ANTENNA MINIATURIZATION USING FRACTALS

Thesis
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IN
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Submitted by
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Certificate

This is to certify that the thesis entitled **“Antenna Miniaturization using Fractals”** submitted by Mr. Dheeraj Kalra, in partial fulfillment of the requirement for the award of the degree of **Master of Engineering** in **Electronics & Communication** to Thapar Institute of Engineering & Technology (Deemed University), Patiala, India, is a record of candidate’s own work carried out by him under my supervision and guidance. The matter embodied in this dissertation has not been submitted in part or full to any other university or institute for the award of any degree.

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ABSTRACT

The wireless industry is witnessing an volatile emergence today in present era. Today's antenna systems demand versatility and unobtrusiveness. Operators are looking for systems that can perform over several frequency bands or are reconfigurable as the demands on the system changes. Some applications require the antenna to be as miniaturized as possible. Fractal plays a prominent role for these requirements. Fractals have non-integral dimensions and their space filling capability could be used for miniaturizing antenna size and their property of being self-similarity in the geometry leads to have antennas which have a large number of resonant frequencies. Fractal antennas also have Multiband performance is at non-harmonic frequencies. Fractal antennas have improved Impedance, improved SWR(standing wave ratio) performance on a reduced physical area when compared to non fractal Euclidean geometries. Fractal antennas show Compressed Resonant behavior. At higher frequencies the Fractal antennas are naturally broadband. Polarization and phasing of Fractal antenna is possible. In many cases, the use of fractal element antennas can simplify circuit design. Often fractal antenna do not require any matching components to achieve multiband or broadband performance. Perturbation could be applied to shape of fractal antenna to make it to resonate at different frequency.

In this thesis Koch fractal, Sierpinski Triangle, Sierpinski Carpet ,Julia fractal with different iterations have been generated using MATLAB. Koch fractal of length 5.1c.m. with different iterations as a monopole antenna have been simulated using MATLAB and EZNEC code which is a MININEC code, and show the desirable advantages of fractal antennas. Different three iteration Koch fractal monopoles have been studied for GSM900 and GSM1800 bands .The Koch monopole exhibits excellent performance at 925 MHz and 1800Mhz and has radiation properties nearly identical to that of traditional, straight-wire monopoles at that frequency. The greatest

advantage of the Koch monopole design is compactness. A size reduction of nearly 50% was achieved over the straight-wire, , $\lambda/4$ free-space monopole. This is highly significant for applications such as GSM cellular phones. Since it is half the size of the traditional monopole, it could easily be completely integrated within the case of the phone, eliminating the protruding monopoles commonly seen on many cellular phones. Since the radiation pattern is highly uniform and identical to that of a traditional $\lambda/4$ monopole, it could be used in nearly any type of wireless communications receiver. The very similar gain to the traditional $\lambda/4$ monopole is another benefit of the design. Another beneficial of fractal antennas is fractal antennas are in form of a PCB. Thus the Koch monopole presents an excellent, compact solution to the traditional straight-wire monopole.

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Introduction

1.1 Overview

The wireless industry is witnessing an volatile emergence today in present era. Today's antenna systems demand versatility and unobtrusiveness. Operators are looking for systems that can perform over several frequency bands or are reconfigurable as the demands on the system changes. Furthermore, aesthetics in the design of the systems are always important Some applications require the antenna to be as miniaturized as possible. Fractal antennas have entered the view of many as a very promising solution. Fractal antenna theory is a relatively new area. However, fractal antennas and its superset fractal electrodynamics is a state of affairs for research activity. Although fractal geometry has been known to mathematics for a century, fractal antenna engineering research is a relatively very recent development because considerable computing speed is required to complete their design.

In the research journals, we see reports of active research covering such diverse areas of Fractals use in antenna field and their advantages. Fractals are self-similar objects and possess structure at all scales. Fractal geometries have found an intricate place in science as a representation of some of the unique geometrical features occurring in nature. Fractal geometry was first discovered by Benoit Mandelbrot as a way to mathematically define structures whose dimension can not be limited to whole numbers.

Benoit Mandelbrot, the pioneer of classifying this geometry, first coined the term 'fractal' in 1975 from the Latin word *fractus*, which means broken. The field is quite extensive with many applications from statistical analyses, natural modeling, compression and, of course, computer graphics [1]. Soon after scientists discovered the practical aspect of fractal geometry, research began in the field of electrodynamics[2].To date most efforts have been concentrated in understanding the physical process and mathematical background of interaction between electromagnetic waves and fractal structures.

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

Fractals are space filling contours, meaning electrically large features can be efficiently packed into small areas [1]. Since the electrical lengths play such an important role in antenna design, this efficient packing can be used as a viable miniaturization technique. Fractals are structures of infinite complexity with a self-similar nature. What this means, is that as the structure is zoomed in upon, the structure repeats itself. This property could be used to design antennas that can operate at several frequencies.

Fractal antenna theory uses a modern (fractal) geometry that is a natural extension of Euclidian geometry. A fractal can fill the space occupied by the antenna in a more effective manner than the traditional Euclidean antenna. This can lead to more effective coupling of energy from feeding transmission lines to free space in less volume. Therefore, Fractals can be used in two ways to enhance antenna designs. The first method is in the design of miniaturized antenna elements. These can lead to antenna elements which are more discrete for the end user. The second method is to use the self-similarity in the geometry to blueprint antennas which are multiband or resonant over several frequency bands. This would allow the operator to incorporate several aspects of their system into one antenna. Such antennas could be used to improve the functionality of modern wireless communication receivers such as cellular handsets. Because fractal antennas are more compact, they would more easily in the receiver package. Currently, many cellular handsets use quarter wavelength monopoles which are essentially sections of radiating wires cut to a determined length. Although simple, they have excellent radiation properties. However, for systems operating at 900 MHz such as GSM, the length of these monopoles is often longer than the handset itself, posing a nuisance to the user. It would be highly beneficial to design an antenna with similar radiation properties as the quarter-wavelength monopole while retaining its radiation properties. Other prevailing trends in wireless communications technology could also benefit. More and more systems are introduced which integrate many technologies. They are often required to operate at multiple frequency bands and so they require antenna systems which accommodate that requirement.

Other applications included Fractal miniaturization of passive networks and components, fractal filters and Resonators[3].A fractal element antenna, or FEA, is one that has been shaped in a fractal fashion, either through bending or shaping a volume, or introducing holes. They are based on fractal shapes such as the Sierpinski triangle. Mandelbrot tree, Koch curve, and Koch island. The advantage of FEAs, when compared to conventional antenna designs, center around size and bandwidth.

The theory of fractal antenna operation is steeped in mathematics, but in its most basic form, it comes down to this: In order for an antenna to work equally well at all frequencies, it must satisfy two criteria[4]:

1.It must be symmetrical about a point.
2.It must be self-similar, having the same basic appearance at every scale.

Fractal satisfies above conditions that is why it shows wideband and multiple resonant frequencies behavior.

The advantages of fractal over conventional antennas are[4]:

- Size can be shrunk from two to four times with surprising good performance.

- Multiband performance is at non-harmonic frequencies.

- Improved Impedance, Improved SWR(standing wave ratio) performance on a reduced physical area when compared to non fractal Euclidean geometries.

- Compressed Resonant behavior.

- At higher frequencies the FEA is naturally broadband.

- Polarization and phasing of FEAs also are possible.

- In many cases, the use of fractal element antennas can simplify circuit design.

- Reduced construction costs.

- Improved reliability.

- Because FEAs are self-loading, no antenna tuning coils or capacitors are necessary.

- Often they do not require any matching components to achieve multiband or broadband performance.

- Perturbation could be applied to shape of fractal to make it to resonate at different frequency.

1.2 Objectives of the thesis

The objectives of the thesis are:

- To generate Koch fractal, Sierpinski Triangle, Sierpinski Carpet ,Julia fractal for different iterations using MATLAB.

- To generate a Koch fractal monopole of length 5.1c.m. of zero, one, two iterations using MATLAB.

- To plot frequency versus impedance plot of fractal monopole with zero , one ,two iterations for showing the multiband behavior at non-harmonic frequencies of fractals ,and to show that with each iterations the number of resonant frequencies increase.

- To plot frequency versus Reflection coefficient of fractal monopole with zero , one ,two iterations.

- To plot frequency versus SWR plot of fractal monopole with zero , one ,two iterations to show the compressed resonant behavior of fractal antennas.
- To show improved SWR(standing wave ratio) performance.
- To plot radiation pattern of fractal monopole with zero , one ,two iterations.
- To show the size reduction capabilities of fractals.
- Antenna miniaturization using Koch fractal for GSM900 band.
- Antenna miniaturization using Koch fractal for GSM1800 band.

1.3 Organization of the report

In chapter-2, a brief overview of fractals, fractal basics ,types of fractals, generation process, fractal dimensions, properties ,fractals application and fractals antennas, software simulators is mentioned along with a brief overview of key research papers is given to introduce the current state of research in this field.

In chapter-3,various fractals and their multiband property, compressed resonant behavior ,improved SWR performance ,antenna miniaturization capability is described. Results have been shown using MATLAB and EZNEC codes.

In chapter-4 koch fractal antenna with three iteration for GSM900band is described. Results are shown using MMANA code.

In chapter-5 koch fractal antenna with three iteration for GSM1800 band is described. Results are shown using MMANA code.

Finally in chapter 6, the conclusion part of the thesis is outlined which is a result of the iterative work carried out on various fractal antennas

Chapter-2
Fractals

2.1 Fractal's Definition:

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

2.2 Basics of Fractals:

Although fractals are mainly discussed in mathematical forums, they exist in all parts of nature. For example Mandelbrot [5] discusses the basics of fractal theory as applied to the characteristics of a coastline(see Figure 2). The length of a coastline depends on the size of the measuring yardstick. As the yardstick we use to measure every turn and detail decreases in length, the coastline perimeter increases exponentially. As the view of a coastline is brought closer, we discover that within the coastline there lie miniature bays and peninsulas. As we examine the coastline on a rescaled map, we discover that each of the bays and peninsulas contain sub-bays and sub-peninsulas. There is a self-similar trait observed as we look at the coastline at various resolutions. The number of microscopic structures begin to approach infinity. In fact, because of the large number of irregularities, the physical length of a coastline is virtually infinite.

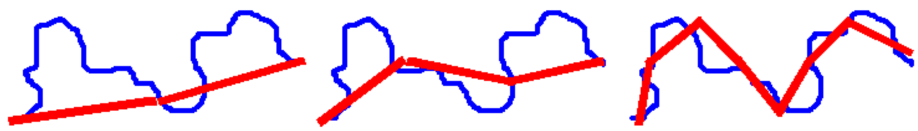


Figure 2: Coastline of Britain[6]

These pictures represent an imaginary coastline of Britain. The red lines are rulers being used to measure the length of the coastline (L). These rulers are of the length S. Using the first ruler we see that it L = 2 * S. When we decrease the length of S the number of times that S is used increases. What these rulers illustrate is that as the size of the measuring device becomes smaller the accuracy of the measurements become more and more accurate. From this fact we can assume that eventually we will be able to get an exact measurement of the coastline. This statement is false. As we decrease the size of the measuring device the length that we have to measure becomes greater. We can see this by zooming in on the coastline. As we get closer and closer we will notice that it looks very similar to how it looked from a greater distance away. Only now we are much closer. This observation show the self similarity of the coastline. Therefore as we decrease the size of the measuring device the length of the coastline will increase without limit. Thus, showing us its fractal nature. Self similarity (seen in the coast example above) is defined by structures that look the same at variable magnifications. This recurring self-similarity is one of the many attributes of many fractals. Much like the coastline described above, any small part in a self-similar fractal is going to look exactly like the fractal as a whole.

The example of coastline shows that the coastline has a dimension greater than 1 but less than 2. The more wiggly the coastline is, its dimension is near to 2. How can a line have a dimension more than 1?.Imagine a very wiggly line that doubles back on itself and wanders around a lot(figure 2.1). Such a line would eventually cover a sheet of paper In other words it would be a "space filling curve". Because it nearly fills a space (a plane with dimension 2) the line must have a dimension close to 2.

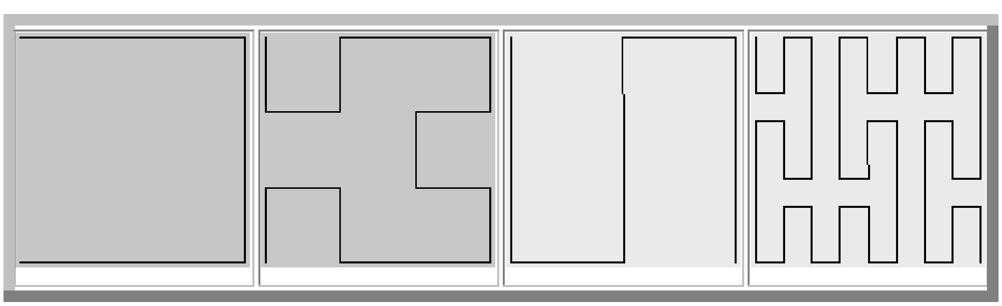


Figure 2.1:shows how lines following simple rules about how they wiggle can fill a space.

Fractal geometries have found intricate place in science as a representation of some of the unique geometrical features occurring in nature. Fractals are used to describe the branching of tree leaves and plants , the sparse filling of water vapor that forms clouds, the random erosion that carves mountain faces , the variability of coastlines and bark and many more examples in nature.

2.3 Problem of defining dimensions:

The complexity of defining dimensions can be summarized in the following visualization depicted in figure2.2 , of a microscopic fly flying towards a piece of paper[7].The fly starts out very far from the object in figure 2.2(a),thus it appears as a zero dimensional speck. As the fly gets closer , in figure 2.2(b), the speck begins to elongate into a one dimensional line. Upon flying over the line , in figure 2.2(c), the fly sees that it is actually a two dimensional plane. Flying even closer in figure 2.2(d). the fly sees that the plane has a depth to it. as well , forming a three dimensional prism ,followed by flying closer still, sees only a two dimensional plane . Finally the fly flies into the piece of paper, seeing a one dimensional network of fibers.

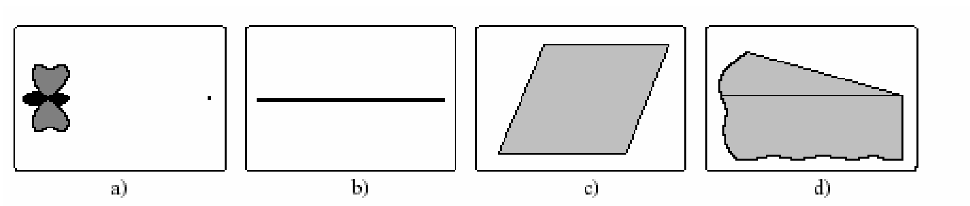


Figure 2.2:A fly flying towards a piece of paper from very far away reveals the problem of defining dimensions[8].

Therefore there is a need for a geometry that handles these situations better than Euclidean geometry. Euclidean structures have whole number dimensions , such as one dimensional line or a two dimensional plane. Benoit Mandelbrot first defined the term “Fractal” meaning fractal dimensions in 1975 to handle geometries with dimensions that do not fall neatly into a whole number category. One property of a certain class of fractals (as shown in the example of coastline),is the unique property that it can have an infinite length while fitting in finite volume. Fractals are structures of infinite complexity with a self similar nature. This means that as the structure is zoomed in upon the structure repeats .There never is a point where the fundamental building blocks are found . This is because the building blocks themselves have the same form as the original object with infinite complexity in each one. An example of this in nature can be seen in a fern , shown in figure 2.3.

Figure 2.3: A fern is a common example of a geometry in nature that is easily modeled using fractal geometry[8].

The entire fern has the same structure as each branch. If the individual branches were zoomed in upon , it is quite conceivable to imagine this as a completely separate fern with branches of its own.

Fractals are self similar under some change in scale either strictly or Statistically. Strictly self similar fractals do not change their appearance significantly when viewed under a microscope of arbitrary magnifying power, where as for statistically self similar fractals when a small portion of it is seemingly but not exactly similar to the original fractal itself .Fractal objects by definition , contain infinite detail ,they contain the same degree of detail in each part as is contained in entire object , no matter how many times section of it are enlarged[9].

2.4 Types of Fractals:

Fractal come into two major variations[10]:

1.Detrminsitic fractal

2.Random fractal

The first category consists of those fractals that are composed of several scaled down and rotated copies of itself, such as Koch curve ,They are called Geometric fractals. Julia set also falls in same category. The whole set can be obtained by applying a non-linear iterated map to all arbitrary small section of it .Thus the structure of Julia set is already contained in any small fraction. They are called algebraic fractals. Hence both algebraic and geometric fractals are termed deterministic fractals. Since the generation requires use of a particular mapping or rule which is repeated recursively over and over again , They exhibit the property of strict self similarity. The second category (Random Fractals) includes those fractals which have an additional element of randomness allowing for simulation of natural phenomenon ,so they exhibit property of statistical self similarity.

2.4.1 Geometric Fractals: The fractals of this class are visual. In two-dimensional case they are made of a broken line (or of a surface in three-dimensional case) so-called *the generator*. Each of the segments which forms the broken line is replaced by broken line generator at corresponding scale for a step of algorithm . As a result of infinite repeating the steps geometrical fractal arises.

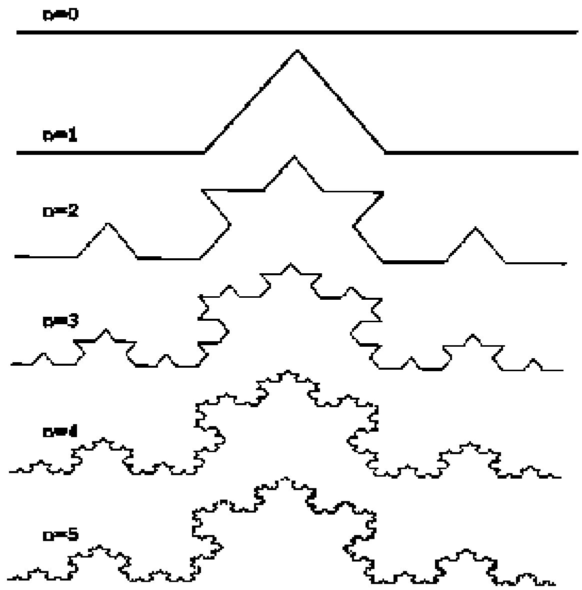


Figure2.4: Construction process of the triad Koch curve[11]

The process of construction begins from the segment of single length (Fig.2.4). It is zero generation of the Koch curve. Then each of section (one segment in zero generation) is replaced by formative element defined on the fig.2.4 as n=1. As a result of the substitution we get the next generation of the Koch curve. There are four rectilinear sections 1/3 length when the first generation is. Thus, to produce the next generation all of the sections of pervious generation are replaced by diminished formative element. The curve of n-th generation is called prefractal when n is finite quantity. When n is infinite quantity the curve is considered a fractal object. [11].

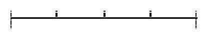
2.4.2 Algebraic fractals: Algebraic is the biggest class of fractals. They are created by using nonlinear processes in n-dimensional spaces.

2.4.3 Stochastic fractals: The stochastic fractals are got in the case iterate process has accidental parameters. Using the way objects like natural can be created. Two-dimensional stochastic fractals are used for designing surface of sea or relief modeling. [12] .

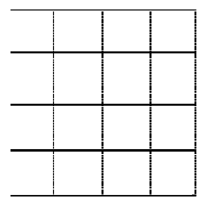
2.5 Dimensions of Fractals[6]**:** Another definition of Fractals is “A fractal is by definition a set for which the Hausdorff-Besicovitch dimension strictly exceeds the topological dimension.”

To understand the second definition we need to be able to understand the fractal dimension. So first we have to look at understanding how to calculate the dimension of an object. Below we have three different objects.

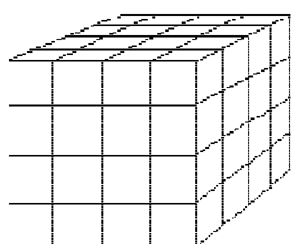
1.As we can see the line is broken into 4 smaller lines. Each of these lines is similar to the original line, but they are all 1/4 the scale. This is the idea of *self similarity*.



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: $N = S^D$

Where N is the number of small pieces that go into the larger one, S is the scale to which the smaller pieces compare to the larger one and D is the dimension. We now have the tools to be able to calculate the dimension. Just solve for D in the previous equation. When we do this we find that the Dimension is:

$$D = \log N / \log S \qquad (2.1)$$

This dimension is the Hausdorff-Besicovitch dimension.

Fractal curves have infinite length in a finite square of R^2 [13]. To characterize the topological properties of fractal structures ,usual length measurement is not adopted. In 1919 Hardroff introduced anew definition of dimension based on the size variation of sets when measured at different scales[14]. Let S be a number N(s) of balls of radius s to cover S. If S is a set of dimension D, with a finite length (D=1),surface(D=2) or volume(D=3), then

$$N(s) = s^{-D} \tag{2.2}$$

so $$D = -\lim\inf \frac{\log N(s)}{\log(s)} \text{ , Here limit is } s \to 0 \tag{2.3}$$

It may be either finite or infinite. The simplest well known examples of fractal sets are koch curve and triadic cantor set. The former is obtained by recursively dividing each segment of length l in four segments of l/3. Each subdivision increases length by 4/3.The limit of these subdivisions is therefore a curve of infinite length and its fractal dimension is D>1. We need N(s)= 4^n balls of size s= 3^{-n} to cover the whole curve, Hence

$$N(3^{-n}) = (3^{-n})^{-\frac{\log 4}{\log 3}}. \tag{2.4}$$

One can verify that at any other scale s , the minimum number of balls N(s) to cover this curve satisfies

$$D = \frac{\log 4}{\log 3} , \tag{2.5}$$

as expected it has a fractal dimension of between 1 & 2.

Function y=F(x) is called fractal if its plot is a fractal set[15].

2.6 Generation process:

There are several techniques to develop and to produce fascinating images. Two techniques popularized by Mandelbrot’s book are the

1.Koch construction

2. Function iteration in the complex domain.

Random fractals are generated by a random process.

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

Iterated function systems (IFS) represent an extremely versatile method for conveniently generating a wide variety of useful fractal structures [16]. These iterated function systems are based on the application of a series of affine transformations, w, defined by[17]

$$w\begin{pmatrix} x \\ y \end{pmatrix} = \begin{pmatrix} a & b \\ c & d \end{pmatrix}\begin{pmatrix} x \\ y \end{pmatrix} + \begin{pmatrix} e \\ f \end{pmatrix} \qquad (2.6)$$

or, equivalently, by

$$w(x, y) = (ax + by + e, cx + dy + f) \qquad (2.7)$$

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

$$\begin{pmatrix} a & b \\ c & d \end{pmatrix} \text{and} \begin{pmatrix} e \\ f \end{pmatrix} \qquad (2.8)$$

such that *a, b,* c, and *d* control rotation and scaling, while *e* and *f* control linear translation.

Now suppose we consider $w_1, w_2, \ldots\ldots, w_N$ as a set of affine linear transformations, and Let *A* be the initial geometry Then a new geometry, produced by applying the set of transformations to the original geometry, A , and collecting the results from $w_1(A), w_2(A), \ldots\ldots W_N(A)$, can be represented by

$$w(A) = \bigcup_{n=1}^{N} w_n(A) \qquad (2.9)$$

where *W* is known as the Hutchinson operator [16]. **A** fractal geometry can be obtained by repeatedly applying *W* to the previous geometry. For example, if the set A_0 represents the initial geometry, then we will have

$$A_1 = w(A_0),\ A_2 = w(A_1), \ldots.. ,\ A_{K+1} = w(A_K) \qquad (2.10)$$

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

$$w_1(x, y) = (\frac{1}{3}x + (0)y0, (0) + \frac{1}{3}y + 0) \qquad (2.11)$$

$$w_2(x, y) = (\frac{1}{6}x - \frac{1.732}{6}y + \frac{1}{3}, \frac{1.732}{6}x + \frac{1}{6}y + 0) \qquad (2.12)$$

$$w_3(x, y) = (\frac{1}{6}x + \frac{1.732}{6}y + \frac{1}{2}, -\frac{1.732}{6}x + \frac{1}{6}y + \frac{1.732}{6}) \qquad (2.13)$$

$$w_4(x, y) = (\frac{1}{3}x + (0)y + \frac{2}{3}, (0)x + \frac{1}{3}y + 0) \qquad (2.14)$$

$$W(A) = w_1(A) \cup w_2(A) \cup w_3(A) \cup w_4(A) \qquad (2.15)$$

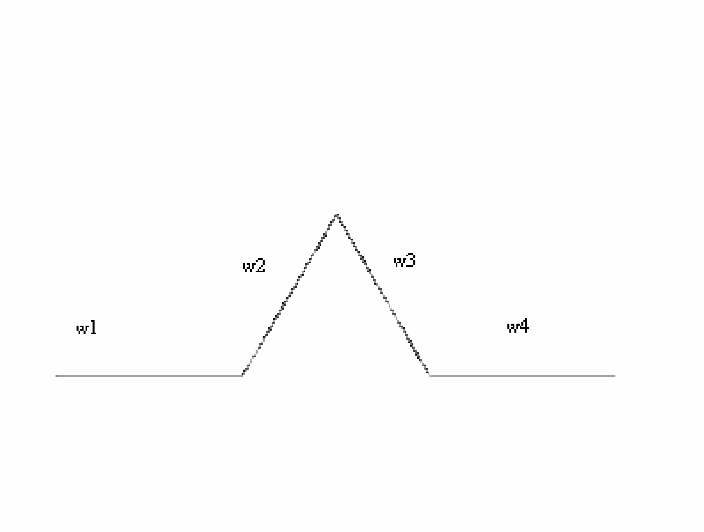


Figure 2.5**:**The standard Koch curve as an iterated function system (IFS)

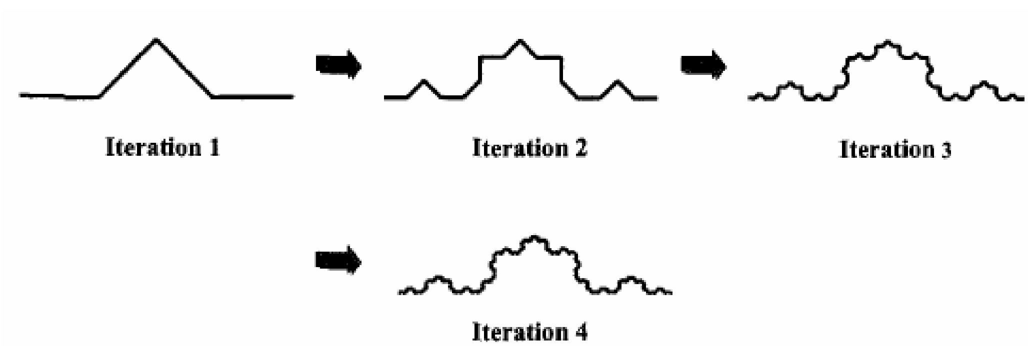


Figure 2.6**:** The first four stages in the construction of the standard Koch curve via an iterated function system (IFS) approach.

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

$$w(A_\infty) = A_\infty \qquad (2.16)$$

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

Figure 2.*6* illustrates the iterated function system procedure for generating the well-known Koch fractal curve. In this case, the initial set, *A,* is the line interval of unit length, i.e., *A,* = { x : x ∈ [0,1]). Four affine linear transformations are then applied to *A,* as indicated in Figure 2.5. Next, the results of these four linear transformations are combined together to form the first iteration of the Koch curve, denoted by A_1 . The second iteration of the Koch curve, A_2, may then be obtained by applying the same four affine transformations to A_1,. Higher-order version:; of the Koch curve are generated by simply repeating the iterative process until the desired resolution is achieved. The first four iterations of the Koch curve are shown in Figure 2.6 . We note that these curves would converge to the actual Koch fractal, represented by A_∞, as the number of iterations approaches infinity[18]. Iterated function systems have proven to be a very powerful design tool for fractal antenna engineers.

This is primarily because they provide a general framework for the description, classification, and manipulation of fractals [17]. In order to further illustrate this important point, the iterated function system code fix such diverse objects as a Sierpinski gasket and a fractal tree have been provided in Figure 2.7 and Figure 2.8 respectively [16].

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

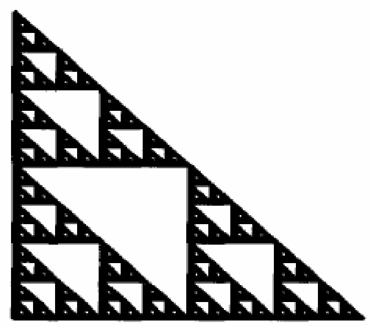


Figure 2.7**:** The iterated function system code for a Sierpinski gasket[16].

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

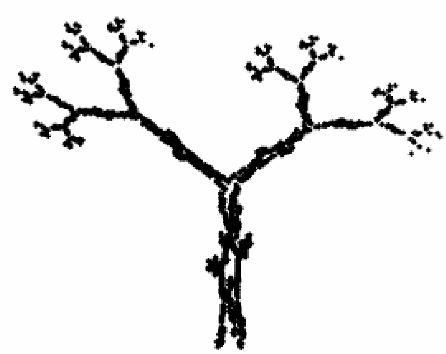


Figure 2.8**:** The iterated function system code for a fractal tree[16].

The basic principle of construction of the triadic Koch curve consists of recursively replacing the edges of an arbitrary polygon (Initiator) by an open polygon (generator)

, reduced and displaced so as to have the same end points as those of interval being replaced. The amount of detail included in final display of curve depends on the number of iterations performed and the resolution of display system. Figure 2.9 shows initiator polygon ,generator polygon and the final curve after successive iterations.

Figure 2.9(a):initiator   Figure2.9(b):Generator

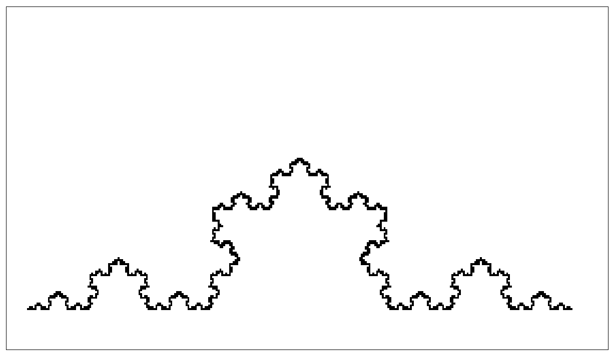


Figure2.9(c):Final curve

2.7 Why Fractals are space filling geometries:

Euclidean geometries are limited to points, lines, sheets & volumes, Fractal include geometries that fall in between these distinctions .Therefore, a fractal can be line that approaches a sheet. These space filling properties lead to curve that are electrically very long [19] , but fit into a compact physical space. This property leads to miniaturization of antenna elements. Fractals could be used to define the spacing in arrays for thinning or to define radiation pattern [20].

With successive iteration the length of koch increases by 1/3 of the original length.

Length of koch after nth iterations :

$$l_n = l_0 (4/3)^n \tag{2.17}$$

where l_n and l_0 are the length after nth iteration and original length(without any iteration) respectively.

For Sierpenski Triangle with each iteration the area of the holes and circumference of solid pieces changes. If the area of original triangle is 1 , then first iteration removes ¼ of the area., second iteration removes a further 3/16 and third iteration 9/64.

Then total area removed after the Nth iteration

$$A_N = 1/3 \sum_{i=1}^{N} (3/4)^i \tag{2.18}$$

$$A_{\infty} = 1 \qquad (2.19)$$

If circumference of original triangle is 1, then after first iteration the circumference increases by 1/2. After second iteration it increases by ¾, after Nth iteration

$$C_N = 1 + 1/3\sum_{i=1}^{N}(3/2)^i \qquad (2.20)$$

and

$$C_{\infty} = \infty \qquad (2.21)$$

This means gasket has no area but boundary is of infinite length.Figure2.10 shows how with each iteration the area of holes and circumference .

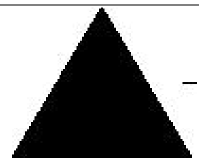
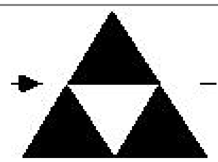
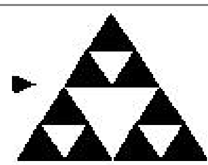
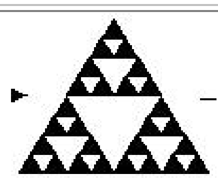
Figure	**Area**	**Perimeter**
	A_0 = sqrt(3)/4	$P_0 = 3$
	$A_1 = 3/4\ A_0$	$P_1 = 3 + 3(1/2)$ $= 3 + 3/2$
	$A_2 = (3/4)^2\ A_0$	$P_2 = 3 + 3/2 + 3*3*1/4$ $= 3 + 3/2 + 9/4$
	$A_3 = (3/4)^3\ A_0$	$P_3 = 3 + 3/2 + 9/4 + 9*3*1/8$ $= 3 + 3/2 + 9/4 + 27/8$
Stage *n*	$A_n = (3/4)^n\ A_0$	$P_n = 3 + 3/2 + \ldots + (3/2)^n$
Sierpenski Triangle	0	infinity (geometric series with r > 1)

Figure2.10:Different iteration of Gasket and variation of area and circumference[21]

2.8 Fractals in nature and Applications:

Fractals are not just complex shapes and pretty pictures generated by computers. Anything that appears random and irregular can be a fractal. Fractals permeate our lives, appearing in places as tiny as the membrane of a cell and as majestic as the solar system. Fractals are the unique, irregular patterns left behind by the unpredictable movements of the chaotic world at work. In theory, one can argue that everything existent on this world is a fractal[22].

- the leaves in trees,
- the veins in a hand,
- water swirling and twisting out of a tap,
- a puffy cumulus cloud,
- tiny oxygen molecule, or the DNA molecule,
- the stock market

Fractals have more and more applications in science.

Astronomy

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

Nature

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

Computer science

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

Fluid mechanics

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

Surface physics

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

Medicine

Biosensor interactions can be studied by using fractals.

Telecommunications

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

2.9 Fractals as Wire Antenna Elements

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

2.10 Fractal Loop Antennas

The space-filling abilities of fractals fed as loop antennas can exhibit two benefits over Euclidean antennas. The first benefit is that the increased space-filling ability of the fractal loop .means that more electrical length can be fitted into a smaller physical area. The increased electrical length leads to a lower resonant frequency, which effectively miniaturizes the antenna. The second benefit is that the increased electrical length can raise the input resistance of a loop antenna when it is used in a frequency range as a small antenna. It can be shown that the resistance increase resulting from the increased wire length for a material with a finite conductivity is insignificant in relationship to the miniaturization of the antenna. Miniaturization of a loop antenna is possible using fractals. [23]. Here, it was observed that the resonant frequency of the loop decreased as the generating iterations were increased[24].

2.11 Fractal antennas are Wideband :

Fractal antennas show multiband or log periodic behavior that has been attributed to self similar scale factor of the antenna geometry. Fractal loop shows improved impedance and SWR performance on a reduced physical area when compared to non fractal Euclidean geometries. Sierpenski Gasket monopole antenna demonstrates a log periodic resonant property . Although fractal structure from these mathematical function could provide attractive multiband performance ,it is clear that such geometry could be modified to enhance their application .Perturbation effectively varies the structural properties and hence electrical properties. In order to enable more operating bands within lower spectrum , a higher scaling factor is required.

Fractal antenna Represents a class of electromagnetic radiators where the overall structure is comprised of a series of repetition of a single geometry and where repetition is at different scale . Compressed resonant behavior is exhibited by Fractal antennas.

2.12 Fractal Patch Antennas

It has also been found if fractals can be used to miniaturize patch elements as well as wire elements. The same concept of increasing the electrical length of a radiator can be applied to a patch element.

2.13 Fractal Frequency Selective Surfaces

Fractals, which are a modern development of geometry that define a class of objects, can be created using an iterative methodology [25]. A fractal starts as a simple geometry. A linear transformation, usually involving copying, scaling, and translation, is applied to this structure. The transformation is then applied again to the entire resulting structure. The fractal is generated by repeating this methodology an infinite number of times while a pre- fractal is the resulting structure if the iterative process is truncated after a finite number of times. The manufacturable fractal objects themselves must result from a truncated generation process and therefore are referred to as pre-fractals to be more precise. These pre-fractals, which contain many scaled versions of the original simple geometry, can be investigated as a frequency selective surface (FSS). A frequency selective surface is a planar periodic structure that has a frequency response to radiation passed through it that correlates to the spacing of the elements. Radiation is either allowed to transmit through or blocked depending on the retransmitted phase of the radiation from the excited elements with the same underlying fundamental principles as array theory. A frequency selective surface has a signature that, in general, is dependent on the frequency of the incident wave, the incident angle, and the incident polarization. A common FSS example is the mesh screen on the door of a microwave oven. The mesh screen blocks electromagnetic radiation from the inside of the microwave oven while allowing the operator to see inside safely. Several iterations of the fractal can be used to design an FSS that has a multiband frequency response that correlates to the scales of the geometry that is present in the structure.

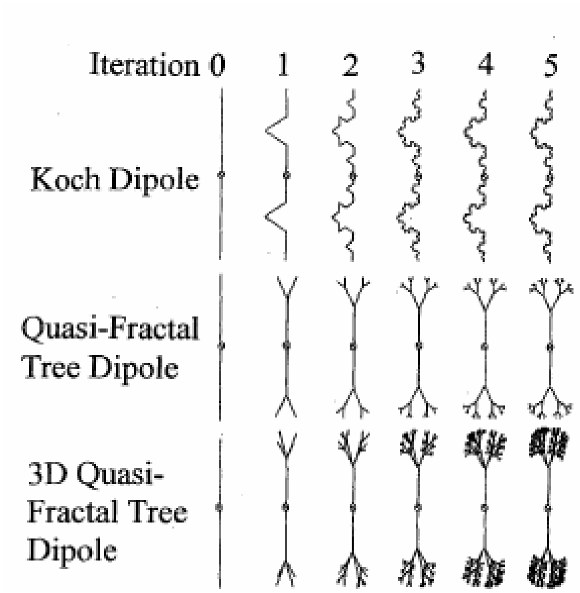


Figure 2.11 Three types of fractals that are used as dipoles, including a Koch curve, a fractal tree, and a three-dimensional fractal tree. The first five growth iterations are shown, along with the common linear-dipole initiator for all three fractals.

2.14 Fractal Dipole Antennas:

An interesting study of the space-filling properties of fractal antennas could be extended to dipole antennas also. Three types of fractals are shown as dipoles. They are depicted in Figure2.11 for the first six stages of growth. They included a Koch curve, a fractal tree, and a three-dimensional fractal tree. The starting structure for each of the fractals is the same dipole antenna. The Koch dipole has been extensively analyzed in [26, 27]. Also, a version of a tree fractal has been studied in [28]. As mentioned in the previous section, the Koch curve is generated by replacing the middle third of each segment with two sides of an equilateral triangle. The resulting curve is comprised of four segments of equal length. As calculated above, the fractal dimension of the Koch curve is 1.2619.

2.15 Antenna Miniaturization using Koch Fractal:

The use of fractal antenna techniques, is to reduce the size of UHF linear dipoles, monopoles. To be an efficient radiator an antenna size must be an appreciable portion

of a wavelength Therefore the antenna that operate at low frequencies are physically very large. This large size hinders their integration into smaller hand held communication equipments.

When the size of antenna is made smaller than the operating wavelength, it becomes highly inefficient .Its radiation resistance decreases while proportionally the reactive energy stored in the antenna neighborhood rapidly increases. Both phenomenon make small antenna difficult to match to the feeding circuit and when matched they display a high Q i.e. a very narrow bandwidth.

Using fractals the process is attractive because of the potential to produce smaller elements without sacrificing bandwidth or efficiency .Fractal antenna represent a class of electromagnetic radiators where the overall structure is comprised of a single geometry and where repetition is at different scales.

Fractal structures may provide size reduction and bandwidth enhancement. Elements size reduction may include the added length attributed to meandering of conductor and reactive loading .The added bandwidth expected from fractal element is generally attributed to fact that resulting structure consists of many scaled self similar “cells” or building blocks.

With each iteration the effective length of Koch antenna increases by 1/3 of the previous length. $l_n = l_0(4/3)^n$,where l_n is length after nth iteration , l_0 is initial length or length at 0^{th} iteration. Therefore if we use Koch as monopole with each iteration the resonant frequency should decrease, but Resonant frequency of a Koch monopole does not decrease at the same rate as the wire length increases.. In fact, the reduction factor in the resonant frequency of the Koch antenna as the iteration number increases tends monotonically to one. A high degree of coupling between parallel wire segments with opposite current vectors causes a significant reduction in the effective length of the total wire, and therefore increases the resonant frequency [29].

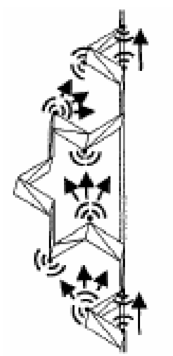


Figure 2.12:Shortcouts

2.15.1 Hypothesis[30]: The observed behavior is due to the coupling between sharp angles at curve segment junctions. These angles radiate a spherical wave with phase center at the vertex (Fig. 2.12). Each angle not only radiates, but also receives signal radiated by the other angles. As a consequence, part of the signal does not follow the wire path, but takes “shortcuts” that start at a radiating angle (Fig. 2.12). The length of the path traveled by the signal is, therefore, shorter than the total wire length. The higher number of iterations in the Koch antenna, the more angles it has and the closer to each other they are, so the more signal takes shortcuts and the less signal follows the whole curve path. For that reason, adding new iterations to a highly-iterated antenna does not reduce the resonant frequency, since the path followed by the signal -taking shortcuts- is not longer, although the curve length increases.

2.16 Simulation Method and Software Simulators:

There are a number of commonly available software packages which allow the simulation of antenna parameters. Some of the best known are SONNET, XFDTD, HFSS and various packages based on the NEC2 code. XFDTD and HFSS are excellent professional design tools which offer a great deal of simulation flexibility and analysis options. Unfortunately, evaluation or academic versions of these programs are not offered . SONNET, however, is offered as a feature-limited evaluation package. It uses the MoM technique to simulate 2D surfaces including traces on dielectric layers, which is essential for microstrip antenna modeling. The software is user-friendly and with some effort it can be used to model realistic structures despite the feature limitations. Software based on the NEC2 code is freely available. NEC2 uses 1D MoM, which allows modeling of wire structures. This is ideal for modeling free-space antennas such as arrays of dipoles. Although not as user-friendly as SONNET, NEC2 is more flexible and offers more analysis options. The computational technique used to investigate the properties of fractal antennas utilizes the moment method. The geometry of the pre- fractal is first mathematically defined either by hand or using recursive loops in Matlab. The geometry is then fed into a moment method code EZNEC code or MMANA code which are different versions of NEC(numerical electromagnetic code) . 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. These codes solve for the surface currents generated on perfectly conducting surfaces or thin wires or combinations of both. From these currents, the far field patterns and input impedances can be determined.

Chapter-3
Simulation of Koch Fractal Antenna

Koch curve, Sierpinski Triangle, Sierpinski Carpet ,Julia fractal were simulated using Matlab. Simulation results are shown below. To demonstrate the behavior of fractal antenna , a Koch fractal monopole antenna of 5.1c.m. length and with wire radius 0.1m.m.,up to two iteration has been simulated. Koch fractal with zero, one and two iterations has been generated by Matlab and simulated using EZNEC code. EZNEC is based upon the method of moments in which the electromagnetic interactions between wire segments can be analyzed. From this program, the impedance, radiation patterns, gain, front to back ratio and VSWR are obtained and have been plotted using Matlab.

Figure 3.1 shows Koch curve for different iterations,3.1(a) shows Koch curve for zero iteration,3.1(b) Koch curve for one iteration, 3.1(c) Koch curve for two iteration, 3.1(d) Koch curve for three iteration, with each iteration the length of Koch increases by one third of its previous length.

Figure 3.1(a) Koch curve with zero Iteration

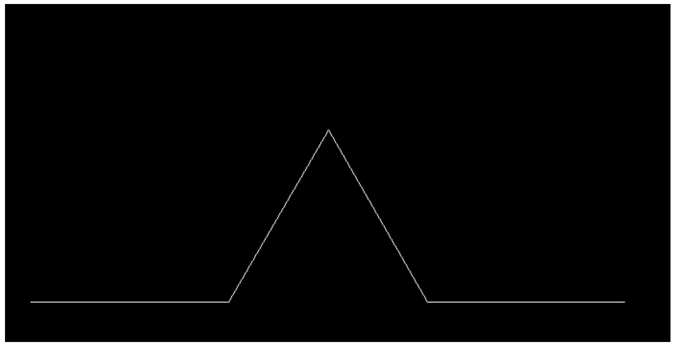


Figure 3.1(b) Koch curve with one iteration

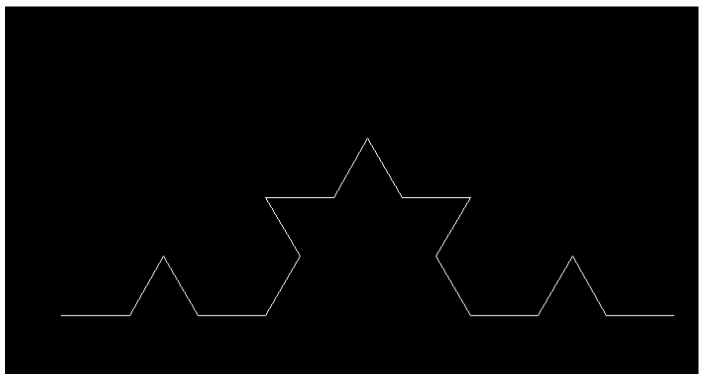


Figure 3.1(c) Koch curve with two iterations

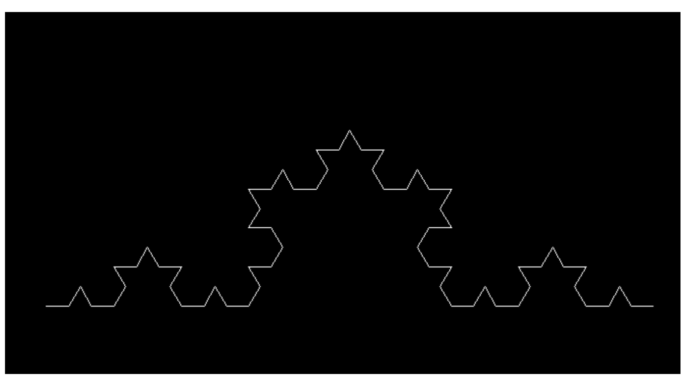


Figure 3.1(d) Koch curve with three iterations

Figure3.2 shows Sierpinski triangle for different iterations, 3.2(a)shows Sierpinski triangle for zero iteration, 3.2(b) shows Sierpinski triangle for one iteration, 3.2(c) shows Sierpinski triangle for two iteration.

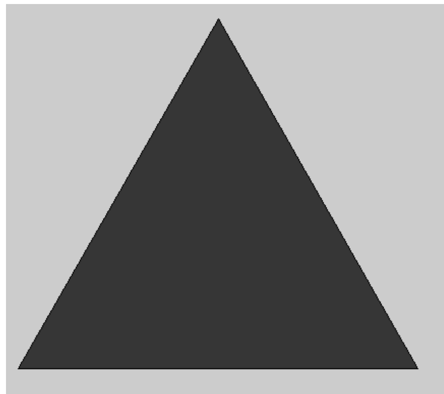


Figure 3.2(a) Sierpinski triangle for zero iteration

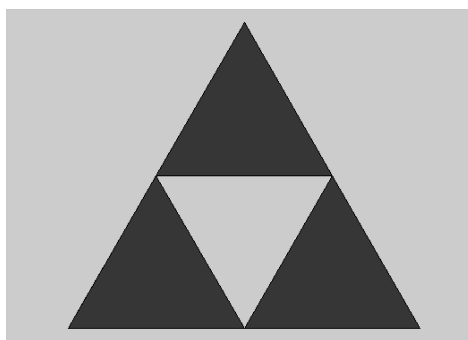


Figure 3.2(b) Sierpinski triangle for one iteration

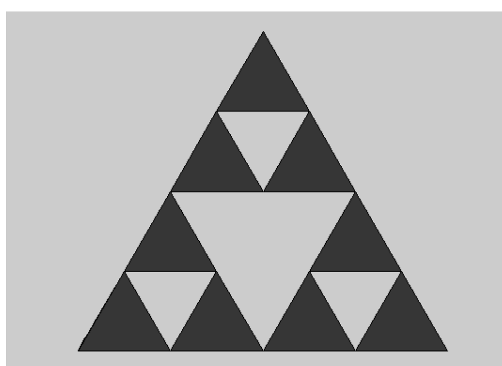


Figure 3.2 (c) Sierpinski triangle for two iteration.

Figure3.3 shows Sierpinski Carpet for different iterations., 3.3(a) shows Sierpinski Carpet for zero iteration, 3.3(b) shows Sierpinski Carpet for one iteration, 3.3(c) shows Sierpinski Carpet for two iteration.

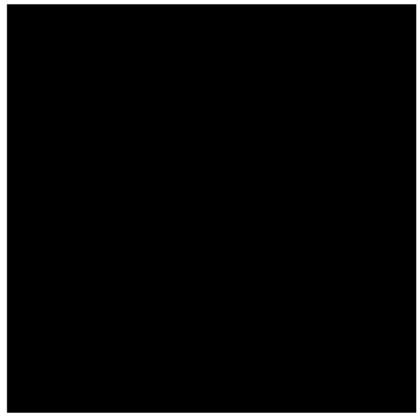


Figure3.3(a) Sierpinski Carpet for zero iteration

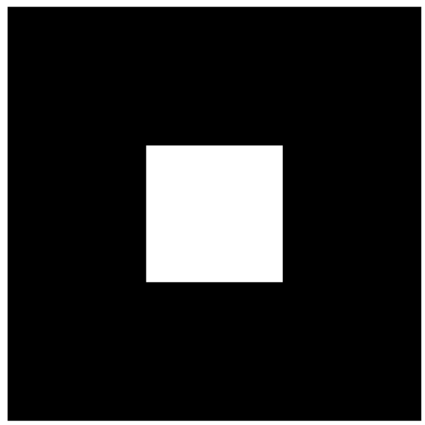


Figure 3.3(b) Sierpinski Carpet for one iteration

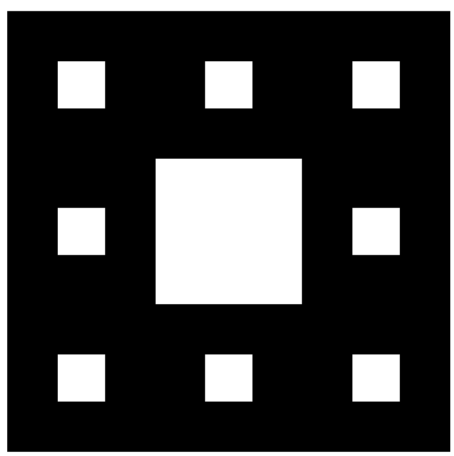


Figure 3.3(c) Sierpinski Carpet for two iteration

Figure 3.4 shows different examples of Julia fractal.

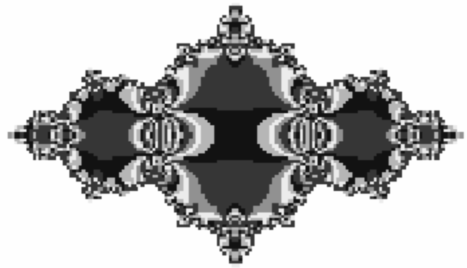


Figure 3.4(a)

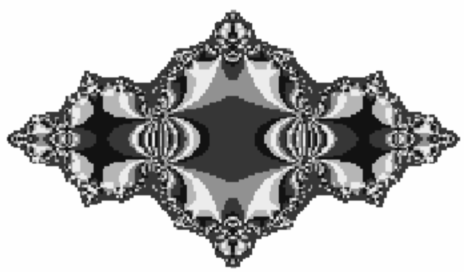


Figure 3.4(b)

Figure 3.5(a) shows straight monopole of length 5.1c.m. with zero iteration erected over a perfect ground. 3.5(b) shows Koch fractal monopole of length 5.1c.m. with one iteration erected over a perfect ground. 3.5(c) shows Koch fractal monopole of length 5.1c.m. with two iteration erected over a perfect ground.

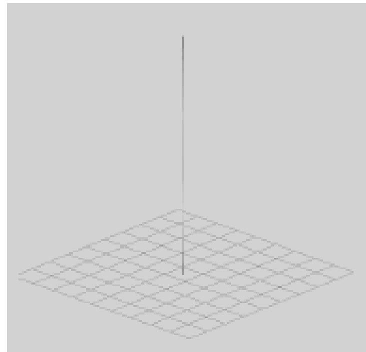


Figure3.5(a):Straight Monopole(K0) of 5.1c.m.length erected over a perfect ground

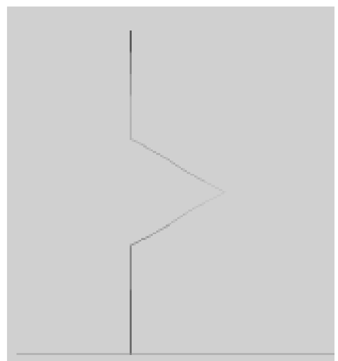


Figure 3.5(b): Koch fractal monopole of length 5.1c.m. with one iteration erected over a perfect ground.

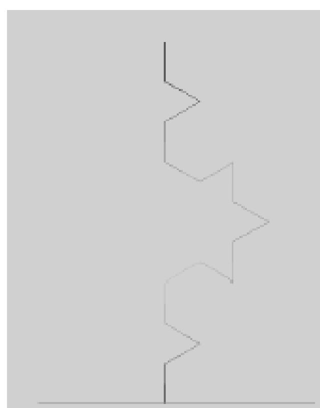


Figure3.5(c): Koch fractal monopole of length 5.1c.m. with two iteration erected over a perfect ground.

Figure 3.6(a) graph shows the frequency versus impedance plot for 5.1c.m.long Koch fractal monopole with zero iteration 3.6(b)graph shows frequency versus impedance plot for 5.1c.m. long Koch fractal monopole with one iteration 3.6(c)graph shows frequency versus impedance plot for 5.1c.m. long Koch fractal monopole with two iteration, as we increase the iterations number of resonant frequency increase, is obvious from the graphs that as iterations is increased the number of times Imaginary part of impedance becomes zero increases. This demonstrates that as number of iteration increases , more and more resonant frequency are there leading to a multiband antenna. This is due to the coupling between the wires. As more contours and iterations of the fractal are added, the coupling becomes more complicated and different segments of the wire resonate at different frequencies.

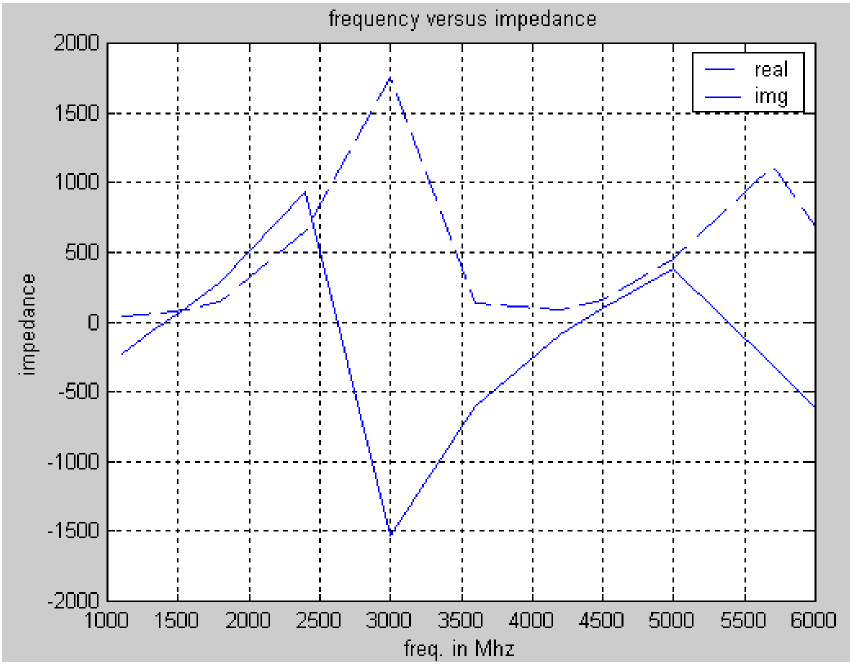


Figure 3.6(a):frequency versus impedance plot for 5.1c.m. long Koch fractal monopole with zero iteration

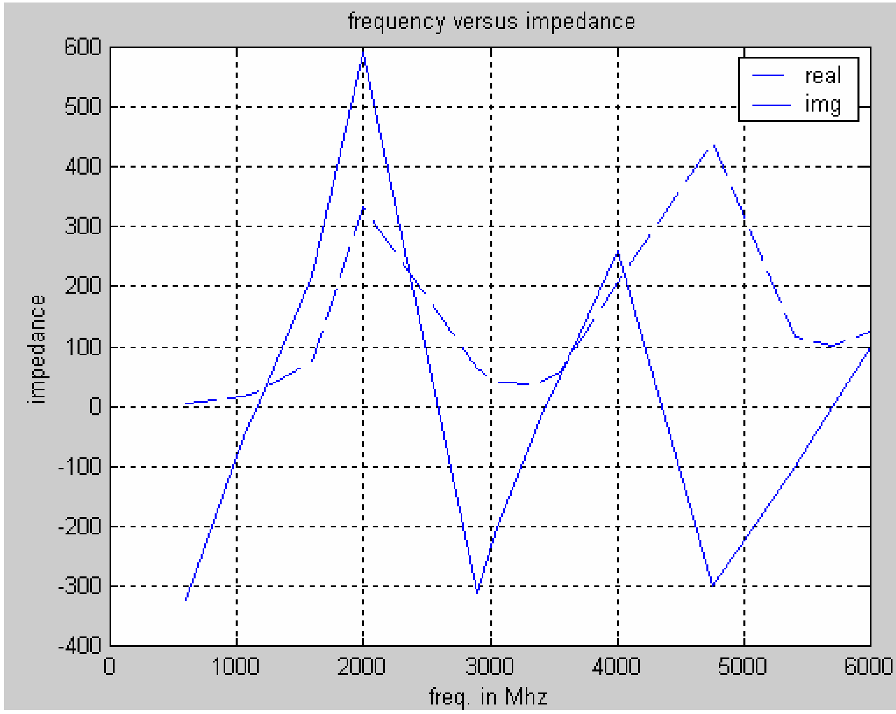


Figure 3.6(b) :frequency versus impedance plot for 5.1c.m. long Koch fractal monopole with one iteration

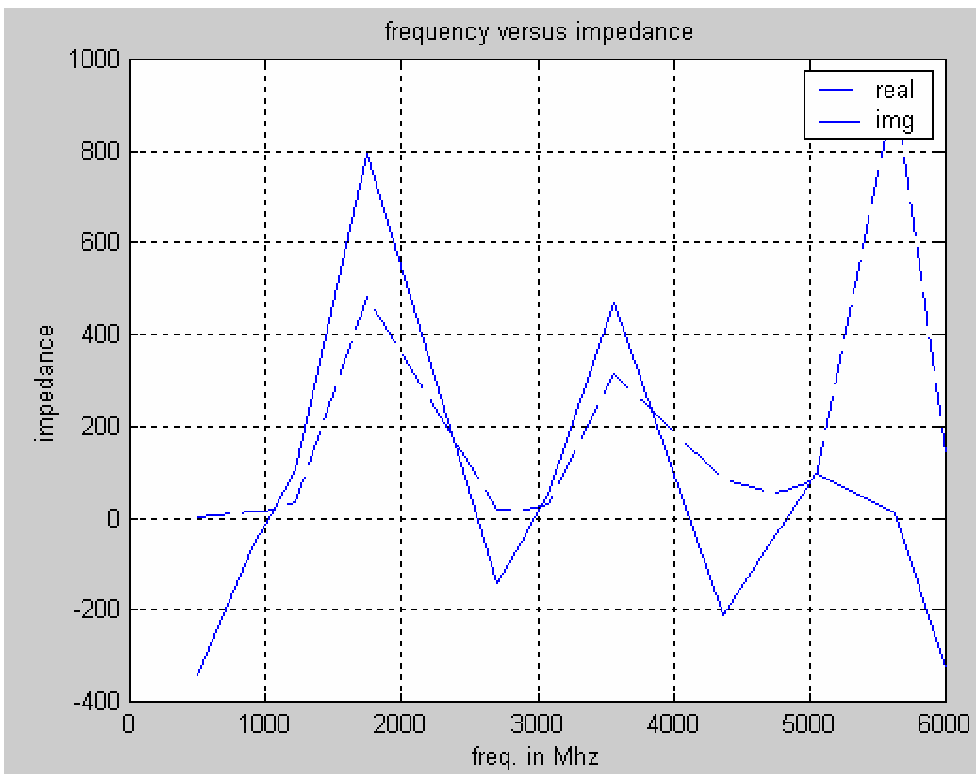


Figure 3.6(c) :frequency versus impedance plot for 5.1c.m long Koch fractal monopole with two iterations

Figure3.7(a):graph shows frequency versus Reflection coefficient plot for 5.1c.m. long Koch fractal monopole with zero iteration, Figure3.7(b):graph shows frequency versus Reflection coefficient plot for 5.1c.m.long Koch fractal monopole with one iteration Figure3.7(c):graph shows frequency versus Reflection coefficient plot for 5.1c.m.long Koch fractal monopole with two iteration, from graphs , observation is that as iteration is increased, the reflection coefficient becomes favorable at more frequencies.

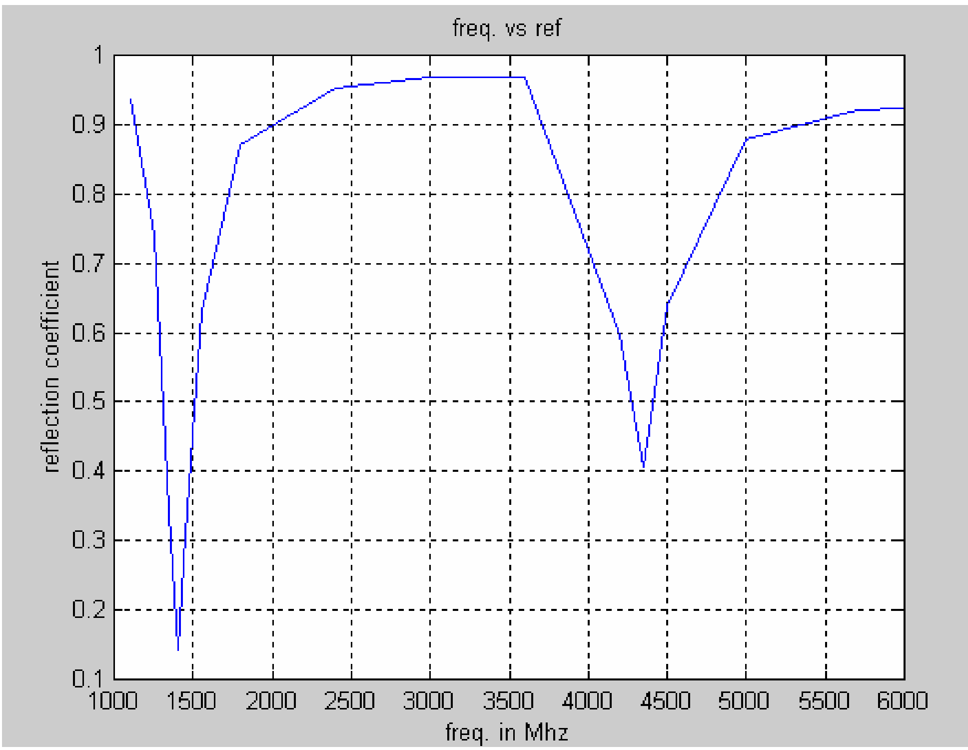


Figure3.7(a):frequency versus Reflection coefficient plot for 5.1c.m. long Koch fractal monopole with zero iteration

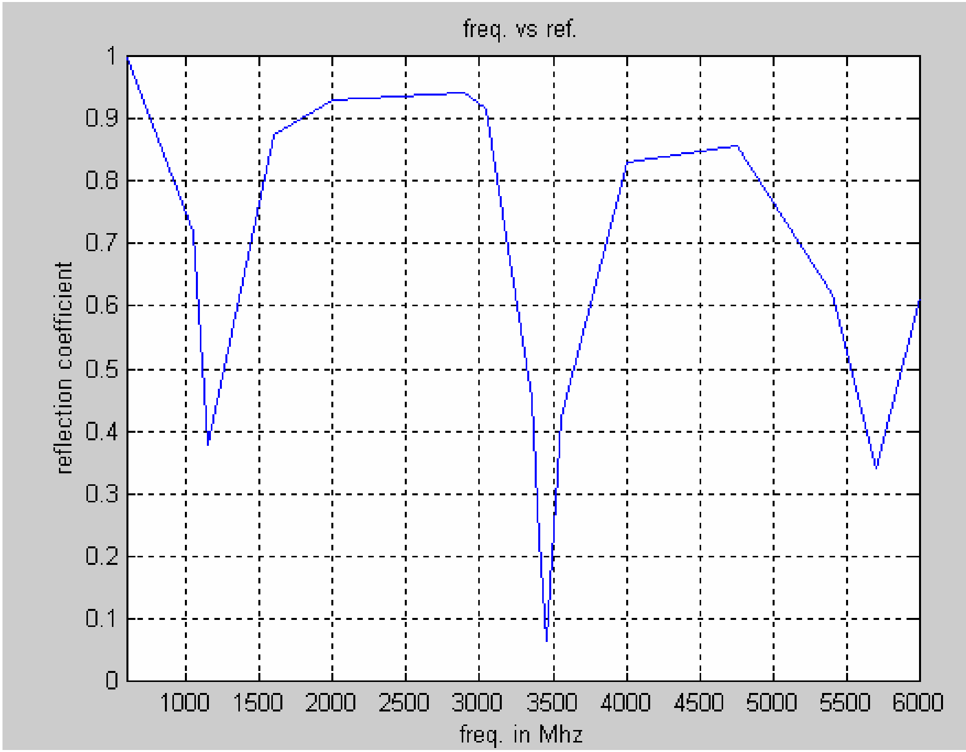


Figure3.7(b):frequency versus Reflection coefficient plot for 5.1c.m. long Koch fractal monopole with one iteration

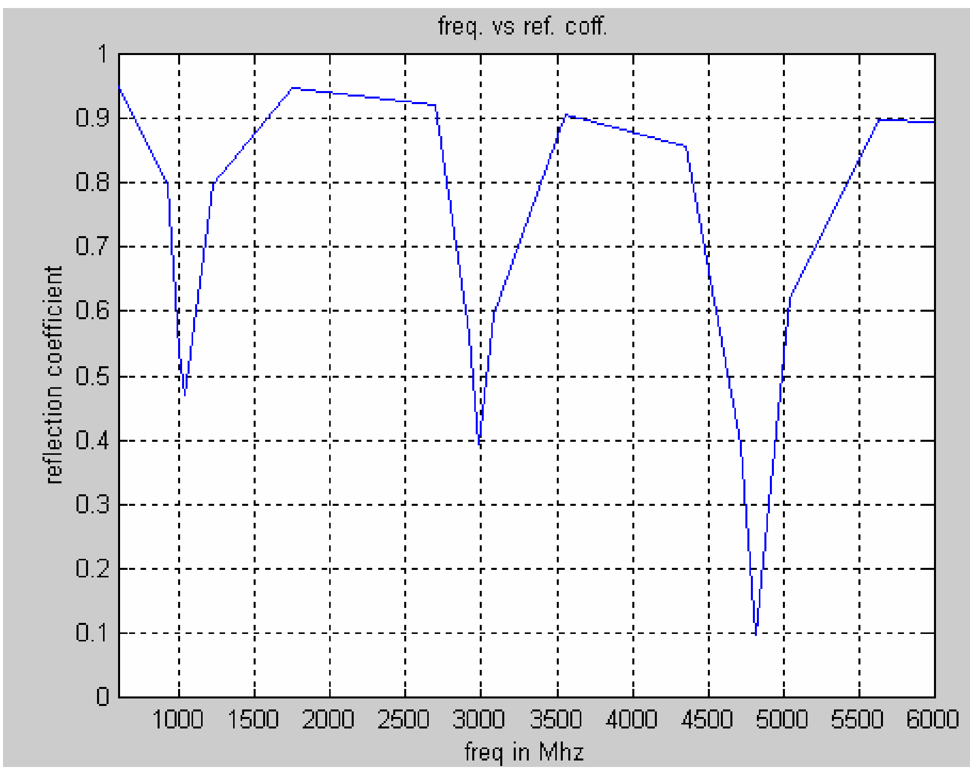


Figure3.7(c):frequency versus Reflection coefficient plot for 5.1c.m.long Koch fractal monopole with two iterations

Figure3.8(a):graph shows frequency versus SWR plot for 5.1c.m. Koch fractal monopole with zero iteration, Figure3.8(b):graph shows frequency versus SWR plot for 5.1c.m. Koch fractal monopole with one iteration, Figure3.8(c):graph shows frequency versus SWR plot for 5.1c.m. Koch fractal monopole with two iteration, graph shows that as we increase iteration the resonant behavior becomes more and more compressed.

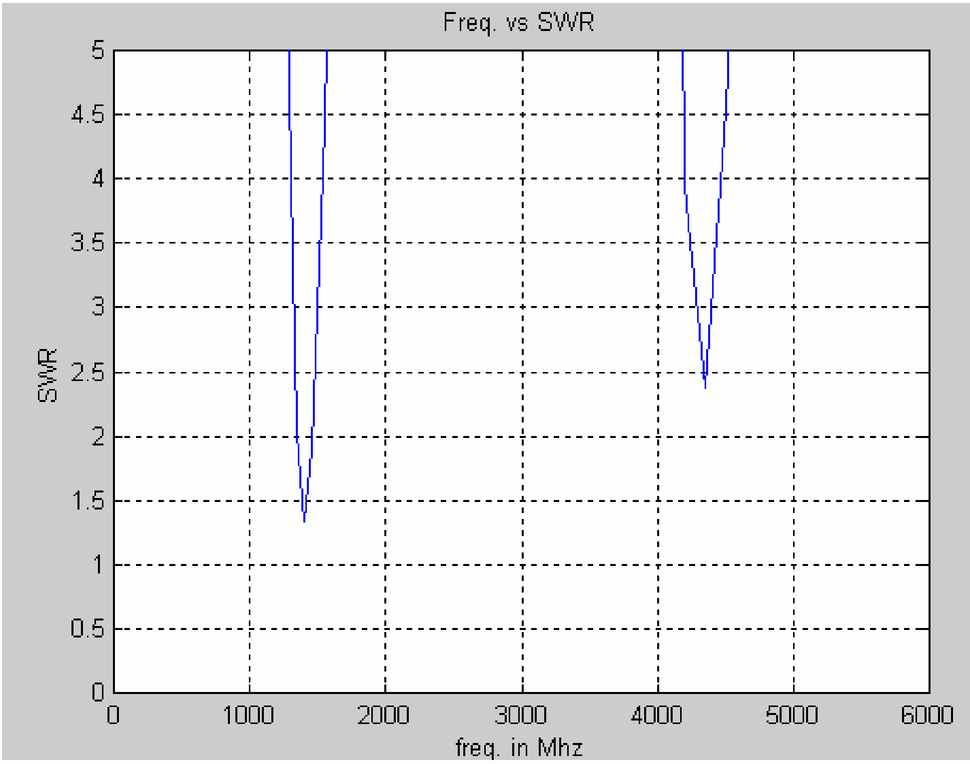


Figure3.8(a):frequency versus SWR plot for 5.1c.m. long Koch fractal monopole with zero iteration

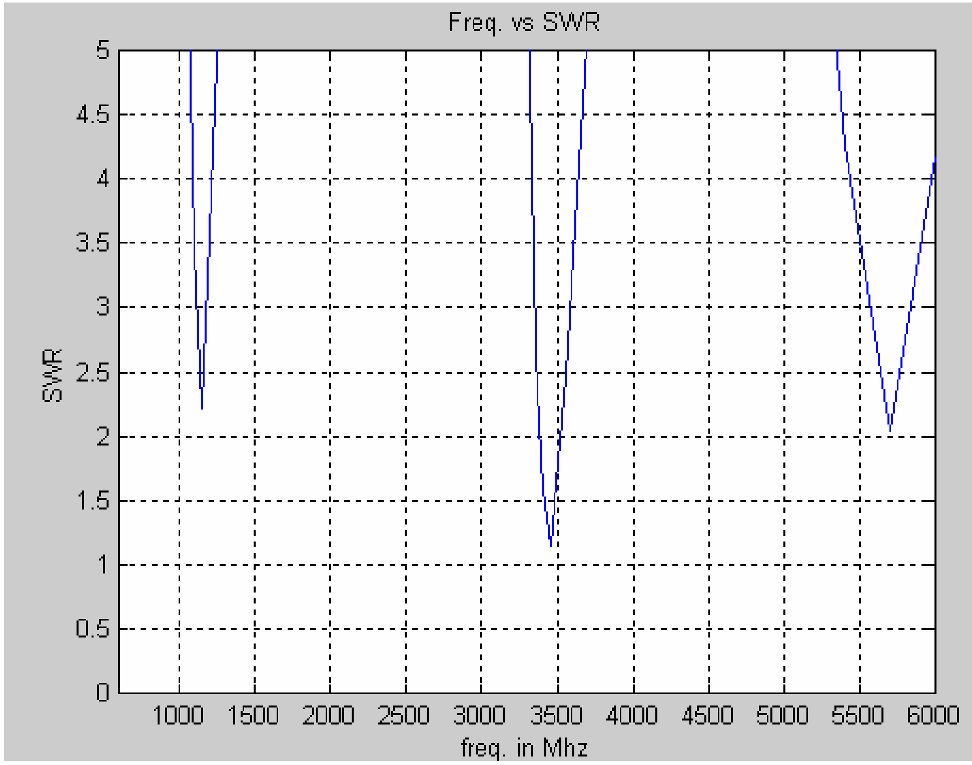


Figure3.8(b):frequency versus SWR plot for 5.1c.m.long Koch fractal monopole with one iteration

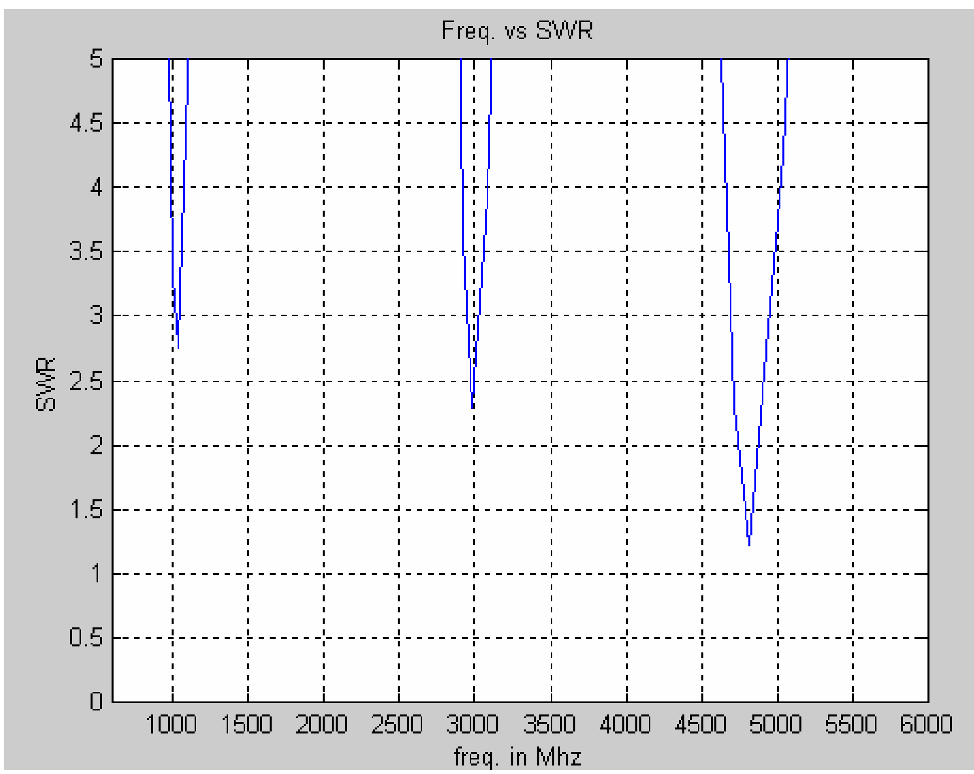


Figure3.8(c):frequency versus SWR plot for 5.1c.m. long Koch fractal monopole with two iteration

Figure3.9(a): figure shows Elevation plot of total field for 5.1c.m. Koch fractal monopole with zero iteration, Figure3.9(b): figure shows Elevation plot of total field for 5.1c.m. Koch fractal monopole with one iteration, Figure3.9(c): figure shows Elevation plot of total field for 5.1c.m. Koch fractal monopole with two iteration Figure 3.9(d):Azimuthal plot of total field for Koch fractal Monopole. It is interesting to note that for the E-plane radiation pattern, the fractal antenna also has a null at 90 degrees. This is due to the symmetry of the fractal and the electric and magnetic fields cancelled in this direction. Due to the symmetry of the fractal antenna at resonance, the electric and magnetic fields are added and cancelled in the far field to give a symmetrical pattern. It is also interesting to note that the fractal antenna has slightly less gain than the straight monopole. This is due to the fact that the fractal antenna is slightly less efficient than the straight monopole.

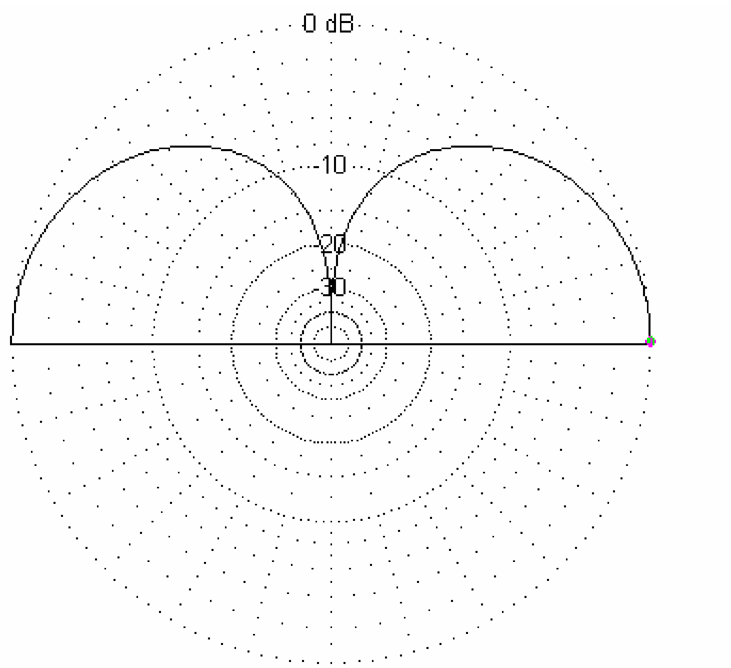


Figure3.9(a): Elevation plot of total field for 5.1c.m. long Koch fractal monopole with zero iteration

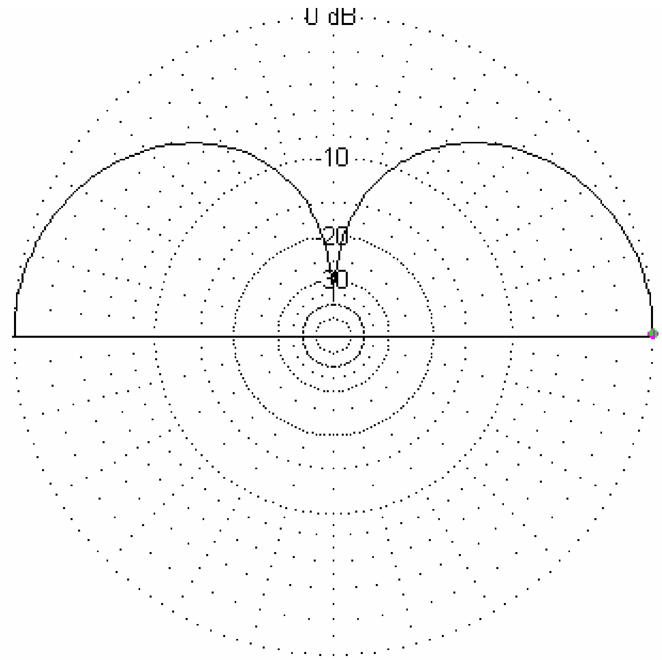


Figure3.9(b): Elevation plot of total field for 5.1c.m. long Koch fractal monopole with one iteration

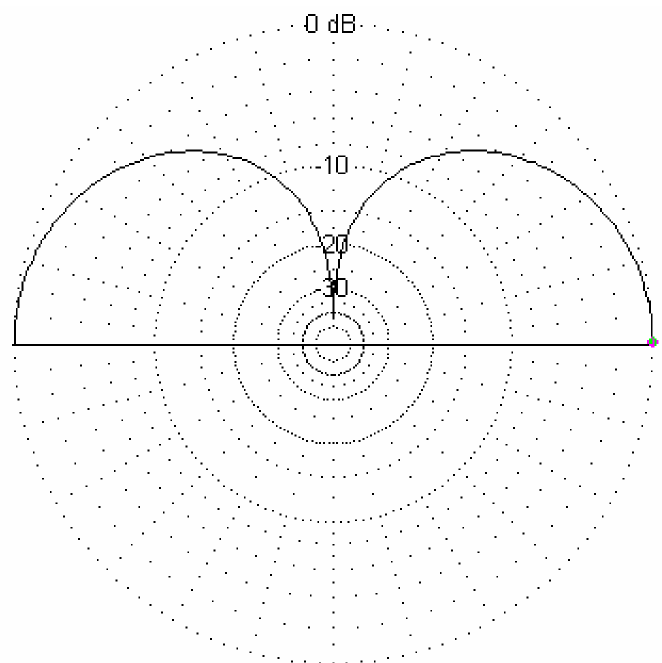


Figure3.9(c): Elevation plot of total field for 5.1c.m. long Koch fractal monopole with two iteration

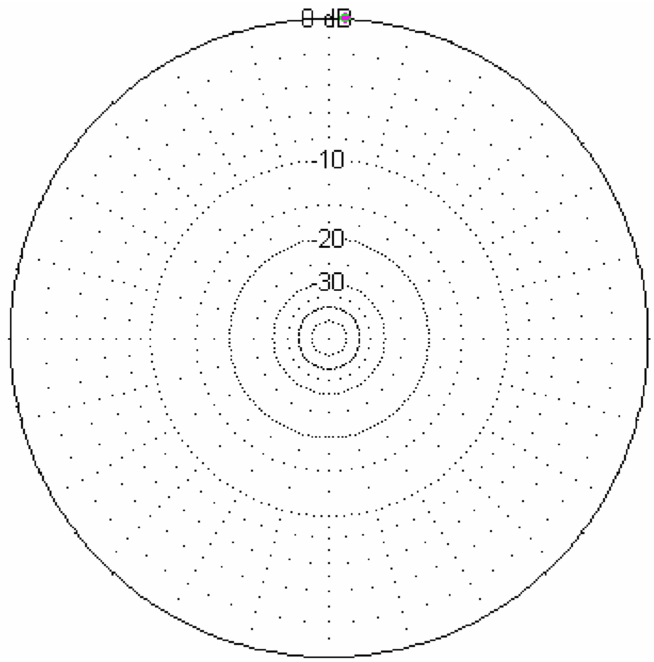


Figure 3.9(d):Azimuthal plot of total field for Koch fractal Monopole

Figure 3.10(a):Graph shows variation of resonant frequency of Koch fractal antenna with each successive iteration and for Euclidean monopole of same length, Figure 3.10(b) shows the same in Tabular form. From the graph and table it is observed that ,Resonant frequency of Koch monopole does not decrease at the same rate as the wire length increases . Infect the reduction factor in resonant frequency of the Koch antenna as the iteration number increases tends monotonically to one. High degree of coupling between parallel wire segment with opposite current vector causes a significant reduction in effective length of total wire and therefore increases the resonant frequency. This can be a limitation for the fractal antenna. After 5 iterations of the fractal, there was very little benefit in reducing the resonant frequency.

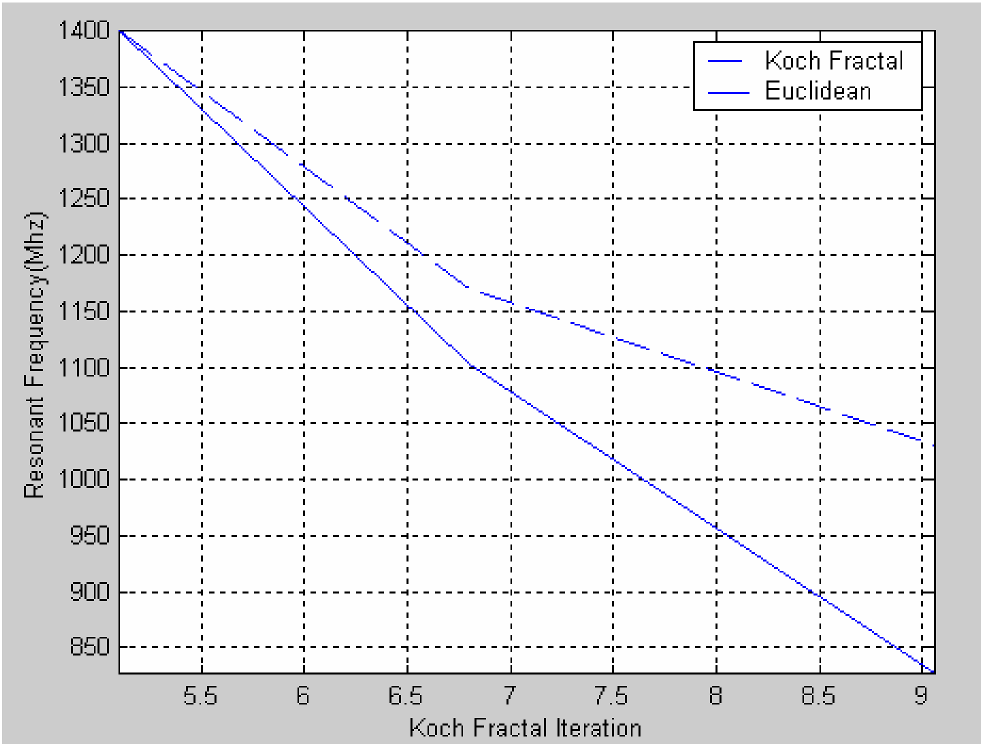


Figure 3.10(a):Graph shows variation of resonant frequency of koch fractal antenna with each successive iteration and for Euclidean monopole of same length

Antenna	**Effective length**	**Resonant Freq.(MHz) from programme**	**Frequency (MHz)from Quarter-wavelength Effective length**
K0	5.1	1400	1400
K1	6.8	1170	1102
K2	9.06	1030	827

Table 3.10(b):Table to demonstrate how resonant frequency decreases as iteration increases.

Table 3.11(a), 3.11(b), 3.11(c) shows real and imaginary part of Impedance, SWR Reflection coefficient for different frequencies for Koch antenna with zero, one and two iterations respectively.

Freq.(MHz)	Impedance (Real)	Impedance (imaginary)	SWR	Reflection coefficient
600	9.446	-810.9	>100	0.9986
1100	35.97	-224.9	30.2	0.9359
1250	49.24	-110	6.76	0.7424
1350	60.15	-38.21	2.03	0.3391
1400	66.35	-3.114	1.33	0.143
1450	73.14	31.74	1.89	0.3089
1550	88.77	101.4	4.43	0.6317
1800	145.2	284.4	14.3	0.8695
2400	649.7	937.5	40.1	0.9513
3000	1751	-1530	61.8	0.9681
3600	129.4	-606.3	59.8	0.9671
4200	92.9	-91.3	3.94	0.5949
4350	118	6.975	2.37	0.4066
4500	156.7	101.6	4.55	0.6397
5000	454.4	383.7	15.6	0.8796
5700	1125	-311.3	24.2	0.9207
6000	680.9	-616.7	24.8	0.9225

Table 3.11(a): For 5.1c.m.long Koch fractal monopole with zero iteration

Freq. (Mhz)	Impedance (Real)	Impedance (Imaginary)	SWR	Reflection Coefficient
600	4.615	-324	>100	0.9957
1050	17.74	-52.44	6.11	0.7187
1100	20.19	-29.27	3.44	0.5493
1150	22.95	-6.434	2.22	0.3796
1600	75.43	218.3	14.7	0.873
2000	333.9	591.8	27.8	0.9305
2300	1750	75.81	35.1	0.9446
2900	62.22	-311	33.1	0.9414
3050	40.22	-202.5	22.4	0.9146
3350	38.03	-42.41	2.64	0.4509
3400	41.17	-19.08	1.58	0.2257
3450	45.27	3.864	1.14	0.06403
3550	56.67	49.21	2.46	0.4228
4000	207.8	259.4	10.8	0.8302
4750	443	-299.3	12.9	0.8565
5400	115.6	-100.7	4.27	0.6202
5700	101.9	-0.1355	2.04	0.3416
6000	125.3	97.39	4.18	0.6319

Table3.11(b): For 5.1c.m long Koch fractal monopole with One iteration

Freq. (Mhz)	Impedance (Real)	Impedance (Imaginary)	SWR	Reflection coefficient
500	2.803	-342.6	>100	0.9977
920	12.68	-55.35	8.92	0.7984
1000	16.31	-13.73	3.32	0.5372
1040	18.51	7.053	2.76	0.4686
1220	33.19	106.3	8.87	0.7973
1750	481.4	796	36	0.946
2040	758.1	-1080	46	0.9574
2700	18.57	-139.9	24.1	0.9204
2920	19.15	-28.98	3.59	0.5645
2980	21.8	0.7628	2.29	0.3929
3080	29.25	52.24	3.93	0.5941
3560	314.8	469.2	20.4	0.9065
4360	84.29	-211.5	12.8	0.8553
4720	57.09	-45.27	2.3	0.3941
4820	59.76	-3.886	1.21	0.09566
5040	82.95	95.97	4.25	0.6188
5620	933.4	11.3	18.7	0.8983
6000	141.1	-325.9	18.2	0.8957

Table 3.11(c): For 5.1c.m.long Koch fractal monopole with two iterations

From the tables 3.11(a),3.11(b),3.11(c),it is apparent that as iterations increase, the resonant frequencies for antenna increases, means antenna shows multiband performance. With each iteration resonant behavior gets more and more compressed, and SWR and reflection coefficients becomes favorable at more frequencies.

Chapter-4
Fractal Antenna in GSM900

GSM900 operates at frequency range 890-915Mhz. for uplink communication and 935-960Mhz. for downlink communication. A monopole on a perfect ground having resonance at 925Mhz is required. and the length of straight wire monopole required is 8.1c.m., But this length will be very large in comparison to the dimensions of handset. By using a three iteration Koch, the length of monopole required is 3.41c.m.(from equation 2.17) to provide effective height of 8.1c.m., but due to the coupling effect described in capter-2 , Koch of length 4.1c.m.of three iteration on a perfect ground with source at bottom end is used. Radius of wire has been taken 0.1m.m.With radius 0.1m.m. the antenna has bandwidth(SWR<2) 21Mhz ,which is very less to cover 900Mhz band ,by increasing wire radius ,bandwidth could be increased. By taking radius 6.8m.m. bandwidth(SWR<2) increases up to 71Mhz. which covers the whole 900Mhz band, and provides a gain of 4.9db. Using Matlab a Koch with three iterations 4.1c.m long . has been generated and using MMANA code which is a MININEC code, antenna is simulated. The Koch monopole exhibits excellent performance at 925 MHz and has radiation properties nearly identical to that of traditional, straight-wire monopoles at that frequency. The radiation pattern is very uniform in all directions The greatest advantage of the Koch monopole design is compactness. A size reduction of nearly 50% was achieved over the straight-wire, , $\lambda/4$ free-space monopole. This is highly significant for applications such as GSM cellular phones . Since it is half the size of the traditional monopole, it could easily be completely integrated within the case of the phone, eliminating the protruding monopoles commonly seen on many cellular phones. Simulation results are shown below.

Figure 4.1 shows Koch of length 4.1c.m. of three iterations with source at bottom on a perfect ground of wire radius 0.1m.m.

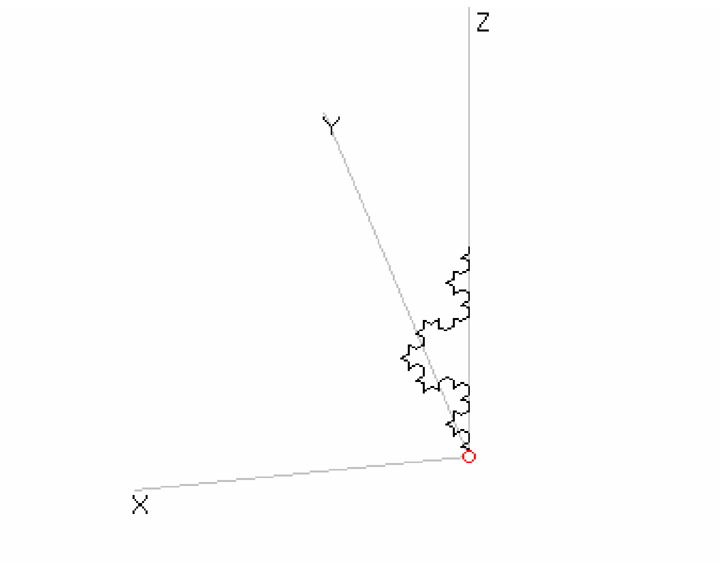


Figure 4.1 : Three iteration Koch of length 4.1cm.with source at bottom on a perfect ground.

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Figure 4.2 to 4.9 shows the results given by MMANA code, that gives frequency versus impedance plot, frequency versus gain and front to back ratio plot , frequency versus SWR plot, azimuthal and elevation plot of radiation pattern. SWR has been taken for 50 ohm feeding impedance. Figure 4.2 to 4.9 shows these results for different values of radius , for radius 0.1m.m., 1m.m., 2m.m.,3m.m. ,4m.m. ,5m.m. , 6m.m. , 6.8m.m., It has been observed that with increase in radius of antenna the bandwidth of antenna increases, gain remains almost same, radiation pattern also remains same.Figure4.9 shows the results of antenna with radius 6.8m.m.,this antenna is having gain of 4.9db ,front to back ratio 0db and bandwidth 71Mhz.

Figure 4.2(a)shows the Frequency versus Impedance plot and figure 4.2(b)shows frequency versus gain and frequency versus front to back ratio for the Koch fractal antenna of three iterations of length 4.1c.m. with radius 0.1m.m.

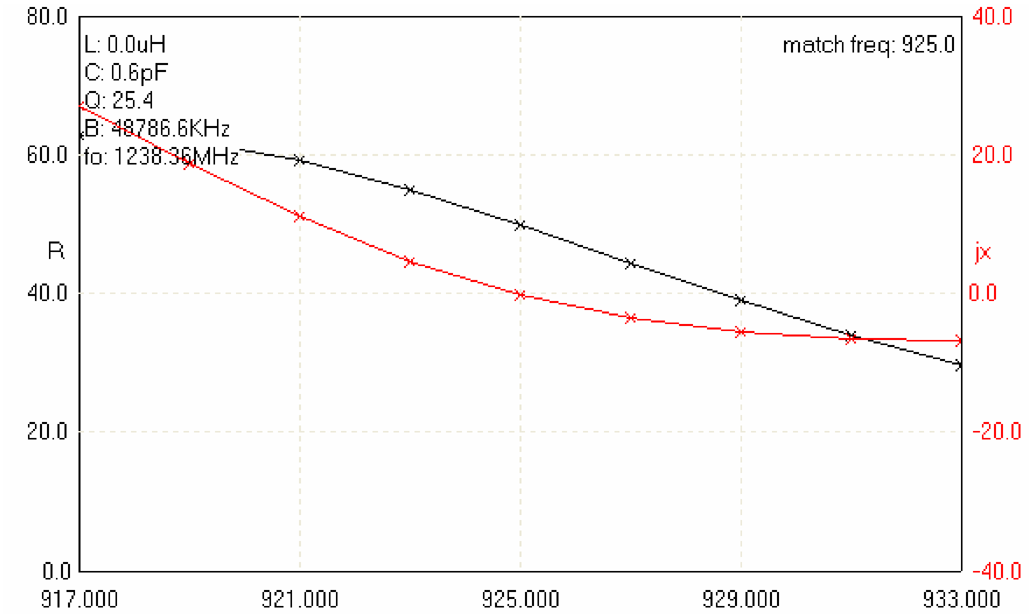

Figure 4.2(a): Frequency versus Real and Imaginary part of impedance plot for radius 0.1m.m.

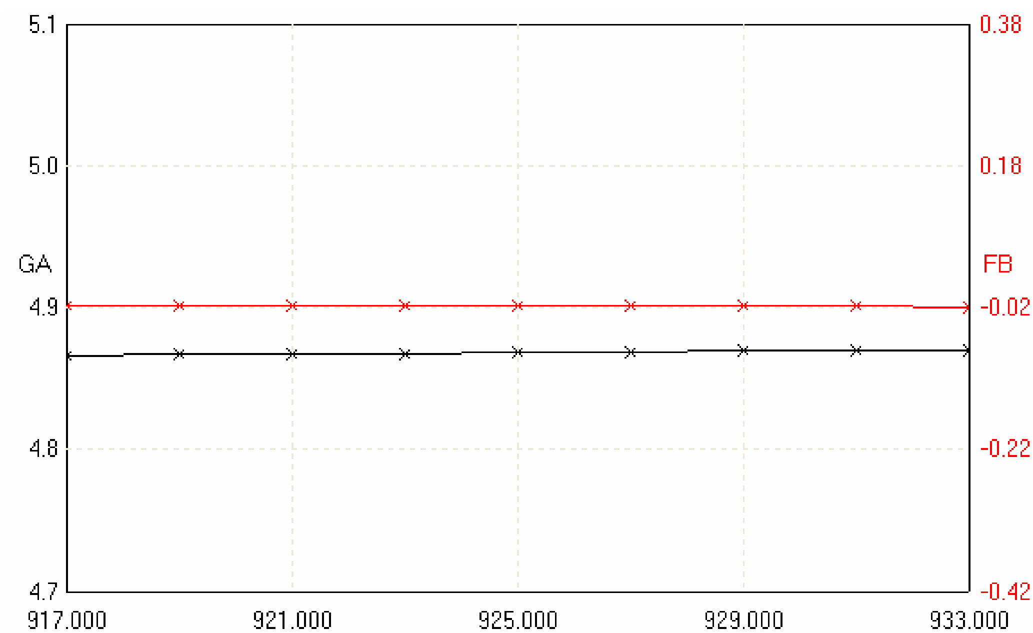

Figure 4.2(b):Frequency versus Gain and front to back ratio Plot for radius 0.1m.m.

Figure 4.2(c)shows the Frequency versus SWR plot and figure 4.2(d)shows Azimuthal and Elevation plot of radiation pattern for Koch fractal antenna of three iterations of length 4.1c.m. with radius 0.1m.m.

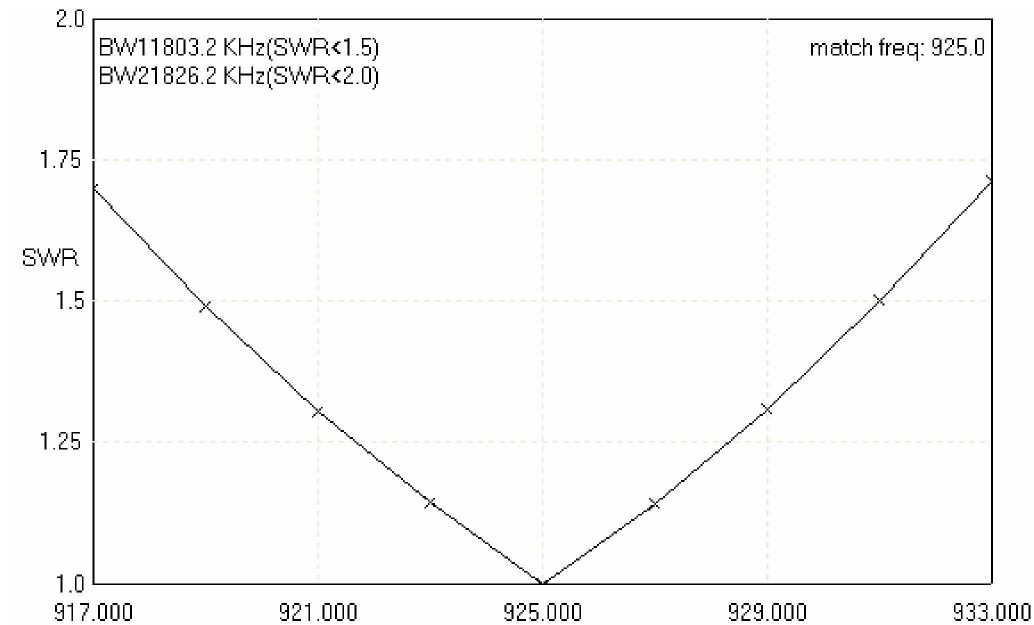

Figure 4.2(c): Frequency versus SWR plot for radius 0.1m.m.

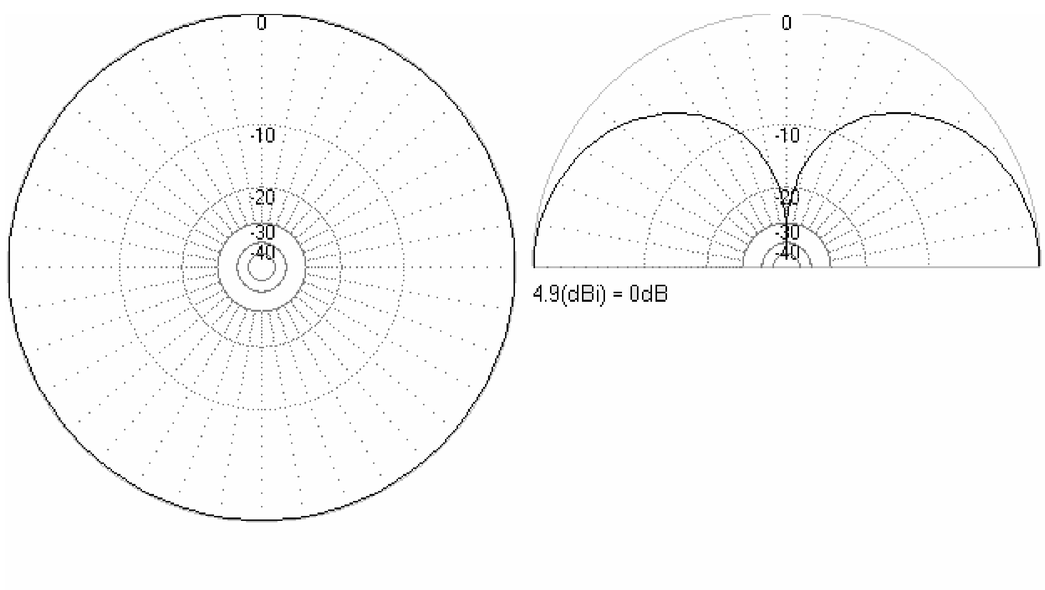

Figure 4.2(d): Azimuthal and elevation plot of Radiation Pattern

Figure 4.3(a)shows the Frequency versus Impedance plot and figure 4.3(b)shows frequency versus gain and frequency versus front to back ratio for the Koch fractal antenna of three iterations of length 4.1c.m. with radius 1m.m.

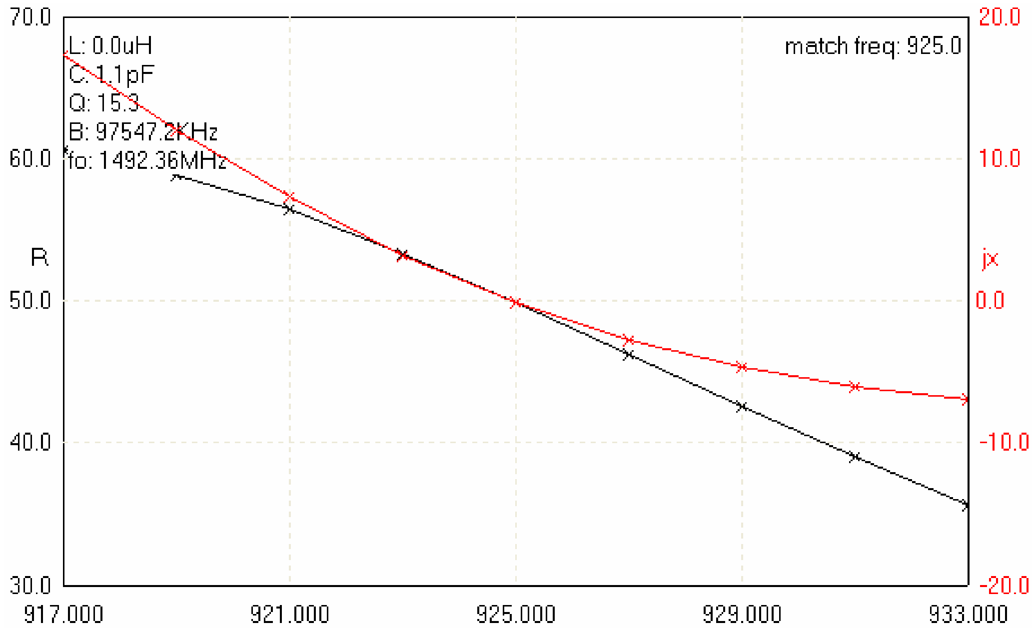

Figure 4.3(a): Frequency versus Real and Imaginary part of impedance plot for radius 1m.m.

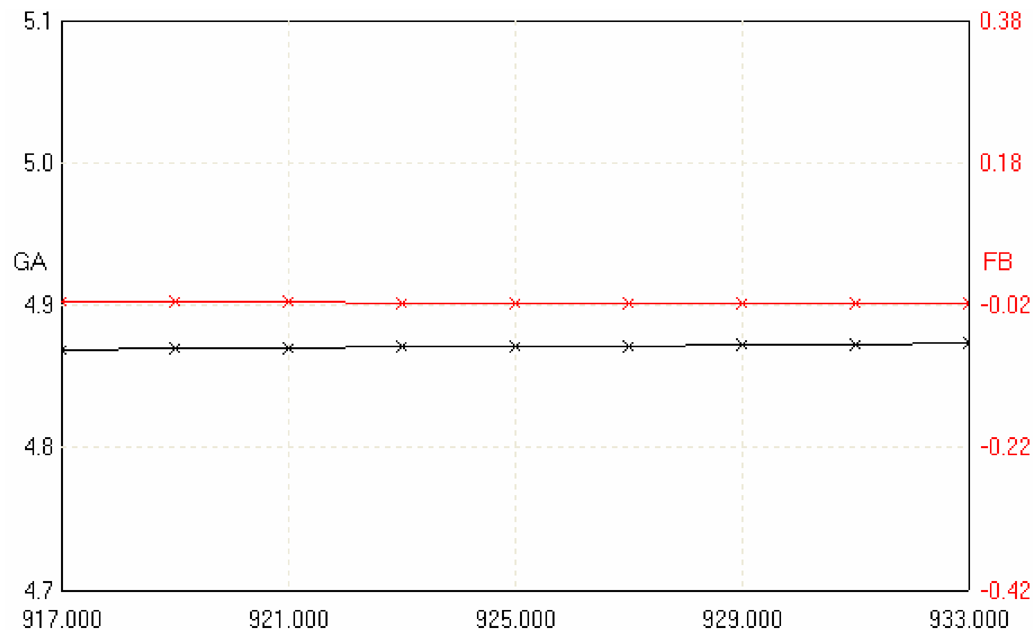

Figure 4.3(b): Frequency versus Gain and front to back ratio Plot for radius 1m.m.

Figure 4.3(c)shows the Frequency versus SWR plot and figure 4.3(d)shows Azimuthal and Elevation plot of radiation pattern for Koch fractal antenna of three iterations of length 4.1c.m. with radius 1m.m.

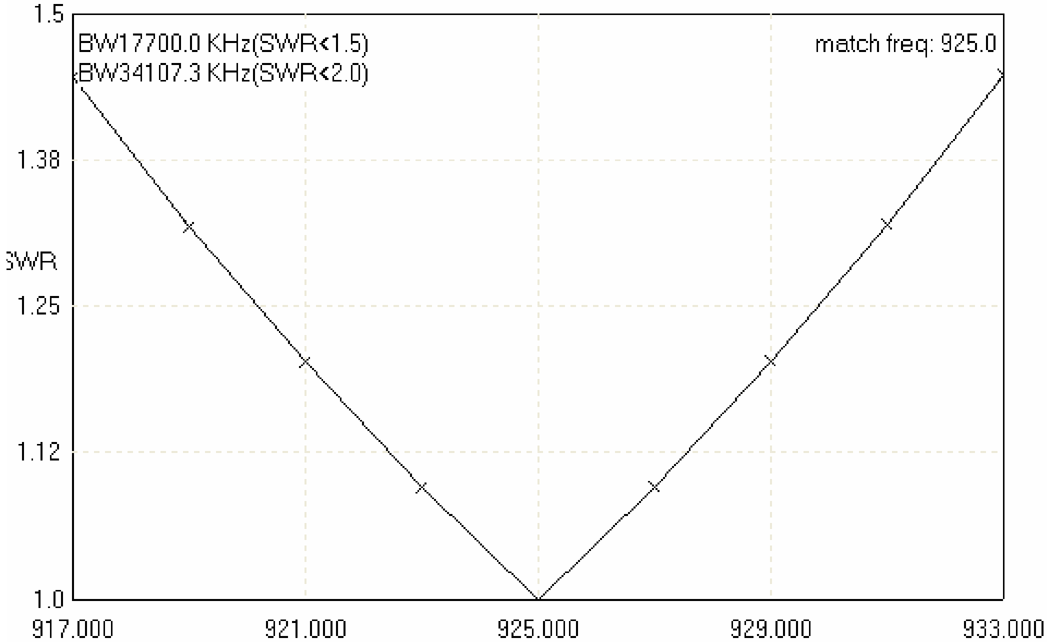

Figure 4.3(c): Frequency versus SWR plot for radius 1m.m.

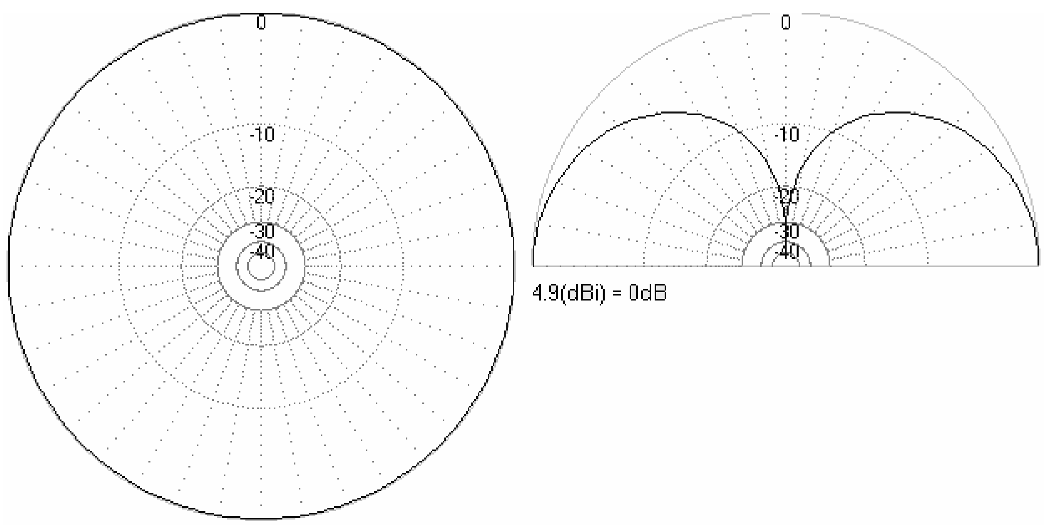

Figure 4.3(d): Azimuthal and elevation plot of Radiation Pattern

Figure 4.4(a)shows the Frequency versus Impedance plot and figure 4.4(b)shows frequency versus gain and frequency versus front to back ratio for the Koch fractal antenna of three iterations of length 4.1c.m. with radius 2m.m.

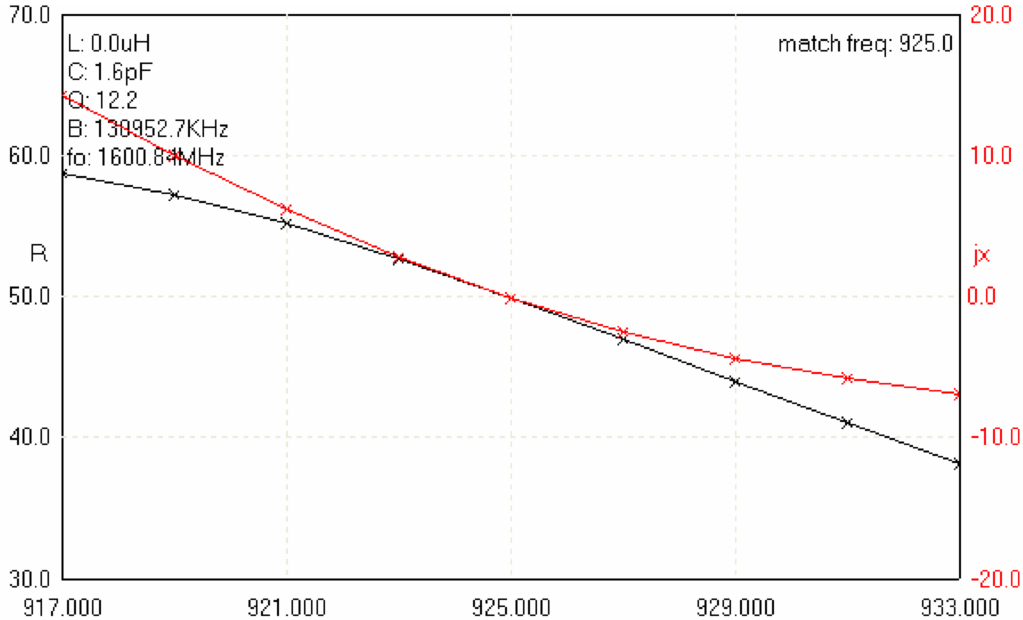

Figure 4.4(a): Frequency versus Real and Imaginary part of impedance plot for radius 2m.m.

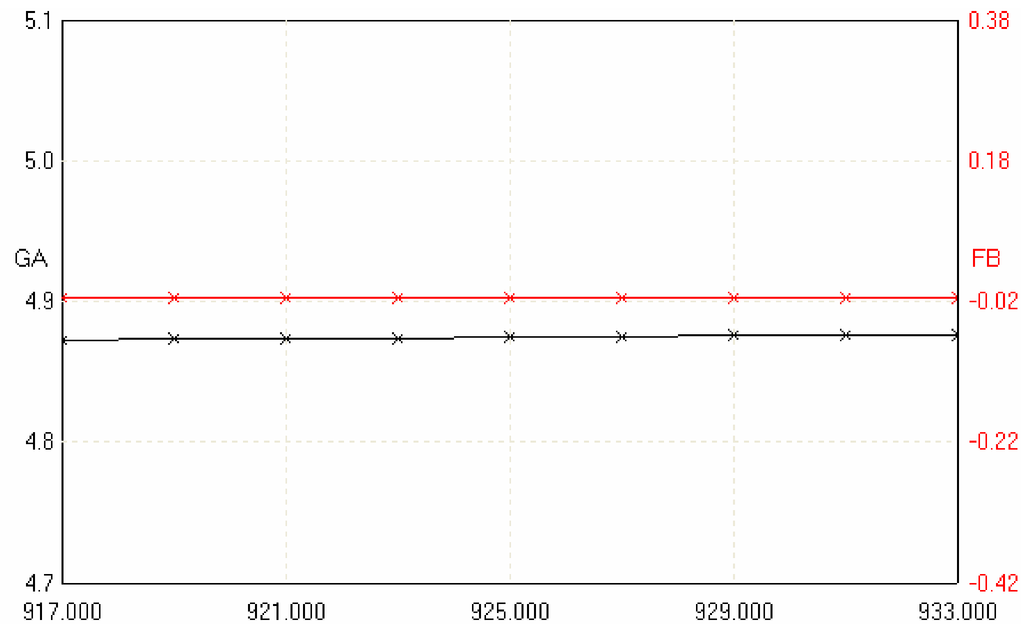

Figure 4.4(b): Frequency versus Gain and front to back ratio Plot for radius 2m.m.

Figure 4.4(c)shows the Frequency versus SWR plot and figure 4.4(d)shows Azimuthal and Elevation plot of radiation pattern for Koch fractal antenna of three iterations of length 4.1c.m. with radius 2m.m.

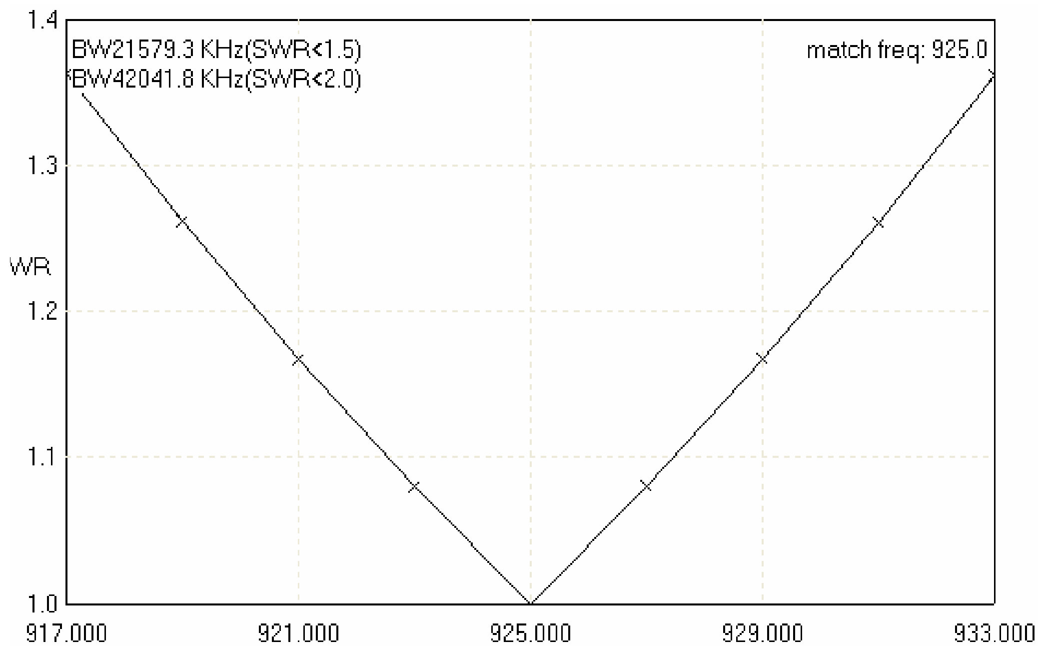

Figure 4.4(c): Frequency versus SWR plot for radius 2m.m.

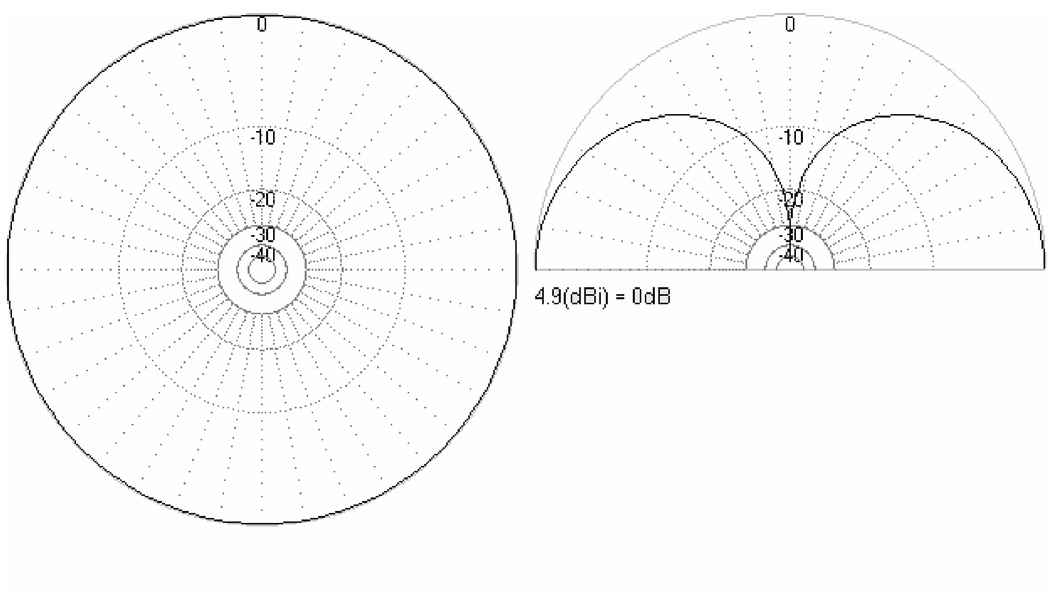

Figure 4.4(d): Azimuthal and elevation plot of Radiation Pattern

Figure 4.5(a)shows the Frequency versus Impedance plot and figure 4.5(b)shows frequency versus gain and frequency versus front to back ratio for the Koch fractal antenna of three iterations of length 4.1c.m. with radius 3m.m.

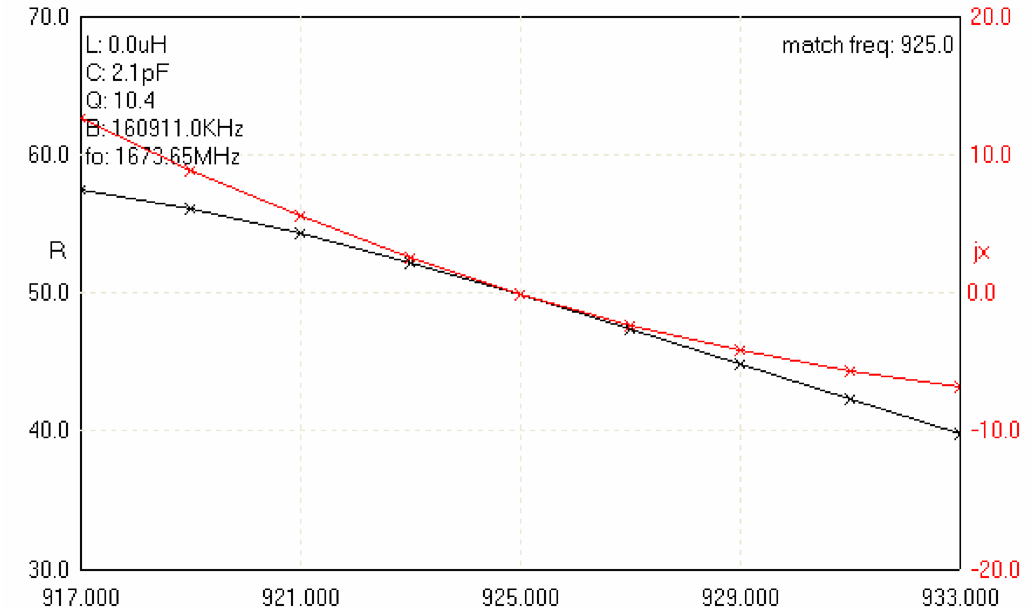

Figure 4.5(a): Frequency versus Real and Imaginary part of impedance plot for radius 3m.m.

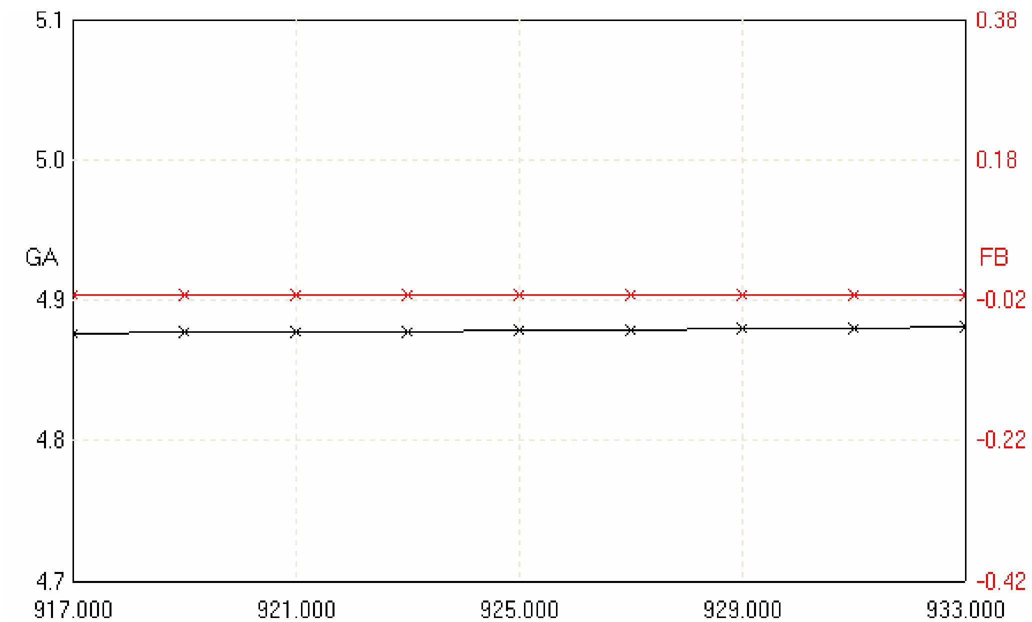

Figure 4.5(b): Frequency versus Gain and front to back ratio Plot for radius 3m.m.

Figure 4.5(c)shows the Frequency versus SWR plot and figure 4.5(d)shows Azimuthal and Elevation plot of radiation pattern for Koch fractal antenna of three iterations of length 4.1c.m. with radius 3m.m.

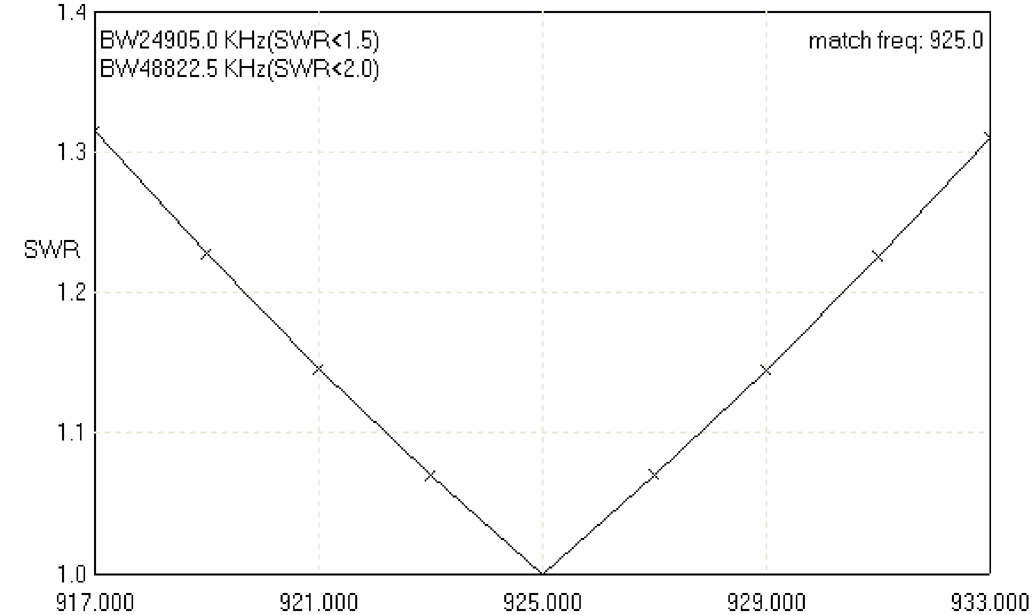

Figure 4.5(c): Frequency versus SWR plot for radius 3m.m.

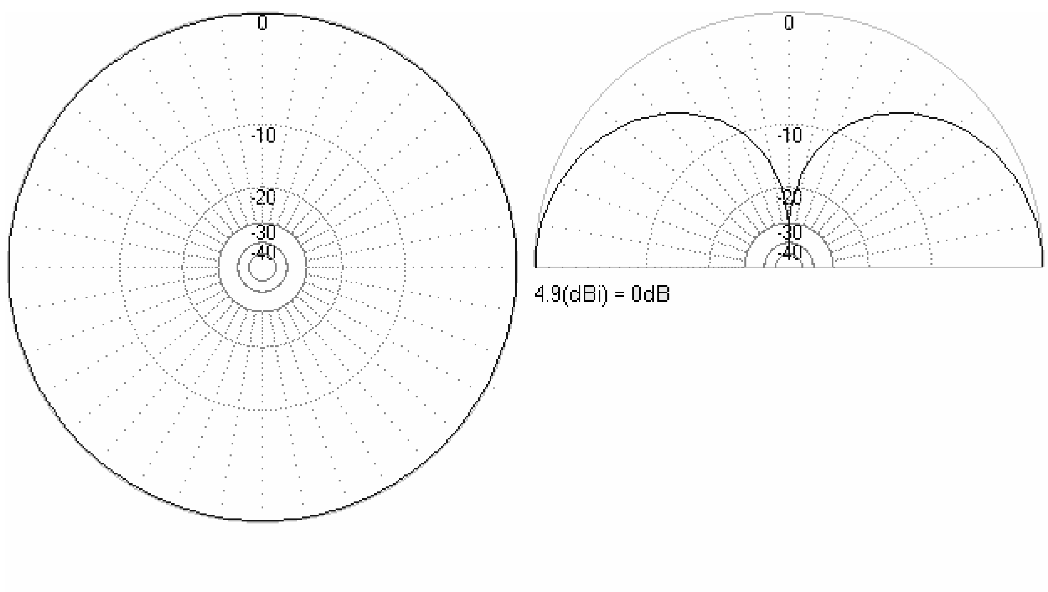

Figure 4.5(d): Azimuthal and elevation plot of Radiation Pattern

Figure 4.6(a)shows the Frequency versus Impedance plot and figure 4.6(b)shows frequency versus gain and frequency versus front to back ratio for the Koch fractal antenna of three iterations of length 4.1c.m. with radius 4m.m.

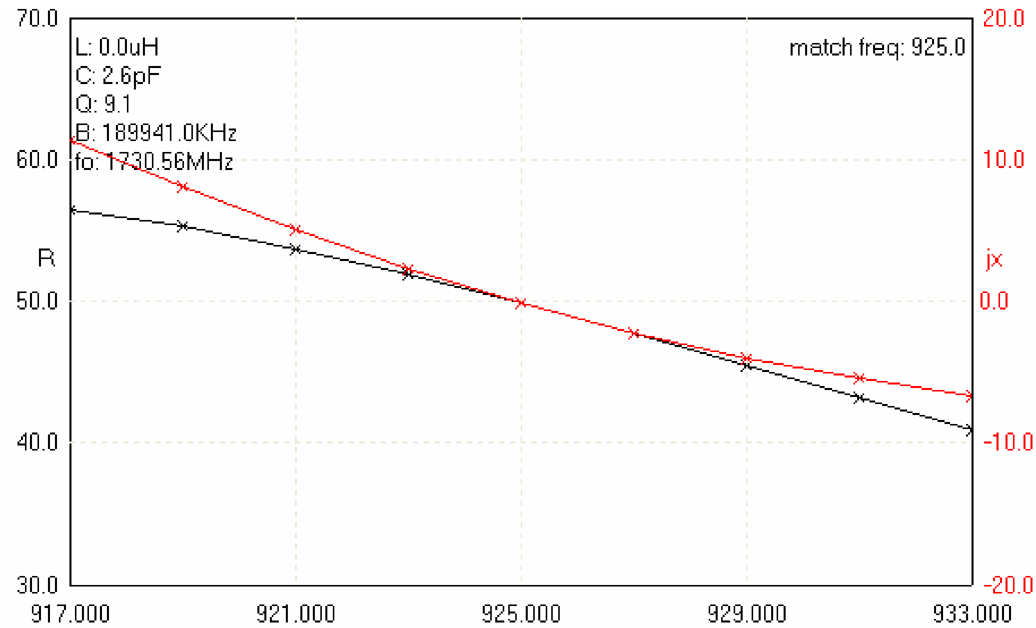

Figure 4.6(a): Frequency versus Real and Imaginary part of impedance plot for radius 4m.m

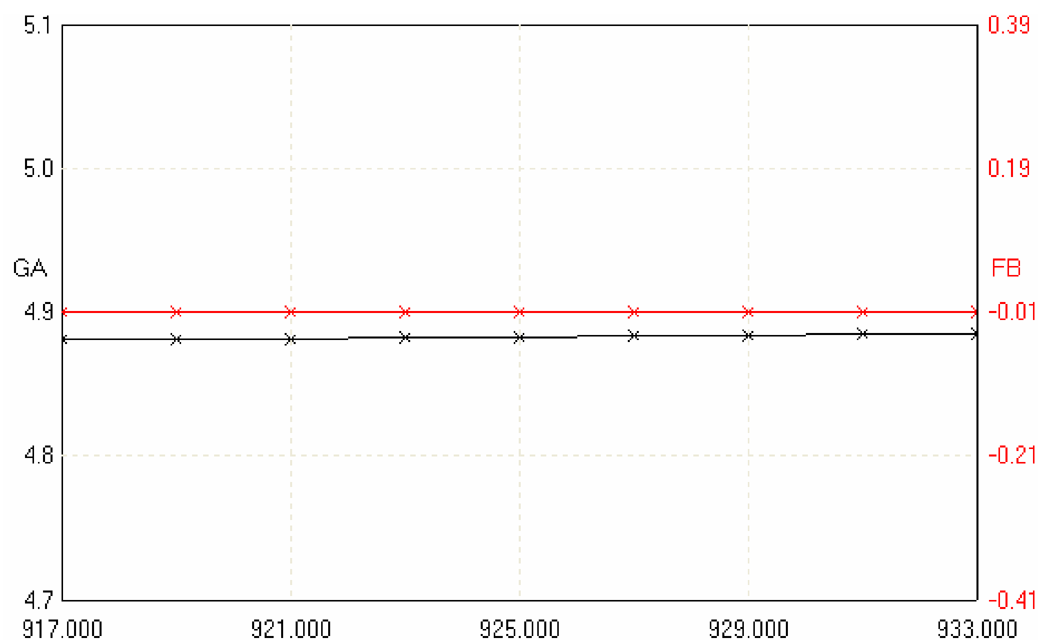

Figure 4.6(b): Frequency versus Gain and front to back ratio Plot for radius 4m.m.

Figure 4.6(c)shows the Frequency versus SWR plot and figure 4.6(d)shows Azimuthal and Elevation plot of radiation pattern for Koch fractal antenna of three iterations of length 4.1c.m. with radius 4m.m.

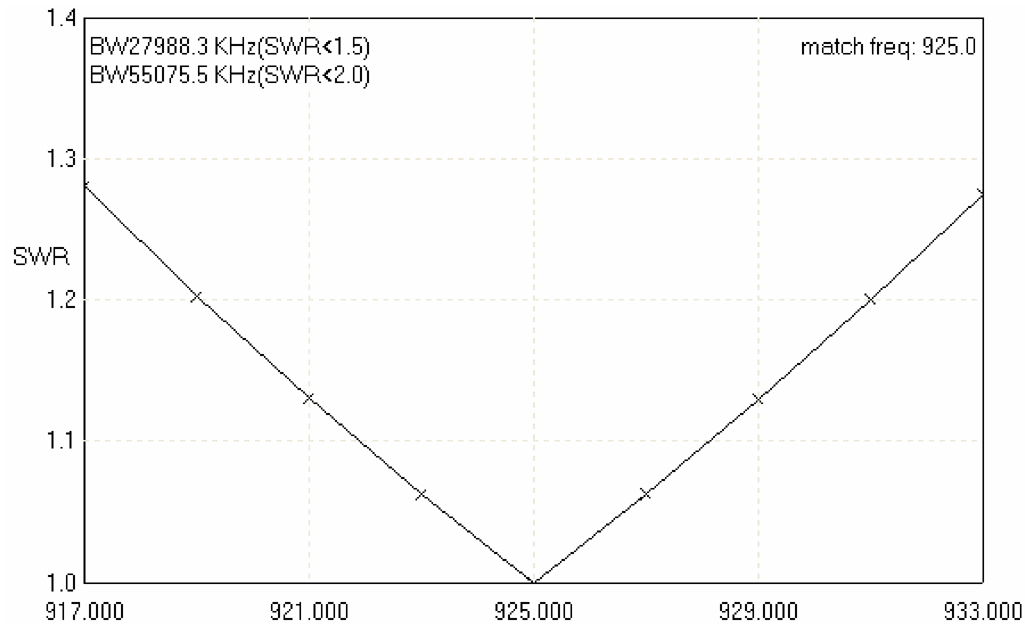

Figure 4.6(c): Frequency versus SWR plot for radius 4m.m.

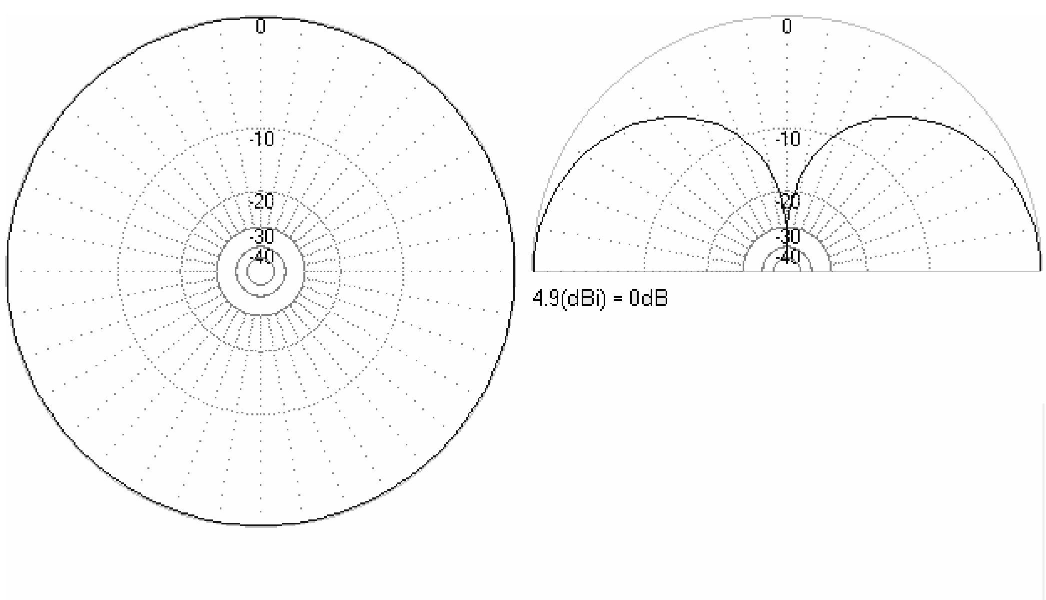

Figure 4.6(d): Azimuthal and elevation plot of Radiation Pattern

Figure 4.7(a)shows the Frequency versus Impedance plot and figure 4.7(b)shows frequency versus gain and frequency versus front to back ratio for the Koch fractal antenna of three iterations of length 4.1c.m. with radius 5m.m.

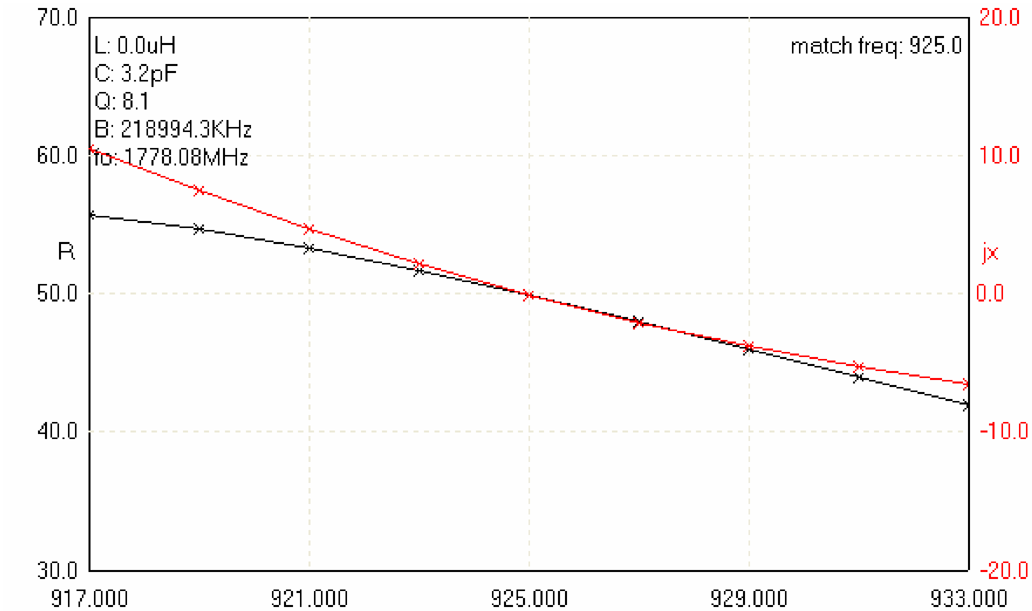

Figure 4.7(a): Frequency versus Real and Imaginary part of impedance plot for radius 5m.m.

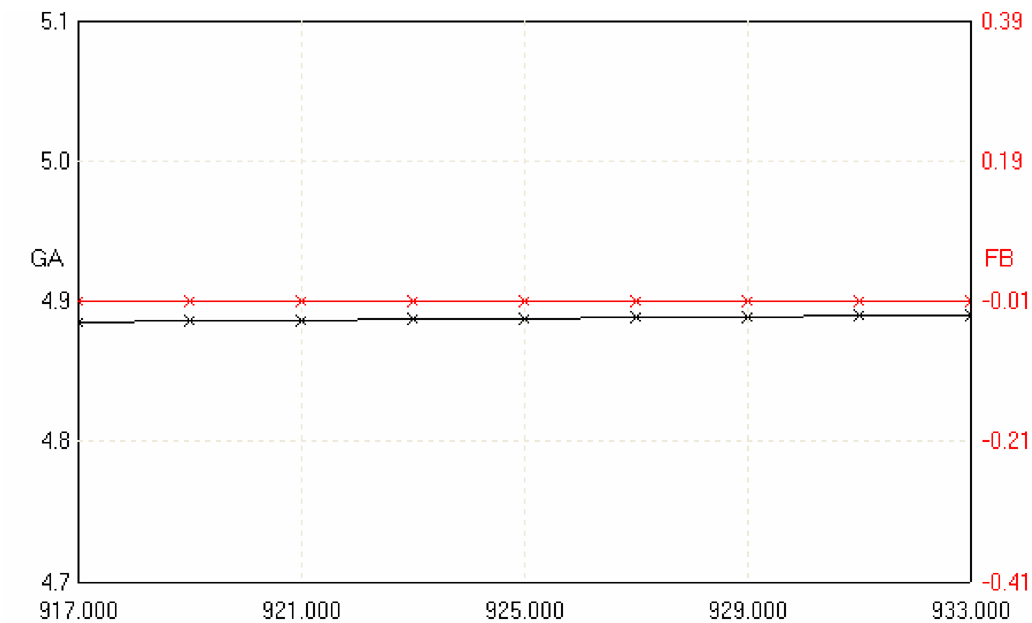

Figure 4.7(b): Frequency versus Gain and front to back ratio Plot for radius 5m.m.

Figure 4.7(c)shows the Frequency versus SWR plot and figure 4.7(d)shows Azimuthal and Elevation plot of radiation pattern for Koch fractal antenna of three iterations of length 4.1c.m. with radius 5m.m.

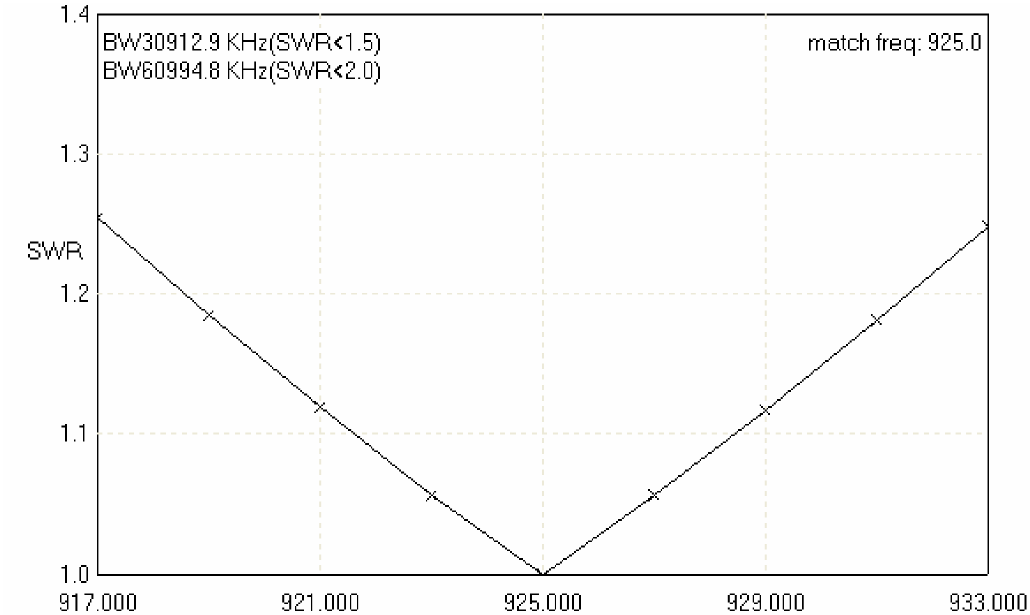

Figure 4.7(c): Frequency versus SWR plot for radius 5m.m.

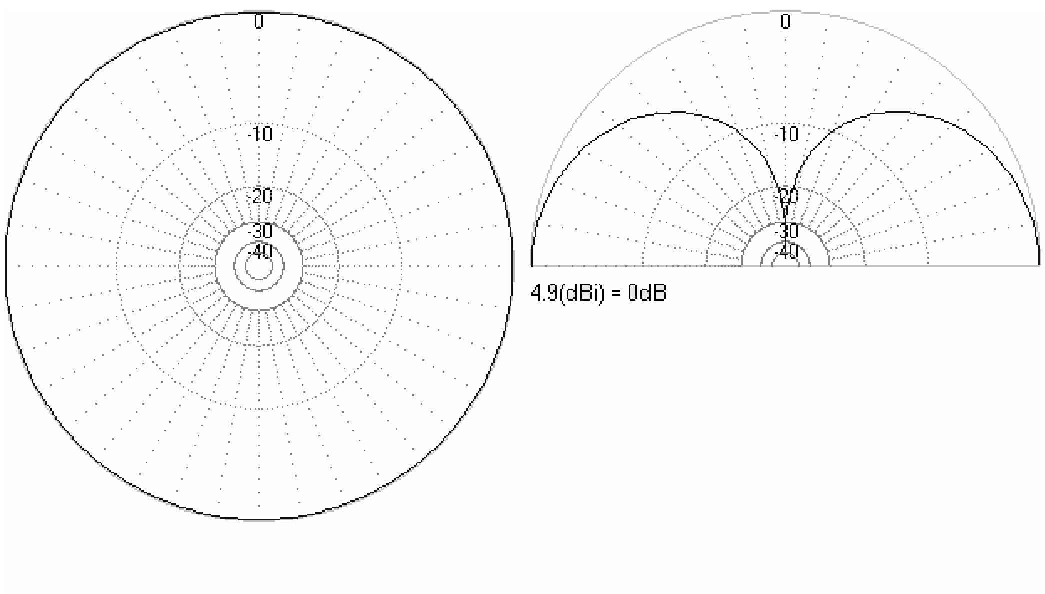

Figure 4.7(d): Azimuthal and elevation plot of Radiation Pattern

Figure 4.8(a)shows the Frequency versus Impedance plot and figure 4.8(b)shows frequency versus gain and frequency versus front to back ratio for the Koch fractal antenna of three iterations of length 4.1c.m. with radius 6m.m.

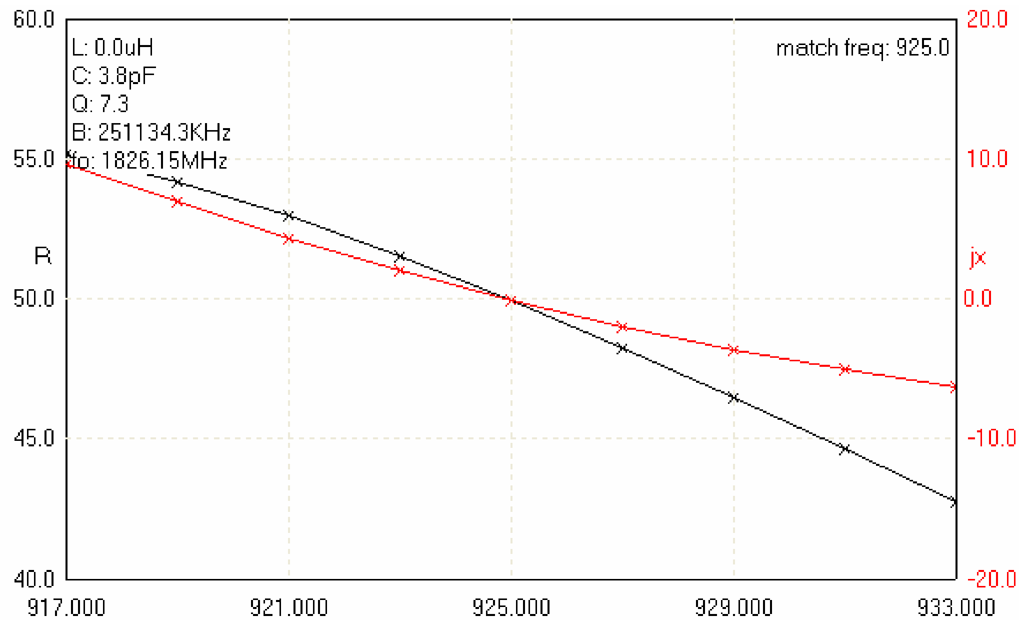

Figure 4.8(a): Frequency versus Real and Imaginary part of impedance plot for radius 6m.m.

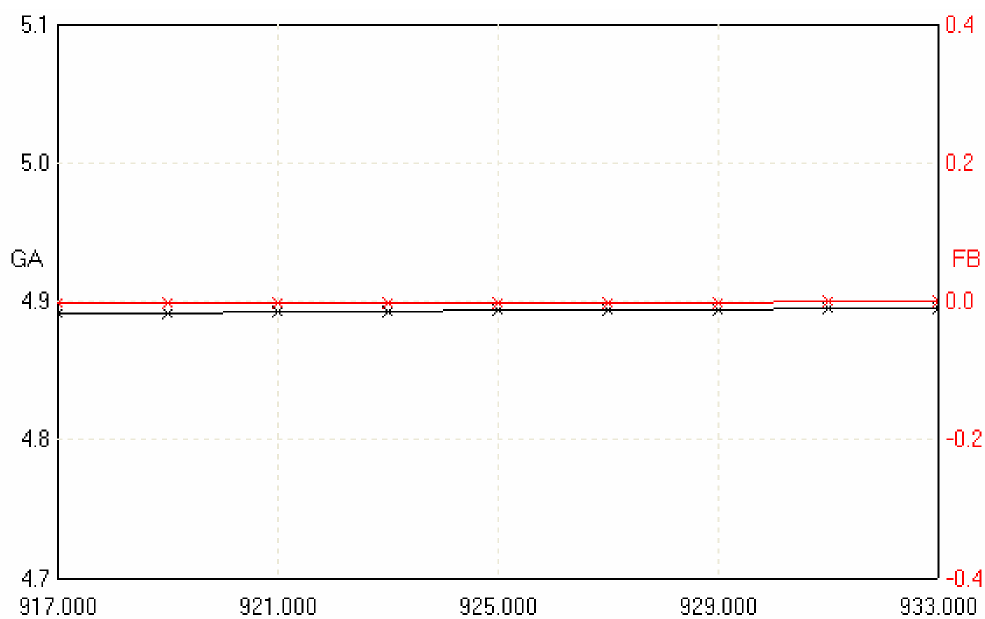

Figure 4.8(b): Frequency versus Gain and front to back ratio Plot for radius 6m.m.

Figure 4.8(c)shows the Frequency versus SWR plot and figure 4.8(d)shows Azimuthal and Elevation plot of radiation pattern for Koch fractal antenna of three iterations of length 4.1c.m. with radius 6m.m.

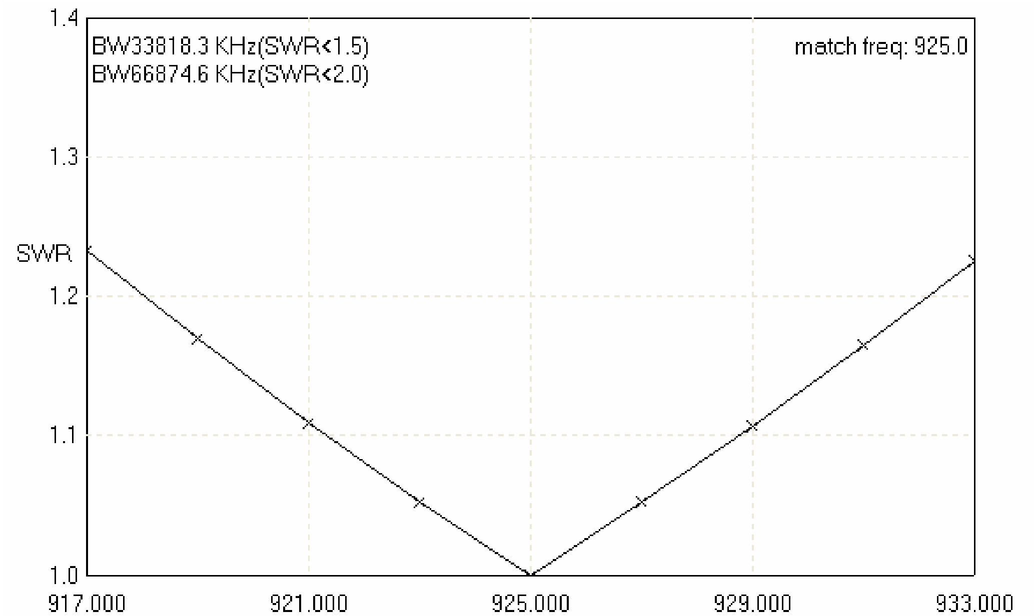

Figure 4.8(c): Frequency versus SWR plot for radius 6m.m.

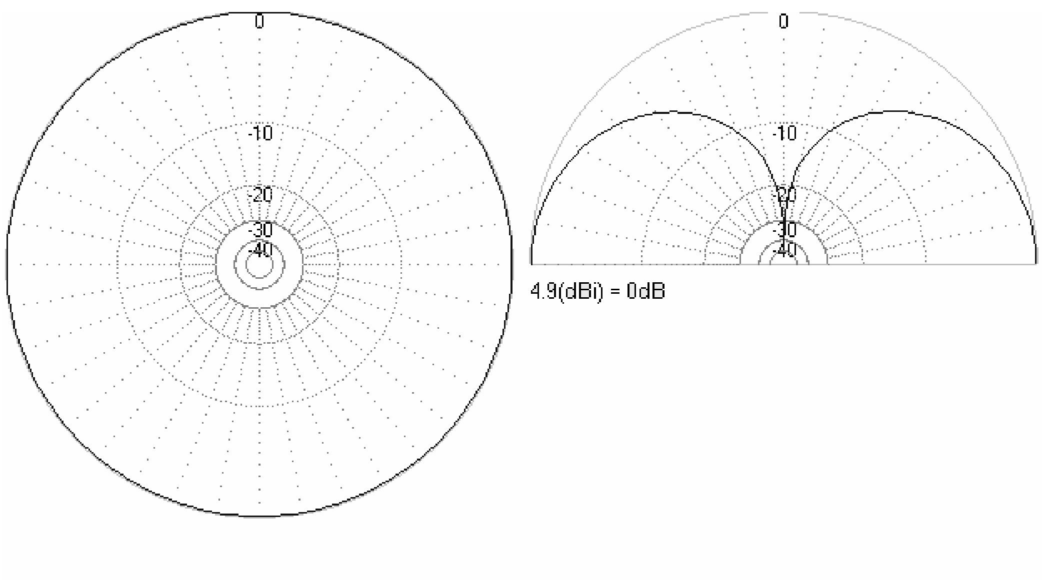

Figure 4.8(d): Azimuthal and elevation plot of Radiation Pattern

Figure 4.9(a)shows the Frequency versus Impedance plot and figure 4.9(b)shows frequency versus gain and frequency versus front to back ratio for the Koch fractal antenna of three iterations of length 4.1c.m. with radius 6.8m.m..

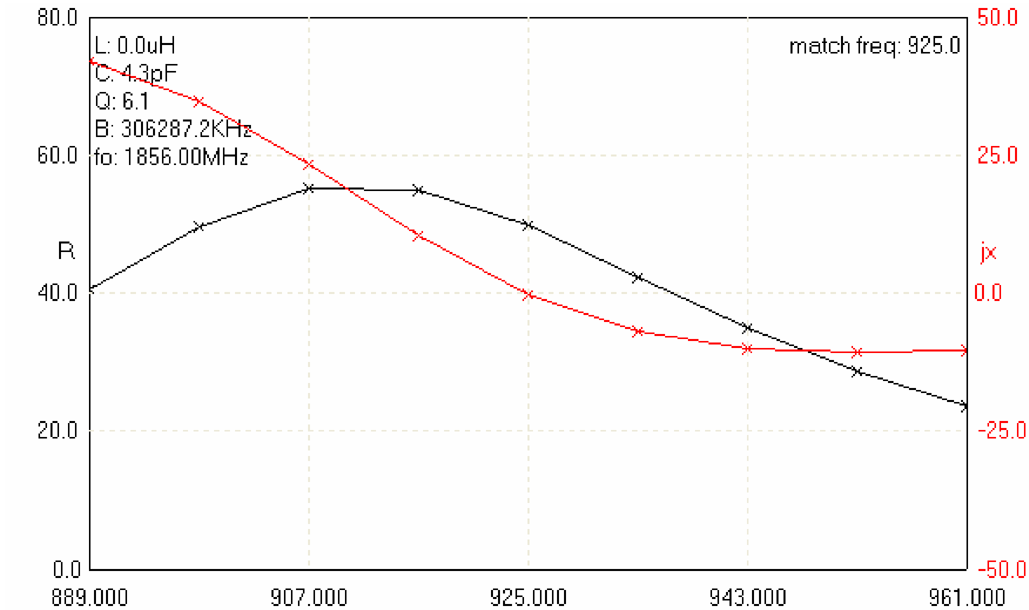

Figure 4.9(a): Frequency versus Real and Imaginary part of impedance plot for radius 6.8m.m.

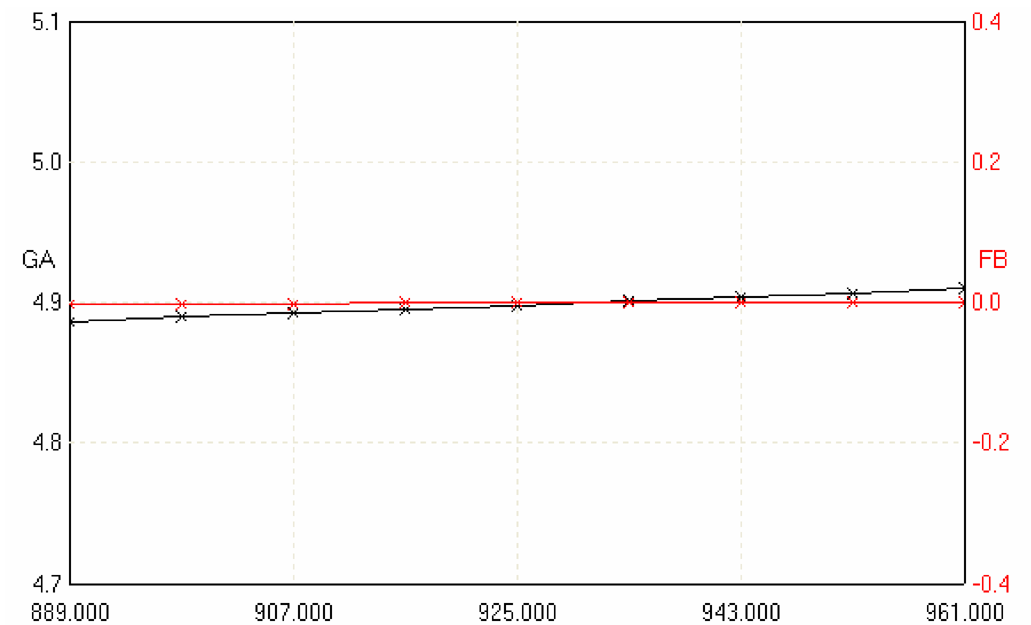

Figure 4.9(b): Frequency versus Gain and front to back ratio Plot for radius 6.8m.m.

Figure 4.9(c)shows the Frequency versus SWR plot and figure 4.9(d)shows Azimuthal and Elevation plot of radiation pattern for Koch fractal antenna of three iterations of length 4.1c.m. with radius 6.8m.m.

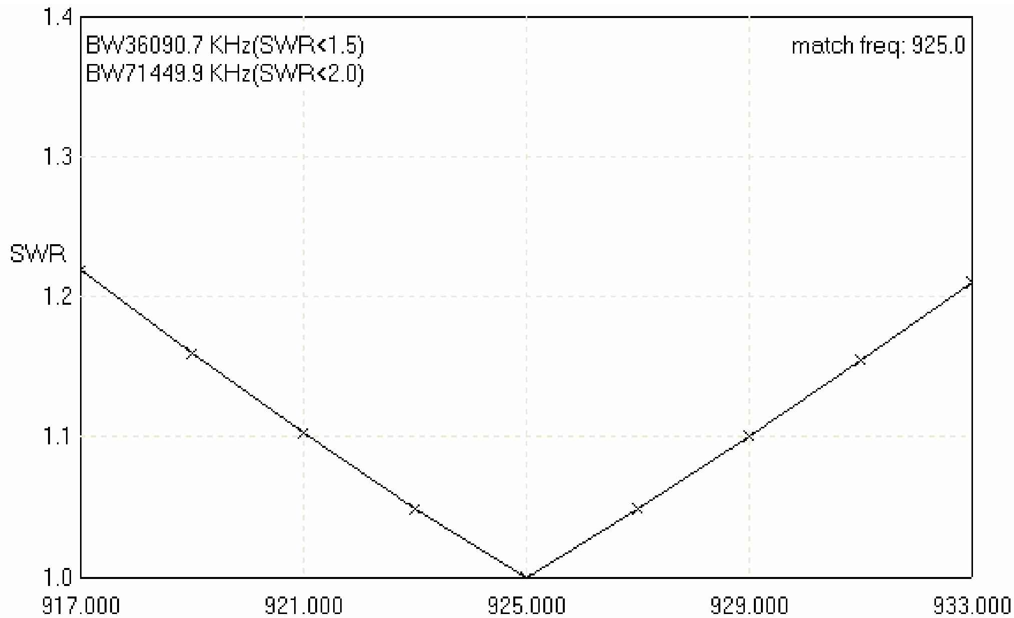

Figure 4.9(c): Frequency versus SWR plot for radius 6.8m.m.

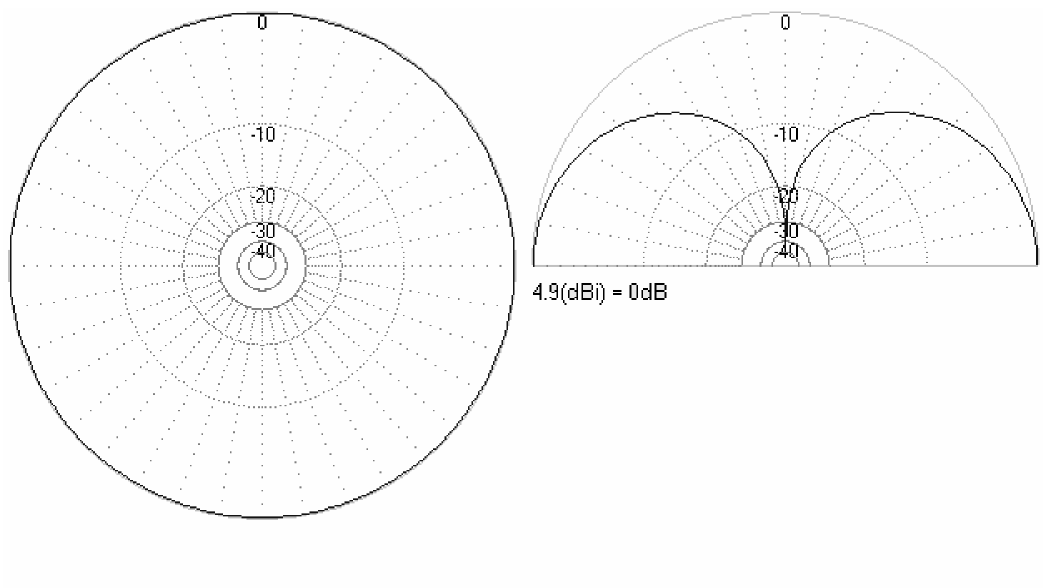

Figure 4.9(d): Azimuthal and elevation plot of Radiation Pattern

Figure 4.10 shows the variation of Quality Factor with Radius of Koch Fractal Antenna, it is observed that with increase in radius the quality factor decreases and for radius 6.8m.m.,the quality factor is 6.7

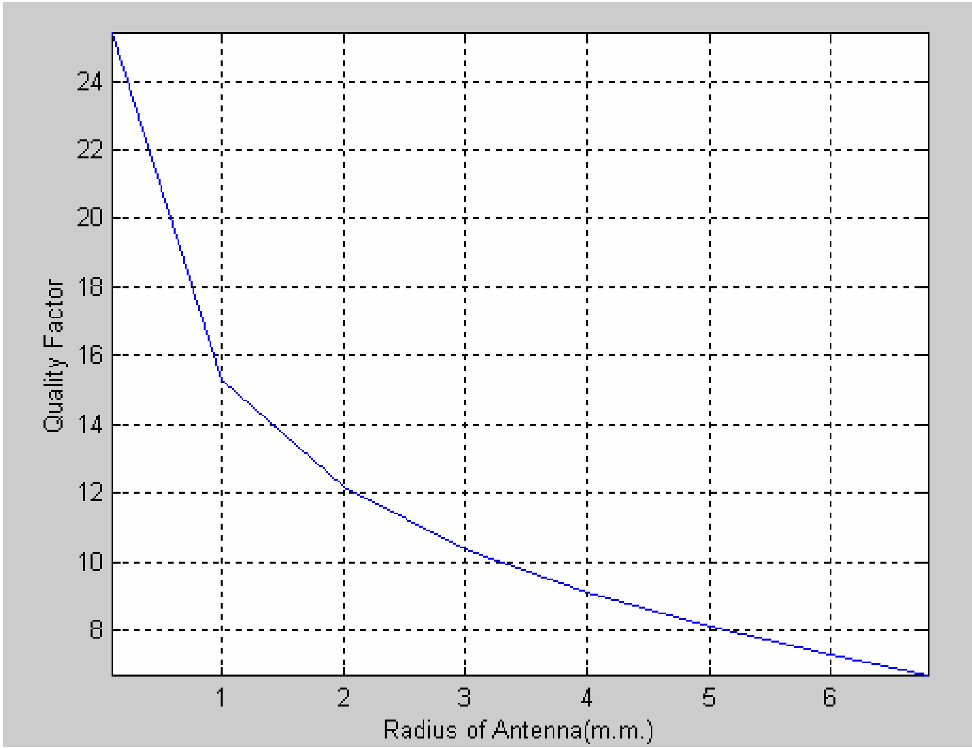

Figure 4.10:Variation of Quality Factor with Radius of Koch Fractal Antenna

Figure 4.11shows the variation of Bandwidth(SWR<2) with Radius of Koch Fractal Antenna, it is observed that with increase in radius of antenna the bandwidth increases, for radius 6.8m.m.,the bandwidth(SWR<2) is 71Mhz.,which covers the whole GSM900 band.

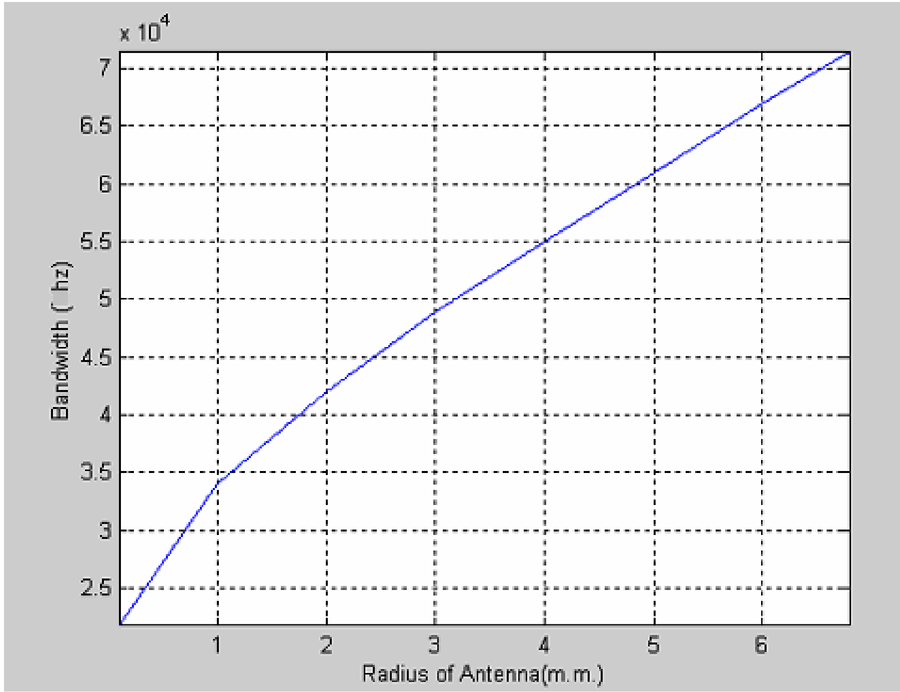

Figure 4.11:Variation of Bandwidth with Radius of Koch Fractal Antenna

Figure 4.12 shows variation of Q, Bandwidth, Impedance ,Gain and Front to Back ratio with Radius of antenna at925Mhz in tabular form. With increase in radius the quality factor decreases, bandwidth(SWR) increases, impedance of the antenna keep on decreasing, gain and front to back ratio remains same.

Radius of	**Quality**	**Bandwidth**	**Real part**	**Imaginary part**	**Gain**	**Front to**

Antenna (m.m.)	Factor(Q)	(KHz)	of Impedance	of Impedance	(db)	Back Ratio(db)
0.1	25.4	21826.2	7.7	-117.9	4.9	0.0
1	15.3	34107.3	5.9	-92.4	4.9	0.0
2	12.2	42041.8	5.0	-72	4.9	0.0
3	10.4	48822.5	4.3	-57.8	4.9	0.0
4	9.1	55075.5	3.8	-47.5	4.9	0.0
5	8.1	60994.8	3.4	-39.7	4.9	0.0
6	7.3	66874.6	3.1	-33.8	4.9	0.0
6.8	6.7	71449.9	2.9	-29.9	4.9	0.0

Figure 4.12:Table showing variation of Q, Bandwidth, Impedance ,Gain and Front to Back ratio with Radius of antenna at925Mhz.

The Koch fractal antenna of length 4.1c.m.with radius 6.8c.m.,has quality factor 6.7 ,has bandwidth(SWR<2) 71Mhz ,has gain 4.9 db and a front to back ratio 0db.The bandwidth covers the GSM900 band. It has radiation pattern which is uniform in all directions, same as that of traditional monopole .But using fractals a reduction of nearly 50% in the size antenna over conventional monopole has been achieved without sacrificing the performance of antenna up to much extent. This is highly significant for applications such as GSM cellular phones.

Chapter-5
Fractal Antenna in GSM1800

GSM1800 operates at frequency range 1710-1785Mhz for uplink communication and 1805-1880Mhz. for downlink communication. A monopole on a perfect ground having resonance at 1800Mhz is required. and the length of straight wire monopole required is 4.16c.m., But this length will be very large in comparison to the dimensions of handset. By using a three iteration Koch, the length of Koch monopole required is 1.75c.m.(from equation 2.17) to provide effective height of 4.16c.m., but due to the coupling effect described in capter-2 , Koch of length 2c.m. with three iteration on a perfect ground with source at bottom end is used. Radius of wire has been taken 0.1m.m.With radius 0.1m.m. antenna has bandwidth(SWR<2) 38.7Mhz which is very less to cover 1800Mhz band ,by increasing wire radius ,bandwidth could be increased. By taking radius 6.5m.m. bandwidth increases up to 180Mhz. which covers the whole 1800Mhz band, provide a gain of 4.9db. Using Matlab a Koch of three iterations on height 2c.m. has been generated and using MMANA code which is a MININEC code, antenna is simulated. The Koch monopole exhibits excellent performance at 1800 MHz and has radiation properties nearly identical to that of traditional, straight-wire monopoles at that frequency. The radiation pattern is very uniform in all directions. The greatest advantage of the Koch monopole design is compactness. A size reduction of nearly 50% was achieved over the straight-wire, , $\lambda / 4$ free-space monopole. This is highly significant for applications such as GSM cellular phones . Since it is half the size of the traditional monopole, it could easily be completely integrated within the case of the phone, eliminating the protruding monopoles commonly seen on many cellular phones. Simulation results are shown below.

Figure 5.1shows Koch of length 2c.m. of three iterations with source at bottom on a perfect ground of wire radius 0.1m.m.

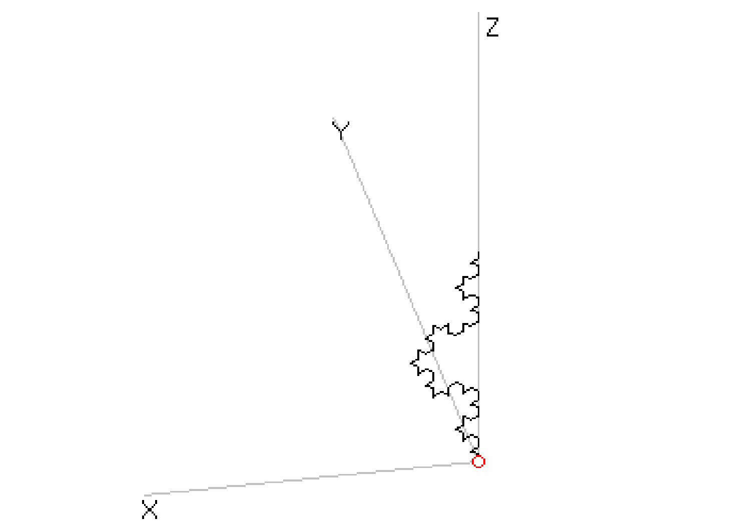

Figure5.1 : Three iteration Koch of length 2cm.with source at bottom on a perfect ground.

Figure 5.2 to 5.9 shows the results given by MMANA code, that gives frequency versus impedance plot, frequency versus gain and front to back ratio plot , frequency versus SWR plot, azimuthal and elevation plot of radiation pattern. SWR has been taken for 50 ohm feeding impedance. Figure 5.2 to 5.9 shows these results for different values of radius , for radius 0.1m.m., 1m.m., 2m.m.,3m.m. ,4m.m. ,5m.m. , 6m.m. , 6.5m.m. It has been observed that with increase in radius of antenna the bandwidth of antenna increases, gain remains almost same, radiation pattern also remains same.Figure5.9 shows the results of antenna with radius 6.5m.m.,this antenna is having gain of 4.9db ,front to back ratio 0db and bandwidth 180Mhz.

Figure 5.2(a)shows the Frequency versus Impedance plot and figure 5.2(b)shows frequency versus gain and frequency versus front to back ratio for the Koch fractal antenna of three iterations of length 2c.m. with radius 0.1m.m.

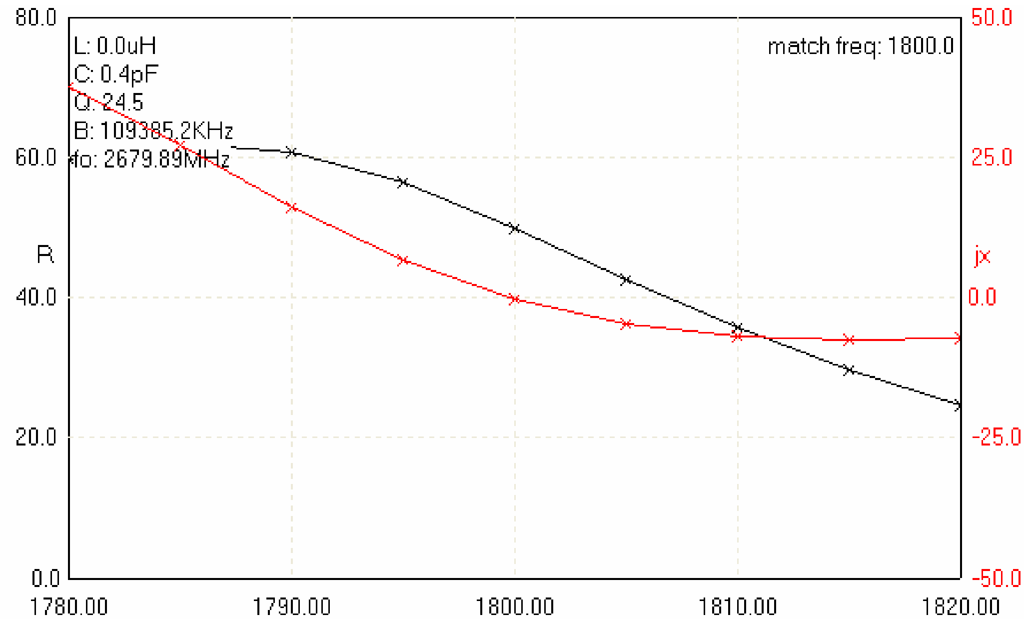

Figure 5.2(a): Frequency versus Real and Imaginary part of impedance plot for radius 0.1m.m.

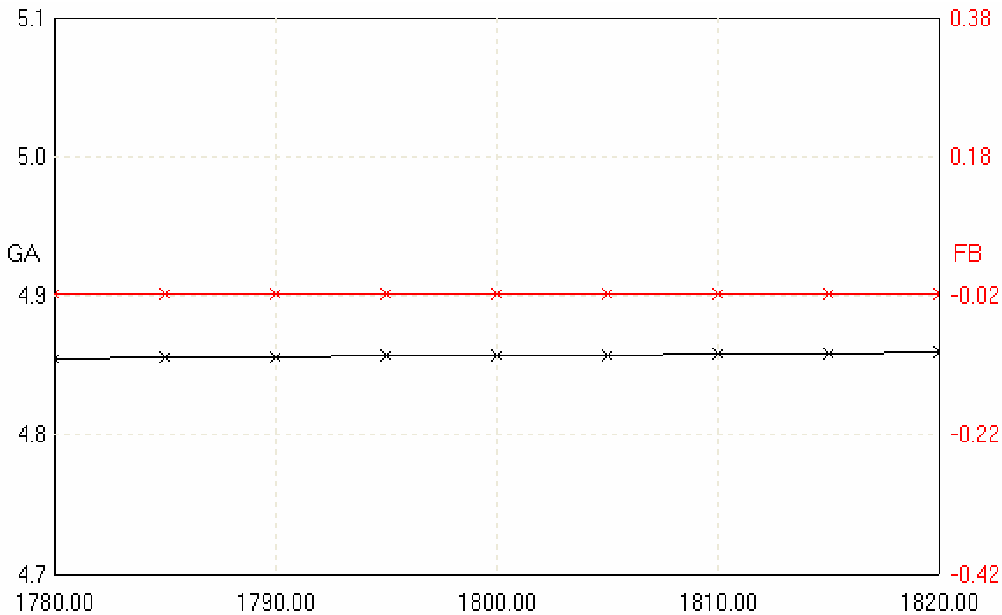

Figure 5.2(b):Frequency versus Gain and front to back ratio Plot for radius 0.1m.m.

Figure 5.2(c)shows the Frequency versus SWR plot and figure 5.2(d)shows Azimuthal and Elevation plot of radiation pattern for Koch fractal antenna of three iterations of length 2c.m. with radius 0.1m.m.

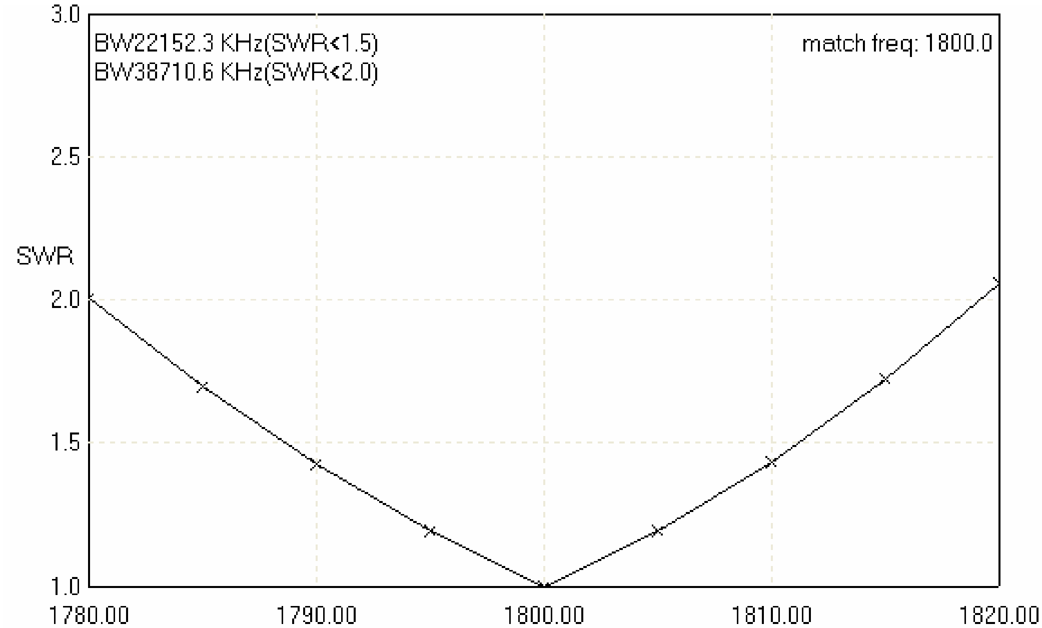

Figure 5.2(c): Frequency versus SWR plot for radius 0.1m.m.

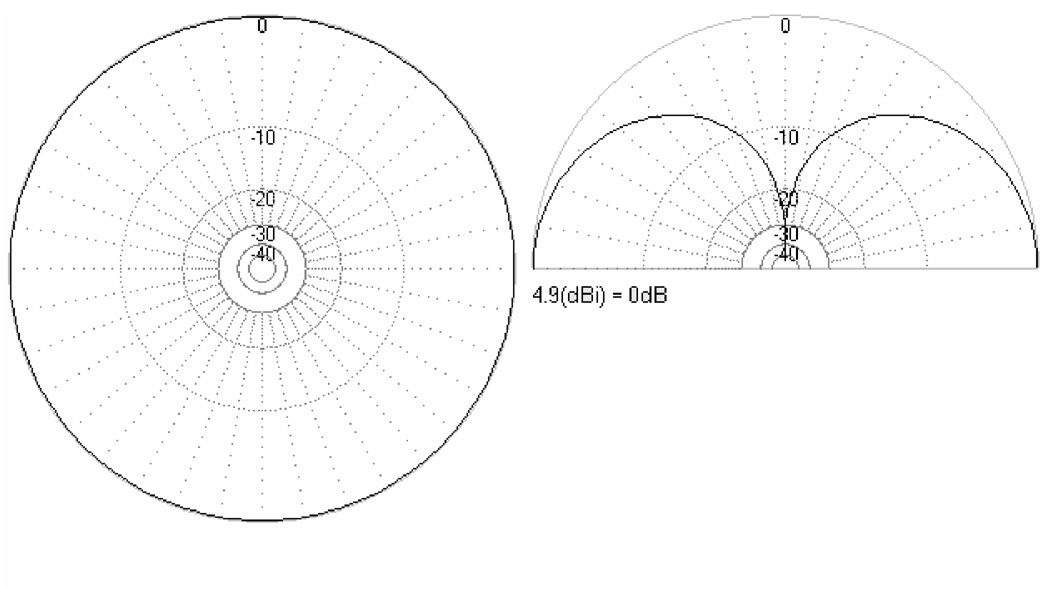

Figure 5.2(d): Azimuthal and elevation plot of Radiation Pattern

Figure 5.3(a)shows the Frequency versus Impedance plot and figure 5.3(b)shows frequency versus gain and frequency versus front to back ratio for the Koch fractal antenna of three iterations of length 2c.m. with radius 1m.m.

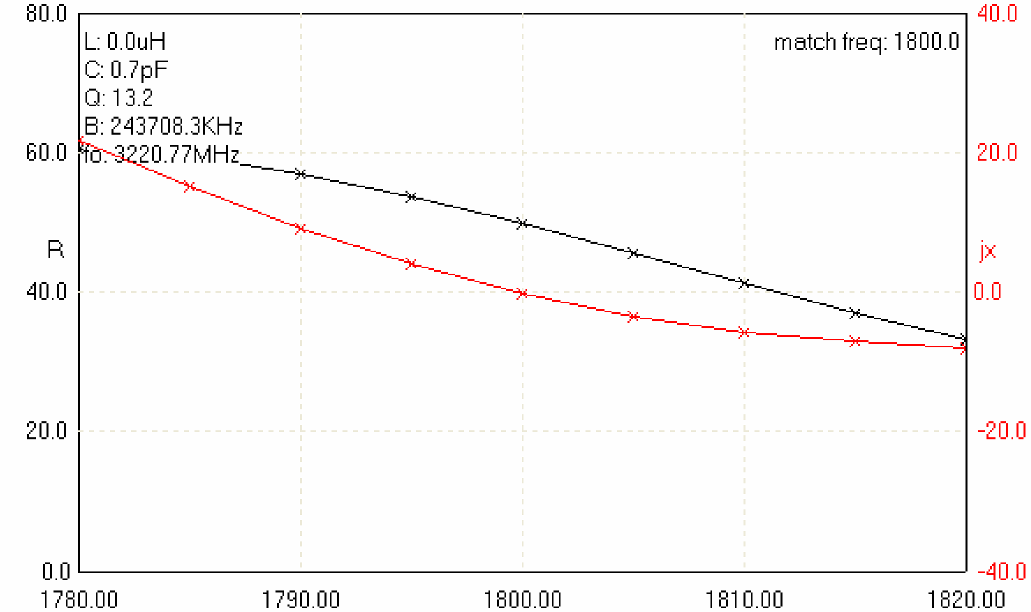

Figure 5.3(a): Frequency versus Real and Imaginary part of impedance plot for radius 1m.m.

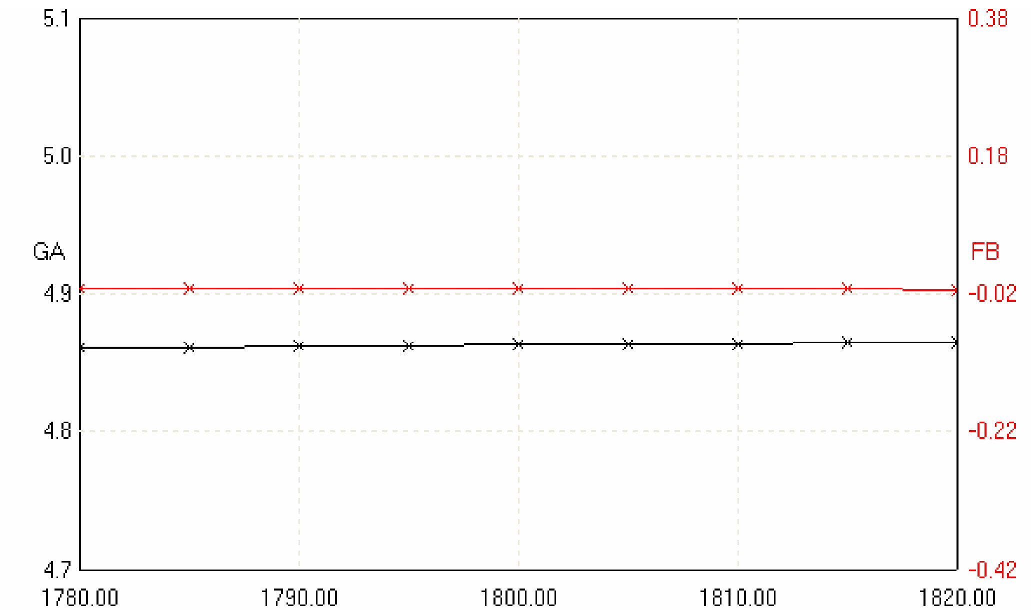

Figure 5.3(b):Frequency versus Gain and front to back ratio Plot for radius 1m.m.

Figure 5.3(c)shows the Frequency versus SWR plot and figure 5.3(d)shows Azimuthal and Elevation plot of radiation pattern for Koch fractal antenna of three iterations of length 2c.m. with radius 1m.m.

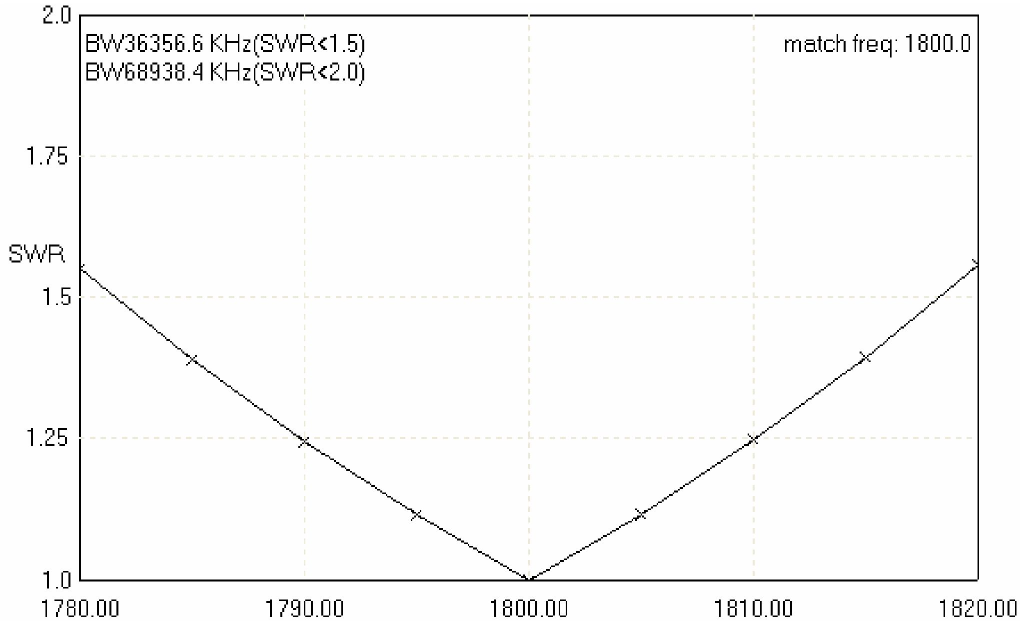

Figure 5.3(c): Frequency versus SWR plot for radius 1m.m.

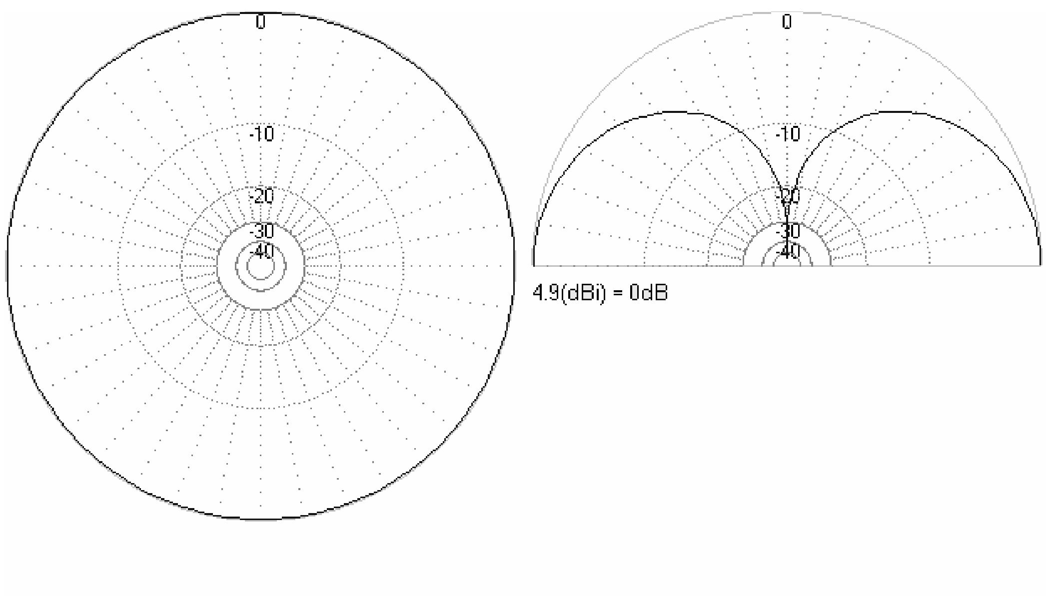

Figure 5.3(d): Azimuthal and elevation plot of Radiation Pattern

Figure 5.4(a)shows the Frequency versus Impedance plot and figure 5.4(b)shows frequency versus gain and frequency versus front to back ratio for the Koch fractal antenna of three iterations of length 2c.m. with radius 2m.m.

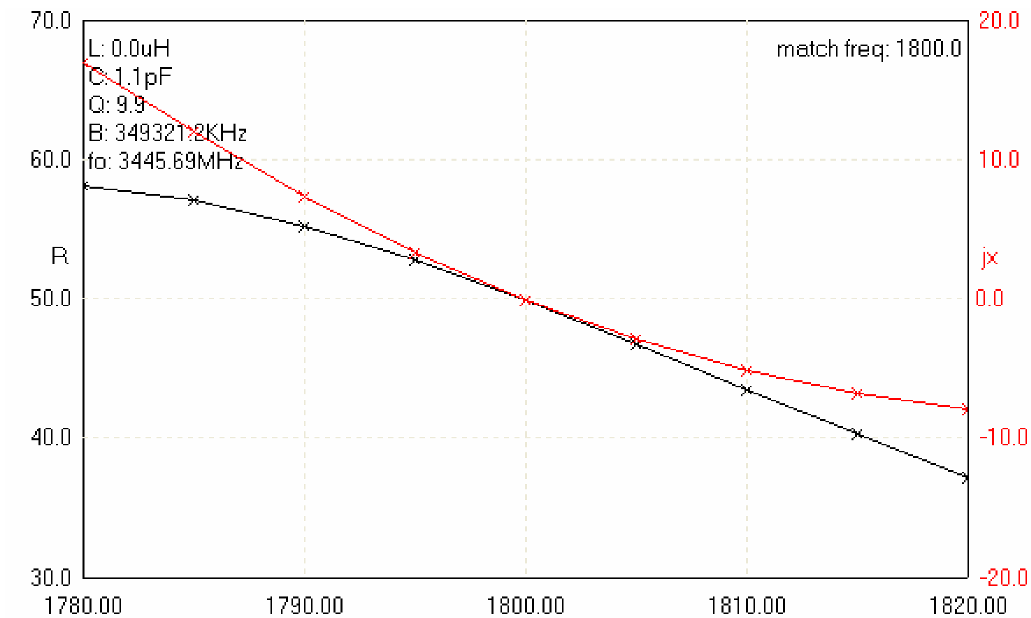

Figure 5.4(a): Frequency versus Real and Imaginary part of impedance plot for radius 2m.m.

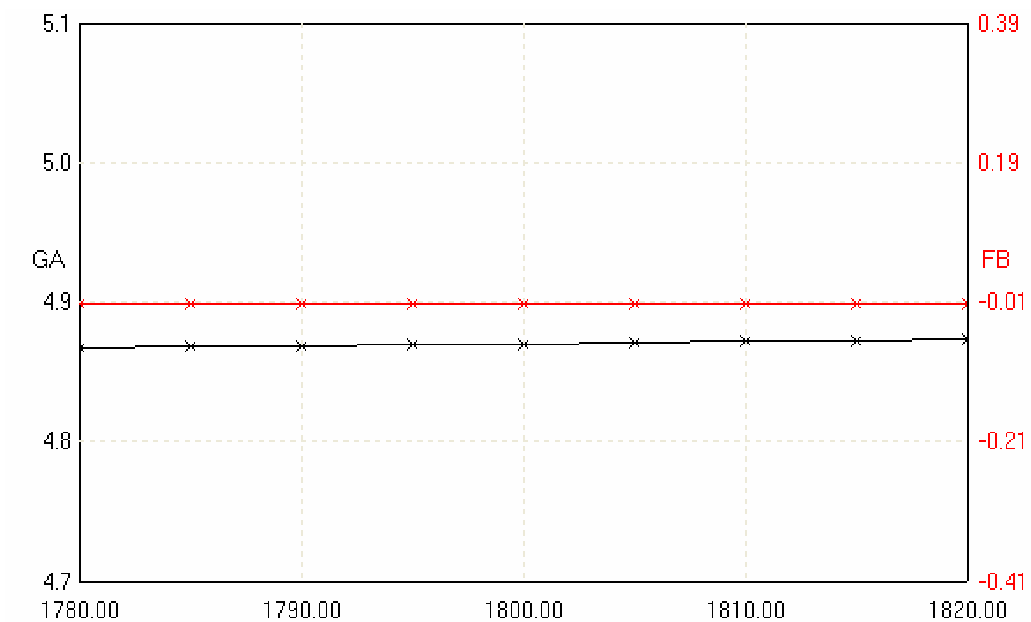

Figure 5.4(b)Freq. versus Gain and front to back ratio Plot for radius 2.m.

Figure 5.4(c)shows the Frequency versus SWR plot and figure 5.4(d)shows Azimuthal and Elevation plot of radiation pattern for Koch fractal antenna of three iterations of length 2c.m. with radius 2m.m.

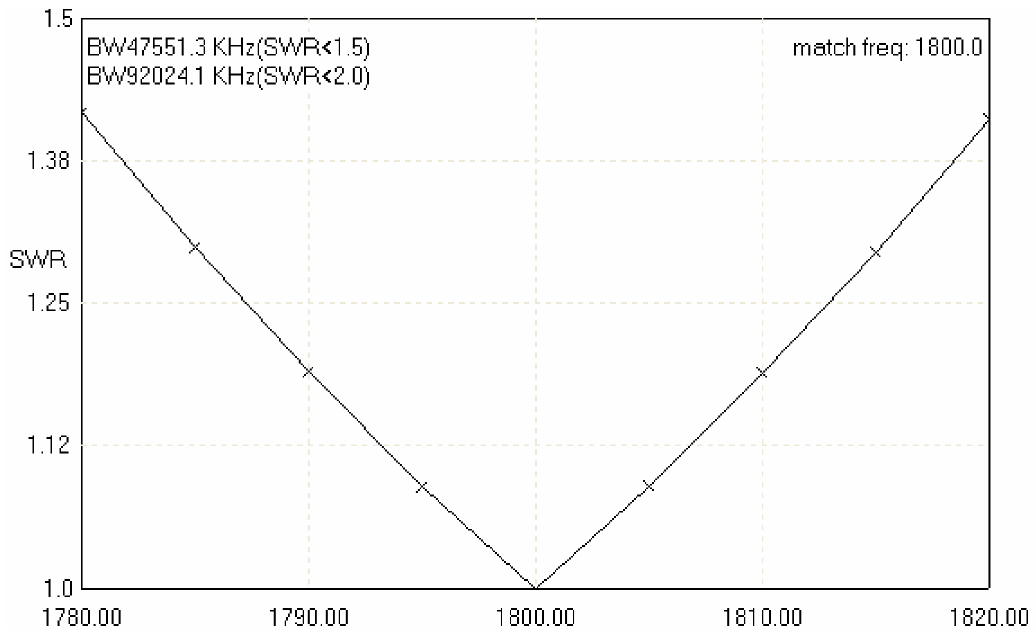

Figure 5.4(c): Frequency versus SWR plot for radius 2m.m.

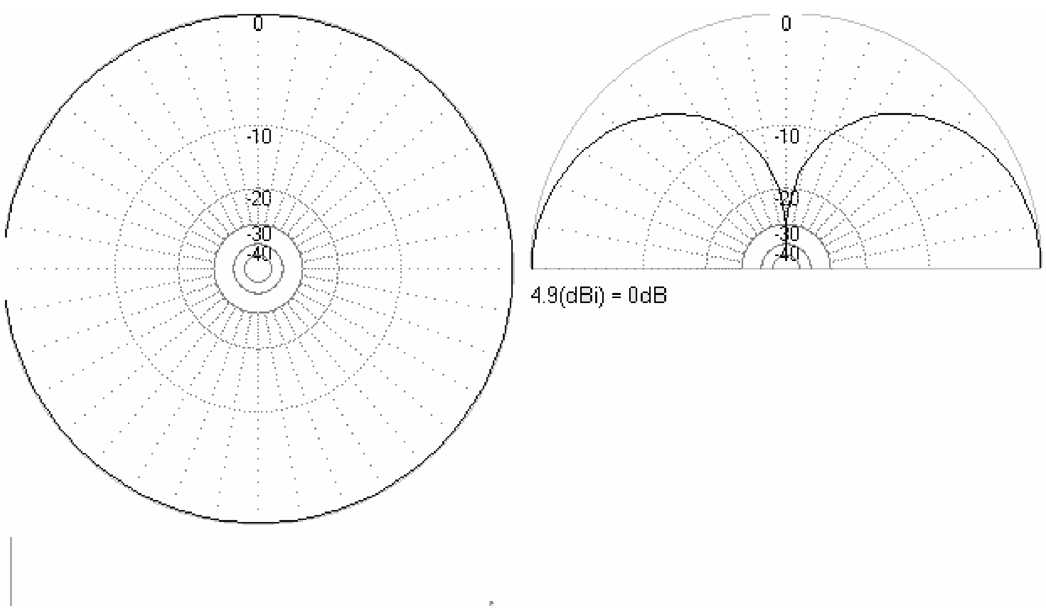

Figure 5.4(d): Azimuthal and elevation plot of Radiation Pattern

Figure 5.5(a)shows the Frequency versus Impedance plot and figure 5.5(b)shows frequency versus gain and frequency versus front to back ratio for the Koch fractal antenna of three iterations of length 2c.m. with radius 3m.m.

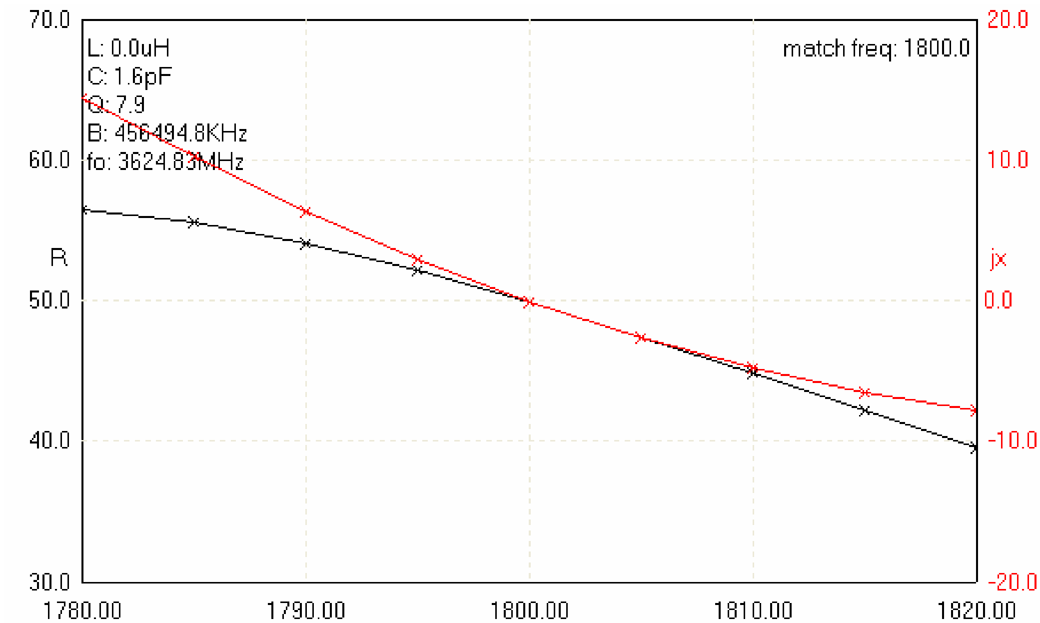

Figure 5.5(a): Frequency versus Real and Imaginary part of impedance plot for radius 3m.m.

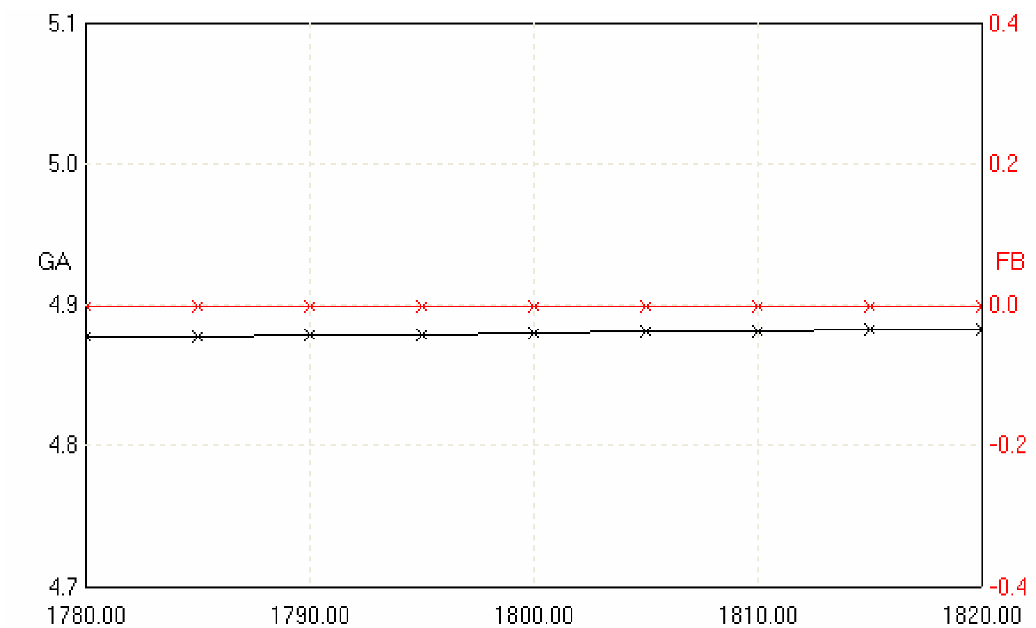

Figure 5.5(b):Frequency versus Gain and front to back ratio Plot for radius 3m.m.

Figure 5.5(c)shows the Frequency versus SWR plot and figure 5.5(d)shows Azimuthal and Elevation plot of radiation pattern for Koch fractal antenna of three iterations of length 2c.m. with radius 3m.m.

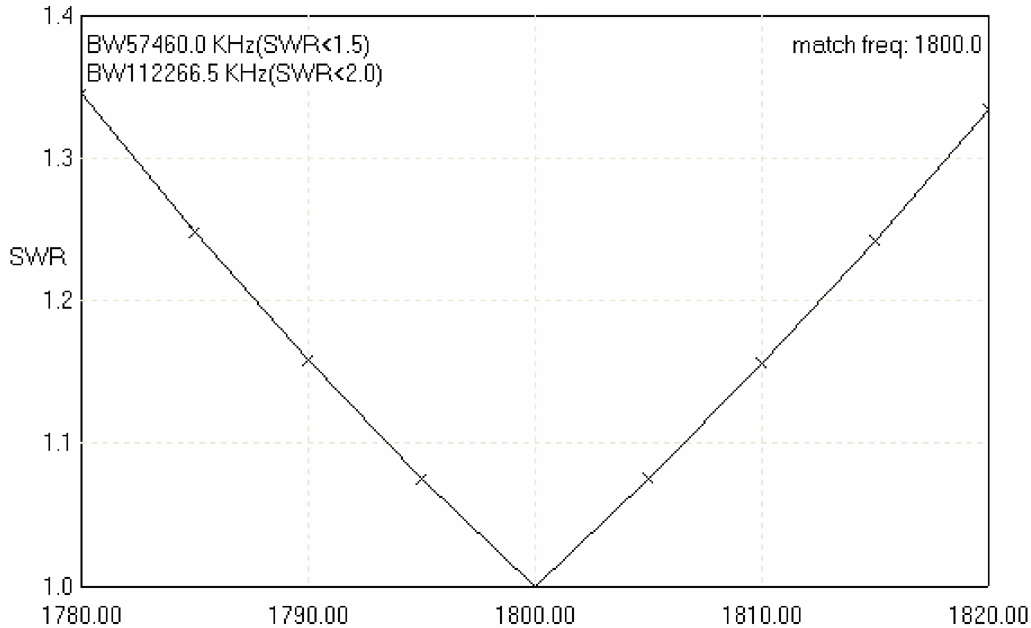

Figure 5.5(c): Frequency versus SWR plot for radius 3m.m.

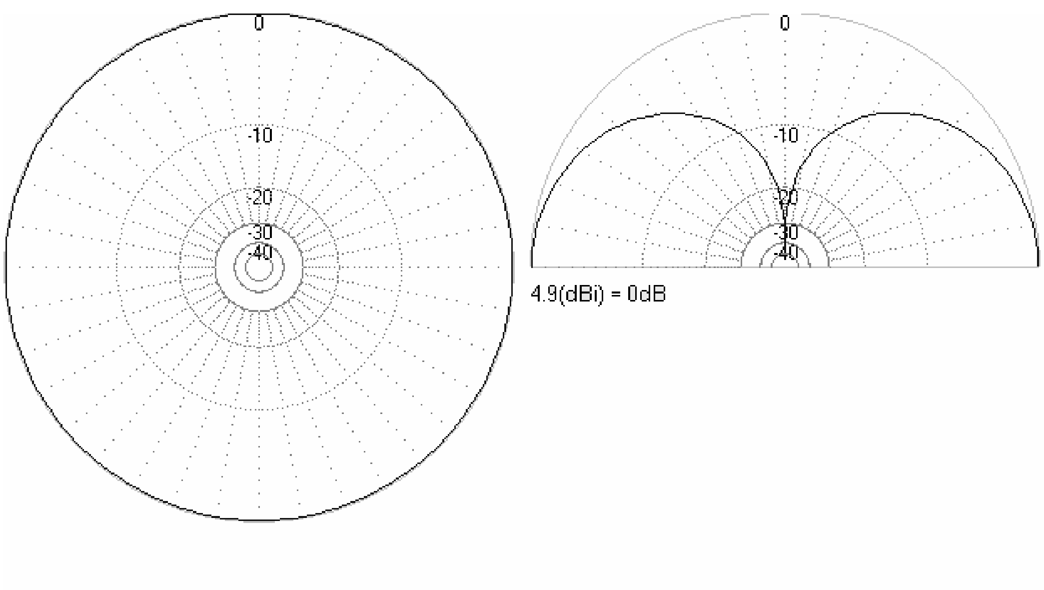

Figure 5.5(d): Azimuthal and elevation plot of Radiation Pattern

Figure 5.6(a)shows the Frequency versus Impedance plot and figure 5.6(b)shows frequency versus gain and frequency versus front to back ratio for the Koch fractal antenna of three iterations of length 2c.m. with radius 4m.m.

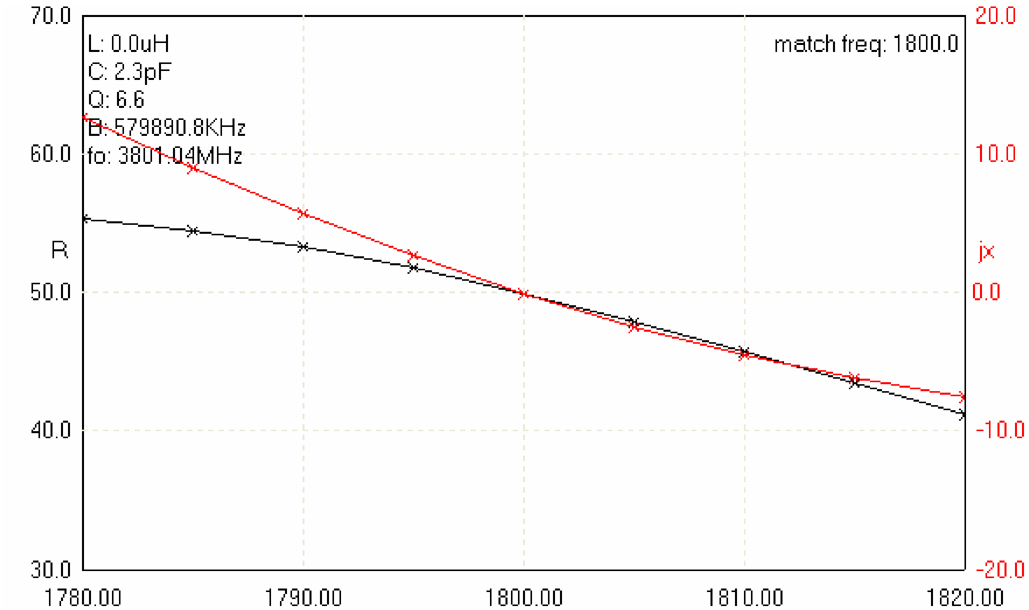

Figure 5.6(a): Frequency versus Real and Imaginary part of impedance plot for radius 4m.m.

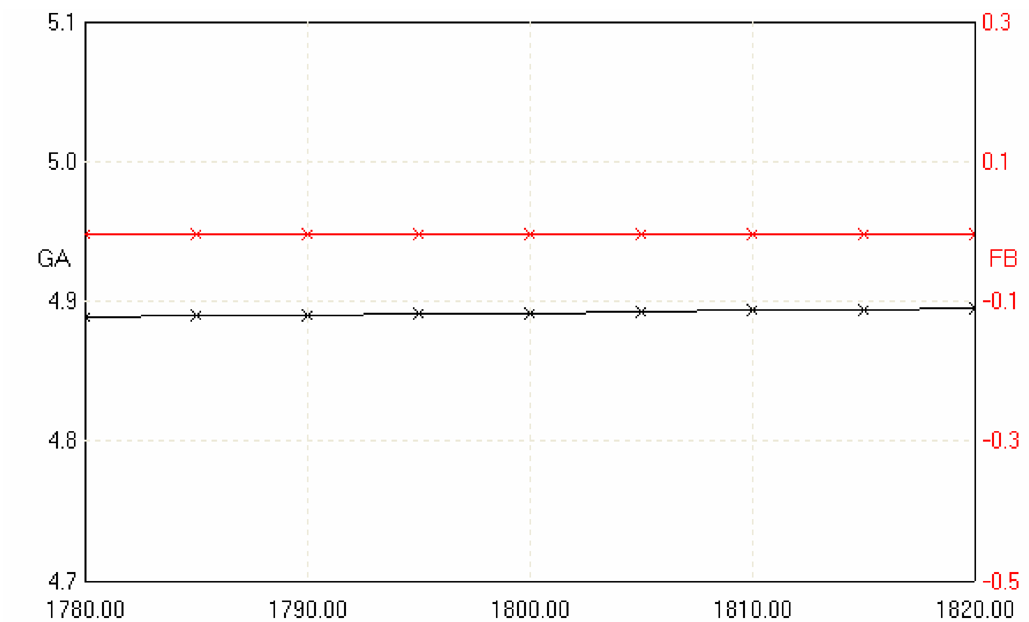

Figure 5.6(b):Frequency versus Gain and front to back ratio Plot for radius 4m.m.

Figure 5.6(c)shows the Frequency versus SWR plot and figure 5.6(d)shows Azimuthal and Elevation plot of radiation pattern for Koch fractal antenna of three iterations of length 2c.m. with radius 4m.m.

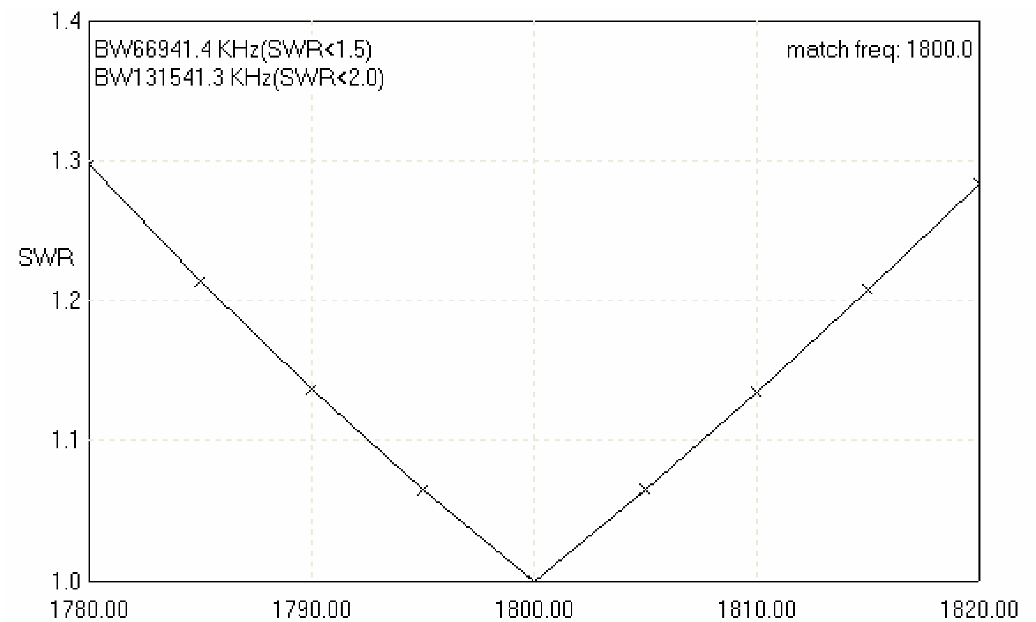

Figure 5.6(c): Frequency versus SWR plot for radius 4m.m.

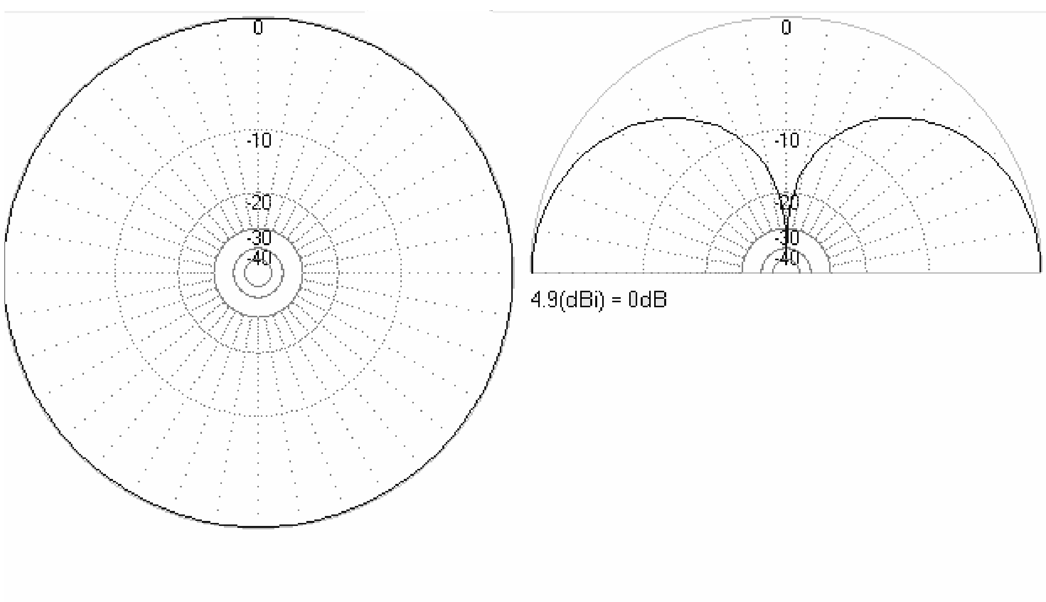

Figure 5.6(d): Azimuthal and elevation plot of Radiation Pattern

Figure 5.7(a)shows the Frequency versus Impedance plot and figure 5.7(b)shows frequency versus gain and frequency versus front to back ratio for the Koch fractal antenna of three iterations of length 2c.m. with radius 5m.m.

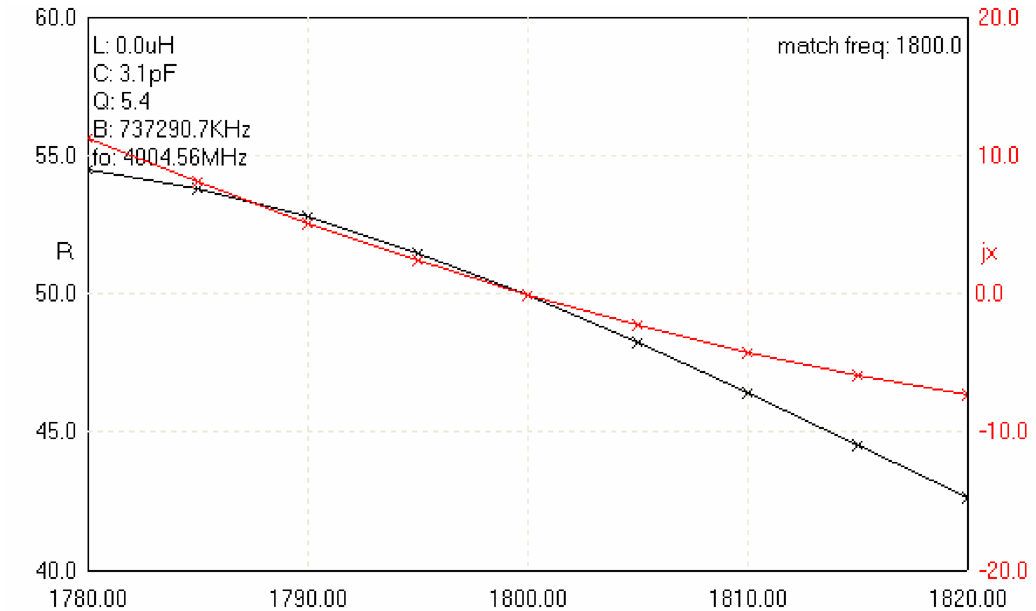

Figure 5.7(a): Frequency versus Real and Imaginary part of impedance plot for radius 5m.m.

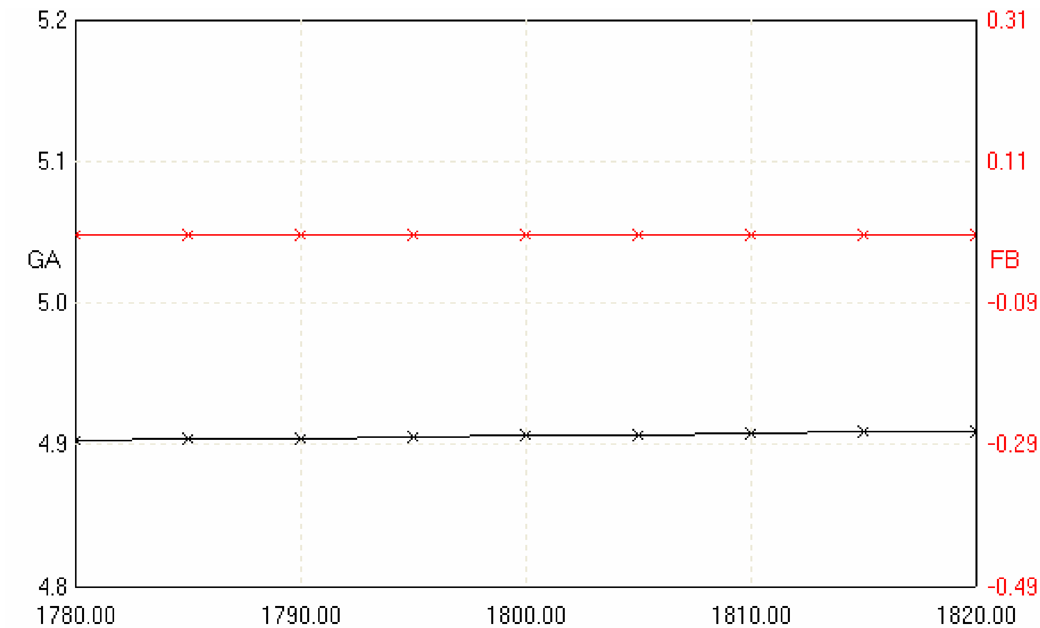

Figure 5.7(b):Frequency versus Gain and front to back ratio Plot for radius 5m.m.

Figure 5.7(c)shows the Frequency versus SWR plot and figure 5.7(d)shows Azimuthal and Elevation plot of radiation pattern for Koch fractal antenna of three iterations of length 2c.m. with radius 5m.m.

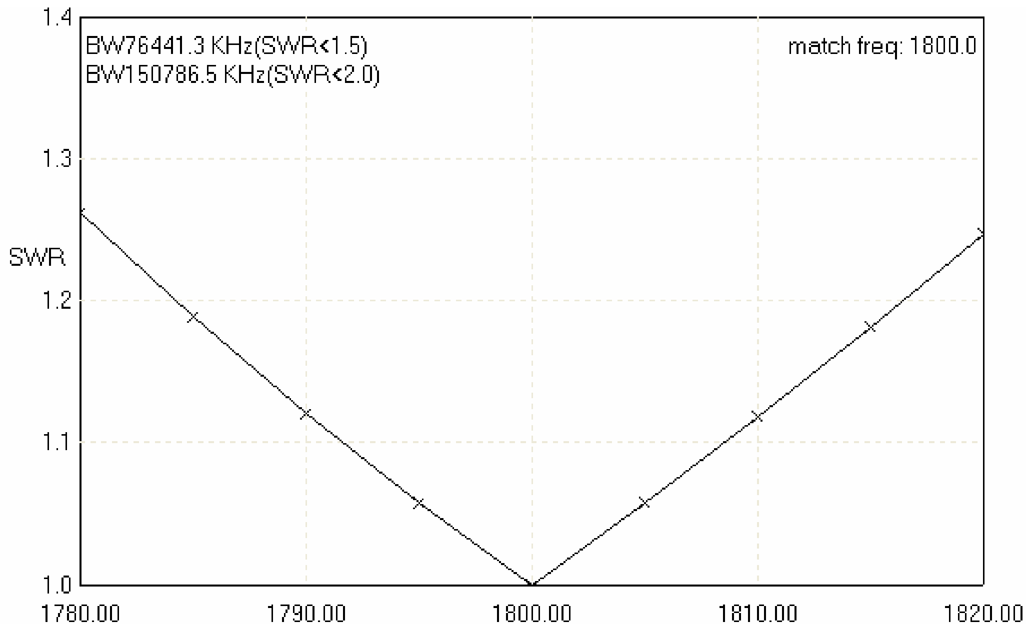

Figure 5.7(c): Frequency versus SWR plot for radius 5m.m.

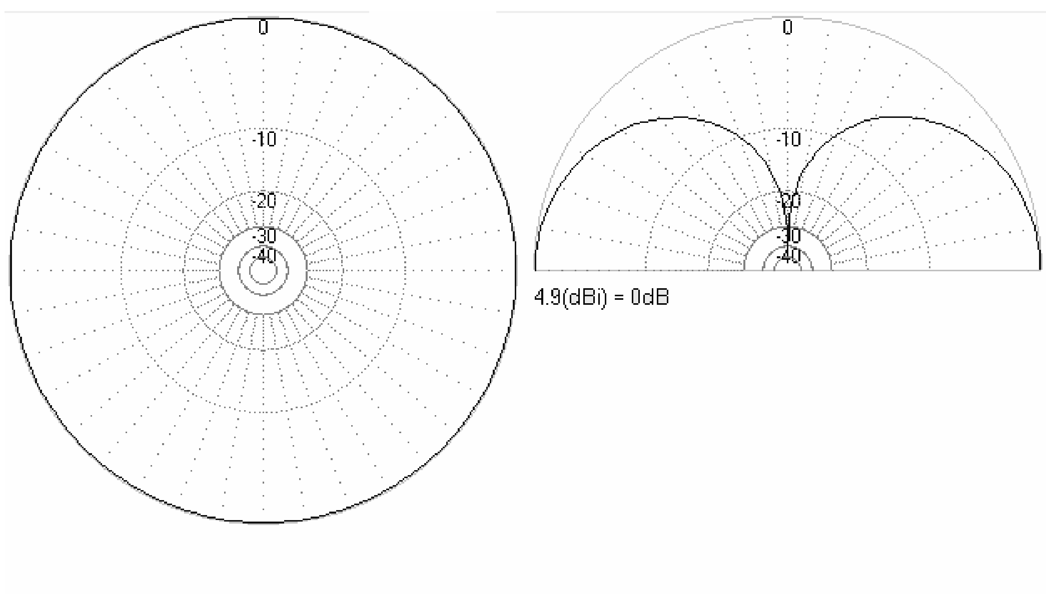

Figure 5.7(d): Azimuthal and elevation plot of Radiation Pattern

Figure 5.8(a)shows the Frequency versus Impedance plot and figure 5.8(b)shows frequency versus gain and frequency versus front to back ratio for the Koch fractal antenna of three iterations of length 2c.m. with radius 6m.m.

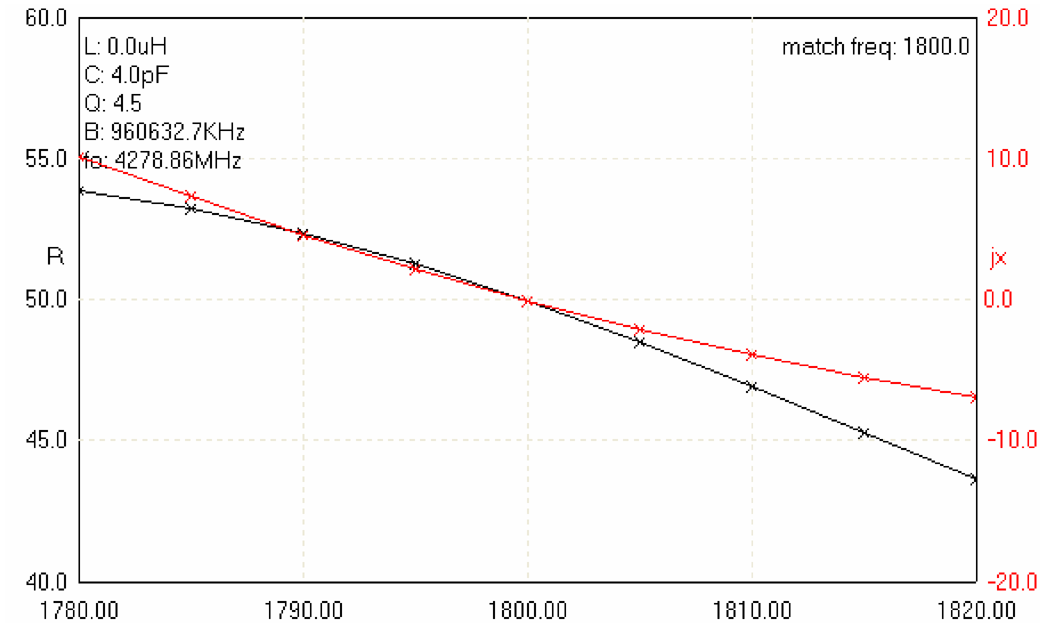

Figure 5.8(a): Frequency versus Real and Imaginary part of impedance plot for radius 6m.m.

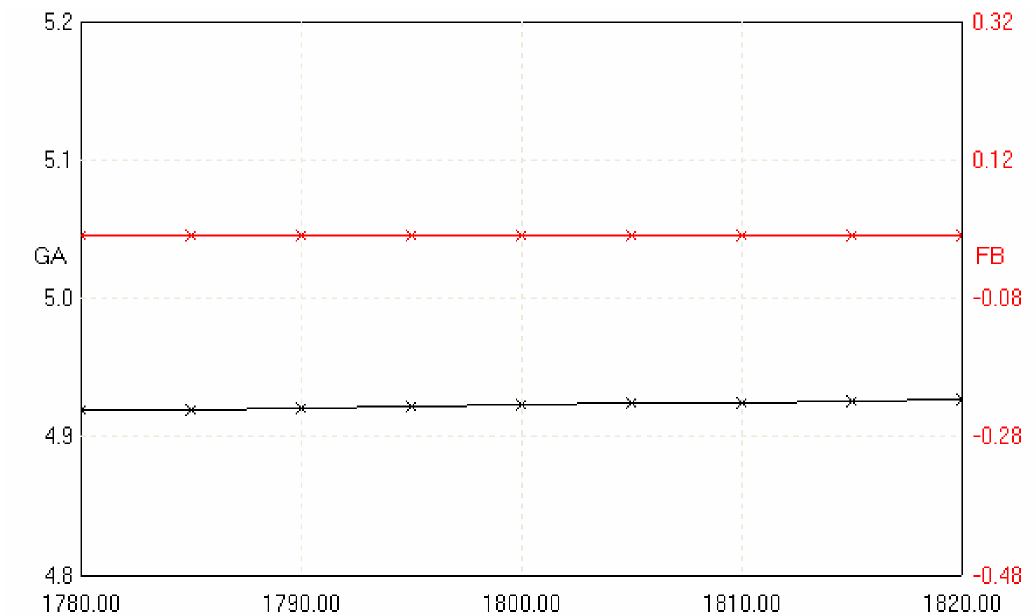

Figure 5.8(b):Frequency versus Gain and front to back ratio Plot for radius 6m.m.

Figure 5.8(c)shows the Frequency versus SWR plot and figure 5.8(d)shows Azimuthal and Elevation plot of radiation pattern for Koch fractal antenna of three iterations of length 2c.m. with radius 6m.m.

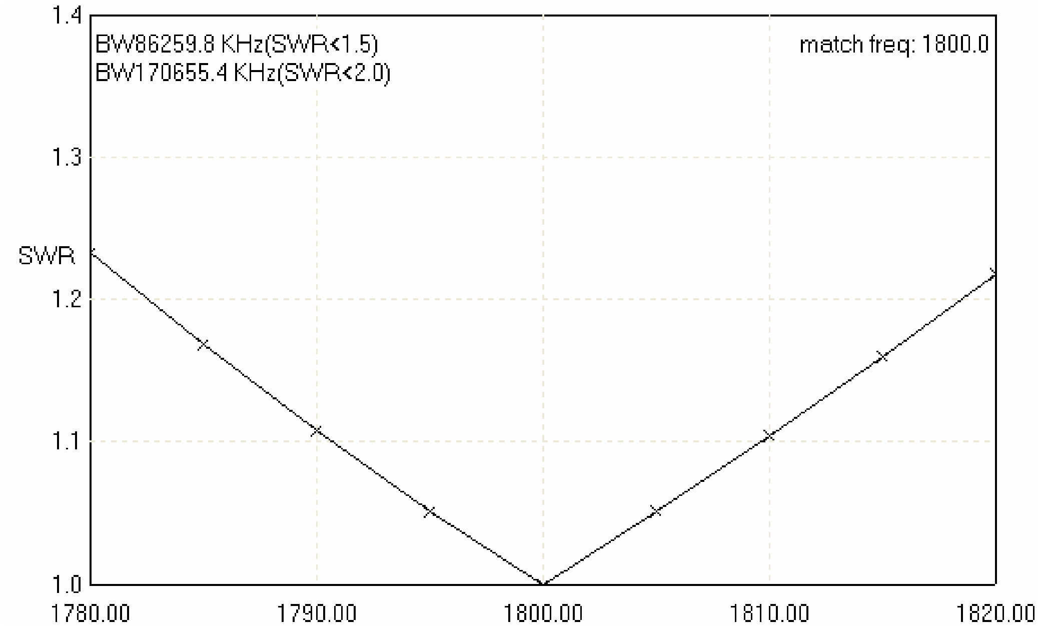

Figure 5.8(c): Frequency versus SWR plot for radius 6m.m.

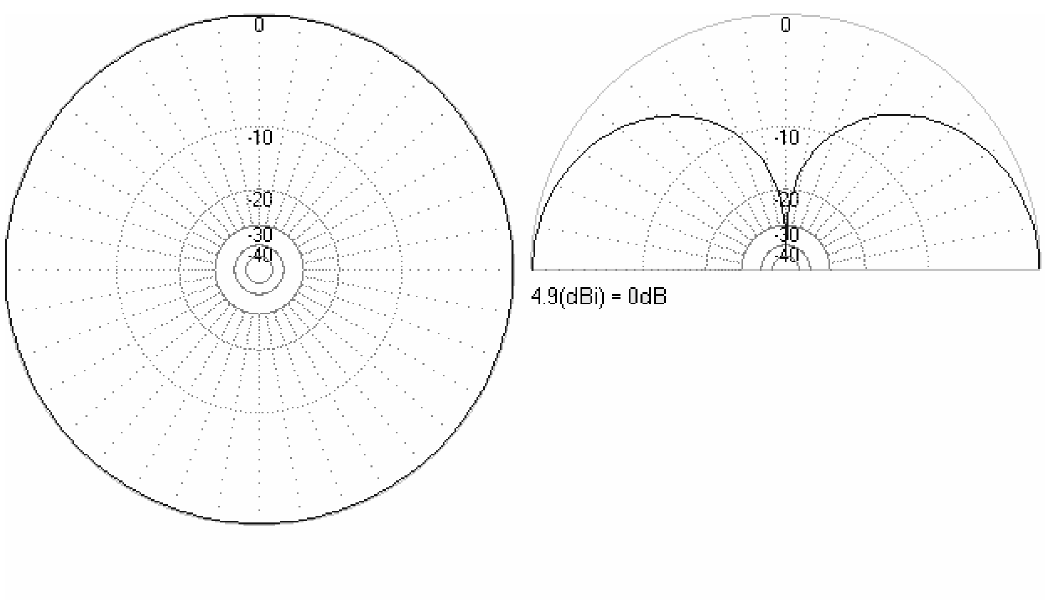

Figure 5.8(d): Azimuthal and elevation plot of Radiation Pattern

Figure 5.9(a)shows the Frequency versus Impedance plot and figure 5.9(b)shows frequency versus gain and frequency versus front to back ratio for the Koch fractal antenna of three iterations of length 2c.m. with radius 6.5m.m.

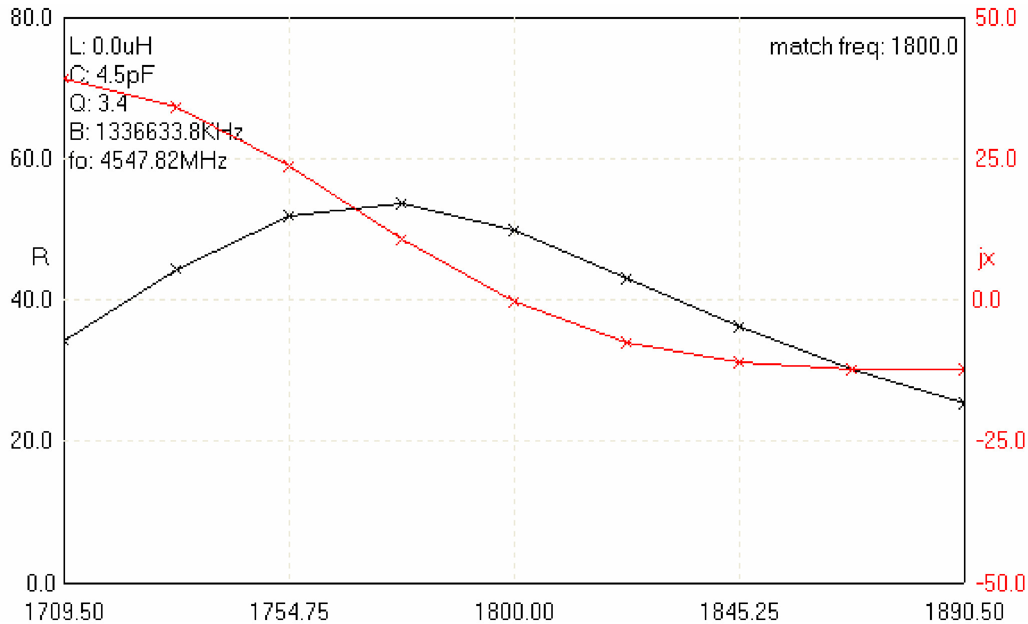

Figure 5.9(a): Frequency versus Real and Imaginary part of impedance plot for radius 6.5m.m.

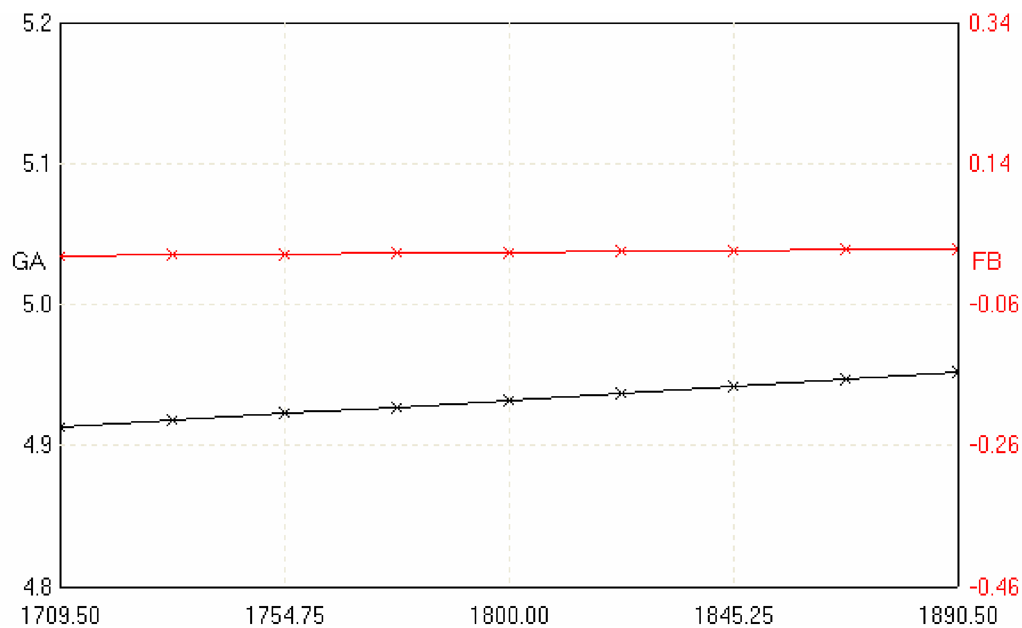

Figure 5.9(b):Frequency versus Gain and front to back ratio Plot for radius 6.5m.m.

Figure 5.9(c)shows the Frequency versus SWR plot and figure 5.9(d)shows Azimuthal and Elevation plot of radiation pattern for Koch fractal antenna of three iterations of length 2c.m. with radius 6.5m.m.

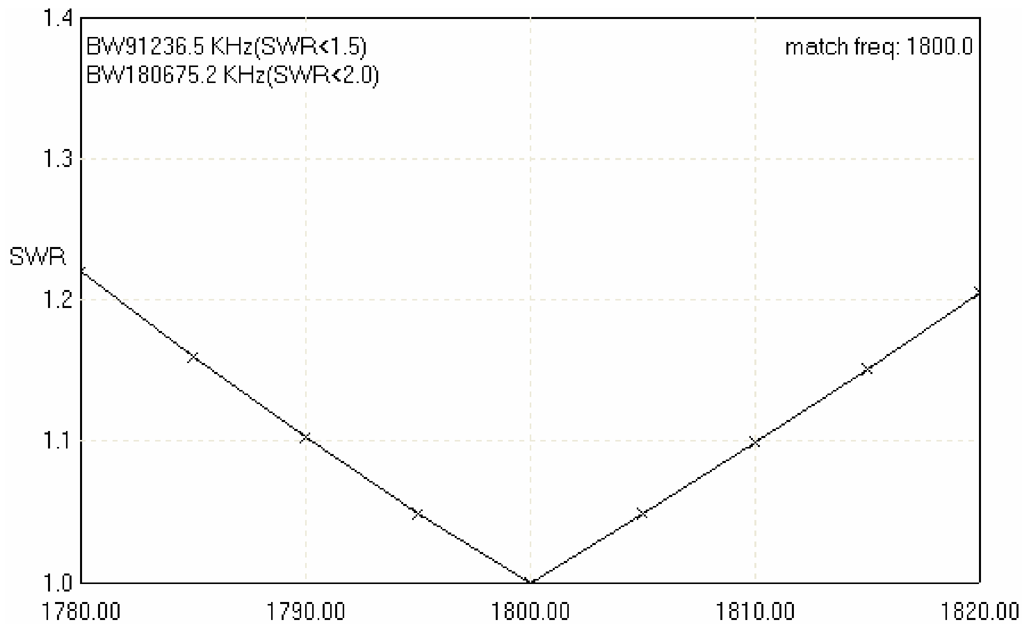

Figure 5.9(c): Frequency versus SWR plot for radius 6.5m.m.

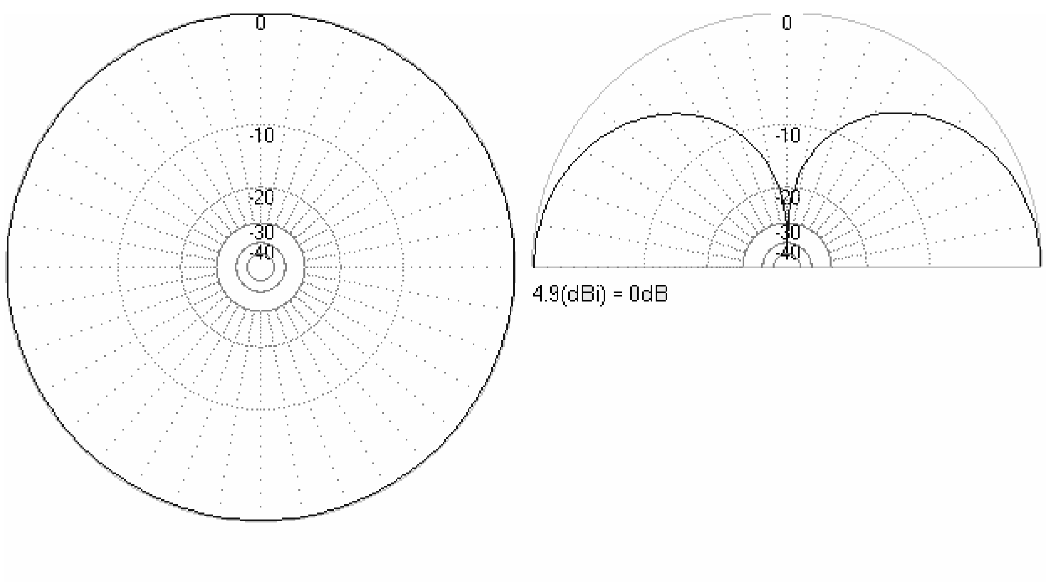

Figure 5.9(d): Azimuthal and elevation plot of Radiation Pattern

Figure 5.10 shows the variation of Quality Factor with Radius of Koch Fractal Antenna, it is observed that with increase in radius the quality factor decreases and for radius 6.5m.m.,the quality factor is 4.

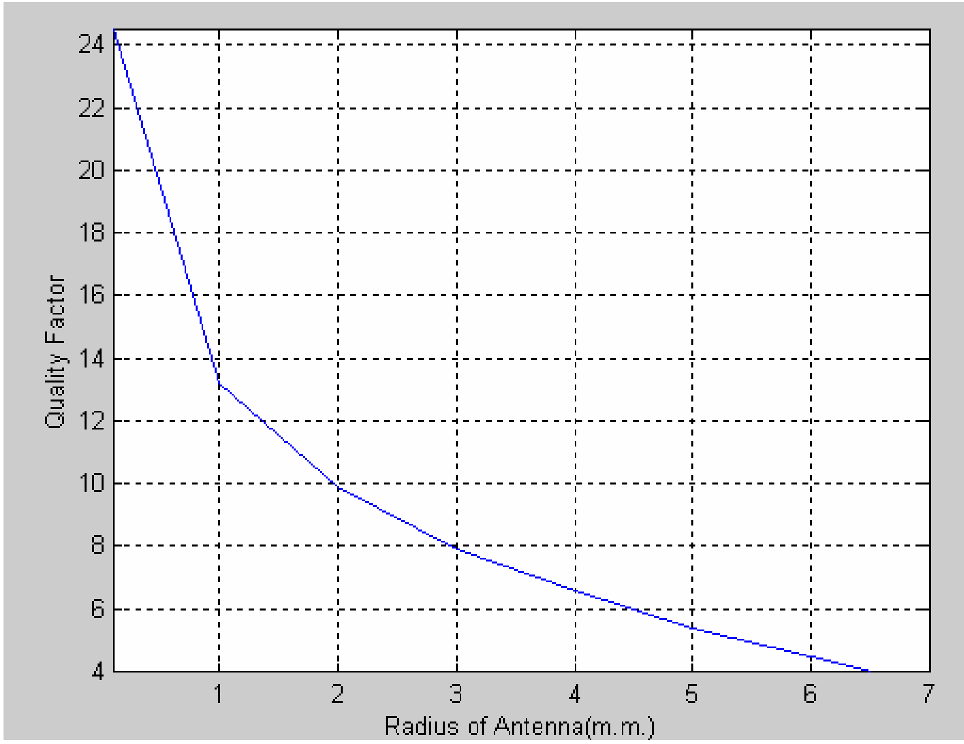

Figure 5.10:Variation of Quality Factor with Radius of Koch Fractal Antenna

Figure 5.11shows the variation of Bandwidth(SWR<2) with Radius of Koch Fractal antenna, it is observed that with increase in radius of antenna the bandwidth increases, for radius 6.5m.m.,the bandwidth(SWR<2) is 180Mhz.,which covers the whole GSM1800 band.

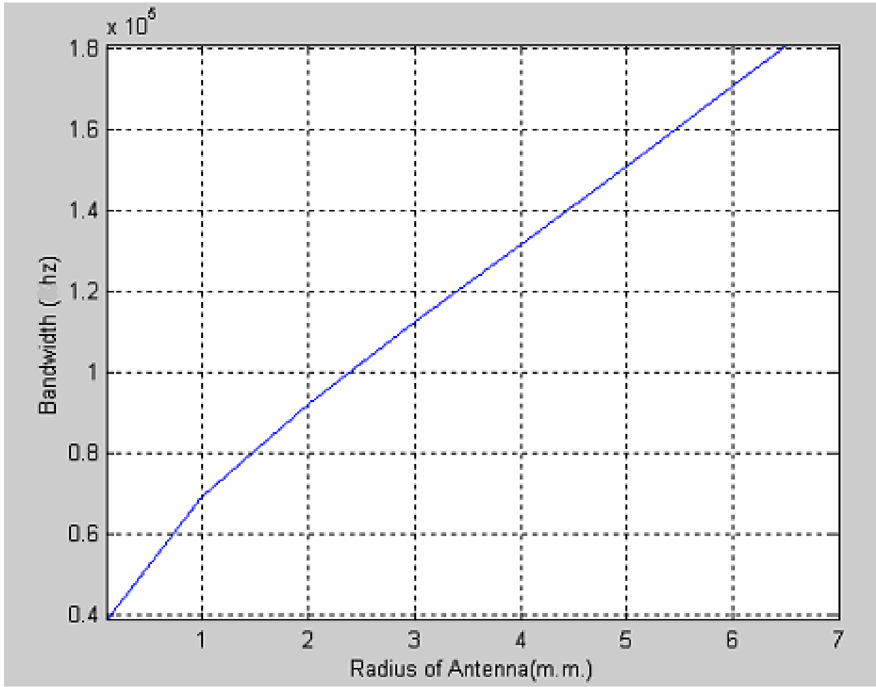

Figure 5.11:Variation of Bandwidth with Radius of Koch Fractal Antenna

Figure 5.12 shows variation of Q, Bandwidth, Impedance ,Gain and Front to Back ratio with Radius of antenna at 1800Mhz in tabular form. With increase in radius the quality factor decreases, bandwidth(SWR) increases, impedance of the antenna keep on decreasing, gain and front to back ratio remains same.

Radius (m.m.)	**Quality Factor**	**Bandwidth (Khz)**	**Real Part of Impedance**	**Imaginary Part of Impedance**	**Gain (db)**	**Front to Back ratio(db)**
0.1	24.5	38710.6	6.6	-136.7	4.9	0.0
1	13.2	68938.4	5.2	-86.7	4.9	0.0
2	9.9	92024.1	4.1	-57.5	4.9	0.0

3	7.9	112266.5	3.2	-40.5	4.9	0.0
4	6.6	131541.3	2.7	-30.0	4.9	0.0
5	5.4	150786.5	2.3	-23.1	4.9	0.0
6	4.5	170655.4	2.0	-18.3	4.9	0.0
6.5	4.0	180675.2	1.9	-16.5	4.9	0.0

Figure 5.12:Table showing variation of Q, Bandwidth, Impedance ,Gain and Front to Back ratio with Radius of antenna at 1800Mhz.

The Koch fractal antenna of length 2c.m.with radius 6.5c.m.,has quality factor 4,has bandwidth(SWR<2) 180Mhz ,has gain 4.9 db and a front to back ratio 0db.The bandwidth covers the GSM1800 band. It has radiation pattern which is uniform in all directions, same as that of traditional monopole .But using fractals a reduction of nearly 50% in the size antenna over conventional monopole has been achieved without sacrificing the performance of antenna up to much extent. This is highly significant for applications such as GSM cellular phones.

Chapter-6
Conclusions and Future Scope

In this dissertation, fractal antenna incorporated into GSM handsets have been purposed. The project involves simulation of Koch fractal antennas. Several Koch fractal antennas have been simulated using MATLAB ,EZNEC and MMANA codes. The results in chapter-3 shows the Multiband performance of fractal antennas at non-harmonic frequencies, improved impedance, improved SWR(standing wave ratio) performance on a reduced physical area when compared to non fractal Euclidean geometries, Compressed Resonant behavior, broadband characteristic, improved reliability and the biggest advantage their size reducing capability, Size can be shrunk from two to four times with surprising good performance and with each iteration the number of resonant frequency increases. Perturbation could be applied to shape of fractal to make it to resonate at different frequency. In chapter-4 , chapter-5 results shows that Koch fractal monopole are an excellent alternative to traditional antenna systems in mobile wireless receivers The Koch monopole exhibits excellent performance at 925 MHz and 1800Mhz and has radiation properties nearly identical to that of traditional, straight-wire monopoles at that frequency. The radiation pattern is very uniform in all directions. It is consistent with the classic doughnut shape characteristic of the straight wire $\lambda / 4$ monopole, and consequently that of the $\lambda / 2$ dipole. The greatest advantage of the Koch monopole design is compactness. A size reduction of nearly 50% was achieved over the straight-wire, , $\lambda / 4$ free-space monopole. This is highly significant for applications such as GSM cellular phones. Since it is half the size of the traditional monopole, it could easily be completely integrated within the case of the phone, eliminating the protruding monopoles commonly seen on many cellular phones. The Koch monopole design has excellent impedance bandwidth, allowing some flexibility in the types of applications where it could be used. Since the radiation pattern is highly uniform and identical to that of a traditional $\lambda / 4$ monopole, it could be used in nearly any type of wireless communications receiver. The very similar gain to the traditional $\lambda / 4$ monopole is another benefit of the design. Another beneficial of fractal antennas is fractal antennas are in form of a PCB. Thus the Koch monopole presents an excellent, compact solution to the traditional straight-wire monopole.

Future Scope

Since the area of fractal antenna engineering research is still in its infancy, there are many possibilities for future work on this topic. The Koch fractal was chosen for this project because this is the best documented fractal antenna types in current research. However, many possible fractal structures exist which may undoubtedly have desirable radiation properties. Thus, a possible approach for future work is to investigate other types of fractals for antenna applications. A novel development is the use of fractal patterns for antenna arrays . Fractal antennas can be studied in several areas. One area of development is to implement fractal antennas into current technologies in practical situations such as expanding wireless market. For this application an analysis of the polarization of these antennas will need to be looked. Another benefit that can be explored is lower covered area of resonant loop antennas. This may lead to antenna with lower cross sections. Also, fractals can be used into microstrip antennas.

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