal algorithm that has been used in this dissertation is making use of cantor shaped fractal geometry as shown in figure 5.1.

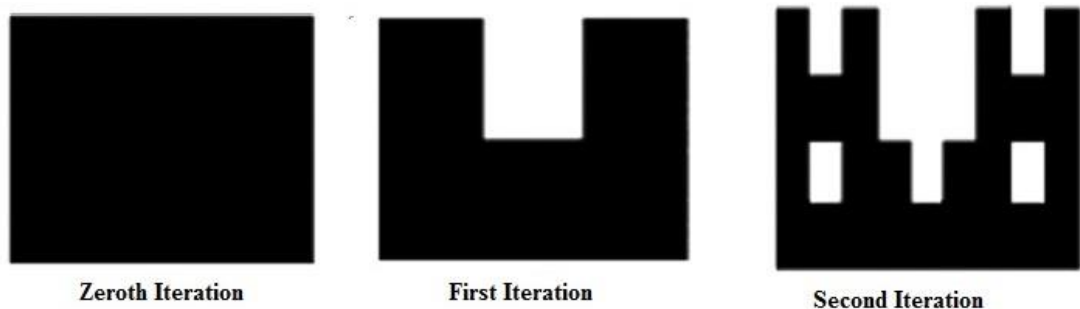


Figure5.1: Cantor Shaped Fractal Geometry

5.2 Design Procedure of Fractal Microstrip Patch Antenna

In order to design any microstrip antenna it is necessary to have knowledge of ground and patch dimensions, application for which antenna is designed. There are different applications at different frequency, based on applications, frequency is decided which further decide dimensions. Benefit of carrying out this procedure is that one can first design zero iteration basic antennas for desired applications, then improve its characteristics by use of fractal geometry, slot configuration and DGS. There are three basic parameters that are decided for designing antennas. Following are steps used in process.

Step 1: Selection of resonant frequency for desired application (f_r): Different wireless band applications use different frequency of operation. Entire frequency band is divided into different bands. Each band has a frequency range with different application as shown in table 5.1. Hence frequency is decided first.

Table 5.1: Various Frequency Bands of Wireless Communication

Microwave Band	Frequency range	Applications
L Band	1 to 2 GHz	Military telemetry, GPS, Mobile phones (GSM), Amateur radio
S Band	2 to 4 GHz	WLAN, Bluetooth, cellular phones, Wi-Fi
C Band	4 to 8 GHz	Long distance radio telecommunications, Satellite, Microwave relay
X Band	8 to 12 GHz	RADAR

Step 2: Substrate selection: It is important parameter that decides dimensions of patch. There are two most commonly substrate used which are FR-4 epoxy with dielectric constant of 4.4, loss tangent of 0.02 and Rogers RT Duroid 5880 with dielectric constant of 2.2 and loss tangent of 0.0009. It was found that as dielectric constant increases,

dimensions of antenna decreases and efficiency and gain also decreases. Hence for selection, these factors are taken into account.

Step 3: Substrate thickness (h): It is find that increase in thickness of substrate causes efficiency and bandwidth to increase but this makes antenna more bulky. In proposed design substrate of thickness 2.4 mm has been used. Comparison is made by changing thickness at different values and characteristics of antenna are compared to obtain best results.

Step 4: Choosing square dimensions: After selecting all three parameters, dimensions can be obtained. It is not necessary that whatever calculations obtained will be used. Optometric analysis has been carried out in order to select that dimensions that give best results.

Step 5: Selection of feed point: There are five different feeding techniques but most commonly used are microstrip and coaxial feeding technique. Advantage of using coaxial feed is that feed point can be adjusted such that impedance matching takes place. Parametric analysis has been done for feed point selection.

Step 6: Applying fractal geometry iterations: Fractal geometry has biggest advantage of providing multiband characteristics. There are different fractal geometries like Koch, Minkowski, Sierpinski carpet, cantor shape. Of all cantor shape fractal geometry has been used to make antenna in which two rectangles from two sides of same level are removed to make T-shape antenna. Different Iterations are performed and results are compared in terms of antenna parameters.

Step 7: Calculation of ground dimensions: It is essential to have finite ground plane for practical considerations. The size of ground plane is selected to be greater than patch dimensions by approximately six times the substrate thickness all around periphery. Ground length and width are given by equation 5.1 and 5.2.

$$L_g = 6.h + L \quad (4.1)$$

$$W_g = 6.h + W \quad (4.2)$$

Here L and W correspond to patch length and width, h is substrate thickness and L_g and W_g are ground length and width. Hence dimensions of ground depend on thickness of substrate and dimensions of patch.

5.3 Design Considerations for Fractal Antenna

It is necessary to design antenna in such a way that desired characteristics are obtained. Fractal geometry is applied to antenna so as to obtain multiband characteristics. It is important to take into account size of antenna. If all characteristics are good but size of antenna is large, so antenna will not be much useful. Similarly small size antenna with not good characteristics is not useful. Dimensions of antenna depend on desired frequency of application. If antenna is designed for small frequencies size would be large. Size of antenna also depends on dielectric substrate. If substrate has large dielectric constant, size would be small but efficiency and bandwidth decreases.

5.4 Design of Fractal Microstrip Patch Antenna

Design of T-shaped fractal microstrip patch antenna has been obtained by applying fractal geometry. Patch is taken is known to be square whose dimensions has been calculated as per antenna specifications. Although length of antenna had been rectangular but by parameter optimization, length of antenna has been taken as square. Patch length has been taken as square of length 36mm. Dimension of ground has been taken as been taken as 50 mm. The substrate used in this dissertation is FR-4. This substrate has been chosen to reduce antenna dimension of antenna. Substrate used for this antenna is FR-4 with dielectric constant of 4.4 and loss tangent of 0.02. Table 5.2 shows dimensions of antenna.

Table 5.2: Dimensions of Reference Antenna

Variable	Value
Length of patch	36 mm
Width of patch	36mm
Length of ground	50 mm
Width of ground	50 mm
Thickness of substrate	2.4 mm
Feeding technique used	Coaxial Feeding Technique

Substrate used	FR-4
Dielectric constant	4.4
Feed point	(0, 4, 0)
First Iteration slot cut size	12X18 mm ²
Second iteration slot cut size	4X9 mm ²

Initially, square patch of length 36 m is taken and results are analyzed. The square patch is shown in figure 5.2(a). Coaxial feed is given at feed point (0, 8, 0). Results are analyzed corresponding to this initiator. After that first iteration of fractal geometry is applied to make T shape patch. This T shape patch is obtained by cutting two rectangles of dimensions 18 X 12 mm. The entire length is divided into three parts of 12 mm each and entire width is divided into two equal parts. Scale factor of one by three is chosen length wise and half along width side. Feed to antenna is given at feed point (0, 8, 0). The geometry of T shape patch is shown in figure 5.2 (b). By cutting slot, area of patch decreases. Second iteration of fractal geometry is applied by cutting slot of 4 X 9 mm² from rectangles of size 12 X 18 mm². Each rectangle of size 12 X 18 mm² has been divided into six parts and two equal parts have been cut out so as to obtain self-similar structures. Feed to antenna is coaxial feed and feed point is adjusted such that impedance matching takes place. Feed is given at (0, 4, 0). Geometry of all three iterations is shown in figure 5.2.

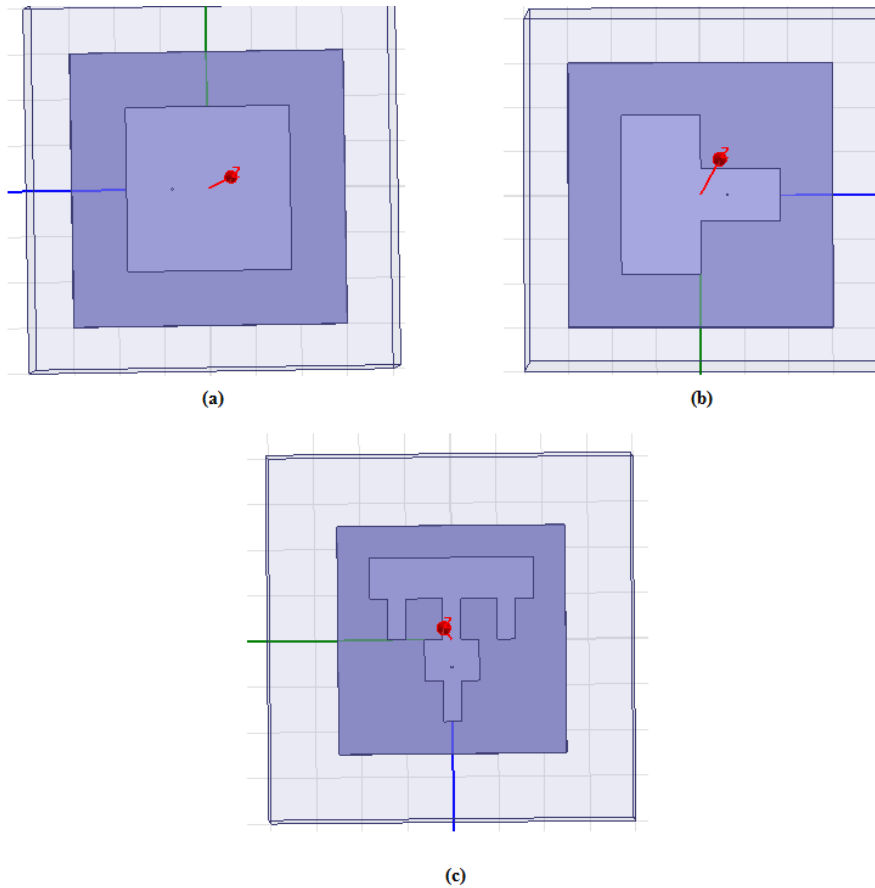


Figure 5.2: T- Shaped FMPA (a) 0th Iteration, (b) 1stIteration and (c) 2nd Iteration

These geometries as shown in figure 5.2 (a), 5.2 (b) and 5.3 (c) shows self-similarity characteristics. These dimensions show as number of iterations increases, area decreases. Beyond a certain level of iteration, complexity increases and fabrication of antenna becomes difficult.

5.5 Parametric Analysis of Proposed Antenna

It has been analyzed that by applying two iterations of fractal geometry, characteristics of antenna improves a lot. Parametric analysis includes making use of feed point change, substrate selection and thickness of substrate. It is found with help of parametric analysis, one may obtain best configuration that has better result. It is also found that results can also be analyzed by changing feed to microstrip line

- Effect of changing feed point of coaxial feed
- Effect of changing substrate

- Effect of Changing Feed
- Effect of changing substrate thickness

5.5.1 Effect of changing Dielectric Substrate

In this dissertation, substrate used is FR-4, but there are many substrates that can also be used in order to analyze results. FR-4 is having dielectric constant of 4.4 and loss tangent of 0.02. There are many other substrates that can be used for analyzing results. One of substrate that has been used is Rogers RT-duroid 5880. This antenna has dielectric constant of 2.2 and loss tangent of 0.0009. Feed to antenna has not changed. It has been found that when dielectric constant of antenna has been changed then dimension of antenna changes or resonant frequency changes. Geometry corresponding to it has been shown in figure 5.3.

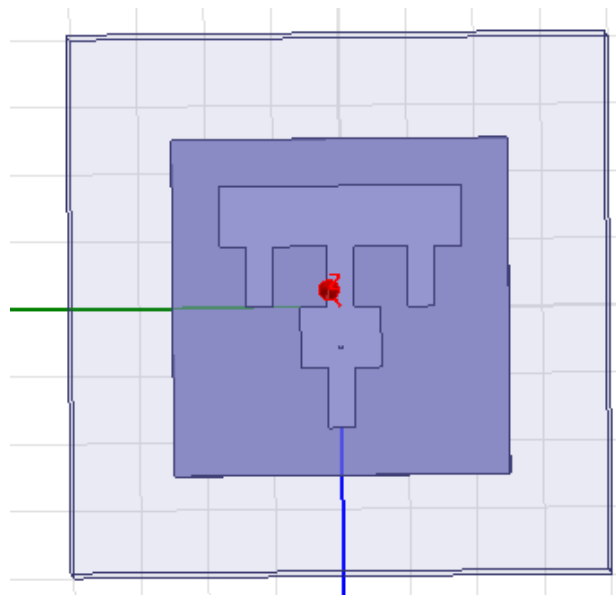


Figure 5.3: Antenna with DGS using Different Substrate

5.5.2 Effect of Changing Feed Point

Proposed T-shape fractal patch antenna has been designed using FR-4 as substrate. It has been found that feed point plays an important role in design characteristics. The T shape fractal patch antenna is analyzed by varying feed point. Feed point is selected in such a way that impedance matching takes place. Feed point is important characteristics. Coaxial feed is varied by varying feed at (0, 4), (0, 6) and (0, 8). Variation of feed point has been shown in figure 5.4(a), 5.4(b) and 5.4(c).

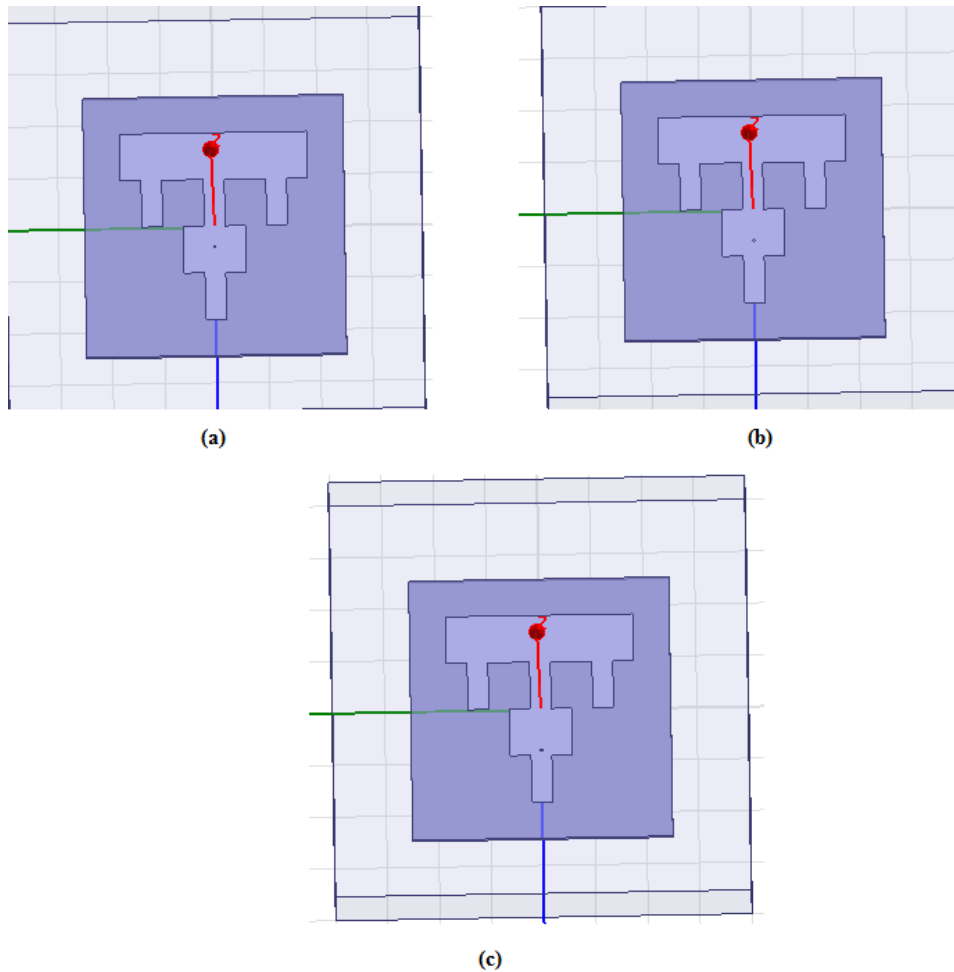


Figure 5.4: T-shaped Fractal Antenna with (a) Feed Point at (0,4), (b) Feed point at (0,6) and (c) Feed Point at (0, 8).

5.5.3 Effect of Changing Thickness of Substrate

Proposed T shape fractal patch antenna has been designed using FR-4 as substrate. Effect of varying substrate has been analyzed. It has been found that by changing thickness of substrate, characteristics of antenna changes. By increasing thickness of patch bandwidth and polarization also increases. Parametric analysis has been carried out in HFSS simulation software by selecting range from 1.6 to 2.4 at step size of 0.4 mm. The geometry corresponding to antenna has been shown in figure 5.5.

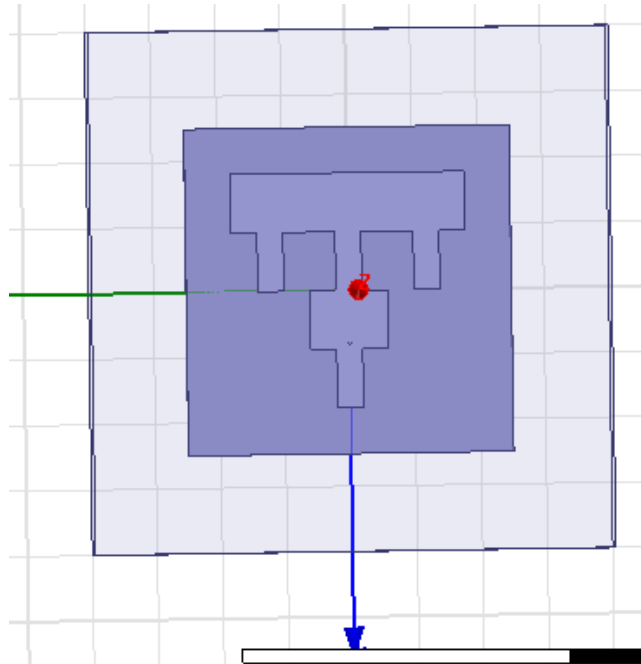


Figure 5.5 T-shape Fractal Antenna with Substrate Thickness 2.4 mm

Figure 5.6 shows how parametric analysis has been carried out to compare antenna characteristics for different heights.

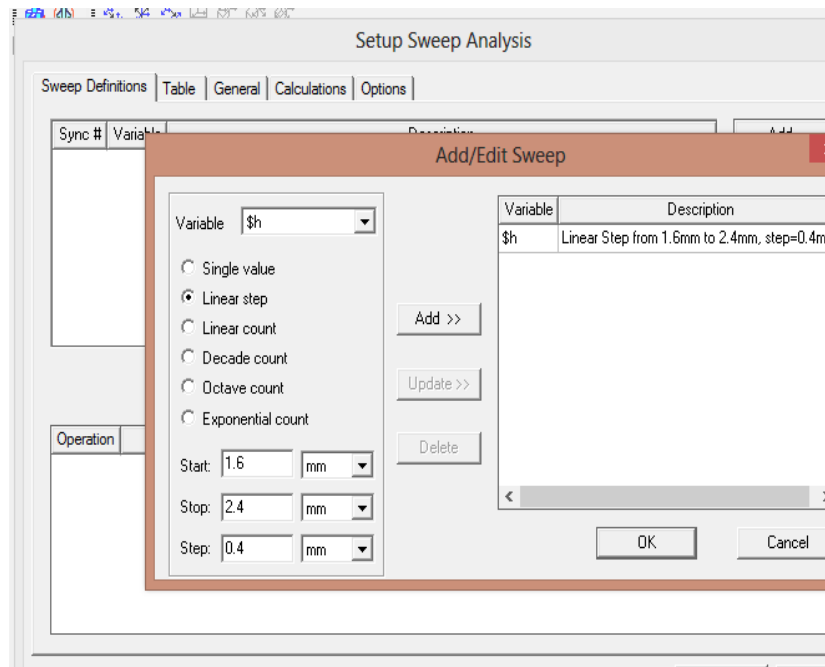


Figure 5.6 Parametric analyses for Microstrip Patch Antenna

5.6 Effect of Changing Feed

It is found that coaxial feed is easy method for feeding antenna. Feed point is chosen such that antenna impedance matching takes place. There are other feeding techniques which can be used like microstrip feeding technique and inset feed. In this dissertation, microstrip feeding technique has been used. Strip length is of 2 mm wide and 7 mm long. Geometry correspond to it is shown in figure 5.7. It is found that bandwidth of antenna increases by using microstrip line technique.

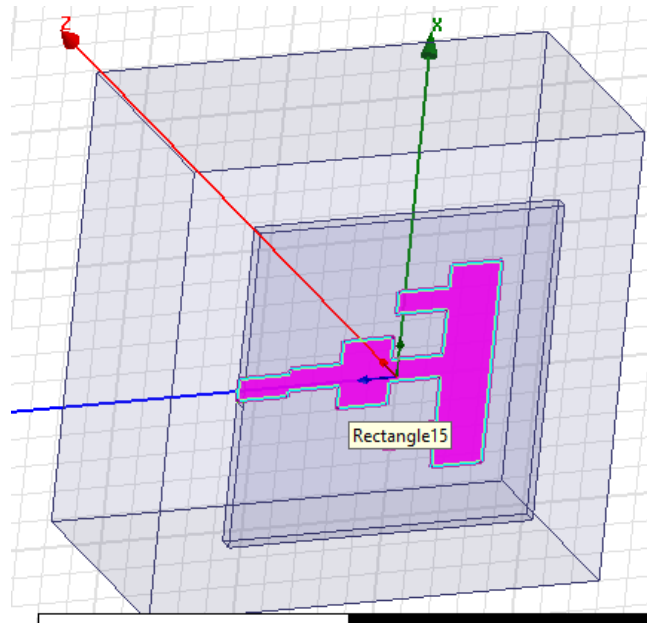


Figure 5.7 Effect of Using Microstrip Feeding Technique

Chapter 6

RESULTS AND DISCUSSIONS

In this chapter simulation results of different antenna parameters in terms of antenna characteristics are mentioned. Performance of antenna characteristics is measured in terms of return loss, gain, directivity and bandwidth. Characteristics of antenna parameters are compared for various iterations of T- shape fractal antenna.

6.1 T-Shaped Fractal Patch Antenna

In this section, simulation results of different iterations of fractal geometry are compared. T shape fractal antenna is made by cutting slots as shown in figure 5.2. These cause self-similar T-shaped structure. Return loss vs. frequency for various iteration of T-shaped fractal geometry are shown in figure 6.1.

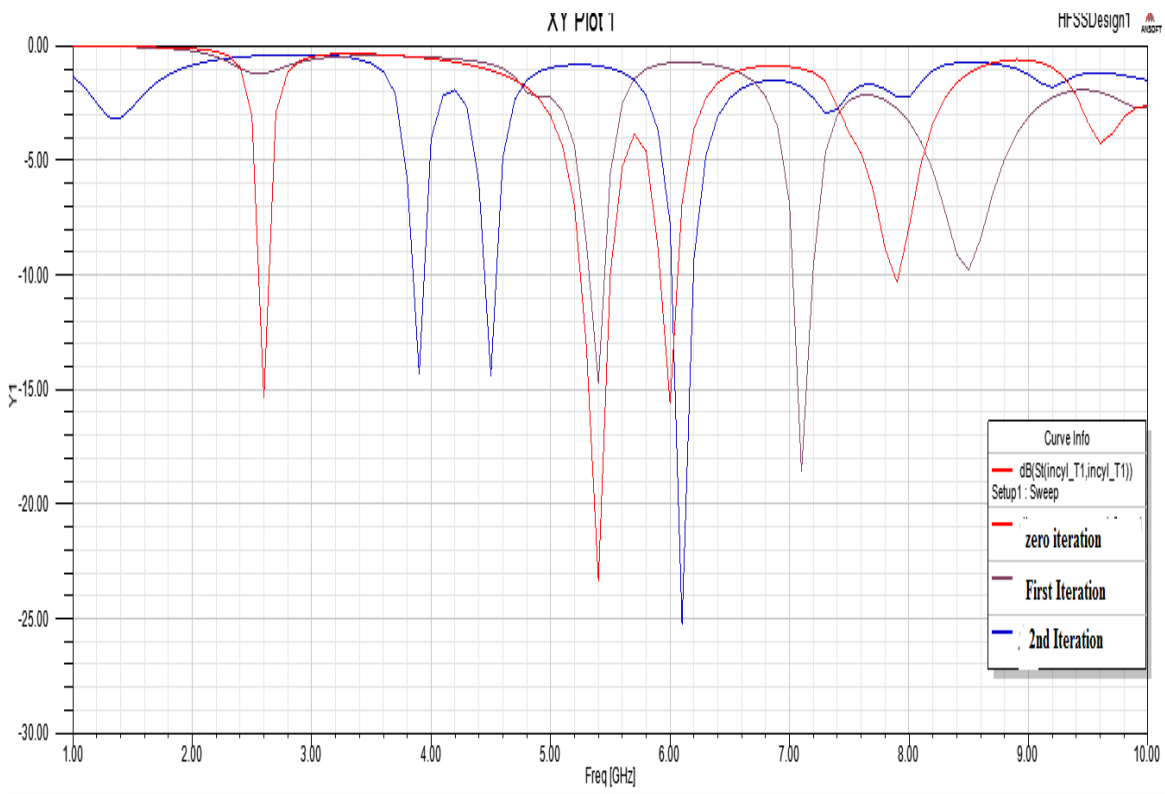


Figure 6.1: Return Loss Vs. Frequency for Different Fractal Iterations of T-shaped FMPA

From figure 6.1 it is found that characteristics of antenna increases as number of iterations increases, initially square antenna resonates at 2.6GHz, 5.4GHz and 6 GHz with return loss of -16 dB, -23 dB and -16 dB and bandwidth of 110 MHz, 100 MHz and 125 MHz since characteristics of antenna at zero iteration are not good so fractal geometry has been applied to improve characteristics. Two slots are cut as shown in figure 5.2 (b). This antenna resonates at two bands at 5.4 GHz and 7.10 GHz with return loss of -16 dB and -14.72 dB. This antenna had bandwidth of 180 MHz and 170 MHz at resonant frequency. As results obtained are good but resonant frequency bands are having more return loss hence second iteration of fractal geometry is applied. When second iteration of fractal geometry is applied as shown in figure 5.2(c), antenna resonates at three bands with return loss of 3.9 GHz, 4.5 GHz and 6.1 GHz. This antenna had return loss of -14.34 dB, -14.40 dB and -25.85 dB with bandwidth of 100 MHz, 110 MHz and 200 MHz at resonant frequencies. Further this antenna has good gain of 3.5dBi, 3.6 dBi and 6.1 dBi at corresponding frequencies. Further radiation patterns at 3.9 GHz, 4.5 GHz and 6.1 GHz have been shown in figure 6.2(a), 6.2(b), and 6.2(c). This radiation pattern show s that antenna is having maximum energy corresponds to that in particular direction. There are different radiation patterns like fan based, pencil based radiation pattern.

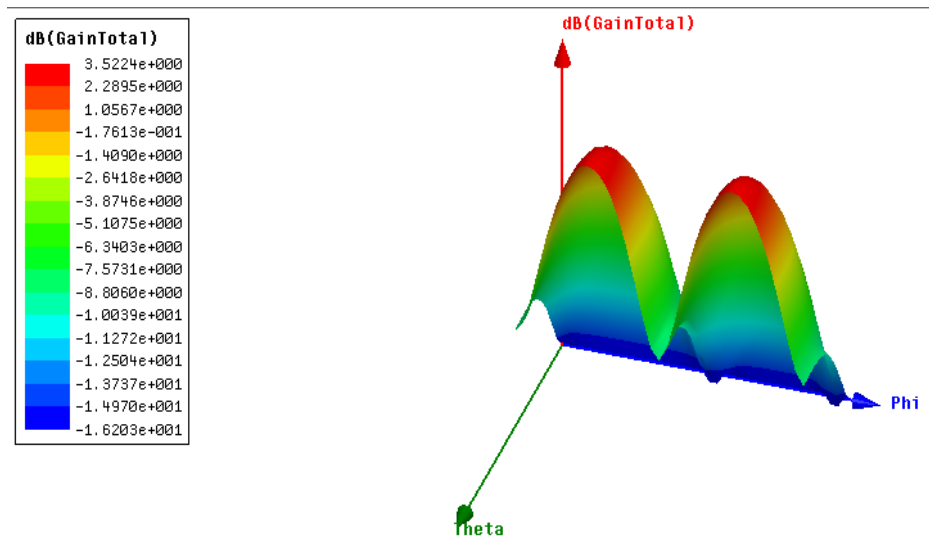


Figure 6.2(a): Radiation Pattern of T-shaped FMPA at 3.9 GHz

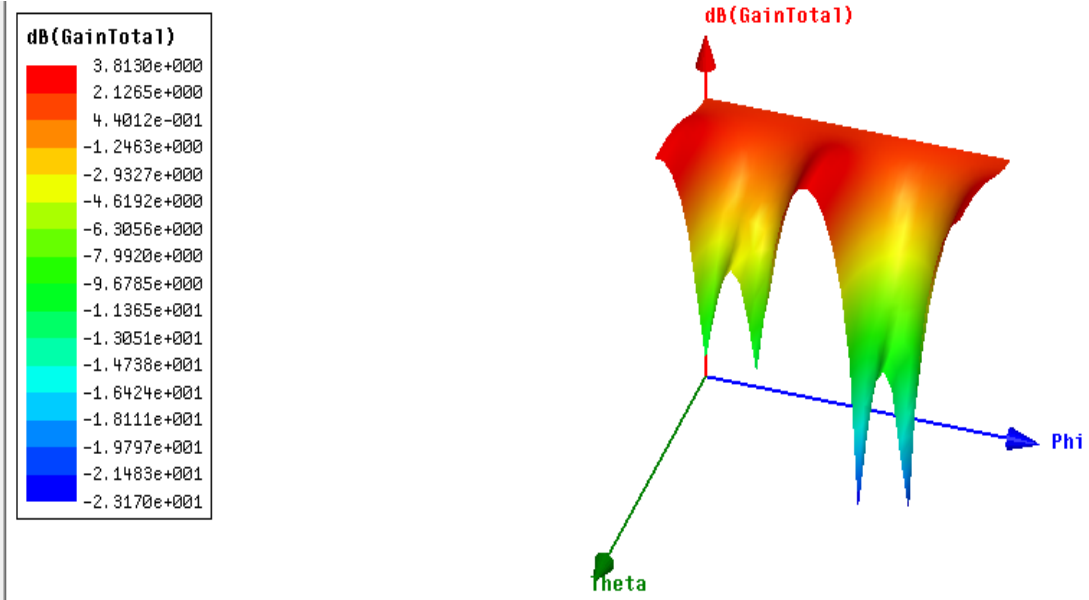


Figure 6.2(b): Radiation Pattern of T-shaped FMPA at 4.5 GHz

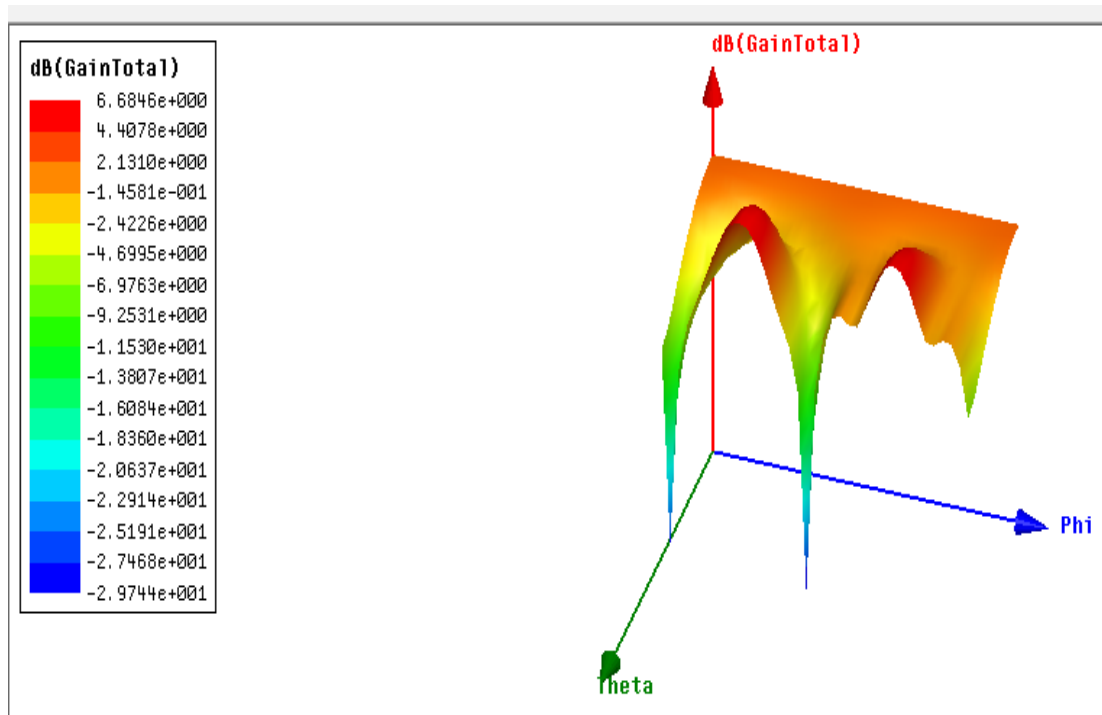


Figure 6.2(c): Radiation Pattern of T-shaped FMPA at 6.1 GHz

Table 6.1 shows comparison of results of different iterations of T-shaped fractal geometry applied on square patch as shown in figure 5.1. Results are analyzed in terms of

return loss and bandwidth. It is found from results that antenna characteristics improves as number of iterations increased.

Table 6.1: Comparison Results of Different Iterations of T-shaped FMPA

Iteration Number	Resonance Frequency (GHz)	Return Loss (dB)	Bandwidth (MHz)
0 th Iteration	2.6	-16	100
	5.4	-23	200
	6	-16	110
1 st Iteration	5.4	-14.72	180
	7.10	-18.60	170
2 nd	3.9	-14.34	100
	4.5	-14.40	110
	6.1	-25.85	200

Results showed that as the number of iterations increased, results of antenna showed improvement, VSWR of antenna for different frequencies is shown in figure 6.3.

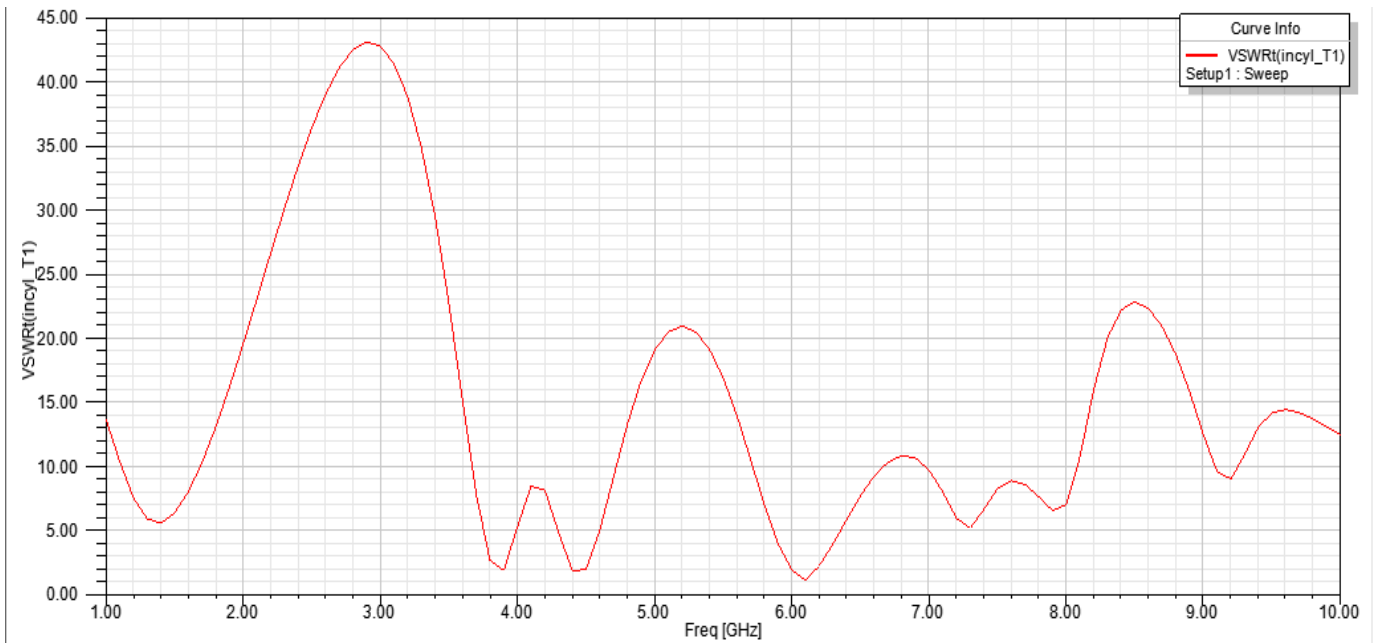


Figure 6.3: VSWR Vs Frequency for Proposed Antenna

VSWR stands for voltage standing wave ratio. At resonance frequency, VSWR must be less than two but it must be greater than unity. VSWR is measure of return loss, more negative return loss, more better is system. Bandwidth can also be defined in terms of VSWR. Range of frequency on either side of resonant frequency where VSWR is between one and two defines bandwidth. This antenna has VSWR of 1.91, 1.17 and 1.91 at 3.9 GHz, 4.5 GHz and 6.1 GHz at corresponding frequencies. Smith chart is best method of representing complex frequencies with respect to represent complex impedances with respect to reflection coefficient. Figure 6.4 shows smith chart of proposed antenna.

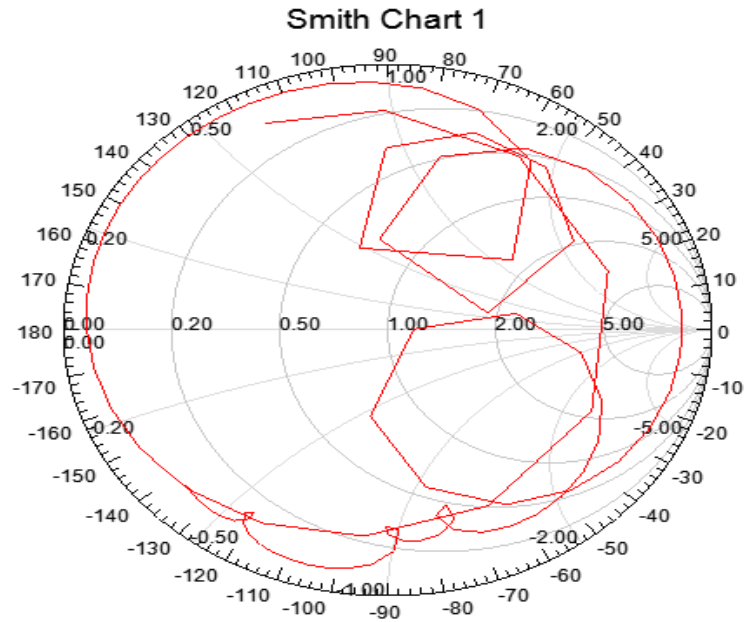


Figure 6.4: Smith Chart of Proposed Antenna

6.2 Simulation Results of T-shaped Fractal Antenna with Different Substrate

There are different substrates that can be available for use. These include Rogers RT-duroid 5880 as substrate and FR-4. It is found that by making use of FR-4 antenna dimension decreases, hence size of antenna decreases and bands start shift towards right side. Two iterations of fractal antenna are performed so as to obtain best antenna characteristics. It was found that antenna resonates at three different bands with small return loss, high gain and good bandwidth. It is found that by using Rogers RT-duroid 5880 as substrate, antenna characteristics become well in terms of efficiency and polarization. By using FR-4 as substrate, when second iteration of fractal geometry is applied as shown in figure 4.2(c), antenna resonates at three bands with return loss of 3.9 GHz, 4.5 GHz and 6.1 GHz. This antenna had return loss of -14.34 dB, -14.40 dB and -25.85 dB with bandwidth of 100 MHz, 110 MHz and 200 MHz at resonant frequencies. Further this antenna has good gain of 3.5 dBi, 3.6 dBi and 6.1 dBi at corresponding frequencies and by using Rogers RT-duroid 5880 as substrate, antenna resonated at 5.2 GHz and 5.9 GHz with return loss of -12.10 dB and -19.10 dB and bandwidth of 100 MHz and 110 MHz. Return loss versus frequency for different iterations has been shown in figure 6.5.

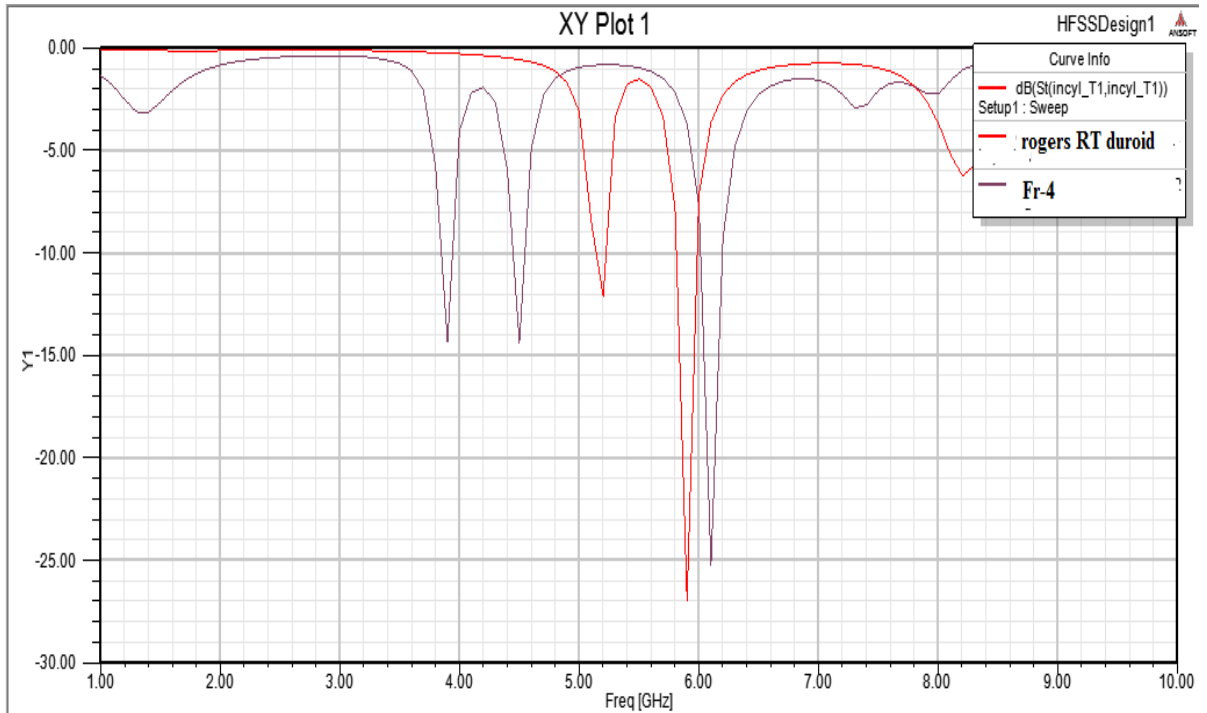


Figure 6.5: Return Loss Vs Frequency for Different Substrate Fractal Antennas

Effect of changing substrate has been observed. Comparison of performance of all antenna parameters is made in terms of return loss, gain and bandwidth. The results of all antenna parameters of both substrates have been shown in table 6.2. From this it is found that best substrate for FR-4 as compare to Rogers RT Duroid. One can also use other substrates and can find comparison.

Table 6.2: Antenna Characteristics by Changing Substrate

Substrate Used	Resonant Frequency (GHz)	Return Loss (dB)	Bandwidth(MHz)
FR-4	3.9	-14.34	100
	4.5	-14.40	110
	6.1	-25.85	200
	5.2	-12.11	110

Rogers RT	5.9	-26.95	150
Duroid			
5880			

6.3 Effect of Changing Antenna Height

Effect of varying dielectric constant of substrate has been analyzed in previous section. Apart from that there are different parameters which govern antenna performance. Antenna performance is tested for heights of 2mm; 2.2 mm and 2.4 mm. Return loss versus frequency curve for different heights are shown in figure 6.6.

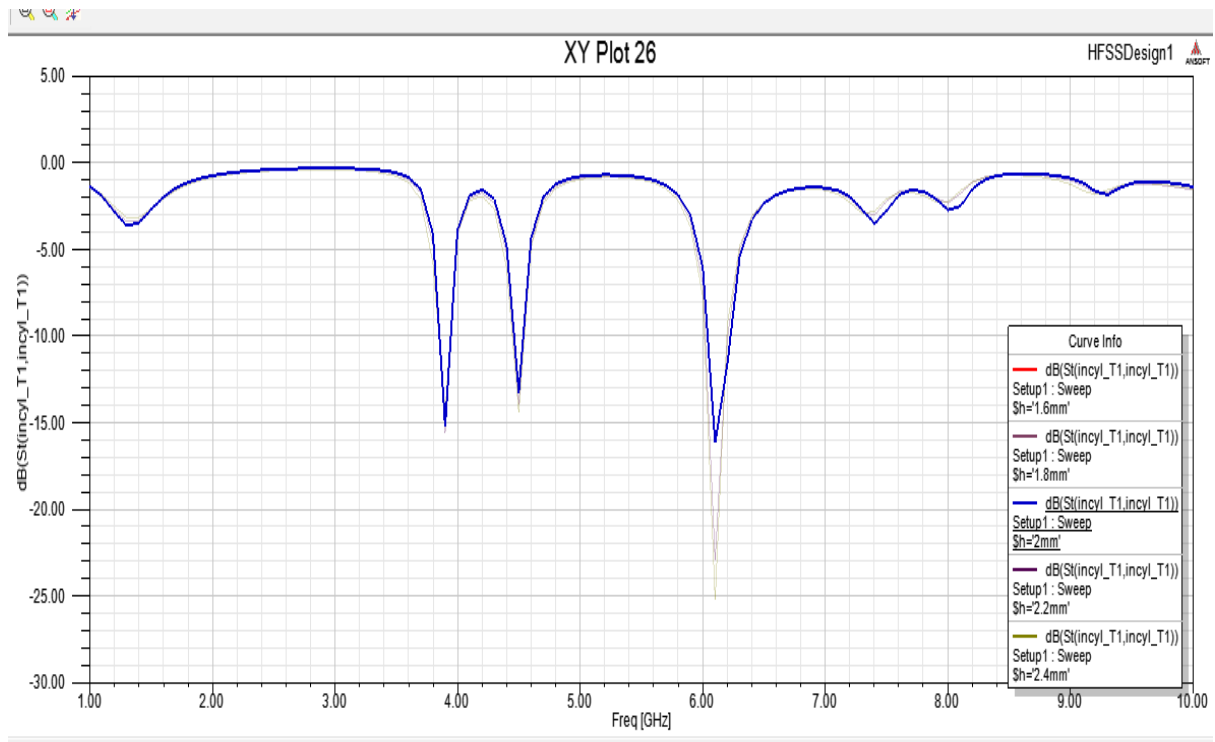


Figure 6.6: Return Loss Vs Frequency for Antenna with Different Height

Effect of varying dielectric constant of substrate has been analyzed in previous section. Apart from that there are different parameters which govern antenna performance. Antenna performance is tested for heights of 2 mm; 2.2 mm and 2.4 mm. Return loss versus frequency curve for different heights are shown in figure 5.8. Using substrate of thickness 2 mm, antenna resonates at 3.9 GHz, 4.5 GHz and 6.1 GHz with return loss of -14.34 dB,

-14.40 dB and -25.85 dB and bandwidth of 90 MHz, 100 MHz and 200 MHz. By changing thickness of 2.2 mm, antenna resonated at same bands with return loss of -14.34 dB, -13.40 and -16.20 dB and with bandwidth of 150 MHz and 150 Mhz and 100 MHz. Best characteristics have been obtained using substrate thickness of 2.4 mm as antenna resonates at three bands with return loss of 3.9 GHz, 4.5 GHz and 6.1 GHz. This antenna had return loss of -14.34 dB, -14.40 dB and -25.85 dB with bandwidth of 100 MHz, 110 MHz and 200 MHz at resonant frequencies. Results have been compared in table 6.3

Table 6.3: Antenna Characteristics by Height

Substrate Thickness	Resonant Frequency (GHz)	Return Loss (dB)	Bandwidth(MHz)
2.4 mm	3.9	-14.34	100
	4.5	-14.40	110
2 mm	6.1	-25.85	200
	3.9	-15.10	90
	4.5	-14.10	100
2.2 mm	6.1	-16.20	150
	3.9	-14.34	100
	4.5	-13.40	100

From the above analysis, it is found that as thickness of substrate increases, bandwidth and gain increases but return loss may degrade.

6.4 Effect of changing feed point

Parametric analysis has been conducted so as to vary feed point all along axis. By varying feed point it was found that impedance changes. Feed has given at several points

along y axis at (0, 4), (0, 6) and (0, 8). By applying feed to antenna at x=0 and y=6, antenna resonates at 3.9 GHz, 4.5 GHz and 6.1 GHz with return loss of -14.34 dB, -14.40 dB and -25.85 dB. This configuration had good bandwidth of 100 MHz, 110 MHz and 200 MHz at corresponding frequencies. As feed point shift from y=6 mm to y= 4mm, antenna characteristics changed as now antenna resonates at 4.5 GHz with return loss of -17 dB and bandwidth of 100 MHz. By changing feed point to y=8 mm, antenna resonates at 6.1 GHz with return loss of -16.5 dB and bandwidth of 150 MHz. Analysis of results of different antenna configurations have been shown in table 6.4. It is found that by making such analysis, antenna characteristics become much well.

Table 6.4: Antenna Characteristics by Feed Point

Substrate Thickness	Resonant Frequency (GHz)	Return Loss (dB)	Bandwidth(MHz)
Y=6	3.9	-14.34	100
	4.5	-14.40	110
	6.1	-25.85	200
4	4.5	-17	100
8	6.1	-16.5	150

Results of return loss versus frequency loss versus frequency at different feed points have been shown in figure 6.7.

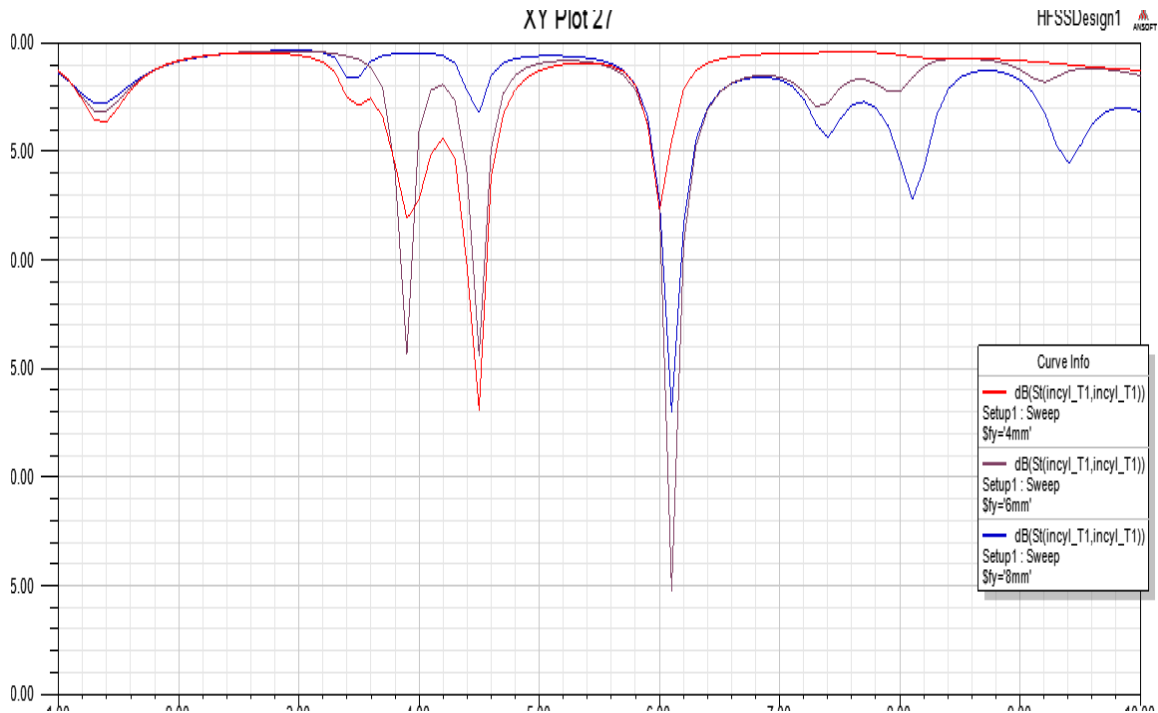


Figure 6.7: Return Loss Vs Frequency for Antenna with Different Height

6.5 Effect of changing feed point

Till now, effect of changing feed has been made. Microstrip line can also be used in place of coaxial feed. Main advantage of using coaxial feed is that feed point can be moved all over patch periphery. By use of microstrip line feeding technique characteristics obtained are analyzed. Feed to antenna is given 2mm in width and 7 mm long. By making use of feed to antenna, characteristics of antenna are good. This antenna resonated at 5.5 GHz, 7.4 GHz and 9.5 GHz with return loss of -10.85 dB, -27.05 dB and -15.06 dB. This antenna had good bandwidth of 100 MHz, 500 MHz and 285 MHz at resonant frequencies. Return loss versus frequency for microstrip line and coaxial line have been shown in figure 6.8.

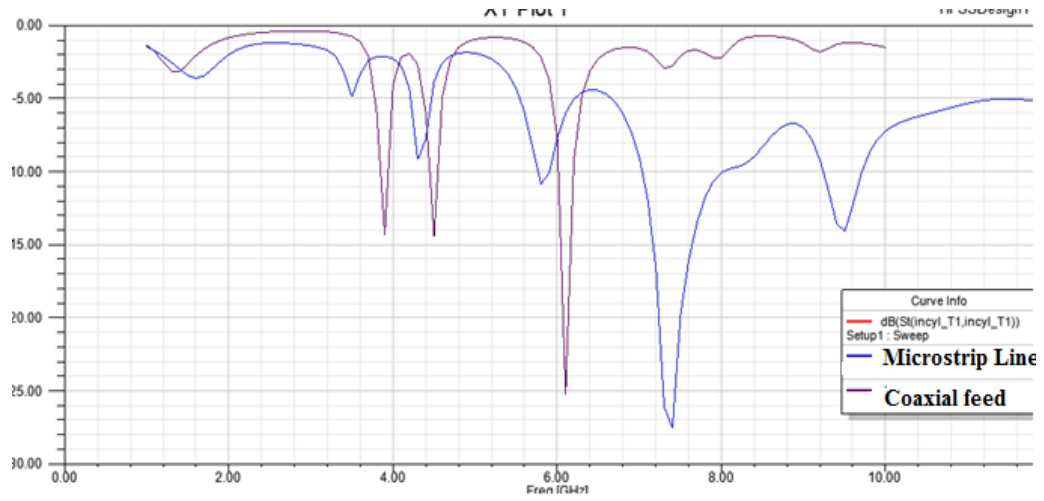


Figure 6.8: Return Loss Vs Frequency for Antenna with Different Height

Chapter 7

CONCLUSION

Multiband T-shaped fractal antenna is obtained by applying fractal geometry. Initially a rectangular patch is taken and fractal geometry is applied. Two iterations of fractal geometry are applied to form T-shaped fractal antenna. This antenna gives multiband characteristics. There are different configurations of changing feed points, changing dielectric substrate which can be applied. In order to analyze characteristics, antenna configurations are observed by using different feeding configurations, it is also observed that one of best comparison is made by using microstrip line and comparing result by use of coaxial feed Design and simulations are carried out using HFSS. From results it is found that parametric analysis had been carried out in terms of substrate thickness, feed point and number of iterations. It is found that by making use of fractal geometry, characteristics of antenna improve a lot. In this paper, T-shaped Patch antenna has been designed and fractal geometry has been applied to it in order to obtain self-similar characteristics. Square Patch length has been taken as square of length 36mm. Dimension of ground has been taken as 50 mm. The substrate used in this paper is FR-4. Parametric analysis has been applied in terms of changing microstrip line, feed point, thickness and geometry. Antenna resonates at three bands with return loss of 3.9 GHz, 4.5 GHz and 6.1 GHz. This antenna had return loss of -14.34 dB, -14.40 dB and -25.85 dB with bandwidth of 100 MHz, 110 MHz and 200 MHz at resonant frequencies. Further this antenna has good gain of 3.5dBi, 3.6 dBi and 6.1 dBi at corresponding frequencies and also compared with E shaped fractal geometry. This antenna can be useful for Wi-Max and WLAN applications.

It is concluded that by applying different iterations of fractal geometries multiband characteristics are obtained. Further effect of changing thickness and feed are observed to select that configuration that will give best results

Future Scope

In this dissertation, fractal geometry and effect of changing thickness and feed are observed to select that configuration that will give best results used to improve characteristics of microstrip antenna, Fractal geometry has been applied on patch to obtain multiband characteristics to obtain wideband characteristics. The designed antennas in this dissertation report can be used in different applications like WLAN, WiMAX, satellite communications, RADAR applications and defense and secure communication application. Various techniques can also be used in future to design optimized antennas which are as follows:

- Non Contacting feeding techniques
 - Proximity Coupled Feed
 - Aperture Coupled Feed
- Changing Fractal Geometry
 - Sierpinski Carpet Fractal Geometry In Patch
 - Gusepe Peano Fractal Geometry
- Applying DGS Configuration
 - Defect the ground structure by using fractal algorithms make hybrid fractal

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2. Sunil Kumar, Sukhwinder Kumar, “Minkowski Fractal Geometry based T-shaped Fractal Patch Antenna for wireless applications” *International Journal of Advanced Research in Computer and Communication Engineering Vol. 4, Issue 6, June 2015*