Multiband and Small Size Fractal Square Koch Antenna Design for UHF/SHF Application

By

Dilara Khatun

A project submitted
in partial fulfillment of the requirement for the degree of M.Sc. in
Electrical and Electronic Engineering

Khulna University of Engineering & Technology
Khulna 920300, Bangladesh
October 2013

Declaration

This is to certify that the project work entitled “Multiband and Small Size Fractal Square Koch Antenna Design for UHF/SHF Application" has been carried out by DILARA KHATUN in the Department of Electrical and Electronic Engineering, Khulna University of Engineering & Technology, Khulna, Bangladesh. The above project work or any part of this work has not been submitted anywhere for the award of any degree or diploma.

9.10.2013
Signature of Supervisor

Dilara Khatun
Signature of Candidate 9.10.2013

Approval

This is to certify that the project work submitted by DILARA KHATUN entitled " Multiband and Small Size Fractal Square Koch Antenna Design for UHF/SHF Application" has been approved by the board of examiners for the partial fulfillment of the requirements for the degree of M.Sc. in the Department of Electrical and Electronic Engineering, Khulna University of Engineering & Technology, Khulna, Bangladesh in October, 2013.

BOARD OF EXAMINERS

1. Shahjahan 09/10/2013

Prof. Dr. Md. Shahjahan
Department of EEE
Khulna University of Engineering & Technology

Chairman
(Supervisor)

2. Ahmed 09/10/2013

Head
Department of EEE
Khulna University of Engineering & Technology

Member

3. 09.10.13.

Prof. Dr. Md. Abdus Samad
Department of EEE
Khulna University of Engineering & Technology

Member

4. 09/10/13

Prof. Dr. Md. Nurunnabi Mollah
Department of EEE
Khulna University of Engineering & Technology

Member

5. 09/10/2013

Prof. Dr. Md. Maniruzzaman
Department of ECE
Khulna University, Khulna-9208

Member

Acknowledgement

It's my pleasure to express the greatest and deepest gratitude to the supreme of the universe, the almighty Allah, to whom all praises go for enabling me to complete my project work.

I would like to express my indebtedness to my respected supervisor, **Dr. Md. Shahjahan**, Professor, Department of Electrical and Electronic Engineering, Khulna University of Engineering & Technology, Khulna, for his continuous guidance, keen interest, strong inspiration, time to time help and constructive criticism to carry on the project work. Without his guidance, probing questions and limitless support, I wouldn't have completed this journey.

I also would like to express my humble gratitude to all the respected teachers of EEE discipline for their effective and fruitful inspiration.

At last but not the least, I am grateful to my parents for their true love. Most importantly, without their love, continuous support and patience, this project would not have been possible.

Dilara Khatun

Abstract

There exists various types of antennas for various purposes, but the interest in this area is increasing day by day. There have been ever growing demands for antenna designs that possess the highly desirable properties: compact size, low profile, multi-band, wide bandwidth, high gain, improved SWR etc. Fractal antennas can be used to meet these demands. This paper represents the analysis and design of multiband square Koch fractal dipole antenna, where it is shown that as the iterations are increased, the band of frequencies also increase and the antenna is also compact in size. The designed antenna has operating frequencies for first iteration are of 496 MHz and 1430 MHz, and for second iteration are of 460 MHz, 1248 MHz, 1926 MHz and 4390 MHz with acceptable bandwidth, which has useful applications in UHF/SHF. The radiation characteristics, SWR, reflection-coefficient, input impedance and gain of the proposed antenna are described with 4NEC2 Software package. Here, the antenna is placed in the XY-plane for the first iteration and in YZ-plane for the second iteration.

Contents

Chapter-3 Fractals and Fractal Antennas

Chapter-4 Design of the Square Koch fractal Antenna

Chapter-5 Simulation of Square Koch fractal Antenna

Chapter-6 Conclusion

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

IFS	Iterated Function System
FBR	Front to-Back Ratio
VSWR	Voltage Standing Wave Ratio
MOM	Methods of Moments
FBW	Frequency Bandwidth
MIMO	Multi-Input Multi-Output
UHF	Ultra High Frequency
SHF	Super High Frequency
HPBW	Half Power Beamwidth
FNBW	First Null Beamwidth

Nomenclature

ε	Dimensionless relative roughness
λ	Wavelength (m)
ω	Anglular velocity
C	Speed of light
F	Frequency
D	Largest dimension of the antenna
$r_{\min}$	Minimum distance from the antenna
η	Efficiency of the antenna
R_r	Radiation resistance
R_l	Ohmic loss resistance of antenna conductor
$(1/\varepsilon)$	Reduction factor
N	Total number of distinct copies
l_n	Length after nth iteration
l_o	Original length
I	Current
G	Gain
Z	Impedance

CHAPTER 1

Introduction

1.1 Introduction

With the advance of wireless communication; wideband, 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 which uses fractal shaped antenna elements [1]. Several fractal geometries have been introduced for antenna applications with varying degrees of success in improving antenna characteristics. Some of these geometries have been particularly useful in reducing the size of the antenna, while other designs aim at incorporating multi-band characteristics [2].

The term 'Fractal' [4] was first introduced by Benoit Mandelbrot to classify the structure whose dimensions were not whole numbers. Mandelbrot defined fractal as a fragmented geometric shape that can be subdivided in parts, each of which is a reduced-size copy of the whole. In the mathematics, fractals are a class of complex geometric shapes commonly exhibit the property of self-similarity, such that small portion of it can be viewed as a reduced scale replica of the whole.

Since the pioneering work of Mandelbrot and others, a wide variety of applications for fractals has been found in many branches of science and engineering. One of the most promising areas of fractal is its application to antenna theory and design [3]. These are low profile antennas with moderate gain and can be made operative at multiple frequency bands and hence are multi-functional.

The Simplest example of antenna using fractal geometry is given by the Swedish mathematician H. von Koch in 1904, which is known as Koch fractal.

In this project a wire square Koch fractal antenna is designed based on the first and second iterations of square Koch curve geometry [4].Here, it is shown that as the iterations are increased, the band of frequencies also increase and the antenna is also compact in size [5].

1.2 Objective of the Project

The main purposes of the project work are given below:

i. To design the multiband and miniaturized [24] square Koch fractal antenna.

ii. To show that as the iterations are increased, the band of frequencies also increases.

iii. To plot Return loss versus frequency, SWR versus frequency, Gain versus frequency, Input Impedance versus frequency and radiation pattern of square Koch fractal antenna.

1.3 Outline of the Project

Chapter 1 explains the introduction of the project and describes the objective of this project.

Chapter 2 discusses the different types of antennas and antenna properties.

Chapter 3 discusses the fundamental concepts of fractal, fractal dimension, advantages and disadvantages of fractal antenna, features of fractal antenna, different types of fractal antennas, application of fractal antenna etc.

Chapter 4 discusses the design of square Koch fractal antenna and antenna geometry of the proposed antenna.

Chapter 5 presents the simulated result of square Koch fractal antenna.

Chapter 6 highlights the overall conclusion of the project.

CHAPTER 2

Antenna Theory

2.1 Introduction

An antenna [2] is a transducer designed to transmit or receive radio waves which are a class of electromagnetic waves. In other words, antennas convert radio frequency electrical currents into electromagnetic waves and vice versa.

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 (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.

In some sense the first antenna dates from 1887, when Heinrich Hertz designed brilliant set of wireless experiments to test James Clerk Maxwell's hypothesis. Hertz used a flat dipole for a transmitting antenna and a single turn loop for a receiving antenna. For the next fifty years antenna technology was based on radiating elements configured out of wires and generally supported by wooden poles. These "wire "antennas were the mainstay of the radio pioneers, including: (1) Galileo Marconi, (2) Edwin Howard Armstrong and (3) Lee deforest. Each of these engineers has been called the Father of the Radio. The first generation antennas were narrowband and were often used to increase directivity. Development of the array culminated in the work of Hidetsu Yagi and Shintaro Uda (1926). During this period broadband antennas were also developed. The Yagi-Uda antenna remained king until after the war. Then during the 1950s and 1960s research at the University of Illinois culminated in the development of a class of antennas that became known as frequency independent. These have performance that is periodic in a logarithmic fashion and have come to be known as "log-periodic" antennas. In recent years, fractal antennas are coming out smaller, cheaper and more reliable.

2.2 Classification of Antennas

2.2.1 Antenna Classification on Frequency Basis

Table 2.1: Classification of antenna on the basis of frequency

Frequency Band	Designation	Typical service
3-30 KHz	Very Low frequency(VLF)	Navigation, SONAR
30-300 KHz	Low Frequency (LF)	Radio beacons, Navigational Aids
300-3000 KHz	Medium Frequency (MF)	AM broadcasting, maritime radio, coastguard communication, direction finding
3-30 MHz	High Frequency (HF)	Telephone, Telegraph and Facsimile, amateur radio, ship-to-coast and ship to-aircraft communication
300-3000 MHz	Ultra High Frequency (UHF)	Television, satellite communication, RADAR, navigational aids
3-30 GHz	Super High Frequency (SHF)	Airborne RADAR, Microwave Links, Satellite Communication
30-300 GHz	Extremely High Frequency(EHF)	RADAR

2.2.2 Antenna Classification on Aperture Basis

Aperture antennas transmit and receive energy from its aperture. Different kinds of aperture antennas are-

1. Wire antenna
2. Horn antenna
3. Parabolic antenna
4. Microstrip patch antenna

1. Wire Antenna

A wire antenna is simply a straight wire of length $\lambda/2$ (dipole antenna) and $\lambda/4$ (monopole antenna), where λ is the transmitted signal wavelength. A wire antenna can be a loop antenna such as circular loop, rectangular loop etc. Basically all vertical radiators are come into wire antenna categories.

- **Inverted-F Antenna**

The inverted-F antenna is shown in Figure 2.1. While this antenna appears to be a wire antenna, after some analysis of how this antenna radiates, it is more accurately classified as an aperture antenna.

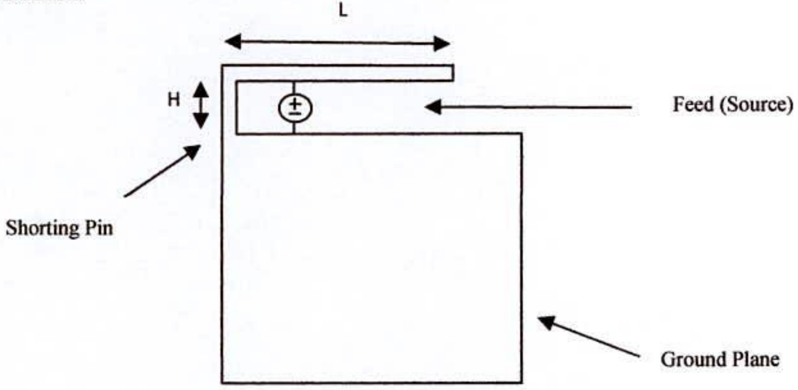


Fig. 2.1: Geometry of Inverted-F Antenna (IFA)

The feed is placed from the ground plane to the upper arm of the IFA. The upper arm of the IFA has a length that is roughly a quarter of a wavelength. To the left of the feed, the upper arm is shorted to the ground plane. The feed is closer to the shorting pin than to the open end of the upper arm. The polarization of this antenna is vertical and the radiation pattern is roughly donut shaped, with the axis of the donut in the vertical direction. The ground plane should be at least as wide as the IFA length (L), and the ground plane should be at least lambda/4 in height. If the height of the ground plane is smaller, the bandwidth and efficiency will decrease. The height of the IFA (H) should be a small fraction of a wavelength.

2. Horn Antenna

A horn antenna may be regarded as a flared out or opened out waveguide. A waveguide is capable of radiating radiation into open space provided the same is excited at one end and open at the other end. If flaring is done in one direction, then sectorial horn is produced. Flaring in the direction of Electric vector and Magnetic vector, the sectorial E-plane horn and sectorial H-plane Horn are obtained respectively. If flaring is done along both walls (E and H) of the rectangular waveguide, then pyramidal horn is obtained. By flaring the walls of a circular waveguide, a conical horn is formed.

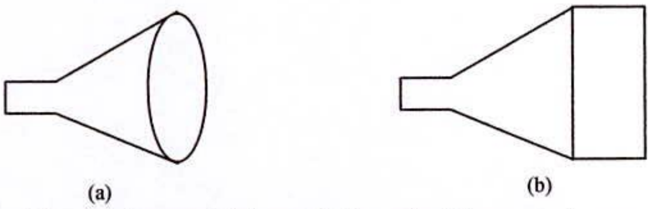


Fig. 2.2: (a) Pyramidal and (b) conical horn antennas

3. Parabolic Antenna

A parabolic antenna is an antenna that uses a parabolic reflector, a curved surface with the cross-sectional shape of a parabola, to direct the radio waves. The most common form is shaped like a dish and is popularly called a dish antenna or parabolic dish. The main advantage of a parabolic antenna is that it is highly directive. It functions similarly to a searchlight or flashlight reflector to direct the radio waves in a narrow beam or receive radio waves from one particular direction only. Parabolic antennas have some of the highest gains of any antenna type. In order to achieve narrow beam widths, the parabolic reflector must be much larger than the wavelength of the radio waves used. So, parabolic antennas are used in the high frequency part of the radio spectrum at UHF and microwave

(SHF) frequencies, at which wavelengths are small enough that conveniently sized dishes can be used.

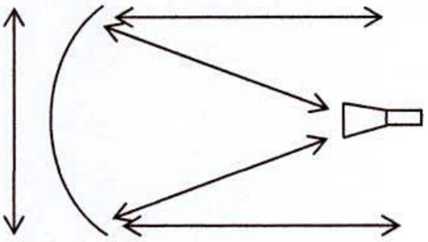
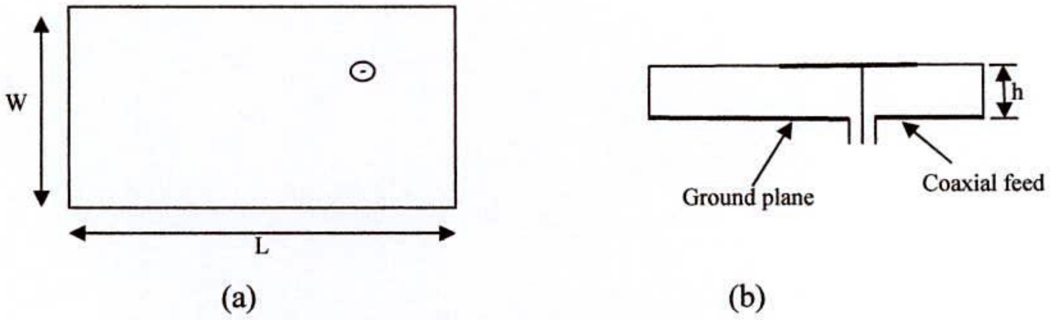


Fig. 2.3: Parabolic Antenna

4. Microstrip Patch Antenna

A patch antenna is a type of radio antenna with a low profile, which can be mounted on a flat surface. It consists of a flat rectangular sheet or patch of metal, mounted over a larger sheet of metal called a ground plane. The assembly is usually contained inside a plastic radiomen, which protects the antenna structure from damage. Patch antennas are simple to fabricate and easy to modify and customize. They are the original type of microstrip antenna described by Howell. The two metal sheets together form a resonant piece of microstrip transmission line with a length of approximately one-half wavelength of the radio waves. The radiation mechanism arises from discontinuities at each truncated edge of the microstrip transmission line. It is used in spacecraft or aircraft applications, where size, weight, cost, performance, ease of installation and aerodynamic profile are constraints. The major disadvantage of patch or microstrip antennas are their inefficiency and very narrow bandwidth.



(a) (b)

Fig. 2.4: Micro strip patch antenna (a) Top View (b) Side View

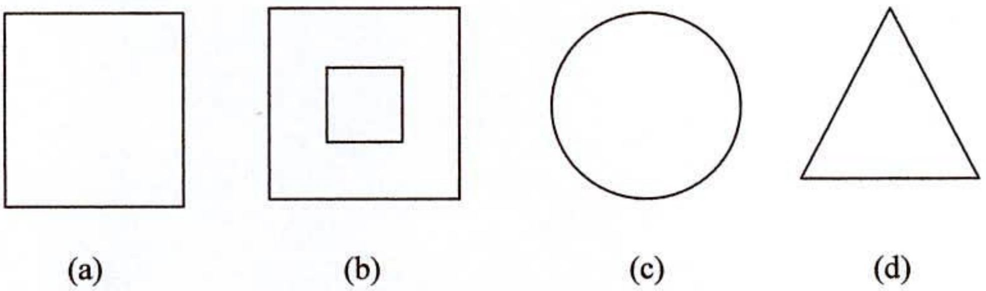


Fig. 2.5: Shapes of patch (a) Square, (b) Square ring, (c) Circular, (d) Triangular

2.2.3 Antenna Classification on Polarization Basis

1. Linearly (Vertically/Horizontally) Polarized Antenna

If antenna is transmitting/receiving vertical E field vector, then antenna is said to be vertically polarized antenna. If antenna is transmitting/receiving horizontal E field vector, then antenna is said to be horizontally polarized antenna. Dipole, Log periodic, yagi-uda and horn antennas are the examples of linearly polarized antenna.

2. Circularly Polarized Antenna

If the antenna is able to transmit or receive E field vectors of any orientation, then antenna is said to be circularly polarized antenna.

2.2.4 Antenna classification on Radiation Pattern Basis

1. Isotropic Antenna

An isotropic antenna is defined as an antenna which radiates uniformly in all directions. It is also called as isotropic source or omnidirectional antenna or simply unipole. An isotropic antenna is a hypothetical lossless antenna with which the practical antennas are compared. Thus an isotropic antenna is used as reference antenna. Let us assume that practical antenna is having a gain of 3 dBi means that gain of practical antenna is three times more than that of isotropic antenna when both the antenna are connected with same source.

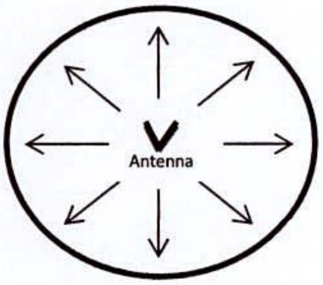


Fig. 2.6: Isotropic antenna

2. Omnidirectional Antenna

In radio communication, an omnidirectional antenna is an antenna which radiates radio wave power uniformly in all directions in one plane, with the radiated power decreasing with elevation angle above or below the plane, dropping to zero on the antenna's axis. Note that this is different from an isotropic antenna, which radiates equal power in all directions and has a spherical radiation pattern. Omnidirectional antennas are widely used for radio broadcasting antennas and in mobile devices that use radio such as cell phones, FM radios, walkie-talkies, wireless computer networks, cordless phones, GPS as well as for base stations that communicate with mobile radios such as police and taxi dispatchers and aircraft communications. Basically most of the wire antennas are having omnidirectional radiation pattern. Examples are Whip antenna, Dipole antenna etc. The radiation patterns of omnidirectional antennas are shown below.

Fig. 2.7: Omni directional antenna.

3. Directional Antenna

Antennas which directs its energy in one particular direction is said to be directional antennas. These antennas are having very high gain and directivity to cover large wireless distance. Examples are parabolic reflector antenna, Yagi-Uda antenna, Log periodic antenna etc. Radiation pattern of these antennas are shown below.

Fig. 2.8: Directional antenna

4. Hemispherical Antenna

Antenna whose radiation pattern will cover the one half of the hemisphere either upper hemisphere or lower hemisphere is said to be antenna with hemispherical radiation pattern. Such types are antennas are implemented on aircraft body to cover the lower hemisphere for data link purpose. Examples are all Monopoles antennas with large ground plane. The radiation pattern of these antennas is shown below.

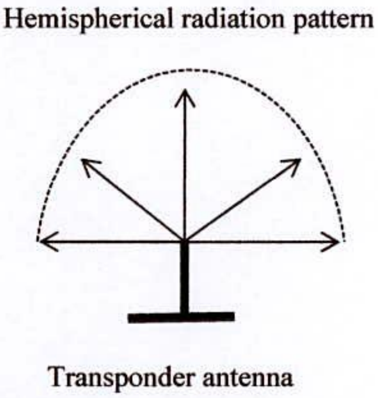


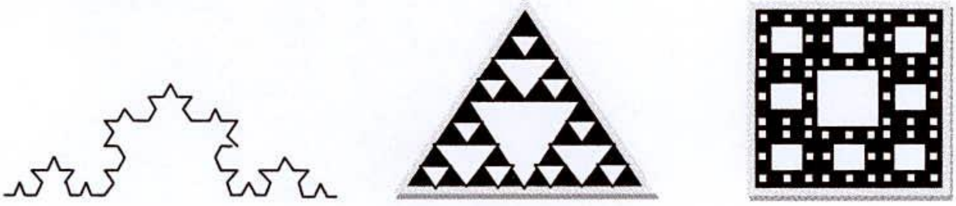
Fig. 2.9: Upper hemispherical radiation pattern

2.2.5 Fractal Antenna

The word fractal is derived from the Latin word ‘fractus’ that means broken. It was first introduced by Mandelbrot [4]. A fractal is a rough or fragmented geometric shape that can be subdivided in parts, each of which is a reduced-size [6] copy of the whole. Fractals are generally self-similar and independent of scale. 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 [7].

In recent years, Fractal geometries have been applied to antenna design to make multiband [8] and broadband antennas. In addition, fractal geometries have been used to miniaturize [15] the size of the antennas. However, miniaturization has been mostly limited to the wire antennas.

We can use fractal geometry in both wire and patch antennas. Fractal wire antennas include Koch Fractal, Hilbert Curve etc. Fractal Patch antennas include Sierpinski gasket, Sierpinski carpet etc.



(a) (b) (c)

Fig. 2.10: Fractal antennas (a) Koch Fractal (b) Sierpinski gasket (c) Sierpinski carpet

2.3 Properties of Antenna

There are several important antenna characteristics that should be considered when choosing an antenna. These are described below-

2.3.1 Operating Frequency

The operating frequency is the frequency range through which the antenna will meet all functional specifications. It depends on the structure of the antenna in which each antenna types has its own characteristic towards a certain range of frequency. The operating frequency can be tuned by adjusting the electrical length of the antenna.

2.3.2 Wavelength

We often refer to antenna size relative to wavelength. For example, a half-wave dipole, which is approximately a half-wavelength long. Wavelength is the distance that a radio wave will travel during one cycle. The formula for wavelength is-

$$\lambda = \frac{c}{f} \tag{1}$$

Where,

λ = wavelength

C = speed of light

f = frequency

2.3.3 VSWR

VSWR determines the matching properties of antenna. It indicates that how much efficiently antenna is transmitting/receiving electromagnetic wave over particular band of frequencies. The VSWR is given by,

$$VSWR = \frac{1 + S_{11}}{1 - S_{11}} \tag{2}$$

2.3.4 Return Loss

The return loss is another way of expressing mismatch. It is a logarithmic ratio measured in dB that compares the power reflected by the antenna to the power that is fed into the antenna from the transmission line. The relationship between SWR and return loss is the following,

$$RL = 20 \log_{10} \frac{SWR}{SWR - 1} \tag{3}$$

2.3.5 Bandwidth

Bandwidth can be defined as "the range of frequencies within which the performance of the antenna, with respect to some characteristics, conforms to a specified standard". Bandwidth is a measure of frequency range and is typically measured in hertz. For an antenna that has a frequency range, the bandwidth is usually expressed in ratio of the upper frequency to the lower frequency where they coincide with the -10 dB return loss value. The antenna's bandwidth is the number of Hz for which the antenna will exhibit an SWR less than 2. The bandwidth can also be described in terms of percentage of the center frequency of the band,

$$BW = 100 \frac{F_H - F_L}{F_C} \tag{4}$$

Where,

F_H = Highest frequency

F_L = Lowest frequency

F_C = Center frequency

In this way, bandwidth is constant relative to frequency. If bandwidth was expressed in absolute units of frequency, it would be different depending upon the center frequency. Different types of antennas have different bandwidth limitations.

2.3.6 Antenna Radiation Pattern

The radiation or antenna pattern describes the relative strength of the radiated field in various directions from the antenna, at a constant distance. The radiation pattern of any antenna determines its coverage area in free space. The radiation pattern is a "reception pattern" as well, since it also describes the receiving properties of the antenna. Example of radiation pattern is shown in Fig.2.11.

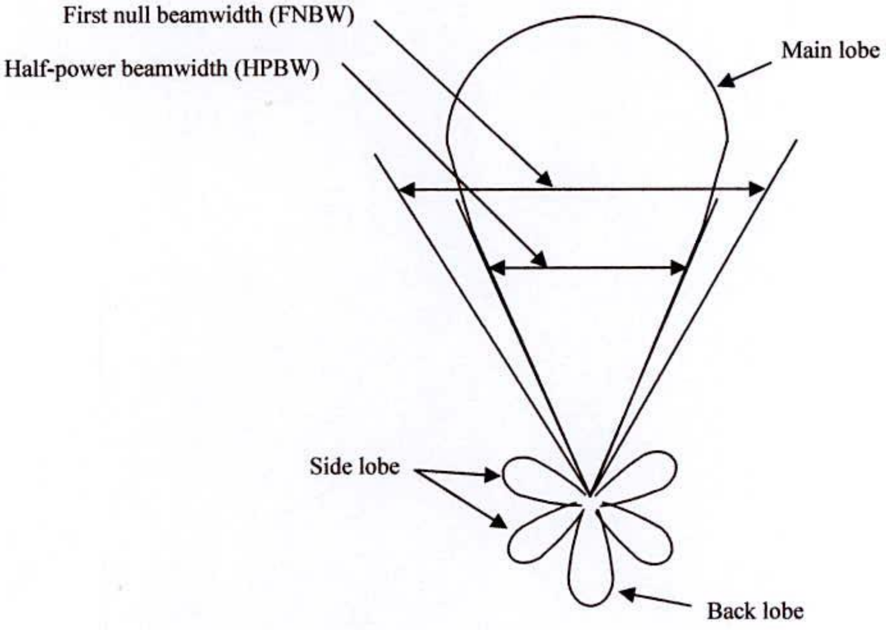


Fig. 2.11: Radiation pattern

2.3.7 Impedance

For efficient transfer of energy, the impedance of the radio, the antenna, and the transmission line connecting the radio to the antenna must be the same. Radios typically are designed for 50 ohms impedance and the coaxial cables (transmission lines) used with them also have a 50 ohm impedance. Efficient antenna configurations often have impedance other than 50 ohms; some sort of impedance matching circuit is then required to transform the antenna impedance to 50 ohms. If the return loss is known the input impedance is given by,

$$Z_{in} = Z_0 \left(\frac{1 + S_{11}}{1 - S_{11}}\right) \tag{5}$$

2.3.8 Radiation Resistance

The radiation resistance is a hypothetical resistance and does not correspond to a real resistor present in the antenna but to the resistance of space coupled via the beam to the antenna terminals. Antenna presents impedance at its terminals,

$$Z_A = R_A + jX_A \tag{6}$$

Where,

$R_A = R_r + R_l$

R_r = Radiation resistance

R_l = Ohmic loss resistance of antenna conductor

2.3.9 Antenna Efficiency (η)

The efficiency of antenna is defined as the ratio of power radiated to the total input power supplied to the antenna and is denoted by η.

Antenna Efficiency, η =Power Radiated/Total Input Power.

In terms of resistances,

$$\eta = [R_r / (R_r + R_l)] * 100 \tag{7}$$

Where,

R_r = Radiation resistance

R_l = Ohmic loss resistance of antenna conductor

CHAPTER 3

Fractals and Fractal Antennas

3.1 Introduction

The word fractal is derived from the Latin word 'fractus' that means broken, fragmented, fractional or irregular. The term 'Fractal' [4] was first introduced by Benoit Mandelbrot to classify the structure whose dimensions were not whole numbers. A fractal is a rough or fragmented geometric shape that can be subdivided in parts, each of which is a reduced-size copy of the whole. Fractals are generally self-similar and independent of scale. Examples are- length of a coastline, density of clouds and branching of trees, just as nature is not confined to Euclidean geometries.

The geometry of the fractal antenna encourages its study both as a multiband [9] solution and also as a small antenna. First, the self similar property to operate in a similar way at several wavelengths. Second, the space- filling properties of fractals allow fractal shaped small antennas [19] to better take advantage of the small surrounding space.

3.2 Definition of Fractal

Mandelbrot defines the term fractal in several ways. A fractal is a set for which the Hausdorff Besicovich dimension strictly exceeds its topological dimension. Every set having non-integer dimension is a fractal [10]. Fractal objects have some unique geometrical properties. This are-

i. A complex structure at any level of magnification.

ii. A non-integer dimension. We know that the dimension of lines, squares, and cubes are respectively 1, 2, and 3. The dimension of a fractal may be 1.342.

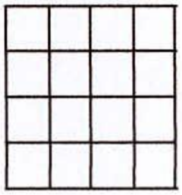
iii. Self-similar antenna [14] (which contains many copies of itself at several scales) to operate in a similar way at several wavelengths. That is, the antenna should keep similar radiation parameters through several bands.

iv. Space- filling properties [15] of some fractal shapes (the fractal dimension) might allow fractal shaped small antennas to better take advantage of the small surrounding space that means an infinite long curve in a finite area.

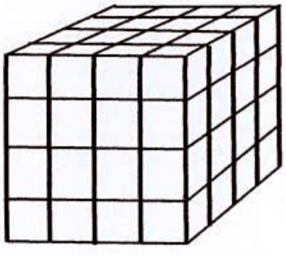
3.3 Dimension of Fractal

1. As we can see the line is broken into 4 smaller lines. Each of these lines is similar to the original line, but they are all 1/4 the scale. This is the idea of self-similarity.

2. The square below is also broken into smaller pieces. Each of which is 1/4th the size of the original. In this case it takes 16 of the smaller pieces to create the original.



3. As with the others the cube is also broken down into smaller cubes of 1/4 the size of the original. It takes 64 of these smaller cubes to create the original cube.



By looking at this we begin to see a pattern,

4 = 4^1

$16 = 4^2$

$64 = 4^3$

This gives us the equation, $N = S^D$

$D = \log N / \log S$

Here, $S = \frac{1}{\varepsilon}$

So, $D = \frac{\log(N)}{\log(1/\varepsilon)}$

Where N is the total number of distinct copies, and $(1/\varepsilon)$ is the reduction factor value which means how the length of the new side will be with respect to the original side length. This dimension is the Hausdorff-Besicovitch dimension.

3.4 Fractal Antenna

As we see fractals [11] have been studied for about a hundred years and antennas have been in use for as long, fractal antennas are new on the scene. These are low profile [24] antennas with moderate gain and can be made operative at multiple frequency bands and hence are multi-functional.

Nathan Cohen, radio astronomer at Boston University, was a fractal antenna [12] pioneer who experimented with wire fractal antennas (von Koch curves) and fractal planar arrays (Sierpinski triangles). He built the first known fractal antenna in 1988 when he set up ham radio station at his Boston apartment.

Puente carried out early work on fractals as multiband antennas, while credit for demonstrating the potential of fractals as small antennas is shared by Puente's group (UPC) and Cohen at the University of Boston.

3.5 Features of Fractal Antenna

3.5.1 Multiband/ Wideband Performance

It has been found that for an antenna, to work well for all frequencies, it should be:

- Symmetrical: This means that the figure looks the same as its mirror image.
- Self-similar: This means that parts of the figure are small copies of the whole figure.

These two properties are very common for fractals and thus make fractals [13] ideal for design of wideband and multiband antennas [16].

Application:

In modern wireless communications more and more systems are introduced which integrate many technologies and are often required to operate at multiple frequency bands. Examples of systems using a multi-band antenna are varieties of common wireless networking cards used in laptop computers. These can communicate on 802.11b networks at 2.4 GHz and 802.11g networks at 5 GHz.

3.5.2 Compact Size

Another requirement by the compact wireless systems for antenna design is the compact size. The fractional dimension and space filling property of fractal shapes allow the fractal shaped antennas to utilize the small surrounding space effectively [19]. This also overcomes the limitation of performance of small classical antennas.

Application:

The fractal antenna technology can be applied to cellular handsets. Because fractal antenna is more compact, it fit 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. However, for systems operating at high frequencies such as GSM, the length of these monopoles is longer than the handset itself. It would be highly beneficial to design an antenna based on fractal design with similar radiation properties as the quarter wavelength monopole [26] while retaining its radiation properties. This designed antenna will fit in a more compact manner.

3.5.3 Cost Effective

One practical benefit of fractal antenna is that it is a resonant antenna in a small space thereby excluding the need of attaching discrete components to achieve resonance [25]. In most of applications fractal antennas are small bendable etched circuit boards or fractal etchings on mother boards and contain no discrete components. This makes design of fractal antennas a cost effective technique [26].

3.6 Advantages and Disadvantages

The various advantages of fractal antennas can be listed as:

- Smaller cross sectional area.
- No impedance matching network required.
- Size can be shrunk from two to four times with surprising good performance.
- Multiband performance at non-harmonic frequencies.
- Improved Impedance, Improved SWR on a reduced physical area.
- No antenna tuning coils or capacitors are necessary.

The two main disadvantages are:

- Fabrication and design is little complicated
- Lower gain in some cases

Further investigations in this field may be helpful in overcoming these disadvantages.

3.7 Different Fractal Antennas

Fractal antennas can take on various shapes and forms depending on the different fractal geometries. Some of the different types of fractal antennas are:

3.7.1 Fractal Wire Antennas

1. Koch Fractal

Square Koch Fractal

Construction

Figure 3.1 shows the first three iterations in the construction of the square Koch curve [19]. This curve is constructed using iterative procedure beginning with the initiator of the set as the unit line segment (iteration 0). The unit line segment is divided into three segments, and the middle segment is removed. The middle segment is then replaced with three equal segments, which are of the same length as the first segment, which form a square (iteration 1). This step is the generator of the curve. At the next step (iteration 2), the middle segment is removed from each of the five segments and each is replaced with three equal segments as before. This process is repeated an infinite number of times to produce square Koch curve.

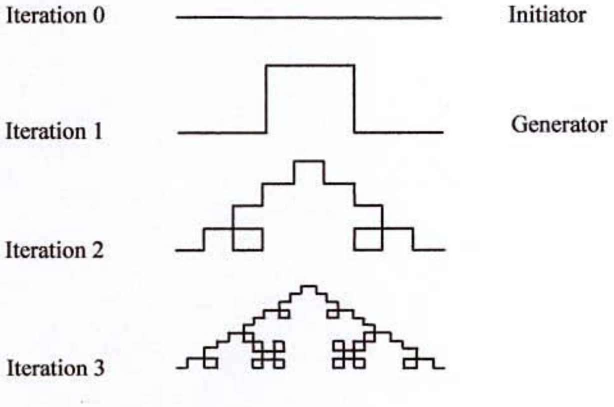


Fig. 3.1: First Three Iterations of the Construction of the Square Koch fractal structure.

Dimension of Square Koch Fractal

N = 5 (Each segment is replaced by 3 new segments)

$\varepsilon = \frac{1}{3}$ (Each new segment is one third the length of the previous segment)

$$s = \frac{1}{\frac{1}{3}} = 3$$

$$d = \frac{\log(5)}{\log(3)} = 1.46$$

Triangular Koch Curve

Construction

Start with a straight line. The straight line is divided into 3 equal parts, and the middle part is replaced by two linear segments at angles 60° and 120°. Then Repeat the steps1 and 2 to the four line segments. Further iterations will generate the following curves.

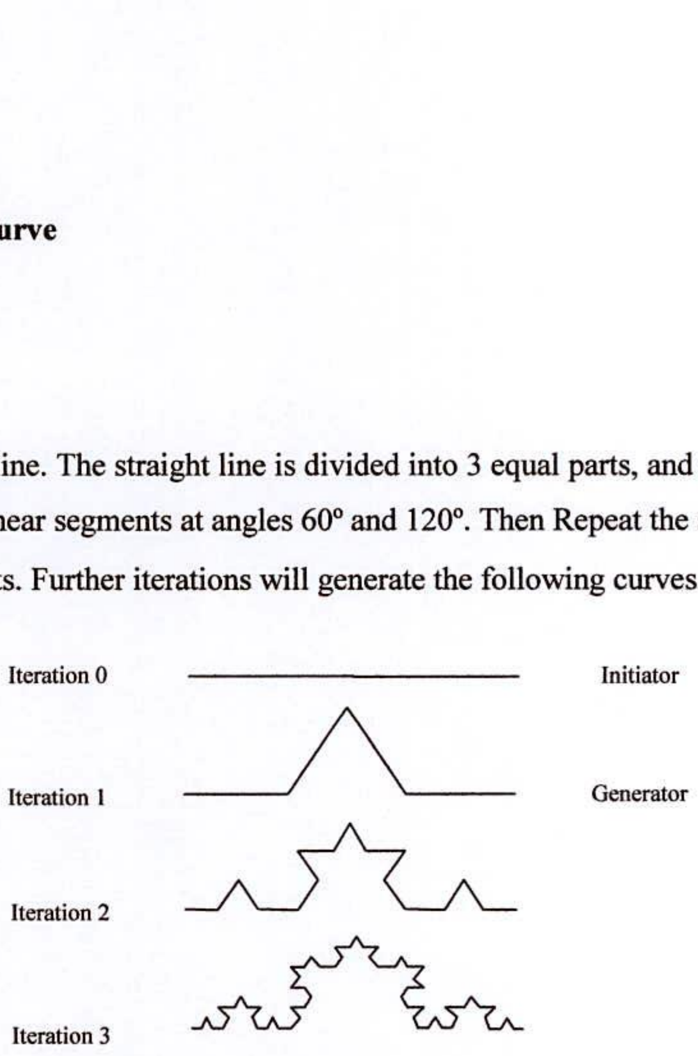


Fig. 3.2: The first four iterations in the construction of the triangular Koch curve

Dimension of Triangular Koch Fractal

N = 4 (Each segment is replaced by 4 new segments)

$\varepsilon = \frac{1}{3}$ (Each new segment is one third the length of the previous segment)

$$s = \frac{1}{\frac{1}{3}} = 3$$

$$d = \frac{\log(4)}{\log(3)} = 1.26$$

3.7.2 Fractal Patch antennas

1. The Sierpinski Triangle

The Sierpinski Triangle is named after the Polish mathematician Waclaw Sierpinski who described some of its interesting properties in 1916. It is one of the simplest fractal shapes in existence.

Construction

Start with the equilateral triangle. Connect the midpoints of each side of the triangle to form four separate triangles [17]. Then, cut out the triangle in the center. Repeat the steps 1, 2, and 3 on the three black triangles left behind. The center triangle of each black triangle at the corner was cut out as well. Further repetition with adequate screen resolution will give the following pattern.

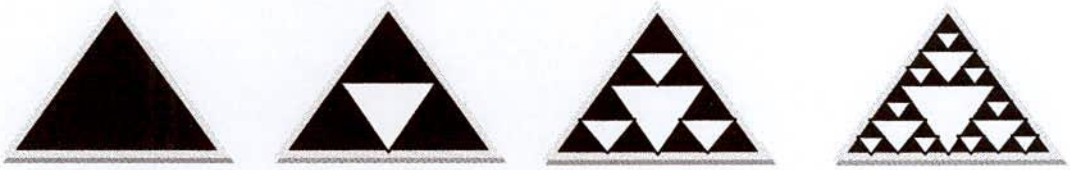


Fig. 3.3: Construction of the Sierpinski Triangle

Dimension of Sierpinski Triangle

N= 3 (Each triangle is replaced by three new triangles)

$\varepsilon = \frac{1}{2}$ (Each segment is one-half the original segment)

$s = 2$

$$d = \frac{\log(3)}{\log(2)} = 1.58$$

2. The Sierpinski Carpet

Construction

The Sierpinski Carpet starts with a square, which is divided into 9 smaller squares, and cuts out the center square. The Sierpinski carpet is designed using squares as shown in Figure 3.4. In order to start this type of fractal antenna [16], it begins with a square in the plane, and then divides it into nine smaller congruent squares where the open central square is dropped. The remaining eight squares are divided into nine smaller congruent squares with each central are dropped.

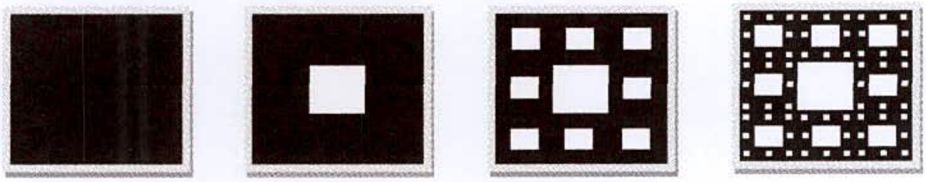


Fig. 3.4: Construction of the Sierpinski Carpet

Dimension of Sierpinski Carpet

N = 8 (Each segment is replaced by 4 new segments)

$\varepsilon = \frac{1}{3}$ (Each new segment is one third the length of the previous segment)

$$s = \frac{1}{\frac{1}{3}} = 3$$

$$d = \frac{\log(8)}{\log(3)} = 1.89$$

CHAPTER 4

Design of the Square Koch Fractal Antenna

4.1 Introduction

The Simplest example of antenna using fractal geometry is given by the Swedish mathematician H. von Koch in 1904, which is known as Koch fractal. In this project a wire square Koch fractal antenna is designed based on the first and second iterations of square Koch curve geometry [23]. It is a very elementary example of fractal, as it follows a simple rule of construction.

The square Koch curve [21] clearly shows the self-similarity of fractal. The same pattern appears everywhere along the curve in different scale, from visible to infinitesimal.

The square Koch curve also shows the space filling property that means an infinite long curve in a finite area and this property helps to make miniaturize[20] antennas.

4.2 Antenna Geometry

Figure 3.1 shows the first three iterations in the construction of the square Koch curve [19]. This curve is simply constructed using iterative procedure beginning with the initiator of the set as the unit line segment (iteration 0). The unit line segment is divided into three segments, and the middle segment is removed. The middle segment is then replaced with three equal segments, which are of the same length as the first segment, which form a square (iteration 1). This step is the generator of the curve. At the next step (iteration 2), the middle segment is removed from each of the five segments and each is replaced with three equal segments as before. This process is repeated an infinite number of times to produce square Koch curve [section-3.7.1].

Figure 4.1 shows the first iteration and Figure 4.2 shows the second iteration of square Koch antenna. The antenna design and simulation has been performed using the 4NEC2 package.

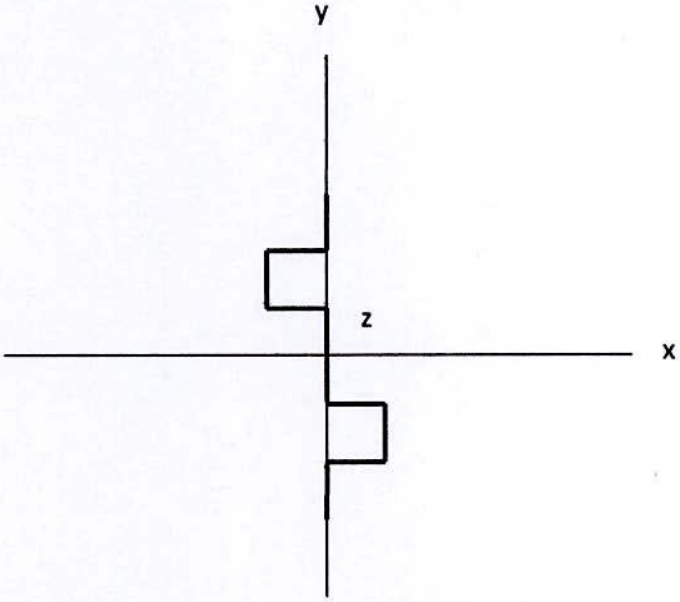


Fig. 4.1: First iteration of square Koch antenna

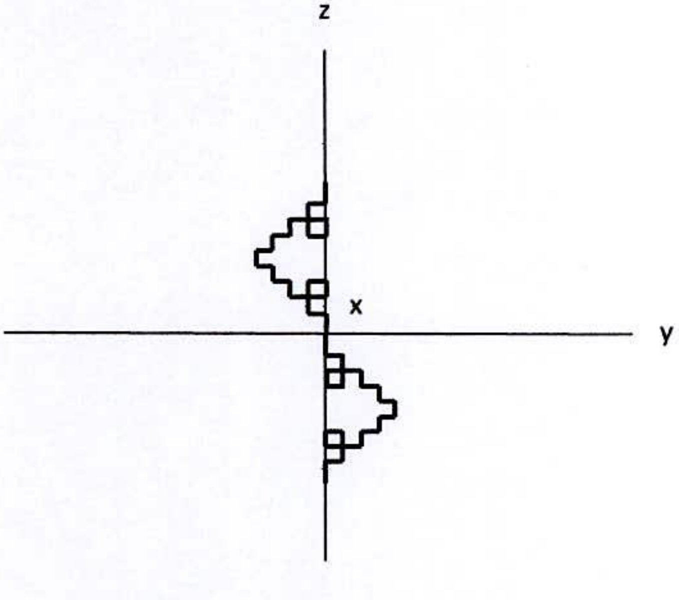


Fig. 4.2: Second iteration of square Koch antenna

4.3 Fractal Dimension

Different from Euclidean geometries, fractal geometries are characterized by their non-integer dimensions. Fractal dimension [18] contains information about the self-similarity and the space-filling properties of any fractal structures [23]. The fractal similarity dimension (FD) is defined as:

$$FD = \frac{\log(\mathrm{N})}{\log(1/\varepsilon)} = \frac{\log(5)}{\log(3)} = 1.46 \tag{8}$$

Where N is the total number of distinct copies, and $(1/\varepsilon)$ is the reduction factor value which means how the length of the new side will be with respect to the original side length.

4.4 Total Length of Square Koch

The space filling properties lead to curve that is electrically very long, but fit into a compact physical space. This property leads to miniaturization of antenna elements. With successive iteration the length of Koch increases by 2/3 of the original length. Length of Koch after nth iterations [22],

$$l_n = l_o(5/3)^n \tag{9}$$

Where l_n and l_o are the length after nth iteration and original length respectively.

4.5 Total Number of Square Koch

After each iteration, every single edge turns into five equal sized segments with length 1/3 of the original length. Thus, after n iterations, the total number of the Koch Edge will be,

$$5\text{^}n \tag{10}$$

4.6 Antenna Design

The antenna, based on the first and second iterations of square Koch curve, has been modeled, analyzed, and its performance is evaluated using the commercially available software 4NEC2. The Method of Moment (MOM) is used to calculate the current distribution along the square Koch curve, and hence the radiation characteristics of the antenna [10]. Typical geometry of square Koch fractal antenna is based on the first and second iterations as shown in Figure 4.1 and 4.2, where the antenna is placed in the XY and YZ-plane.

The feed source point of this antenna is placed at the origin (0, 0, 0) and this source is set to 1 volt. The design frequency has been chosen to be 750 MHz for which the design wavelength λ is 0.4m (40 cm) then the length of the corresponding $\lambda/2$ dipole antenna length will be 20 cm, as shown in Figure 4.1 and 4.2.

In designing multiband [9] and small size fractal square Koch antenna design for UHF/SHF [5] Application, the numerical simulations of the antenna system are carried out via the method of moments [18]. Commercial Numerical Modeling software 4NEC2 is used in all simulations. The NEC is a computer code based on the method of moment for analyzing the electromagnetic response of an arbitrary structure consisting of wires or surfaces, such as Hilbert and Koch curves [23]. The modeling process is simply done by dividing all straight wires into short segments where the current in one segment is considered constant along the length of the short segment. It is important to make each wire segment as short as possible without violation of maximum segment length-to-radius ratio computational restrictions. In 4NEC2, to model wire structures, the segments should follow the paths of a conductor as closely as possible.

CHAPTER 5

Simulation of Square Koch Fractal Antenna

5.1 Introduction

This chapter represents the simulation of multiband square Koch fractal antenna, where it is shown that as the iterations are increased the bands of frequencies also increase and the size is also reduced. The designed antenna has operating frequencies for first iteration are of 496 MHz and 1430 MHz, and for second iteration are of 460 MHz, 1248 MHz, 1926 MHz and 4390 MHz with acceptable bandwidth, which has useful applications in UHF/SHF. The radiation characteristics, SWR, return loss, input impedance, and gain of the proposed antenna are described with 4NEC2 software package. Here, the antenna is placed in the XY-plane for first iteration and in YZ-plane for second iteration.

Figure 3.1 shows the first three iterations in the construction of the square Koch curve [19]. This curve is constructed using iterative procedure beginning with the initiator as the unit line segment (iteration 0). The unit line segment is divided into three segments, and the middle segment is removed. The middle segment is then replaced with three equal segments, which are of the same length as the first segment, which form a square (iteration 1). At the next step (iteration 2), the middle segment is removed from each of the five segments and each is replaced with three equal segments as before. This process is repeated an infinite number of times to produce square Koch curve [section-3.9.1].

5.2 Simulation Results

In this work, Method of Moment simulation code (NEC) is used to perform a detailed study of SWR, reflection coefficient, input impedance, gain and radiation pattern characteristics of the square Koch antenna in a free space.

For first iteration, the frequency range is from 0 GHz to 3 GHz which is used in UHF application and for second iteration, the frequency range is from 0 GHz to 5 GHz which is used in UHF/SHF application.

SWR:

For First Iteration:

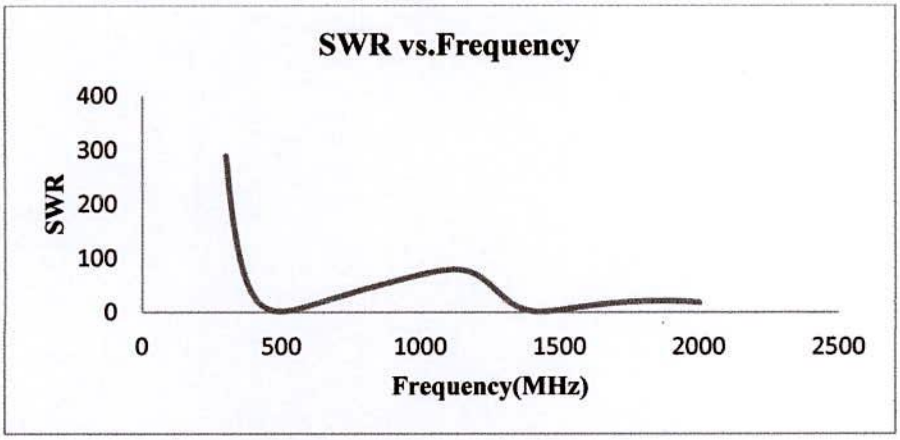


Fig. 5.1: SWR vs. Frequency for first iteration

For Second Iteration:

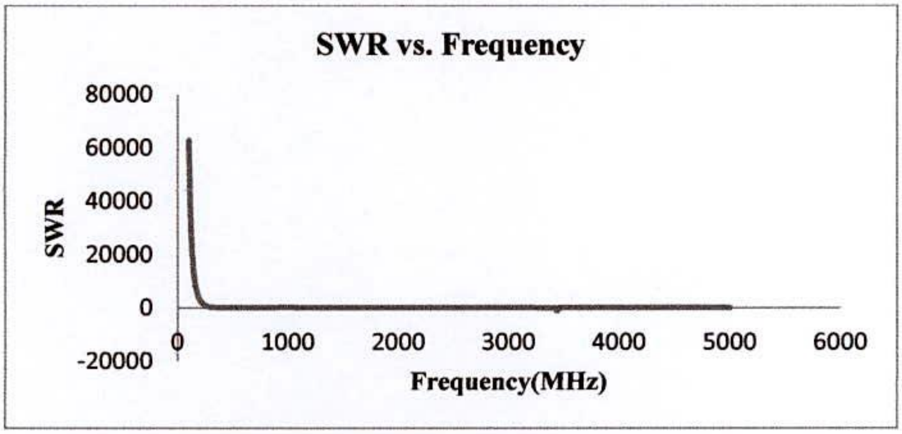


Fig. 5.2: SWR vs. Frequency for second iteration

As per the theory voltage standing wave ratio should be ≤ 2. Ideally it should be 1. Here, for both iteration SWR is less than 2.

Return Loss:

For First Iteration:

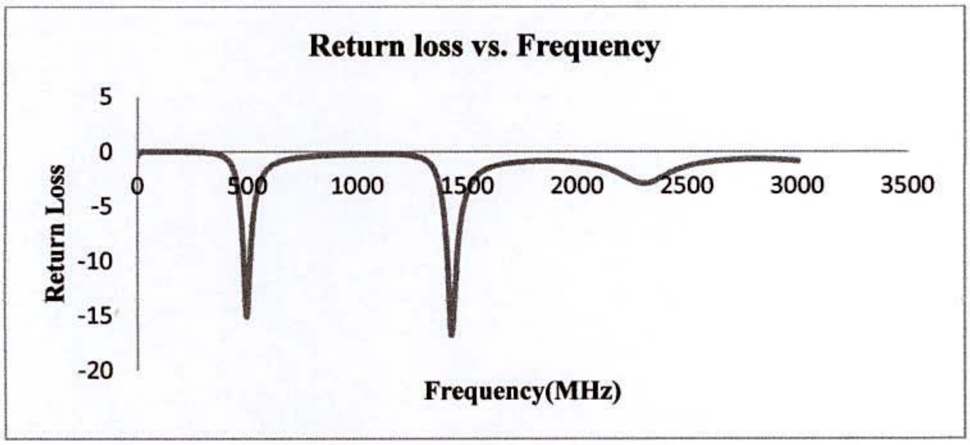


Fig. 5.3: Return loss vs. Frequency for first iteration

For Second Iteration:

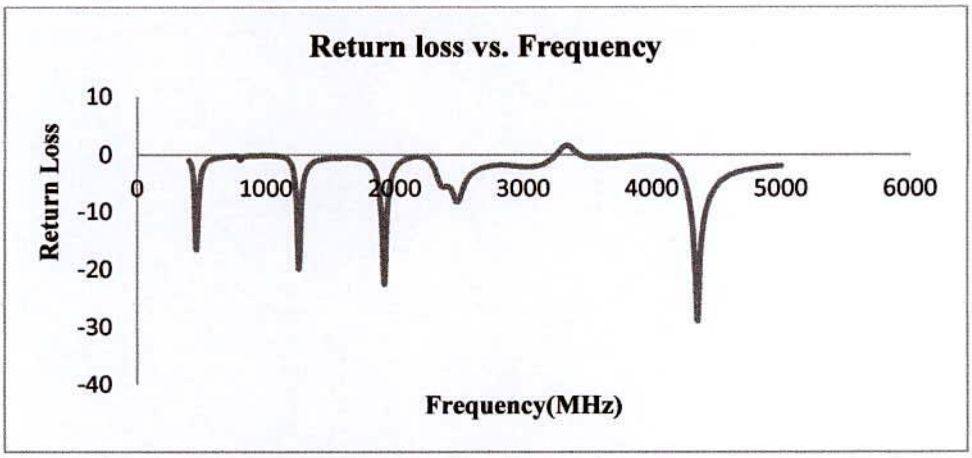


Fig. 5.4: Return loss vs. Frequency for second iteration

The return loss is shown in Figure 5.3 and 5.4. It shows that the antennas have a good return loss with respect to -10 dB. It seems that the resonance frequency of the antenna is increasing when more iteration is applied on the Koch curve. It is important to note that the return loss is calculated with 50 load impedance.

Gain:

For First Iteration:

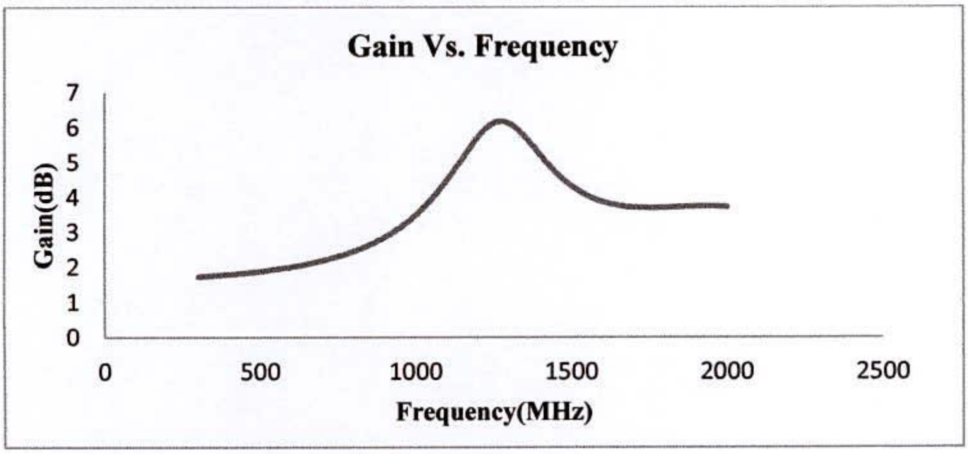


Fig. 5.5: Gain vs. Frequency for first iteration

For Second Iteration:

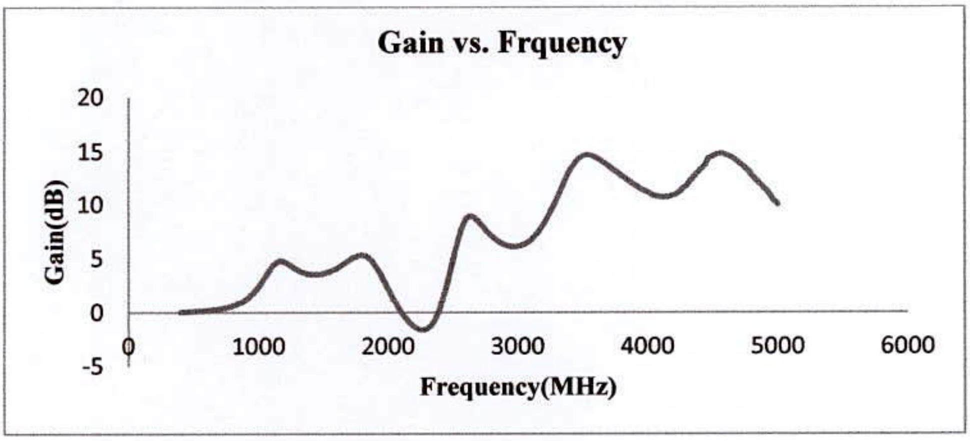


Fig. 5.6: Gain vs. Frequency for second iteration

For first iteration, the gain of the antenna at 496 MHz is 1.88 dB and at 1430 MHz the gain is 4.91 dB. For second iteration, the gain is .58 dB, 4.36 dB, 1.26 dB, and 12 dB at frequencies 460 MHz, 1248 MHz, 1926 MHz, and 4390 MHz respectively. Obviously, the fractal antenna exhibits a wider bandwidth, but the gain is smaller. The antenna has a higher gain when it gives higher values at that particular frequency. However, it might have a lower gain when it is working outside its operating region.

Real Part of Input Impedance:

For First Iteration:

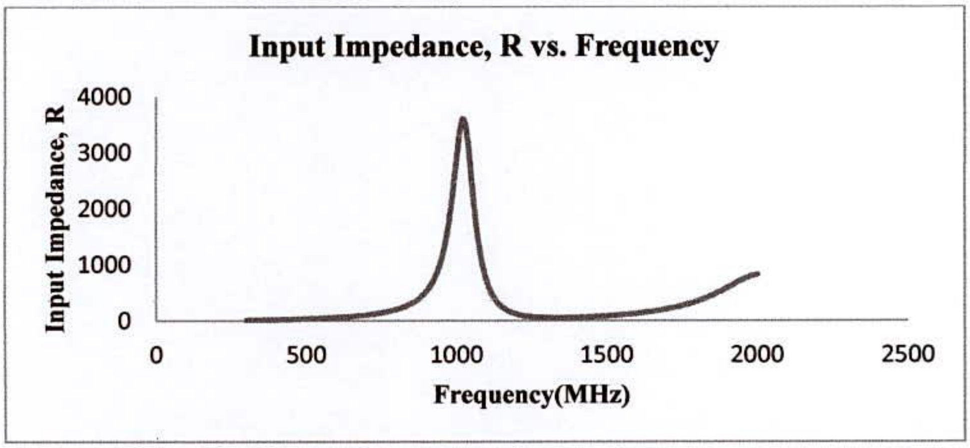


Fig. 5.7: Input Impedance(R) vs. Frequency for first iteration

For Second Iteration:

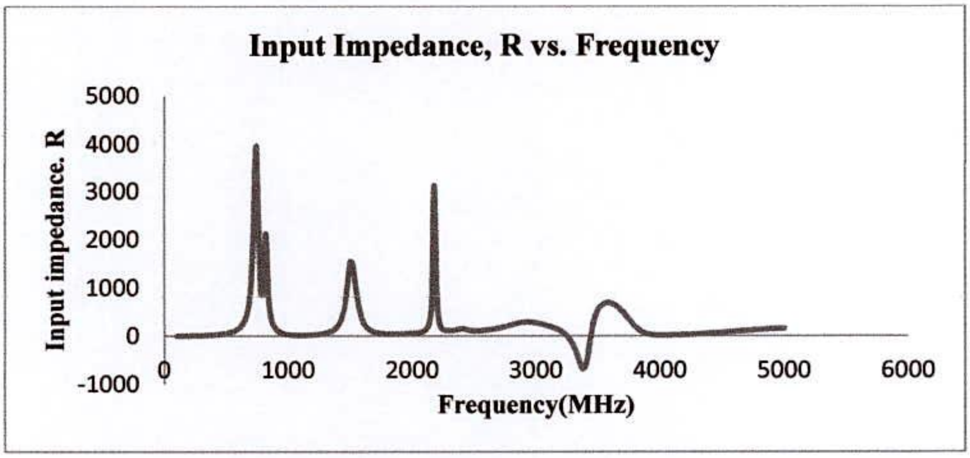


Fig. 5.8: Input Impedance(R) vs. Frequency for second iteration

In Figure 5.7 and 5.8 the real part of the impedance can be seen after different number of iteration of the Koch curve. It can be observed that the peak value of the curve is increasing and the position of the peak is decreasing in the function of the iteration number. Normally its value is 50 ohm.

Imaginary Part of Input Impedance :

For First Iteration:

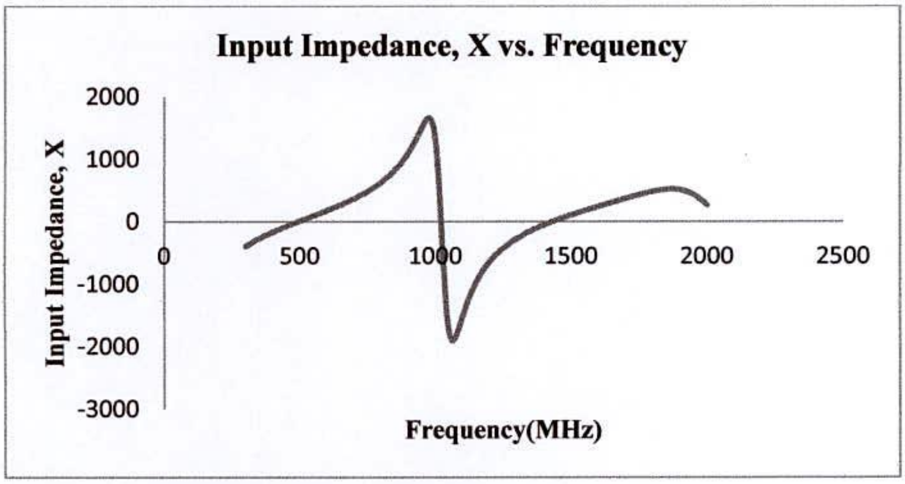


Fig. 5.9: Input Impedance(X) vs. Frequency for first iteration

For Second Iteration:

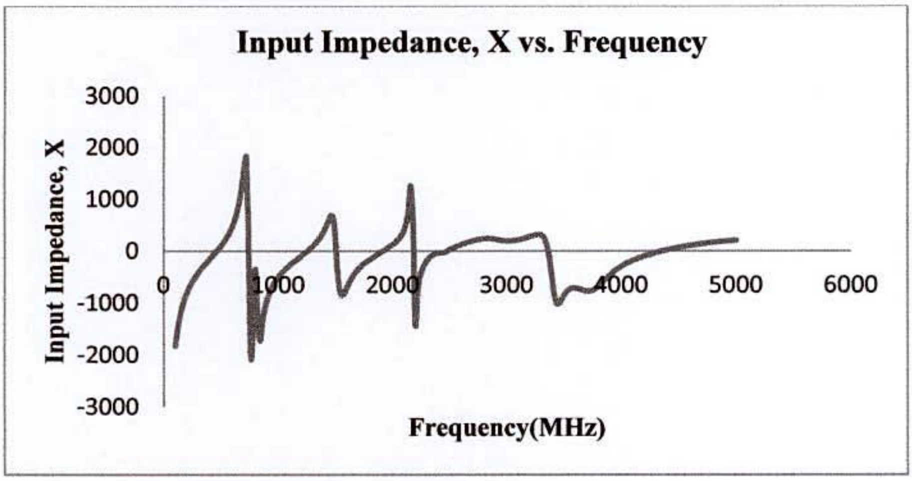


Fig. 5.10: Input Impedance(X) vs. Frequency for second iteration

The imaginary part of the input impedance can be seen in Figure 5.9 and 5.10. The peak values are increasing and the frequency of the peak is decreasing in the function of the iteration number. By the modification of the iteration number, the length and the angle between the components of the Koch curve the impedance of the antenna can be set.

These resonant frequencies, input impedance, SWR, return loss and gain for first and second iteration are shown in table 5.1 and 5.2

Table 5.1: Resonant Frequency and Input Impedance, SWR, Return Loss, and Gain for First Iteration

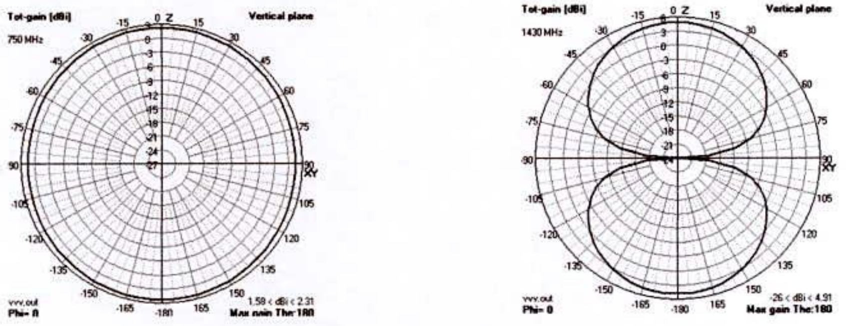
Frequency(MHz)	SWR	Return Loss	Gain (dB)	Input Impedance	
				R	X
496	1.42	-15.048	1.88	35.362	3.750
1430	1.31	-17.292	4.91	65.817	0.181

Table 5.2: Resonant Frequency and Input Impedance, SWR, Return Loss, and Gain for Second Iteration

Frequency (MHz)	SWR	Return Loss	Gain(dB)	Input Impedance	
				R	X
460	1.20	-16.747	0.58	41.622	-0.711
1248	1.23	-19.649	4.36	40.568	0.299
1926	1.07	-22.506	1.26	46.397	-0.360
4390	1.59	-28.841	12	78.942	-5.297

Radiation Pattern:

For First Iteration:

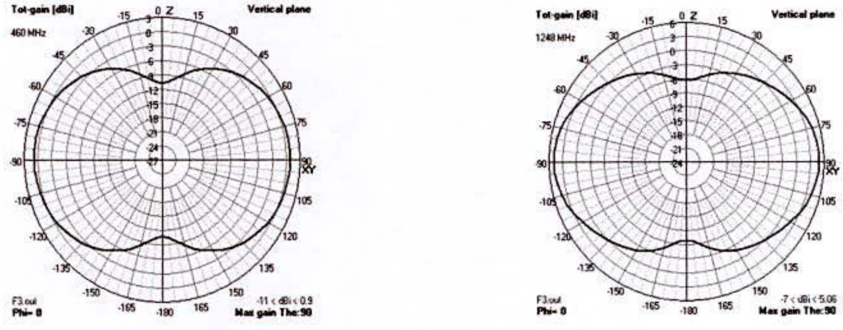


(a) f =496 MHz

(b) f =1430 MHz

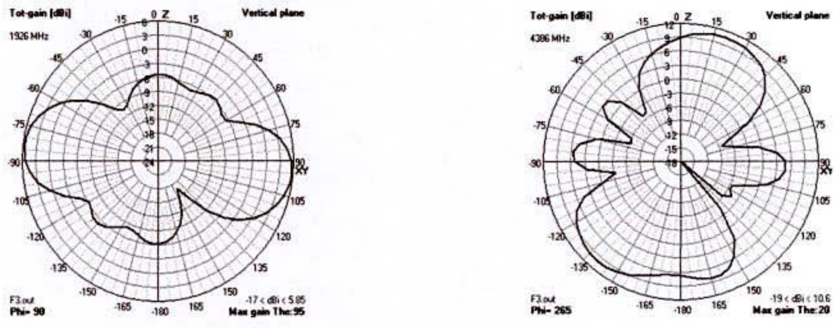
Fig. 5.11: XY-plane Radiation Patterns at Resonant Frequencies of (a) f= 496 MHz, (b) f= 1430 MHz

For Second Iteration:



(a) f =460MHz

(b) f =1248MHz



(c) f =1926MHz

(d)f =4390MHz

Fig. 5.12: YZ-plane Radiation Patterns at Resonant frequencies of (a) f= 460 MHz, (b) f= 1248 MHz, (c) f= 1926 MHz (d) f= 4390 MHz

The analysis for radiation patterns for Fractal Koch antennas for the first and second iterations is discussed in Fig. 5.11 and 5.12. The radiation pattern for the 1st iteration at 496 MHz and 1430 MHz is depicted in Figure 5.11 and the radiation patterns for second iteration at 460 MHz, 1248 MHz, 1926 MHz and 4390 MHz are shown in Figure 5.12. The measured radiation patterns show that the antennas are linearly polarized.

The simulation results show that this antenna can be efficiently operated as a multiband antenna. The proposed antenna has two resonance bands for first iteration at frequencies of 496 MHz and 1430 MHz. Also the antenna has four resonance bands for second iteration at frequencies 460 MHz, 1248 MHz, 1926 MHz and 4390 MHz. From this, we can say that, as the iterations are increased, the band of frequencies also increase. At these frequencies the antenna has SWR<2, Return loss is less than -10. The gains at these frequencies are also acceptable.

5.3 Miniaturization Technique of Square Koch Fractal Antenna

With successive iteration the length of Koch increases by 2/3 of the original length. Length of Koch after nth iterations,

$$l_n = l_o(5/3)^n \tag{11}$$

Where l_n and l_o are the length after nth iteration and original length respectively. And, after nth iterations, the total number of the Koch Edge will be

$$5\text{^}n \tag{12}$$

By using the above two formulas, the miniaturization of square Koch fractal can be calculated.

CHAPTER 6

Conclusion

6.1 Conclusion

In this project, the square Koch fractal antenna based on the first and second iterations is investigated and its performance is evaluated. The simulation results show that this antenna can be efficiently operated as a multiband antenna and it is also compact in size. The proposed antenna has two resonance bands for first iteration at frequencies of 496 MHz and 1430 MHz. Also the antenna has four resonance bands for second iteration at frequencies 460 MHz, 1248 MHz, 1926 MHz, and 4390 MHz. From this, we can say that, as the iterations are increased, the band of frequencies also increase but the physical length does not increase. At these frequencies the antenna has SWR<2, Return loss is less than -10. The gains at these frequencies are also acceptable. The radiation pattern is very uniform in all directions. And the antenna has the required band for UHF/SHF. So, this antenna can operate as a small multiband antenna in the UHF/SHF applications.

REFERENCES

1. B.B. Mandelbrot, "The Fractal geometry of Nature," New York, 1983.
2. Balanis C.A., "Antenna Theory: Analysis and Design", Second Edition, New York, John Wiley& Sons, Inc., 2003.
3. K.D Prasad, "Antennas & wave propagation", ISBN no. 81-7634-025-4, third edition.
4. Jibrael, F. J.: Miniature Dipole Antenna Based on the Fractal Square Koch Curve, European Journal of Scientific Research, Vol. 21, No.4, 2008, pp. 700-706.
5. Zainud-Deen, S. H., Mallrat, H. A., Awadalla, K. H.: Fractal Antenna for Passive UHF RFID Applications, Progress In Electromagnetic Research B, Vol. 16, 2009, pp. 209-228.
6. Mirzapour, B. and H. R. Hassani, Size reduction and bandwidth enhancement of snowflake fractal antenna," Microwaves, Antennas &Propagation, IET, 180-187, Mar. 2008.
7. D. H. Werner and S. Ganguly, "An Overview of Fractal Antennas Engineering Research", IEEE Antennas and Propagation Magazine, vol. 45, no. 1, pp. 38-57, February 2003.
8. T. Tiehong and Z. Zheng, " A Novel Multiband Antenna: Fractal Antenna", Electronic letter, Proceedings of ICCT – 2003, pp: 1907-1910.
9. Lee. Y., Yeo. J., Mittra R., Ganguly S. and Tenbarge J., "Fractal and Multiband Communication Antennas", IEEE Conf. on Wireless Communication Technology, pp. 273-274, 2003.

10. Cohen N., "Fractal Antennas: Part I", Communications Quarterly, summer, pp. 7-22, 1995.

11. Cohen N., "Fractal Antennas: Part 2", Communications Quarterly, summer, pp. 53-66, 1996.

12. Kravchenko V.F., "The theory of fractal antenna arrays", Antenna Theory and Techniques IVth Inter. Conf., Vol. 1, pp. 183- 189, 2003.

13. Gianvittorio, J., Fractal antenna: Design, characterization, and Progress In Electromagnetics Research, PIER 100, 2010.

14. Nima Bayatmaku, Parisa Lotfi, Mohammadnaghi Azarmanesh, Member, IEEE, and Saber Soltani," Design of Simple Multiband Patch Antenna For Mobile Communication Applications Using New E-Shape Fractal", IEEE antennas and wireless propagation letters, vol. 10, 2011.

15. Gianviffwb J.P. and Rahmat-Samii Y., "Fractals Antennas: A novel Antenna Miniaturization Technique, and Applications", IEEE Antennas and Propagation Magazine, Vol. 44, pp. 20- 36, 2002.

16. Kuem C. Hwang, "A Modified Sierpinski Fractal Antenna for Multiband Application" proceedings of the IEEE Antennas and Propagation Letters, Vol. 6, 2007.

17. Yeo J. and Mittra R., "Modified Sierpinski Gasket Patch Antenna for Multiband Applications'', IEEE International Symp. On Antennas and Propagation Digest, 2001.

18. K.J. Vinoy, K.A. Jose, and V.K. Varadan, "Multiband characteristics and fractal dimension of dipole antennas with Koch curve geometry," IEEE 2002 AP-S Inter. Symp., 2002.

19. Puente C., Romeu J., Pous R., Ramias J. and Hijazo A., "Small but long Koch fractal monopole", IEE Electronic Letters, Vol. 34, 1, pp. 9-10, 1998.

20. C.P. Baliarda, J. Romeu, and A. Cardama, "The Koch monopole: A small fractal antenna," IEEE Trans. Ant. Propagat., vol. 48 pp. 1773-1781, 2000.

21. S.H Zainud-Deen, K.H. Awadalla S.A. Khamis and N.d. El-shalaby, March 16-18, 2004. Radiation and Scattering from Koch Fractal Antennas. 21st National Radio Science Conference (NRSC), B8 - 1-9.

22. JAMIL, A., YUSOFF, M.Z., YAHYA, N. Small Koch fractal antennas for wireless local area network. In Proceedings of the International Conference on Communication Systems ICCS 2010. Singapore: National University of Singapore, 2010, p. 104–108.

23. BEST, S.R. On the resonant properties of the Koch fractal and other wire monopole antennas. *IEEE Antennas and Wireless Propagation Letter,* 2002, vol. 1, no. 1, p. 74–76.

24. JAMIL, A., YUSOFF, M.Z., YAHYA, N. Small Koch fractal antennas for wireless local area network. In *Proceedings of the International Conference on Communication Systems ICCS 2010*. Singapore: National University of Singapore, 2010, p. 104–108.

25. www. fractus. com, 2000.

26. www. fractenna. com, 2000.