

“STACKED SIERPINSKI CARPET FRACTAL ANTENNA FOR X-BAND APPLICATIONS”

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

degree of

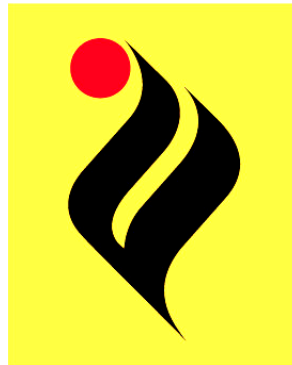
**MASTER OF ENGINEERING
In
ELECTRONICS & COMMUNICATION ENGINEERING**

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July 2013

CERTIFICATE

I, Anuj Attri hereby certify that the work which is being presented in this thesis entitled **“Stacked Sierpinski Carpet Fractal Antenna for X-band Applications”** by me in partial fulfilment of the requirements for the award of degree of Master of Engineering in Electronics and Communication from Thapar University, Patiala is an authentic record of my own work carried under the supervision of Mr. Ankush Kansal.

The matter presented in this thesis has been submitted in any other University/institute for the award of Master of Engineering.



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ACKNOWLEDGMENT

This report is completed with prayers of many and love of my family and friends. However, there are a few people that I would like to specially acknowledge and extend my heartfelt gratitude who have made the completion of this report possible .With the biggest contribution to this report; I would like to thank my guide **Ankush Kansal**, Assistant Professor, ECED, Thapar University had given me his full support in guiding me with stimulating suggestions and encouragement to go ahead in all the time of thesis work. I am very thankful to our P.G coordinator **Dr.Kulbir Singh** for his encouragement, valuable suggestions and support throughout my work.

I am also thankful to **Dr. Rajesh Khanna**, Professor & Head, ECED, Thapar University for providing us with adequate infrastructure in carrying the work.

With deep sense of gratitude I would express my sincere thanks to my parents. I would also like to thank the almighty God for not letting me down at the time of crisis and showing me the silver lining in the dark clouds.



(Anuj Attri)

ABSTRACT

The current use of fractal geometries has significantly impacted many areas of science and engineering; one of which is antennas and their applications. Antennas using fractal geometries for various telecommunications applications are already available in market commercially. The use of fractal geometries had been shown to improve several antenna features to varying extents.

In terms of performance as antenna elements, fractal shaped geometries are believed to result in multi-band and wide-band characteristics and also, reduction of antenna size. Although the utility of different fractal geometries varies in the aspects as mentioned above, nevertheless they are among the primary motives of fractal antenna design. For example, Sierpinski gaskets and carpets have been widely reported and their multiband characteristics have been linked with the self-similarity of the geometry. However, this *qualitative* explanation may not always be realised with all fractal shapes and geometries. A quantitative link between multiband and wideband characteristics of the antenna and a mathematically expressible feature of the fractal geometry is needed for design optimization.

In this thesis, characterisation and analysis of the fractal shapes and correspondingly their antennas is done. A study of fractal geometries and have studied their multiband behaviour using the Sierpinski carpet fractal geometry, in particular, has been done. The concept of stacking of antennas is applied to Sierpinski Carpet, and the change in characteristics with that is studied and analysed. Next, realization of new fractal geometry as an antenna, which can be used in X band applications like amateur radio and military communication satellites (although high power requirements are needed here). The return losses and radiation patterns of these antennas are analysed in detail.

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CHAPTER 1

INTRODUCTION

Present telecommunication systems demands antennas to be compact in size, low profile, multi-band and broadband. There are a variety of different approaches that has been adopted to achieve these goals. This has triggered antenna research in various possible directions, one of which is by using fractal shapes as antenna elements. In recent years, several fractal geometries have been proposed to be used in antenna applications with some varying degrees of success in improving antenna characteristics and thus performance. Many of these geometries have been particularly useful in reducing the size of the antenna, while other shapes aim at incorporating multi-band or wide-band characteristics. Yet, no significant progress has been made in corroborating fractal properties of these geometries with characteristics of antennas. Several antenna configurations based on fractal geometries have been reported in recent years [1] – [4]. These are generally low profile antennas with moderate gain and can be made operative at multiple frequency bands and hence are multi-functional.

1.1 BACKGROUND

1.1.1 Fractal Geometries

Fractals are used to define structures whose dimensions are not whole number. Fractal geometry is that branch of study which deals with properties and behaviour of fractals. These geometries have been used to characterise objects in nature that are difficult to define with the help of Euclidean geometries including length of coastlines, branches of trees etc. Many theories and innovative applications for the fractals have been developed including in the areas of image compression, creation of music from pink noise.

The term *fractal* was coined by the French mathematician B.B. Mandelbrot during 1970's after his pioneering research on several naturally occurring irregular and fragmented geometries not contained within the realms of conventional Euclidian geomet [5]. This term has its roots in the latin word *fractus* which is related to the verb *fangere* (meaning: to break) [6]. Previously, no importance was given to the fractal shapes, as these shapes were considered to be not having any form. Later, Mandelbrot discovered that certain special features can be associated with them. Although, the shapes were well known before Malderbrot, but Mandelbrot's research was path-breaking: he discovered a common

element in many of these seemingly irregular geometries and formulated theories based on his findings.

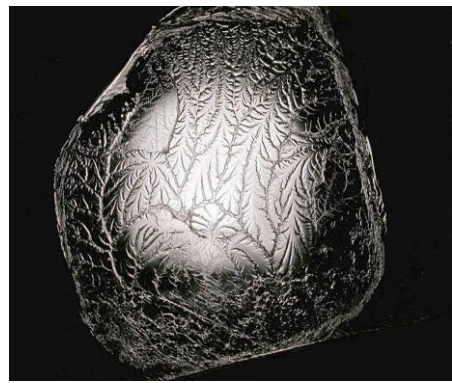
Fractals represent a class of geometry with properties including:

- Self-similarity
- Fractional dimension
- Formation by iteration
- Plane filling nature

Fractals are largely found in natural phenomenon. Below are shown some fractals occurring in nature.



(a)



(b)



Figure 1: Fractal phenomenon, (a) frost patterns (b) pulling apart 2 glue coloured acrylic sheet (c) High voltage breakdown within a 4" block of acrylic creates a fractal Lichtenberg figure.

Some of the common known fractal shapes are shown below.

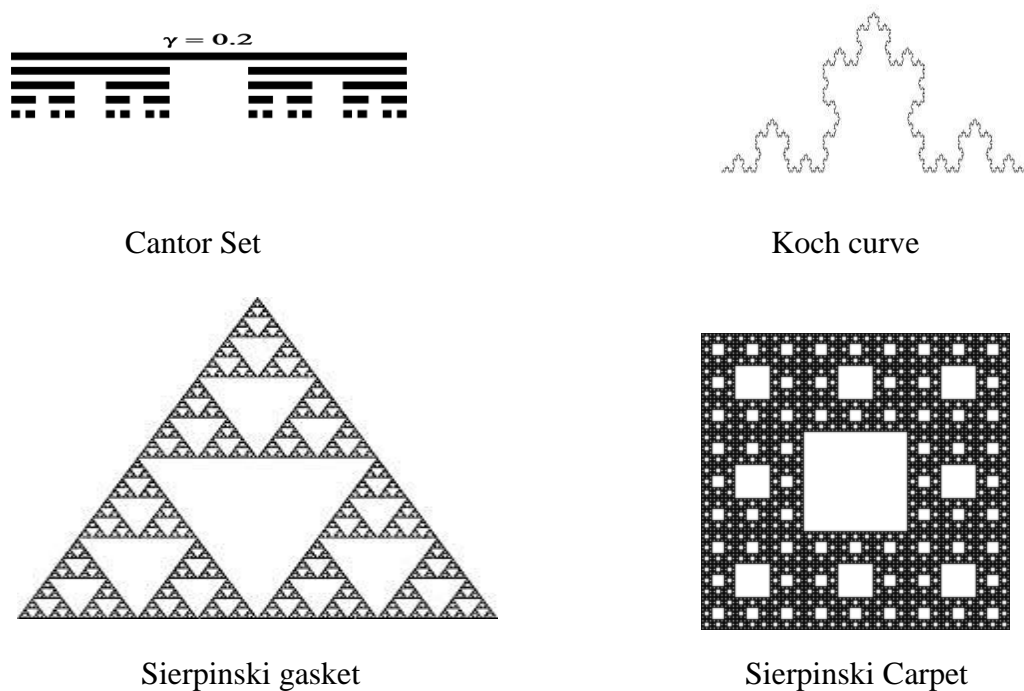


Figure 2: Some common examples of fractals [7].

1.1.2. Defining and measuring fractals

Although there is no proper definition for the fractals. Mandelbrot tried to define the term fractal in several ways. These rely primarily on the definition of their dimension. *A fractal is a set for which the Hausdorff Besicovich dimension strictly exceeds its topological dimension.* Every set having non-integer dimension is a fractal [5]. *But fractals can have integer dimension.* Alternately, fractal is defined as set F such that [7]:

- F has a fine structure with details on arbitrarily small scales,**
- F is too irregular to be described by traditional geometry,**
- F having some form of self-similarity (not necessarily geometric, can be statistical),**
- F can be described in a simple way, recursively, and**
- Fractal dimension of F greater than its topological dimension**

Dimension of a geometry can be defined in several ways, most of the times, these often lead to the same number, although not necessarily. Some examples are topological dimension, Euclidean dimension, self-similarity dimension and Hausdorff dimension. Some of these are special forms of Mandelbrot’s definition of the fractal dimension. However the most easily understood definition is for self-similarity dimension. To obtain this value, the geometry is divided into scaled down, but identical copies of itself. If there

are n such copies of the original geometry scaled down by a fraction f , the *similarity dimension* D is defined as:

$$D = \frac{\text{Log } n}{\text{Log}\left(\frac{1}{f}\right)} \quad (1.1)$$

For example, a square can be divided into 4 copies of $\frac{1}{2}$ scale, 9 copies of $\frac{1}{3}$ scale, 16 copies of $\frac{1}{4}$ scale, or n^2 copies of $\frac{1}{n}$ scale. Substituting in the above formula, the dimension of the geometry is ascertained to be 2.

The same approach can be followed for determining the dimension of several fractal geometries. The dimension of geometries shown in Fig. 2 are listed in Table 1-1.

Table 1: Fractal dimension of some geometries shown in Fig. 2.

| Geometry | Dimension |
|-------------------|-----------|
| Cantor set | 0.6309 |
| Koch curve | 1.2619 |
| Sierpinski gasket | 1.5850 |
| Sierpinski carpet | 1.893 |

Although this approach is very convenient for many such geometries, all fractals are not amenable for this approach. Such is the case with most plane-, or space-filling fractals. In these cases more mathematically intensive definitions such as *Hausdorff dimension* are required. Non-integer dimension is not the only peculiar property of fractals. A glossary of terms used in describing properties of fractals is introduced next. A *self-similar* set is one that consists of scaled down copies of itself. Many fractal geometries are self-similar, a property which makes easier to accurately compute their Hausdorff dimension. In order to define self-similarity mathematically, first the concept of *contraction* is introduced. A map $\psi: \mathbf{R}^n \rightarrow \mathbf{R}^n$ is a contraction if there exists some constant number $c \in (0,1)$ so that the inequality

$$|\varphi(x) - \varphi(y)| \leq c|x - y| \quad (1.2)$$

holds for any $x, y \in \mathbf{R}^n$. For a natural number $m \geq 2$, and a set of m contractions $\{\psi_1, \psi_2, \dots, \psi_m\}$ defined on \mathbf{R}^n , a non-empty compact set V in \mathbf{R}^n is self-similar if

$$V = \cup_{i=1}^m(\varphi_i(v)) \quad (1.3)$$

Each such division of the geometry is termed an *iteration*. Fractal geometries are generally *infinitely sub-divisible*. Self similar sets defined by linear contractions are called *Self-affine* sets. Other properties associated with fractal geometries include *scaleinvariance*, *plane-filling* or *space-filling* nature, and *lacunarity*. Lacunarity is a term coined to express the nature of area fractal having hollow spaces (“gappiness”) [8]. Plane filling fractals are those that tend to fill an area (or space, in more general terms) as the order of iteration is increased.

Some of these properties are qualitatively linked to the features of antenna geometries using them. It is envisaged that the above description of these properties would shed light into a better understanding of such connection. In the following sub-sections a brief introduction is provided on the use of fractal in science and engineering, and antenna engineering in particular.

1.1.3. Engineering Applications of Fractals

Ever since they were mathematically re-invented by Mandelbrot, fractals have found widespread applications in several branches of science and engineering. Disciplines such as geology, atmospheric sciences, forest sciences, physiology have benefited significantly by fractal modelling of naturally occurring phenomena. Several books and monographs are available on the use of fractals in physical sciences. Fracture mechanics is one of the areas of engineering that has benefited significantly from the application of fractals [9]. The space filling nature of fractal geometries has invited several innovative applications. Fractal mesh generation has been shown to reduce memory requirements and CPU time for finite element analysis of vibration problems [10]. One area of application that has impacted modern technology most is image compression using fractal image coding [11] - [13]. Fractal image rendering and image compression schemes have led to significant reduction in memory requirements and processing time. In electromagnetics, scattering and diffraction from fractal screens have been studied extensively. Diffracted fields from self-similar Sierpinski gasket in the Fraunhofer zone have been shown to be self-similar [14]. The study of wave interactions with such selfsimilar structures has later been termed fractal electrodynamics [15] - [17]. Some of these studies indicate that scattering patterns from fractal geometries have features of those geometries imprinted on these. More recently fractal geometries have also been used in frequency selective screens [18] - [20]. The self-similarity of the fractal geometry has been attributed to the dual band nature of their

frequency response. Surface impedance of metallic patterns of fractal geometries on a dielectric slab has also been characterized [21]. Fractal antenna arrays and fractal shaped antenna elements have evolved in 1990's. An overview of the literature on the use of fractals in antenna engineering is given next.

1.1.4. Fractals in Antenna Engineering

The primary motivation of fractal antenna engineering is to extend antenna design and synthesis concepts beyond Euclidean geometry [22] - [23]. In this context, the use of fractals in antenna array synthesis and fractal shaped antenna elements have been studied. Obtaining special antenna characteristics by using a fractal distribution of elements is the main objective of the study on fractal antenna arrays. It is widely known that properties of antenna arrays are determined by their distribution rather than the properties of individual elements. Since the array spacing (distance between elements) depends on the frequency of operation, most of the conventional antenna array designs are band-limited. Self-similar arrays have frequency independent multi-band characteristics [24]. Fractal and random fractal arrays have been found to have several novel features [25]. Variation in fractal dimension of the array distribution has been found to have effects on radiation characteristics of such antenna arrays. The use of random fractals reduce the fractal dimension, which leads to a better control of sidelobes [23]. Synthesizing fractal radiation patterns has also been explored [26]. It has been found that the current distribution on the array affects the fractal dimension of the radiation pattern. It may be concluded that fractal properties such as self-similarity and dimension play a key role in the design of such arrays.

1.1.5. Fractal Shaped Antenna Elements

As with several other fields, the nature of fractal geometries has caught the attention of antenna designers, primarily as a past-time. However with the deepening of understanding of antennas using them several geometrical and antenna features have been inter-linked. This has led to the evolution of a new class of antennas, called fractal shaped antennas. Cohen, who later established the company Fractal Antennas Inc. is among the first to get into the bandwagon. He has tried the usefulness several fractal geometries experimentally. Koch curves, Minkowski curves, Sierpinski carpets are among them [3]. These geometries have a large number of tips and corners, a fact that would help improve antenna efficiency. Fractal trees were explored for the same reason, and were found to have multiband characteristics [27]. Self-similarity of the geometry is qualitatively associated with the multiband characteristics of these antennas. Fractal shaped dipole antennas with Koch curves are generally fed at the centre of the geometry. By increasing the fractal iteration,

the length of the curve increases, reducing the resonant frequency of the antenna. The resonance of monopole antennas using these geometries below the small antenna limit has been reported by Puente et al [4]. They have also studied the shift in resonant frequency by increasing the fractal iteration order. However detailed studies indicated that this reduction in resonant frequency does not follow the same pace as the increase in length with each subsequent iteration [28]. As the fractal iteration is increased the feature length gets smaller. There seems to be a limit in the minimum feature length that influences antenna properties. Several other self-similar geometries have also been explored for multiband antenna characteristics [29] - [31], [1]. Sierpinski gaskets have been studied extensively for monopole and dipole antenna configurations [32]. The self-similar current distribution on these antennas is expected to cause its multi-band characteristics [33]. It has been found that by perturbing the geometry (thereby removing its self-similarity) the multiband nature of these antennas can be controlled [34]. Variation in the flare angle of these geometries have also been explored to change the band characteristics of the antenna [32].

Efforts have also been made to improve bandwidths of these antennas. A stacked antenna configuration with multiple layers of fractal geometries has been found to have some effect in this regard [35]. This configuration has also been made conformal to improve the utilization of the antenna. Similar to Sierpinski gaskets, Sierpinski carpets have also been used in antenna elements [36]. This geometry is also used as microstrip patch antenna with multiband characteristics [37]. The antenna characteristics such as the peak gain is reported to improve by replacing a rectangular geometry with this fractal. To summarize the survey on fractal antenna engineering, key aspects of using fractals in antennas are presented here. For fractal arrays, several novel synthesizing algorithms have been developed to tailor radiation patterns. It has been established that random fractals can be used for better control of sidelobe levels. Multi-band operation and a certain extent of frequency independence are possible with such array designs. The advantages of using fractal shaped antenna elements are manifold. These geometries can be used to design smaller sized resonant antennas. The antenna radiation efficiency is thought to have improved by large number of bends and corners in many of such fractals. These geometries can lead to antennas with multi-band characteristics, often with similar radiation characteristics in these bands.

1.2. OUTLINE OF THESIS

This thesis is organized into five chapters.

Chapter 1 consists of brief introduction of the fractals and their use as an antenna elements. This chapter aims at providing initial knowledge to the reader, who is not familiar to the fractal geometries and antennas.

Chapter 2 describes the work that has been done by the researchers in the area of fractal science and engineering. Literature of the topic, although it is not vast as the other science areas is covered here.

Chapter 3 presents a insight into the properties of the fractals which makes them beneficial to be used as antenna. Small antennas and its relation with the fractal antennas are covered in this part. Later in this chapter, modelling techniques used in the simulation softwares like Ansoft HFSS 13, CST Microwave Studio based on the time and frequency domain classification is presented.

Chapter 4 is dedicated to the study of Sierpinski Carpet fractal. An analysis of SCF is done here. Concept of stacking of antennas with some examples showing advantage is also studied.

Chapter 5 consists of the simulation results of the software Ansoft HFSS 13 using SCF and a novel fractal configuration. The antenna characteristics like Return Loss and radiation Pattern are discussed.

CHAPTER 2

LITERATURE REVIEW

2.1. INTRODUCTION

This chapter presents a literature review of the theory of fractal antennas. Recent efforts by several researchers around the world to combine fractal geometry with electromagnetic theory have led to a plethora of new and innovative antenna designs. In this report, we provide a comprehensive overview of recent developments in the rapidly growing field of fractal antenna engineering.

Douglas H. Werner *et al.* [38] analysed the possibility of developing antenna designs that exploit in some way the properties of fractals to achieve these goals, at least in part, has attracted a lot of attention. Traditional approaches to the analysis and design of antenna systems have their foundation in Euclidean geometry. There has been a considerable amount of recent interest, however, the possibility of developing new types of antennas that employ fractal rather than Euclidean geometric concepts in their design. We refer to this new and rapidly growing field of research as fractal antenna engineering. Because fractal geometry is an extension of classical geometry, its recent introduction provides engineers with the unprecedented opportunity to explore a virtually limitless number of previously unavailable configurations for possible use in the development of new and innovative antenna designs. There are primarily two active areas of research in fractal antenna engineering. These include: 1.) the study of fractal-shaped antenna elements, and 2.) the use of fractals in the design of antenna arrays'. The author also presented a brief overview of some of the most common geometries that have found to be useful. The first fractal that will be considered is the popular Sierpinski gasket. The procedure for geometrically constructing this fractal begins with an equilateral triangle contained in the plane. Another popular fractal is known as the Koch snowflake. This fractal also starts out as a solid equilateral triangle in the plane as explained by Douglas H. Werner *et al.*

A novel fractal-based wideband dipole element was investigated and described [39] by T.L.Hee *et al.* It was formed by two stacked Sierpinski carpet fractals in a dipole configuration, backed by absorbing material. The configuration can be made conformal, or embedded in a low-profile container. Good input return loss performance is seen over a 1 to 4 GHz bandwidth, and acceptable patterns are seen over a 5 to 1 frequency range.



Figure 3: iterations of Sierpinski triangle [2].

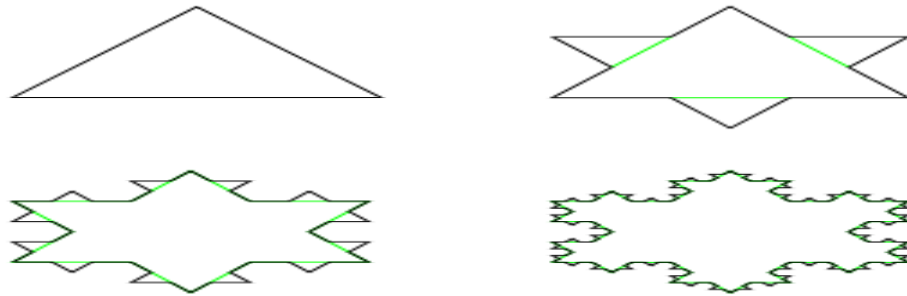


Figure 4 : iterations of Koch snowflake [38].

Further, to look into the properties and change in characteristics of fractal antennas, when stacked, a sierpinski carpet microstrip patch was modified by stacking iterations to achieve multiband frequency operation and miniaturisation. This research work was carried out by Kiyun Han and, F.J.Harackiewicz [40].

Bandwidth enhancement and impedance matching enhancement of fractal monopole antennas using compact grounded coplanar waveguide was the topic of research of Jahromi Naghshvarian *et al.* [41]. Grounded coplanar waveguides (GCPW) are used to enhance antenna characteristics, namely, reference to the $VSWR < 2$ bandwidth and the input impedance dynamic range. A printed fractal monopole such as the Sierpinski-Carpet (SC) antenna can be considered as a good candidate for comparing a coaxial-fed system with a GCPW-fed antenna. Conventional SC can be applied at 6.25-8.4 GHz (ref to $VSWR < 2$), while modified SC matches throughout the 4.65-10.5 GHz (ref to $VSWR < 2$). Clearly, this new feeding technique changes the behaviour of the fractal elements from multiband to wideband. The GCPW-fed antennas have a low cross polar field and a well-behaved pattern over the enhanced ones. This system of antennas is a possible competitor for the FCC ultra wideband radio short, fat pipe systems. In addition, time-domain analyses are performed to realize the proposed antenna time-domain application over ultra wideband.

Mustafa Khalid .T [42] states,” In today’s world of expanding wireless communications, there is increasing need for more compact, multiband, and moderate gain antennas for

portable communications systems to respond to the great demand for both military and commercial communications systems. Fractal antenna designs can assist in meeting these design requirements”. He introduces a novel small size and multiband fractal dipole antenna called combined fractal antenna for 2D and 3D configurations where two different fractal geometries combined together to get the main antenna body. This antenna combines aspects of Hilbert and Koch curves and expected that the resulted antenna have a hybrid or combined properties related to the geometries that constructed this combined geometry.

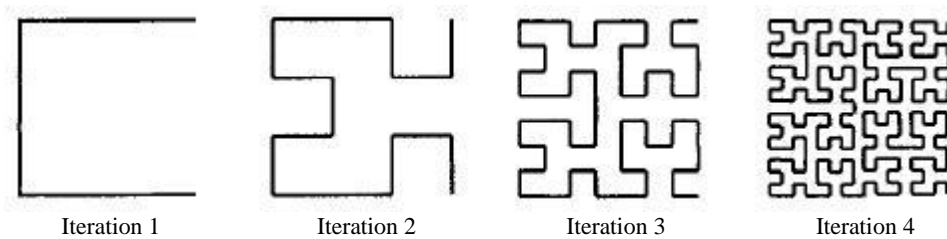


Figure 5 : Construction of Hilbert geometry [42]

Yuan-hai Yu *et al.* [43] says, “Fractal technology has great potential in antenna miniaturization, multi-frequency, ultra-wideband application, and the paper [43] is about fractal technology in the application of multi-frequency microstrip antenna. Based on the fractal structure design of Sierpinski, we studied the multirate characteristics of nested triangle fractal monopole antenna, using electromagnetic field simulation software Microwave Studio. We investigated the antenna structure antenna centre band and reflection losses by changing the parameters so as to control the multirate characteristics of antenna. The similarity of the fractal structure determines the similarity of the current distribution, and the different distribution of electric current scale determines the similarity of fractal antenna with multi-frequency characteristics. Fractal technology in antenna field has become the domestic and foreign research hotspot. Future communications will put more serious technology challenges for antenna, demanding a miniaturized structure to complete antenna miscellaneous tasks. Fractal antenna can meet the need antenna requirements of modern communication thin section, small size, being easy to manufacture and low price. Fractal is produced with the self-similarity of fractal dimension structure through iterative, not only realized the antenna of miniaturization, but also strengthened the directional antenna.

Randy L. Haupt *et al.* [44] say,” Fractal antenna engineering represents a relatively new field of research that combines attributes of fractal geometry with antenna theory. Research

in this area has recently yielded a rich class of new designs for antenna elements as well as arrays. The overall objective of this article has been to develop the theoretical foundation required for the analysis and design of fractal arrays. It has been demonstrated here that there are several desirable properties of fractal arrays, including frequency-independent multi-band behavior, schemes for realizing low-sidelobe designs, systematic approaches to thinning, and the ability to develop rapid beam forming algorithms by exploiting the recursive nature of fractals.”

V. Onufriyenko studied theory of fractal wire antennas [45]. According to the author, search for geometries whose dimensions are not limited to integers may lead to the design of antennas with characteristics improved over those existing today. Fractal geometries have shown a possibility to miniaturize antennas and to improve their input matching. Certain classes of fractal antennas can be configured to operate effectively at various frequency bands. There are three distinct advantages in using the fractal antennas. First, fractal geometries can be implemented to miniaturize resonant loop and dipole antennas. Also, designing with fractal geometries can overcome limitations to improve the input resistance of antennas that are typically hard to match to feeding transmission lines. Furthermore, the self-similar nature in the fractal geometry can be utilized for operating a fractal antenna at various frequencies. Antenna geometry is a topic of considerable interest in the optimization of the resonant properties of wire monopole antennas. These geometries have been used previously to characterize unique occurrences in nature that were difficult to define with Euclidean geometries, including the length of coastlines, the density of clouds, and the branching of trees. Fractals represent a class of geometry with very unique properties that can be enticing for antenna designer.

D.H.Werner *et al.* [46] did analysis for designing genetically engineered multiband fractal antennas. D. H. Werner et al. say,” Fractal antenna engineering concepts have been successfully combined with genetic algorithms to develop a powerful design optimisation tool. The genetic optimisation approach developed can simultaneously optimise the geometry of a fractal antenna, locations of loads, component values of loads, and projected length of the fractal antenna. The results suggest that a 30 to 55% size reduction can be achieved by optimising the fractalisation of a given antenna. The knowledge gained from this study is directly applicable to the design of miniature multiband fractal antennas”. In that section, they briefly introduce we consider w_1, w_2, \dots, w_N as a set of affine linear transformations applying the set of transformations to the geometry A and collects $a_2 =$

$d_2 = 2 - \cos$ & an iterated function system (IFS) that can be employed to generate fractal antenna element geometries.

Fractal microstrip antenna has been a hot area of research nowadays. Y. B. Thakare *et al.* [47] says, "self-similar or self-affine and space filling fractal microstrip antenna increases the effective electrical length of the antenna to reduce the size of the antenna and make them frequency independent. Also, self-similar or self-affine property gives multiband resonance in the antenna. Most practical planar antennas give rise to a very large backscattered field at normal incidence. Geometrical shaping and ferrite substrate use are reported for radar cross section (RCS) reduction. Elimination of specular reflection over a wide range of aspect angles by using strip grating surface is also reported in. Other RCS reduction techniques reported are resistive loading, varactor tuning and substrate–superstrate layer structure. The antenna can be responsible for the larger part of the total RCS of the aircraft designed to have low observability. Therefore scattering behaviour of antennas is important for defence applications. In fact, antenna scattering can be source of electromagnetic compatibility problems and causes interference with other systems on the same platform. Wide usages of fractal antennas make sense in the RCS study and its reduction for antenna designer. Fractal geometries show multiband backscattering reduction. The study can be used to design antenna for low backscattering in the applicable frequency band". They, in their study section presented a present a novel design of star-shaped fractal patch antenna for miniaturisation and backscattering radar cross-section (RCS) reduction. The proposed fractal antenna gives 50% size reduction compared with a conventional circular microstrip patch (CCMP) antenna.

A review of microstrip fractal shaped antennas was done by J. Anguera, C. Borje and C. Puente. J. Anguera [48] *et al.* say, "Microstrip patch antennas offer low profile, low cost (they can be manufactured by the well-known printed-circuit technology) and low volume. These mechanical properties make MPAs interesting for high-performance applications such as military, space and even commercial where space and cost result in a significant constraint factor. Another mechanical advantage is that they can be conformal, i.e., they can adapt to a curved surface; for example, that of an airplane or other motor vehicle. On the electrical side, they also present many advantages: easy to obtain dual or circular polarization; easy to control resonant frequency; compatibility with MMICs; well characterized by several numerical methods; several broadband mechanisms; and a particular kind of microstrip antenna (PIFA) is being used in many handset phones as well as other wireless devices. Combining microstrip antenna and fractal geometry results in a

very interesting area for research and practical applications. In this sense, the presentation will show a review on microstrip fractal-shaped antenna designs focussed in multiband and high-directivity microstrip antennas and arrays. Especially, the self-similar property of fractals is of particular interest in designing microstrip antennas having multi-band properties. On the other hand, stacked technique used in the microstrip field is used in combination with fractal geometries to obtain broadband multi-band radiators. One of the disadvantages of microstrip antennas is their narrow bandwidth when they are electrically close to the groundplane (0.01-0.02 λ). To overcome this problem, stacked patch technique is used.

M.Ismail studied the first three iterations of Sierpinski Gasket and Koch Island fractal microstrip patch antenna with a probe feeding on a single microstrip substrate are studied. He explains the predictable multiband characteristics. A new design of fractal multiband antenna based on both the Sierpinski Gasket and Koch Island is presented. Antenna fabrication is done with photolithographic technique. Experimental measurements are compared with numerical results obtained using the method of moments implemented in the ready-made Zeland IE3D version 10.0 simulator software. Comparison between results verifies the new design idea and characteristics as stated by M.Ismail.

Rajkumar *et al.* says, Conventional microstrip antenna has a limitation of narrow bandwidth, low efficiency, low gain and size. The microstrip antenna [47] is efficient radiator around half wavelength. As the size of the antenna becomes less than $\lambda/2$, the radiation of the antenna, bandwidth, gain and efficiency deteriorates. The problem of ultra wide bandwidth and size can be solved by incorporation of fractal geometry in microstrip antenna". The paper presented the design of an Ultra Wide band (UWB) antenna with CPW-fed. The antenna has been designed on FR4 substrate $\epsilon_r = 4.3$ and thickness 1.53 mm. The antenna has been fabricated and tested using VNA. The experimental results of this antenna offer ultra wide bandwidth from 2.86 GHz to 14.38 GHz. This corresponds to the impedance bandwidth 11.42 GHz and 132.48 %. The experimental results also exhibit the first band from 0.62 GHz to 1.657 GHz corresponds to 1.037 GHz bandwidth. The radiation pattern of this antenna is nearly omnidirectional. This type of antenna can be used for ultra wide band system, positioning system, microwave imaging and Radar application. This CPW-Fed Rotated Square Octal Shaped Fractal UWB Antenna has nearly omnidirectional properties. The monopole rotated square octal shaped fractal antenna exhibits

ultra wide bandwidth at higher frequencies This antenna can be used in Ultra wide band system application, microwave imaging and radar applications.

S.Suganthi *et al.* proposed two microwave antennas of fractal geometry design and simulation [49]. The patch and thin microstrip type antennas of the same outer dimensions have been designed and investigated. The simulation results report that the patch fractal antenna resonates at two frequencies whereas microstrip fractal antenna possesses good size reduction ability while providing a single resonant frequency. Fractal antennas are used in wide range of frequencies for various wireless applications. For designing the antenna, iterations are considered. Here planar fractal antenna is designed from basic square fractal structure. Firstly a fractal structure as a patch is designed. Secondly a thin microstrip type, fractal antenna is designed The main advantage of microstrip antennas such as the low profile, ease of fabrication and the lower cost have made this element very popular. The interaction of electromagnetic waves with fractal bodies has been the study of many researchers in the recent years. Fractals are generally self-similar and independent of scale”.

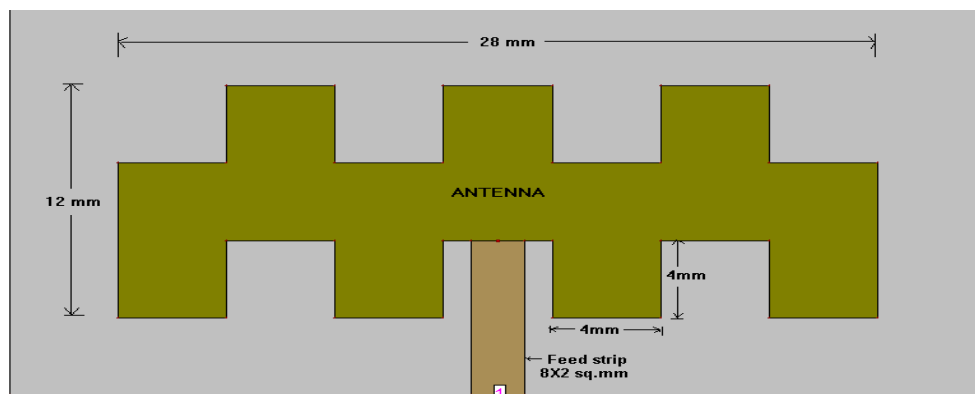


Figure 6 : Patch fractal antenna[75]

J.Guterman [50] presented a novel microstrip patch antenna with a Koch pre fractal edge and a U-shaped slot for multi-standard use in GSM1800, UMTS, and HiperLAN2. Making use of an inverted-F antenna (PIFA) structure, an interesting size reduction is achieved. The multi-band behavior has been obtained by broadening the lower frequency resonance of the fractal patch to cover GSM1800 and UMTS, and inserting a U-slot dimensioned for the HiperLAN2 band. The effect of the small ground plane has been taken into account. Experimental results have validated the design procedure and confirm the fulfillment of the requirements for multistandard mobile terminal applications”.

S.S.mohammad *et al.* state.”A Sierpinski carpet edge-fed microstrip patch antenna is proposed for size reduction of antenna of Wireless Power Transmission (WPT) System. The conventional patch antenna is designed based on transmission line model with the characteristics impedance of 50Ω . The fractal geometry for the conventional antenna is generated up to second iteration and simulated. The results show that the maximum of 27.68% size reduction can be achieved by the Sierpinski Carpet microstrip patch antenna of the second iteration order, without affecting the other performances such as return loss and radiation pattern”.

Design of Broadband Dual-Frequency Microstrip Patch Antenna with Modified Sierpinski Fractal Geometry was studied by Ngu Sze Song *et al.* which states,” Fractal antennas have the characteristic of radiating in multiple frequencies through the property of self-similarity that fractal shapes possess[51]. By connecting fractal shaped antennas, wideband coverage can be achieved. Microstrip patch antennas with Sierpinski fractal geometry can be tuned, by design, to work exactly at the bands of interest, through judicious choice of the fractal designs and iteration. Therefore, a broadband dual-frequency microstrip patch antenna with modified Sierpienski fractal geometry is designed by using Microwave Office 2002 simulation software. The broadband and multiple frequency characteristics of fractal antennas will be demonstrated. The performance of microstrip patch antenna with the classic and modified Sierpinski fractal geometries will be presented”.

H.M.Elkamchouchi *et al.* in his research [52] used a fractal (Sierpinski gasket) patch to enhance the impedance bandwidth of microstrip antenna. A finite difference time domain (FDTD) method full wave simulator FidelityTM is used to simulate, the proposed antenna. Simulation results of a Sierpinski patch microstrip antenna and their comparison with simulation results of a corresponding conventional triangular patch antenna show that using a Sierpinski shaped patch greatly increases the impedance bandwidth of the microstrip antenna (reaching nearly 40%). Using an inhomogeneous substrate along with the Sierpinski patch as well as the effect of the feed line location on both the antenna bandwidth and gain are considered”.

A novel square microstrip fractal patch antenna was Sierpinski carpet was proposed for three-band operation. Measured results indicate that the return loss is better than 10 dB and that the gain is greater than 7 dB in each band. This antenna is an attractive candidate for wireless, satellite and mobile communication applications as stated by R.V.Hara Prasad *et al.* [53].

An analysis of microstrip fractal antennas with uni-planar compact photonic bandgap (UC-PBG) structure was done by Gao Wei [54]. He designed a novel compact microstrip fractal patch antenna with uni-planar compact photonic bandgap (UC-PBG) structure. The proposed antenna is suited for multi-band application in wireless network. A new cell of UC-PBG structures for microstrip antennas is adopted to suppress the surface waves and improve the radiation patterns. With a fractal structure, the antenna represents frequency-independent attributes and based on geometrically self-similarity, it can be widely used in the other multi-band application.

Anuradha *et al.* say [55], “ in response to the ever-increasing needs of antenna bandwidth, a considerable amount of effort is currently underway to develop multi-band antennas. Much has also been achieved in implementing dual-band antennas. Planar designs are mostly preferred for these structures, due to their added advantages of small size, low manufacturing cost, and conformability. Fractal antennas have been used as miniature multi band antennas in which the self-similarity property is used to cause the antenna to resonate in a number of frequency bands. Over the years, various fractal structures have been considered for antenna applications. However, the greatest inconvenience with this category of multi-band antenna is that all the resonating frequencies of the antenna in its classical form are not the user-defined frequencies. Modifications are therefore required to the structure of the antenna for it to work at user-defined frequencies. However, a systematic procedure to obtain a final structure is missing from the literature. In the present work, biologically inspired computational techniques are used for the same purpose. The implementation was accomplished in two phases. In the first phase, a trained artificial neural network was developed to form a black box between the design parameters of the antenna and the corresponding working frequencies. In the second phase, Particle-Swarm Optimization was used as an optimization tool to find the dimension of the antenna when the operating frequencies are supplied, with the help of the trained artificial neural network. Sierpinski fractal and Koch monopole antennas were taken as the test antennas.

2.2 MOTIVATION FOR PRESENT RESEARCH

This thesis work is a study on the suitability of some fractal geometries for multifunctional and small antenna applications. Although many fractal geometries are identified, and mathematically studied for long, their applications into electromagnetics is fairly recent. Within the past decade few fractal geometries have been proposed as antenna elements and special antenna characteristics (?) introduced by the use of these geometries have been

widely acclaimed. It has been claimed that the non-Euclidean nature of these geometries would lead to equally non-conventional antenna performance, and the self-similarity of the geometry is the *cause* of multi-band characteristics of the resulting antenna. This thesis aims at furthering the understanding the effectiveness of these geometries in antennas, and to bring about true advantages of their use in antenna engineering.

2.3. METHODOLOGY

- PC Configuration: Intel Pentium core i3.
- 2.10 GHz.
- 2 GB of RAM.
- Operating System: Windows 7 Home.
- Software: Ansoft HFSS 13.

2.4. OBJECTIVE OF THESIS

The current thesis work is carried out to meet the following objectives:

- To analyse Sierpinski Carpet fractal for different iterations using Ansoft HFSS.
- To study the stacked configuration of Sierpinski carpet fractal and simulate it using the Ansoft HFSS.

To study and model a new carpet based fractal geometry and making it compatible to use with the current technologies like WiFi and in X band(4-8 GHz).

CHAPTER 3

FRACTAL ANTENNA CHARACTERISATION AND MODELLING TECHNIQUES

3.1. INTRODUCTION

This Chapter presents a basic framework for the theoretical understanding of the effectiveness of fractal shaped antenna elements. Many such elements operate as small antennas. Hence a brief discussion is included here on the merits of such antennas. Apart from this, numerical techniques used in simulating the antenna properties, such as the moment method (MoM) and the finite difference time domain (FDTD) technique are also briefly introduced.

3.2. FRACTAL

A fractal is a rough or fragmented geometric shape that can be subdivided in parts, each of which is (at least approximately) a reduced-size copy of the whole. Fractals are generally self-similar and independent of scale. Thus, a fractal is a geometric shapes which:

- (i) Is self-similar and,
- (ii) Has got fractional dimension

These geometries have been used to characterize structures in nature that were difficult to define with Euclidean geometries.

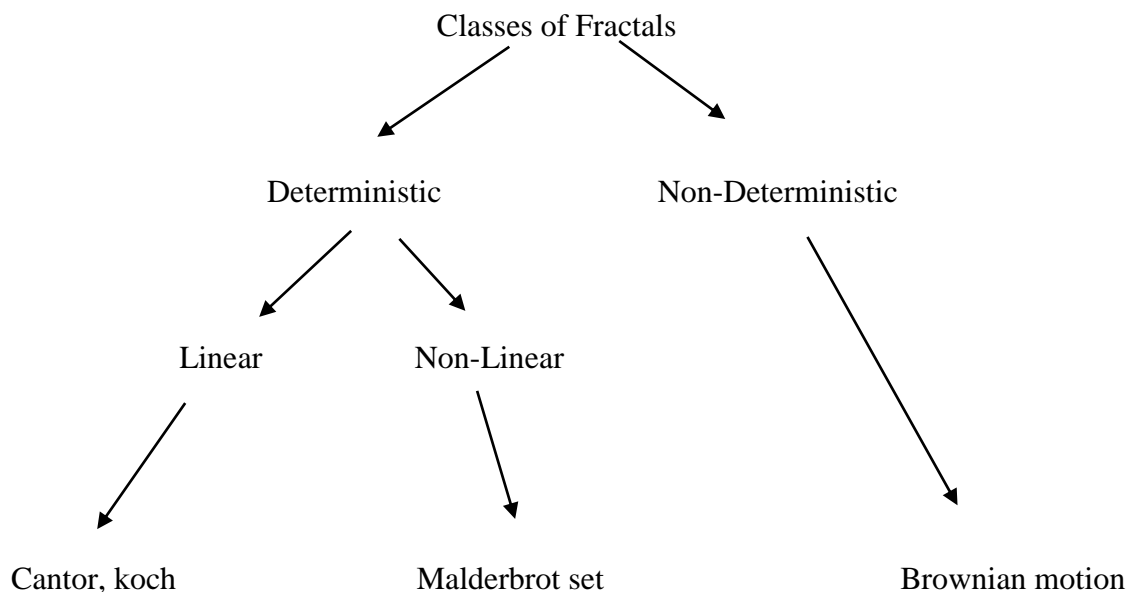


Figure 7 : Classification of fractals

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. Each fractal is composed of multiple iterations of a single elementary shape. The iterations can continue infinitely, thus forming a shape within a finite boundary but of infinite length or area.

Thus, fractals can be produced by using iterations or more accurately, the method is called as Formation by Iteration discussed later in this chapter.

Some of the more common fractal geometries that have found application in antenna engineering are depicted in Fig. 8, 9 & 10, the Koch snowflakes and islands have been primarily used to develop new designs for miniatures lop as well as microstrip patch antennas. New designs for miniaturized dipole antennas have also been develop based on a variety of Koch curves and fractal trees. Finally, the self-similar structure of sierpinski gaskets and carpets has been exploited to develop multi band antenna elements. Applications corresponding to each type of fractal antenna is also briefly stated with the diagrams.



Figure 8 : Some Common Fractal Geometries Found in Antenna Application: Koch snowflakes/islands. These are used in miniaturized loop



Figure 9 : Some Common Fractal Geometries Found in Antenna

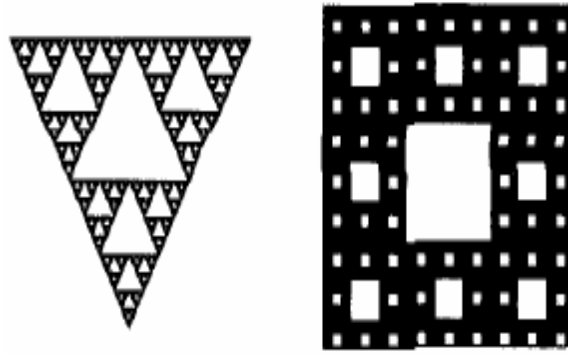


Figure 10: - Some Common Fractal Geometries Found in Antenna (used in multiband and wideband antennas)[59].

3.2.1. Random Fractals

The exact structure of regular fractals is repeated within each small fraction of the whole (i.e., they are exactly self-similar). There is, however, another group of fractals, known as random fractals, which contain a random or statistical elements. These fractals are not exactly self- similar, but rather statistically self-similar. Each small part of a random fractal has the same statistical properties as the whole. Random fractals are particularly useful in describing the properties of many natural objects and processes.

Table 2: General comparison of Euclidean and Fractal geometry.

| Euclidean geometry | Fractal Geometry |
|---|---|
| >2,000 years old | 10-20 years old |
| Applicable for artificial objects | Applicable for natural objects |
| Change shapes with scaling | Invariant under scaling , self-similar |
| Locally smooth ,differentiable | Locally rough, not differentiable |
| Objects defined by analytical equations | Objects defined by recursive algorithms |
| Elements: vertices, edges, surfaces | Elements: iteration of functions |

A simple way to generate a fractal with an element of randomness is to add some probabilistic element to the construction process of a regular fractal. While such random fractals do not have the self-similarity of their nonrandom counterparts, their non-uniform appearance is often rather closer to natural phenomena such as

coastlines, topographical surfaces, or cloud boundaries. Indeed, random fractal constructions are the basis of many impressive computer- drawn landscapes or skyscapes. A random fractal worthy of the name should display randomness at all scales, so it is appropriate to introduce a random element at each stage of the construction. By relating the size of the random variations to the scale, we can arrange for the fractal to be statistically self-similar in the sense that enlargements of small parts have the same statistical distribution as the whole set. This compares with (nonrandom) self-similar sets where enlargements of small parts are identical to the whole.

3.2.2. Iterated Function Systems

Many useful fractals can be generated by Iterated Function Systems (IFS) [60]. An extended discussion of IFS is found in. Briefly, IFS work by applying a series of affine transformations W to an elementary shape an over much iteration. Affine transformation $W(x,y)$ is represented by six Parameters.a,b,c,d,e,f where a,b,c,d are rotation and scaling parameter and e,f are translation parameter.

$$W(x, y) = \begin{bmatrix} a & b & e \\ c & d & f \\ 0 & 0 & 1 \end{bmatrix} \begin{matrix} x \\ y \\ 1 \end{matrix} \quad (3.1)$$

The set of affine transforms $W (A)$, known as the Hutchinson operator is given by:

$$W(A) = \cup_1^n w_n(a) \quad (3.2)$$

The fractal then can be generated by applying operator W to the previous geometry.

$$A_1 = W(A_0) = W(A_1) \dots \dots W(A_{k+!}) = W(A_k) \quad (3.3)$$

Sierpinski gasket is a special case of a wider class of fractals that can be derived from the well-known Pascal'triangle. A Sierpinski Gasket fractal is generated by the IFS method. As depicted in Figure 11, a triangular elementary shape is iteratively scaled, rotated and translated, then removed from the original shape in order to generate a fractal. It is interesting to note that after infinite iterations of the fractal, the entire shape has an infinite area but is bounded by a finite perimeter. Thus, by repeated application of the series of IFS affine transformations given in (3.1), we can generate fractals like Koch curves, Hilbert curve,



Figure 11: A 4-Iterations Sierpinski Gasket.

Sierpinski Carpet and many more as well by the operations like scaling, rotating and translation.

3.3. SELF-AFFINE SETS

Self-affine sets form an important class of sets, which include self-similar sets as a particular case. An affine transformation $S: R^n \rightarrow R^n$ is a transformation of the form

$$w(x,y)=t(x, y) + t \tag{3.4}$$

where t is a linear transformation on R^n (which may be represented by an $n \times n$ matrix) and t is a vector in R^n . Thus an affine transformation w is a combination of a translation, rotation, dilation, and perhaps reflection. In particular, w maps spheres to ellipsoids, squares to parallelograms, and so forth. Unlike similarities, affine transformations contract with differing ratios in different directions.

If $w_1 \dots \dots w_m$ are self-affine contractions on R^n , the unique compact invariant set F for w_i is termed a self-affine set. An example is given in Figure 1.7. If $w_1 \dots \dots w_m$ are defined as the transformations that map the square onto the three rectangles in the obvious way.

It is natural to look for a formula for the dimension of self-affine sets that generalizes formula for self-similar sets. We would hope that the dimension depends on the affine transformations in a reasonably simple way, easily expressible in terms of the matrices, and vectors that represent the affine transformation. Unfortunately, the situation is much more complicated than this. If the affine transformations are varied in a continuous way,

the dimension of the self-affine set need not change continuously. With such discontinuous behaviour, which becomes worse for more involved sets of affine transformations, it is likely to be difficult to obtain a general expression for the dimension of self-affine sets.

3.4. FRACTAL AS SPACE FILLING CURVES

In mathematical analysis, a space-filling curve is a curve whose range contains the entire 2-dimensional unit square. 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 [61], 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 [62]. With successive iteration the length of Koch increases by 1/3 of the original length. Length of Koch after nth iterations:

$$l_n = l_0 \left(\frac{4}{3}\right)^n \quad (3.4)$$

Where l_n and l_0 are the length after nth iteration and original length (without any iteration) respectively. For Sierpensi Triangle with each iteration the area of the holes and circumference of solid pieces changes. Diagram below shows the filling of space using the iterations in the Hilbert curve (6th iteration).

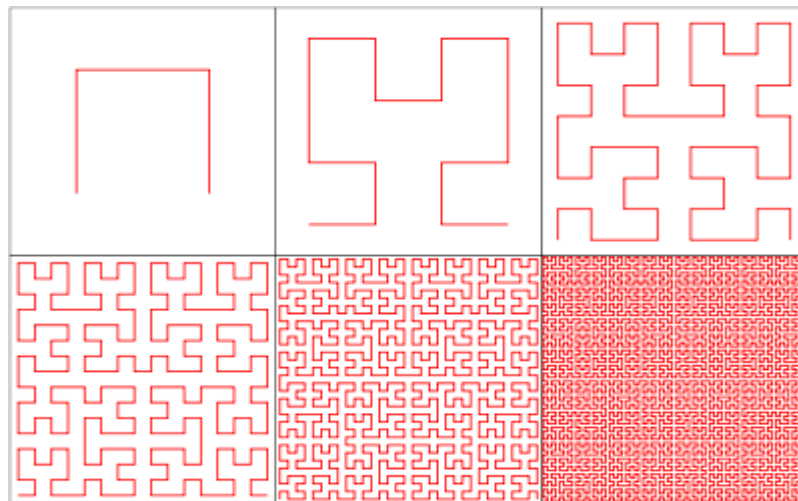


Figure 12 : Six iterations of Hilbert curve construction showing the filling of 2-D space.

3.5. SMALL ANTENNAS

The quest for smaller sized resonant antennas has been on for decades. Several of antenna design principles may have to be modified while dealing with small-sized antennas. By convention, a small antenna is defined as one occupying a fraction (typically $<1/6$) of the wavelength [63]. The primary concern in their design is in the impedance matching. This is better explained in the context of dipole antennas. As the length of a dipole antenna is reduced, the real part of its input impedance approaches zero, while the imaginary part tends to be an extremely large negative number. This causes major reflections at the input terminal as the transmission line connected to it generally has a standard characteristic impedance (50Ω). The reactive part of the impedance is contributed by the induction fields in the near-zone of the antenna. The resistive part on the other hand may be attributed to various loss mechanisms present in and around the antenna, including the radiation “loss”. Losses due to the finite conductivity of the antenna structure, and that due to currents induced on nearby structures including ground contribute to the antenna input resistance.

3.5.1 Issues in designing of small antennas

It is often preferred to operate an antenna around its resonance to obtain proper impedance match with the transmission line. There are several artificial ways of obtaining similar input characteristics without actually making the dipole $\lambda/4$ long. One is to use reactive elements at the input that cancel out the reactance of the antenna. However this approach often limits the bandwidth of operation of the antenna. Another method extends the length of the dipole, without actually making it longer. Meandered and zigzag lines are examples of this approach. Bends and corners introduced by this modification adds to the inductance of the line, but does not significantly impact the real part of impedance. Hence the study on small resonant antennas is still ongoing and antenna applications of several fractal geometries have been approached with this objective. An important issue that remains is the low bandwidth, which in other words is a high quality factor. At resonance, the quality factor is defined as [64], [65]

$$Q = \frac{2Ww}{p} \quad (3.5)$$

where, W is larger of W_e or W_m are the time averaged electric or magnetic energy stored in the near field of the antenna. P is the radiated power from the antenna. The factor of 2 is used to incorporate the effects of adding additional network components required to make the antenna resonant. This value is reduced by the losses in the tuning elements. It is also

stated that for large Q , the antenna bandwidth is defined as the reciprocal of Q . The minimum Q of a small antenna is obtained as:

$$Q_{min} = \frac{1}{2(\beta a)^3} + \frac{1}{\beta a} \quad (3.6)$$

where, a is the smallest possible sphere that encloses the antenna. In general Q is evaluated by treating the antenna as a one port device and obtaining its RLC equivalent circuit. Another issue that concerns the design of small antennas is radiation efficiency. Several techniques are available for evaluating the radiation efficiency of small antennas. One of the improved techniques is to enclose the antenna in a special waveguide fixture, by a transmission measurement using a reference antenna [66]. The efficiency is calculated from measured S-parameters.

3.6. FUNDAMENTALS OF MODELING TECHNIQUES USED.

This research work relies to a great extent on the modeling studies using commercially available EM simulation softwares such as Ansoft HFSS and CST Microwave Studio. An understanding of the fundamental theory behind these numerical techniques is essential in creating the antenna models and to evaluate the results obtained with them. Hence a brief exposition into the theory behind these techniques is presented in this section.

3.6.1 Method of Moments (MoM)

The electromotive force (emf) method for calculation of antenna impedance is applicable to a very limited number of antenna configurations. Numerical techniques are essential in more general antenna structures, especially when complicated geometry such as fractals is involved. One very common method in electromagnetics, suitable for antenna analysis as well as for scattering and diffraction problems is the method of moments (MoM) [67]. MoM is a very powerful and versatile technique which can be applied to linear, planar, as well as three-dimensional structures. The method involves segmentation of the antenna structure and choosing suitable basis functions to represent currents on these segments. A set of equations is generated by enforcing the boundary conditions with a suitable set of testing functions. This results in a matrix whose order is proportional to the number of segments on which the current distribution is represented. The solution to the problem is found by inverting this matrix.

3.6.2 Time-Domain Modelling

In this section, we shall discuss some time-domain computational electromagnetics (CEM) methods for antenna analysis. Due to space limitations, we will focus on the finite-

difference time-domain (FDTD) and finite-element time-domain (FETD) methods [68]. These are two of the most popular methods presently available and widely used in many commercially available software packages.

FDTD and FETD: Basic Considerations

Time-domain simulations of antenna problems are sometimes an attractive alternative to frequency-domain simulations because they can produce wideband data with a single code execution. As a result, they are particularly suited, for example, to ultra-wideband antenna problems, as will be illustrated later on in this section. Antenna scenarios involving nonlinear and/or time-varying media/components are more easily tackled in the time-domain as well. In general, a time-domain discretization strategy for Maxwell's equations may involve either explicit or implicit "marching-on-time" updates (also called "time-stepping"). Explicit updates refer to time-domain discretizations whereby the fields to be determined at a given time step depend only on (known) field values at previous time steps. On the other hand, implicit updates refers to time-domain discretizations whereby present field values depend not only on previous field values but also on each other. As a result, implicit updates require the solution of a linear system (typically sparse) at every time step, whereas explicit update may not (the latter are denoted "matrix-free"). This is a clear advantage for explicit updates. The most celebrated explicit time-domain method is the conventional Yee's FDTD scheme [68]. However, explicit updates are subject to the so-called Courant limit, which sets a bound on the maximum size of the time increment from numerical stability considerations. In contrast, some implicit updates are not subject to the Courant limit and the time increment size in this case can be chosen from accuracy considerations only, which can lead to a time increment much larger than the one set by the Courant limit. In its basic form as introduced by Yee and pioneered by Taflove, the FDTD method is conceptually very simple and relies on the approximation of time and space derivatives of Maxwell curl equations by central differences on staggered grids, leading to a scheme which is second-order accurate in both space and time. The grid in FDTD is typically a structured rectangular grid. Because FDTD is matrix-free, its memory requirements scale only linearly with the number of unknowns. This, added to the fact that FDTD is massively parallelizable, makes FDTD quite suited for petascale computing and beyond. Higher-order versions of FDTD also exist, which trade simulation accuracy by sparsity. Being naturally constructed for unstructured irregular grids, FETD is quite suited for numerical solution of antenna problems in complex geometries where the use of a rectangular FDTD grid would give rise to stair casing error. FETD is also suited for

implementations with p- refinement and h - refinement capabilities. However, FETD methods in irregular grids lead to implicit schemes requiring the solution of a sparse linear system at every time step. For Maxwell's equations, it is possible to obtain explicit ("matrix-free") FEM using, for instance, mass (matrix) lumping, but not without shortcomings (in particular, they are prone to numerical instabilities). There are two basic approaches for constructing FETD algorithms for Maxwell equations. The first approach is based on the discretization of the second-order vector Helmholtz wave equation (for either the electric or magnetic field) by expanding the unknown field in terms of local basis functions—most commonly (curl-conforming) Whitney edge elements—followed by application of the method of weighted residuals via an inner product with test functions. In order to produce symmetric matrices (assuming reciprocal media), the set of test functions is chosen identical to the set of basis functions (Galerkin testing). The second FETD approach is based on the discretization of the first-order Maxwell curl equations by expanding the electric and magnetic fields in terms of "mixed" elements, most commonly Whitney edge elements for the electric field and (div-conforming) Whitney face elements for the magnetic flux density. This choice avoids the appearance of spurious modes (by satisfying a discrete version of the de Rham diagram). This is followed by either (a) application of the method of weighted residuals with appropriate (also mixed) test functions or (b) by the use of incidence matrices and construction of discrete Hodge operators.

3.6.3 Frequency-Domain FEM

Geometrical and material modeling flexibility of the FEM, has made it one of the most versatile design tools for modern antenna engineering. Recent advances in FEM modeling, coupled with fast and robust solution methods and general purpose mesh generation/graphical interface tools, have been instrumental in the proliferation of several commercial FEM packages in the past decade. Today, such commercial software are the antenna engineers' most efficient tools in tackling modern antenna design challenges.

3.7. EXPERIMENTAL SET UP FOR ANTENNA MEASUREMENTS

Antenna characteristics are generally measured using the network analyzer HP 8510 C. It is very convenient and easy to obtain antenna input characteristics using a network analyzer. This is because this equipment measures both amplitude and phase simultaneously. The return loss (S11), VSWR, or input impedance are measured using single port calibration. The radiation characteristics of antennas can be measured in an anechoic chamber using a network analyzer. The experimental set up is shown in Fig. 13.

Since the distance between transmitting and receiving antennas is approximately 3 meters, an amplifier is often used in the transmitter side. An RF amplifier HP 8347 A (100 KHz – 3 GHz) or a microwave amplifier HP 8349B (2-20 GHz) can be used depending on the frequency of interest. When a standard antenna is used as the transmitter and test antenna as the receiver, S₂₁ is measured using the analyzer. The advantage of using a network analyzer for this measurement is that a band of frequencies can be swept in a single measurement, thus saving time. Custom-software is used to control the positioner as well as to download data from the network analyzer. This software is also capable of generating radiation pattern plots at individual frequencies, or S₂₁ versus frequency at different look angles of the test antenna.

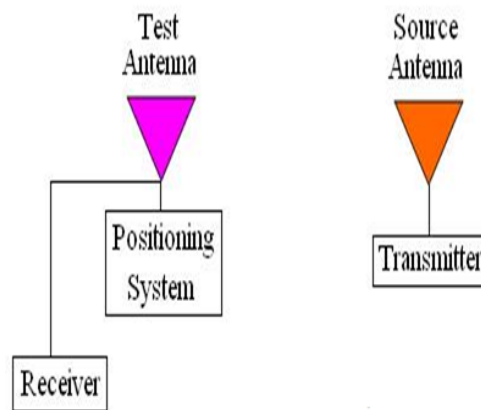


Figure 13 : Experimental setup inside an anechoic chamber.

3.8. 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. 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 scientist's 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 favourite 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 creates 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 analyse 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 reduces 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 part 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.

CHAPTER 4

SIERPINSKI CARPET GEOMETRY AND EFFECT OF STACKING

4.1. INTRODUCTION

The Sierpinski curves (gaskets and carpets) are perhaps the most widely studied fractal geometry for antenna applications. Sierpinski gaskets have been investigated extensively for monopole and dipole antenna configurations. The self-similar current distribution on these antennas is expected to cause its multi-band characteristics. It has been found that by perturbing the geometry the multi-band nature of these antennas can be controlled. Lots of efforts have been made on the fractal antennas based on the Sierpinski fractal in recent years. For the self-similarity properties of fractal antenna shapes, Sierpinski fractal antennas, such as Sierpinski gasket and Sierpinski carpet, have been experimentally found to perform better multiband, broadband and miniaturisation.

The Sierpinski carpet is a plane fractal first described by Waław Sierpiński in 1916. The carpet is a generalization of the Cantor set to two dimensions (another is Cantor dust. Sierpiński demonstrated that this fractal is a universal curve, in that any possible one-dimensional graph, projected onto the two-dimensional plane, is homeomorphic to a subset of the Sierpinski carpet. For curves that cannot be drawn on a 2D surface without self-intersections, the corresponding universal curve is the Menger sponge, a higher-dimensional generalization. The technique can be applied to repetitive tiling arrangement; triangle, square, hexagon being the simplest. It would seem impossible to apply it to other than rep-tile arrangements.

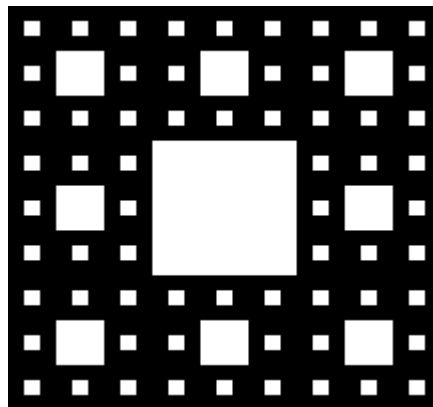


Figure 14 : Sierpinski Carpet Fractal

The construction of the Sierpinski carpet begins with a square. The square is cut into 9 congruent sub squares in a 3-by-3 grid, and the central subsquare is removed. The same procedure is then applied recursively to the remaining 8 subsquares, *ad infinitum*. It can be realised as the set of points in the unit square whose coordinates written in base three do not both have a digit '1' in the same position.

The area of the carpet is zero (in standard Lebesgue measure). The Hausdorff dimension of the carpet is $\log 8/\log 3 \approx 1.8928$.

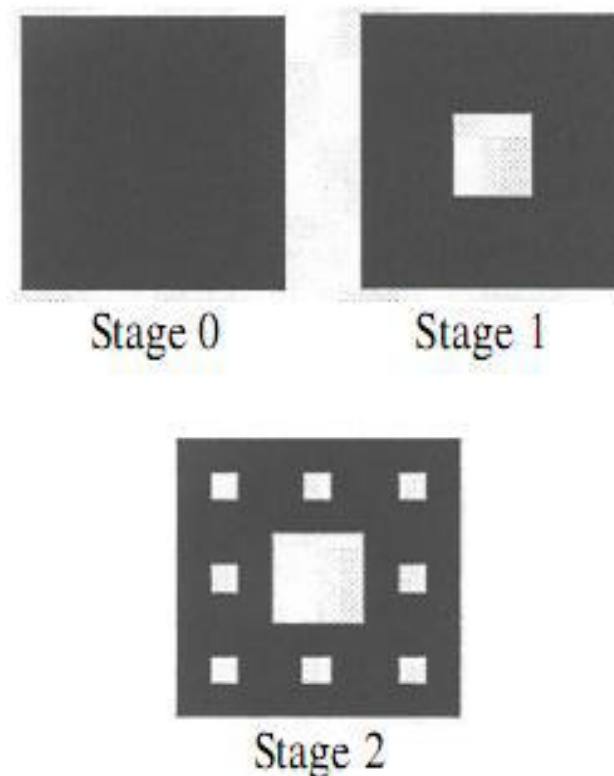


Figure 15 : Iterations of Sierpinski Carpet antenna.

Similarly, for other fractal structures, we can find the Hausdorff dimension.

4.2. RECTANGULAR MICROSTRIP ANTENNAS

Microstrip or patch antennas are becoming increasingly useful because they can be printed directly onto a circuit board. Microstrip antennas are becoming very widespread within the mobile phone market. Patch antennas are low cost, have a low profile and are easily fabricated.

Consider the microstrip antenna shown in Figure 16, fed by a microstrip transmission line. The patch antenna, microstrip transmission line and ground plane are made of high conductivity metal (typically copper). The patch is of length L , width W , and sitting on top of a substrate (some dielectric circuit board) of thickness h with permittivity. The thickness of the ground plane or of the microstrip is not critically important. Typically the height h is much smaller than the wavelength of operation, but not much smaller than 0.05 of a wavelength.

The frequency of operation of the patch antenna of Figure 4.1 is determined by the length L . The centre frequency will be approximately given by:

$$f_c = \frac{c}{2\pi\sqrt{\epsilon_r}} = \frac{1}{2\pi\sqrt{\epsilon_0\mu_0\epsilon_r}} \quad (4.1)$$

The above equation says that the microstrip antenna should have a length equal to one half of a wavelength within the dielectric (substrate) medium. The width W of the microstrip antenna controls the input impedance. Larger widths also can increase the bandwidth. For a square patch antenna fed in the manner above, the input impedance will be on the order of 300 Ohms. By increasing the width, the impedance can be reduced. However, to decrease the input impedance to 50 Ohms often requires a very wide patch antenna, which takes up a lot of valuable space. The width further controls the radiation pattern. Thus a demand for impedance matching and radiation pattern efficiency control has always been there as far as microstrip, which are further a class of small antennas (most of the cases), already introduced in the previous chapter. One can readily use the impedance matching techniques like adding Quarter Wave Transformer to the transmission lines or microstrip lines to provide the perfect matching between the antenna load and the feed transmission line. Fig. 16 shows the conventional methodology of the microstrip antennas.

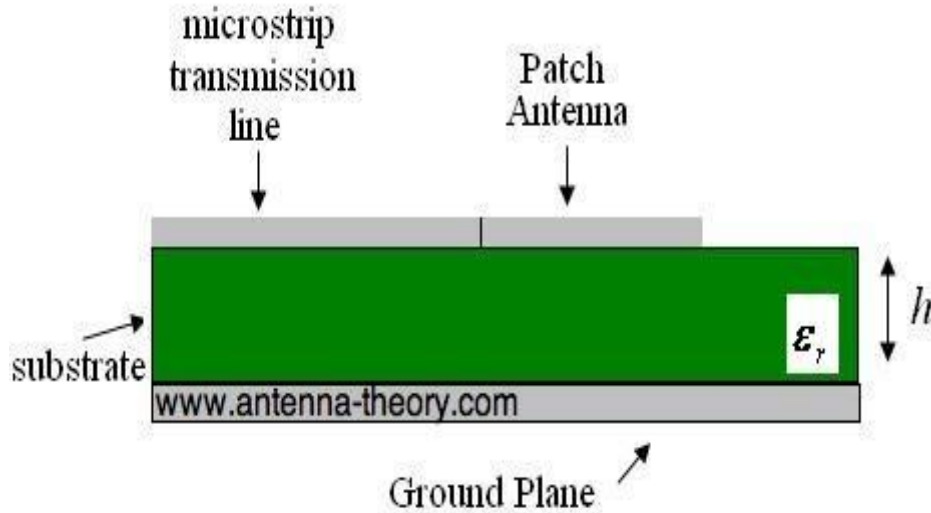


Figure 16 :Side view of microstrip antenna.

4.3 ANALYSIS OF THIRD ORDER SCF ANTENNA

The analysis for third-order SCF antenna will be described here. Configuration of a third-order SCF antenna is shown in Fig. 17(a). It consists of a square patch with square rings of different sizes, supported on a dielectric substrate thickness of h and relative permittivity ξ_r . The modes of resonance in the ring are TM_{mn0} because the dielectric thickness is much smaller than the operating wavelength.

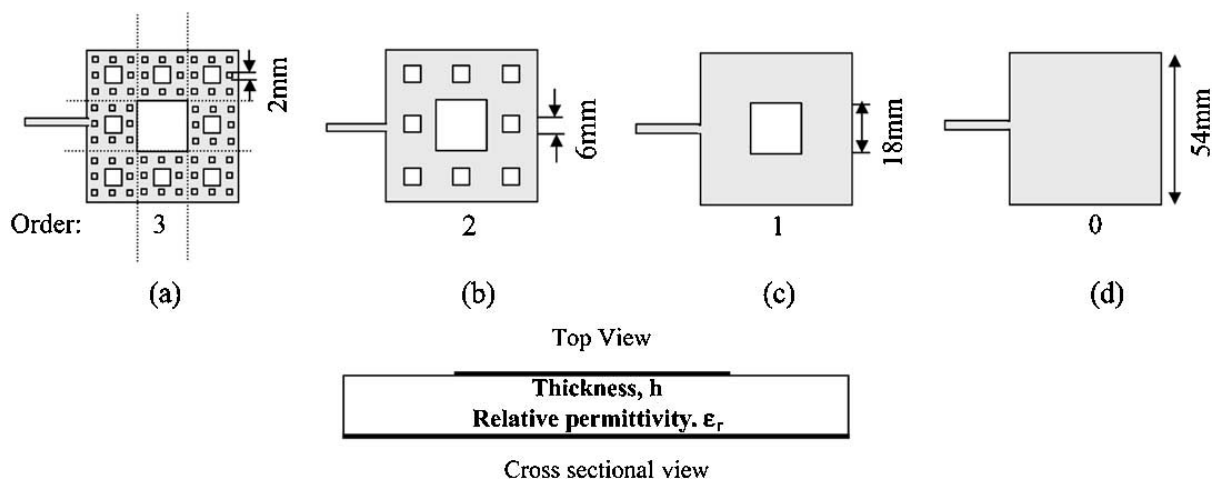


Figure 17 : Configuration of microstrip SCF antennas of (a) order three, (b) order two, (c) order one, and (d) order zero [76].

Various steps in this analysis are summarized as follows.

- 1) Magnetic wall model of a given geometry is developed first, by replacing the fringing fields at the contour of the geometry by an equivalent outward extensions terminated in magnetic walls. The extension depends on planar dimensions, shape, relative permittivity, and thickness of the substrate [69].
- 2) The geometry is divided into several sections to cut down the computation time of impedance matrix for individual segment. The equivalent geometry of the antenna shown in Fig. 4.4(a) is divided into eight segments along the dash lines.
- 3) We further divide the interconnection between segments into M incremental sections. The number of ports M is determined by the length of the interconnection. Usually the number of port is assigned to be $\frac{\lambda_g}{20}$ of the interconnection length, so that the magnetic and electric field intensities can be assumed to be constant over each width of these sections.

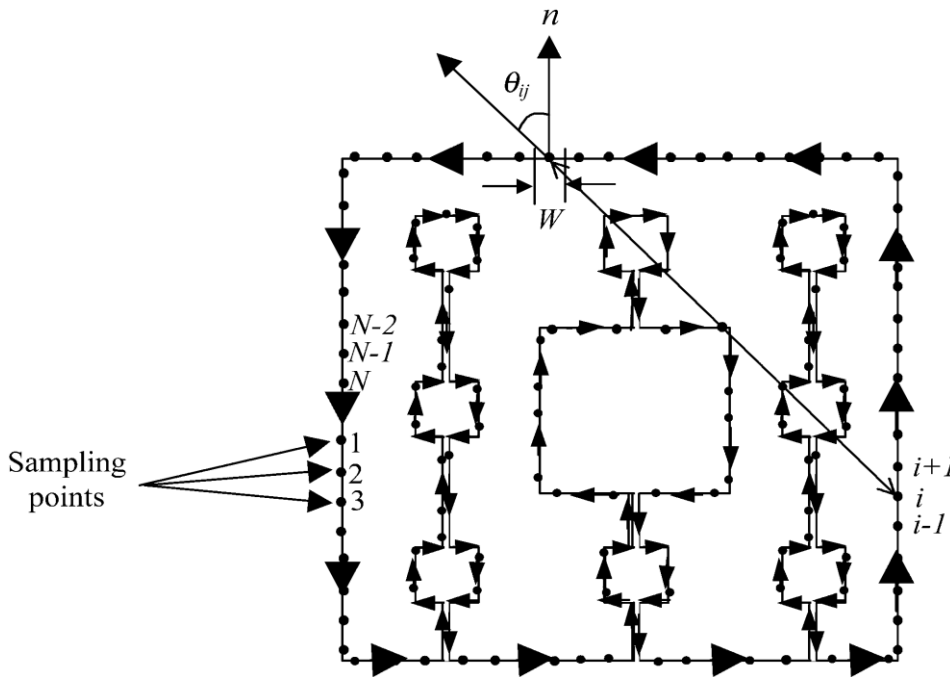


Figure 18 : Configuration of a planar segment and division of contour into N section for the BIM analysis and multiply connected subsection of fractal antenna[76].

- 4) The multiport impedance matrices for individual segments are evaluated using the BIM [70]. The multiport impedance matrix is found by solving the integral equation relates the voltage and current along the segment periphery. To solve the integral equation numerically, the circuit periphery is divided into incremental sections having width, $w_1 w_2 \dots w_N$, respectively, (note that $M \in \mathbb{N}$). Since the geometry is complex and the

slots are relatively small, the contour along the slots is divided into smaller sections, so that the slots can be better represented. The presence of holes in each segment is taken care of, assuming the outer and inner boundaries are connected to two infinitesimally separated contours, as shown in Fig. 18.

5) We combine these impedance matrices together by the multiport connection method [71] to yield the overall impedance matrix for the given geometry. The continuity of electric and magnetic fields at the boundary planes are taken care of in the interconnection constraints based on Kirchoff's voltage and current laws.

6) The input reflection coefficient of the geometry can then be obtained from the overall impedance matrix. If the coupling ports extend to more than one section, these coupling ports are treated like sub-port to obtain the overall impedance matrix.

For the Fractal design, this procedure has to be followed:

Let N_n be the no. of black boxes,

L_n , the ratio for the length

A_n , the ratio for the fractional area after nth iteration

and d_n is the capacity dimension.

Then,

$$N_n = 8^n \quad (4.2)$$

$$L_n = \left(\frac{1}{3}\right)^n \quad (4.3)$$

$$A_n = \left(\frac{8}{9}\right)^n \quad (4.4)$$

$$d_n = -\lim_{n \rightarrow \infty} \left(\frac{\ln N_n}{\ln d_n} \right) \quad (4.5)$$

Table 3: Fractal antenna properties

| | Zero iteration | First iteration | Second iteration |
|-------|-----------------------|------------------------|-------------------------|
| N_n | 1 | 8 | 64 |
| L_n | 1 | 0.33 | 0.111 |
| A_n | 1 | 0.889 | 0.781 |

4.4. STACKING OF MICROSTRIP ANTENNAS

Microstrip antenna are low profile and cost effective antennas. Nevertheless, microstrip antennas inherit narrow bandwidth. However, stacked configuration is able to provide larger bandwidth suitable for the desired operation.

Stacked microstrip antenna is a configuration that uses two or more patches on different layers of the dielectric substrates which are vertically stacked on each other. The driven patch can be directly fed by either coaxial probe or microstrip line. The upper patch is electromagnetic coupled by the lower patch. Figure 19 shows the cross-sectional view of the stacked microstrip antenna with two layers of dielectric substrate. Generally, the driven patch uses a high dielectric substrate and the parasitic patch uses a low dielectric substrate, similar to that proposed in [72]. Such combination will result in high surface wave efficiency and low cross polarization. This will ensure the feed radiation to be negligibly low. The combination is also known as hi/lo. The driven patch is chosen to be the conventional square patch. The computation of the design dimension is available in the literature. The parasitic patch is designed with the Sierpinski carpet fractal configuration.

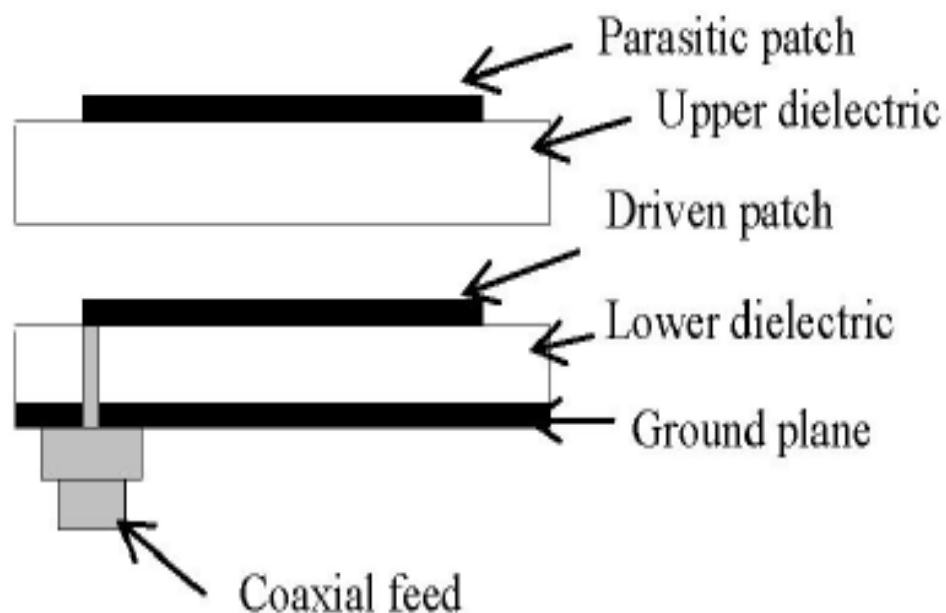


Figure 19 : Single stacked microstrip antenna [73].

The important advantage of microstrip antenna stacking is improvement in bandwidth. A simple second iteration Sierpinski Carpet antenna would be having lesser bandwidth than

a corresponding Stacked Sierpinski Carpet. This thing has been concluded by me after doing stacking analysis of antennas on the EM software Ansoft HFSS. In stacking, when the air gap between the two dielectric is altered, there may be a considerable amount of variation in the characteristics like Return Loss, VSWR and radiation pattern (Half Power Beam Width). A plot of Return Loss with varying width of sandwiched air layer in a microstrip antenna[72] has been shown in Fig 20.

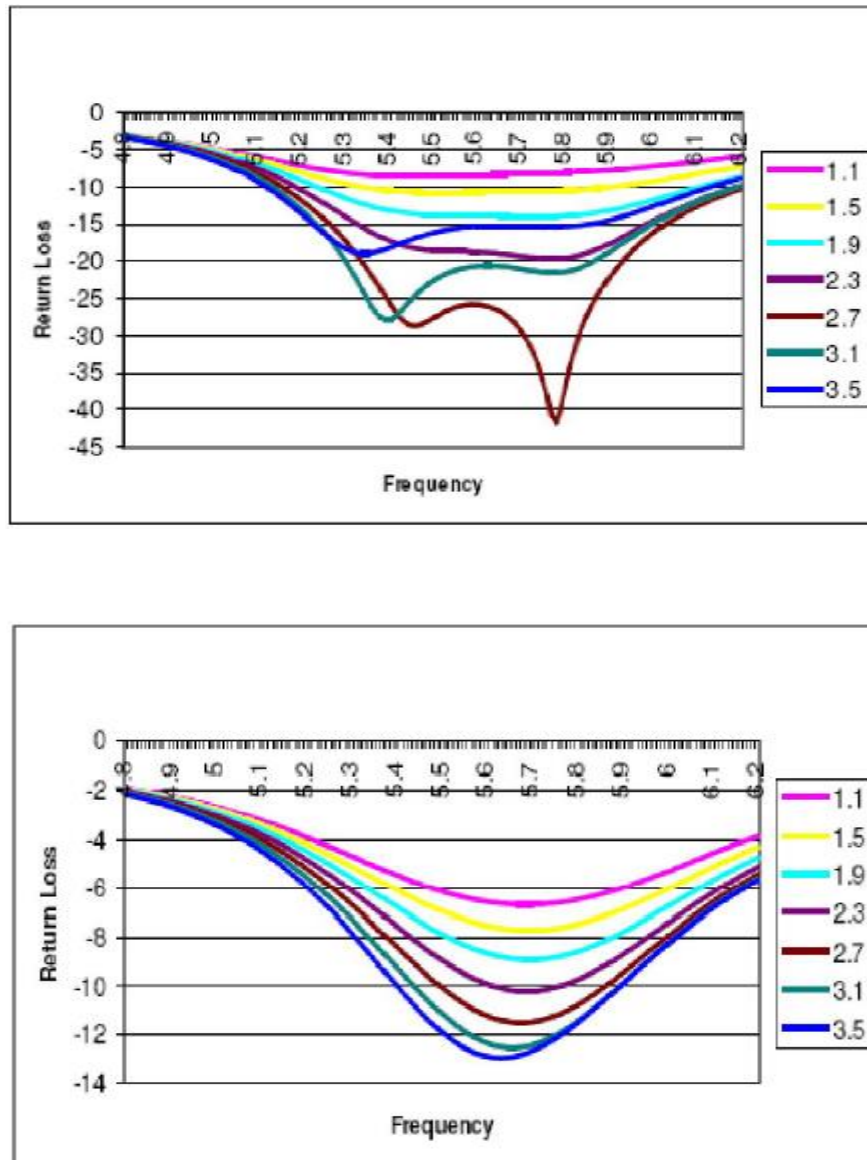
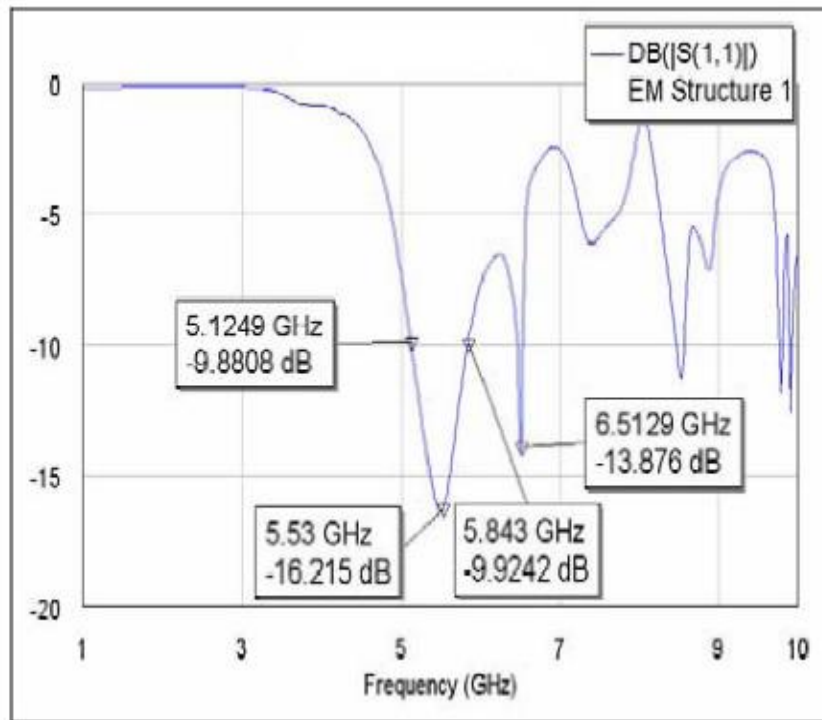
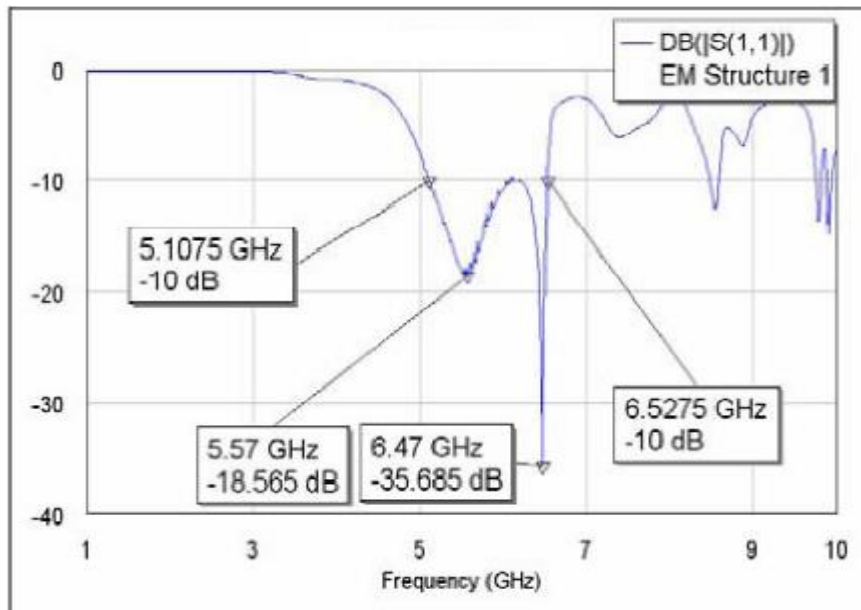


Figure 20 : - Return losses of the stacked antenna of identical radiating elements due to varying sandwich air layer thicknesses [72].

Now, to further compare the result and advantages, Return Loss is also shown for the same antenna.



(a) Not stacked



B

(b) Stacked

Figure 21 : Return Loss for stacked and non stacked antenna [72].

Figure 21 shows the simulated return loss response and radiation pattern of the first iterated stacked fractal antenna. The lowest resonant frequency observed is 5.57 GHz, which is slightly higher than that of the zero iterated antenna. The antenna operates well with good

corresponding return loss of -18.565 dB, clearly indicating the advantages of stacking of antennas.

CHAPTER 5

RESULTS & DISCUSSION

5.1 STACKED SIERPINSKI CARPET FRACTAL (SCF) ANTENNA

In this work, first a Sierpinski carpet antenna using microstrip line feeding is shown. It was made up to first iteration. The radiating elements were based on a copper clad material called FR-4. The simulation of the basic structure resulted in an antenna size of 38.04mm \times 29.46mm. Figure 2 shows the design of a Sierpinski Carpet fractal antenna starting with a rectangular geometry of single patch antenna.

The model of the antenna is as shown in the Figure 3. As shown in the figure, initial design, rectangular Sierpinski Carpet (dimensions described above for patch) is modeled. This antenna is designed upto first iteration.

Table 4: Antenna configuration used.

| | |
|----|--|
| 1. | Second iteration Sierpinski carpet |
| 2. | Stacked Sierpinkki Carpet with Electromagnetically coupled parasitic Patch |
| 3. | Stacked Sierpinkki Carpet with Feeding for parasitic patch |

To improve the characteristics further, stacked configuration of this square patch is modelled and simulated. The stacked patch is shown in the Fig. 4. The dimension of the initial design was calculated using the microstrip design equations for rectangular microstrip antennas. Further, to obtain the impedance matching in both the cases, quarter wave transformer is used to match the load to the transmission line. The dimensions calculated using the equations come out be 6.034 mm \times 0.52 mm. The transformer is connected to 50 Ω transmission line to one end and to the patch at the another end providing impedance matching between the two and less power reflections from the output side to the load. Further, two stacked configurations are shown in the paper. First, there is no feed attached to the parasitic patch while in the second, there is a proper feed, including the quarter wave transformer is attached to the parasitic patch. In the first case, the parasitic patch is solely driven by the electromagnetic coupling from the driven patch. It is necessary here to add that, the driven substrate has a dielectric constant as compared to the parasitic substrate, to enhance the fringing field, including the quarter wave transformer is attached

to the parasitic patch. In the first case, the parasitic patch is solely driven by the electromagnetic coupling from the driven patch. It is necessary here to add that, the driven substrate has a dielectric constant as compared to the parasitic substrate, to enhance the fringing field [74]. A decrease in the dielectric constant will increase the ratio h_i/l_o . In turn, this will increase the resonance frequency of the antenna and widens the operating bandwidth. In the stacked configuration, the lower substrate is chosen to be of FR4 epoxy having a dielectric constant of 4.4 and upper of Arlon Diclاد 880(tm) having a dielectric constant of 2.2 The stacked configuration is

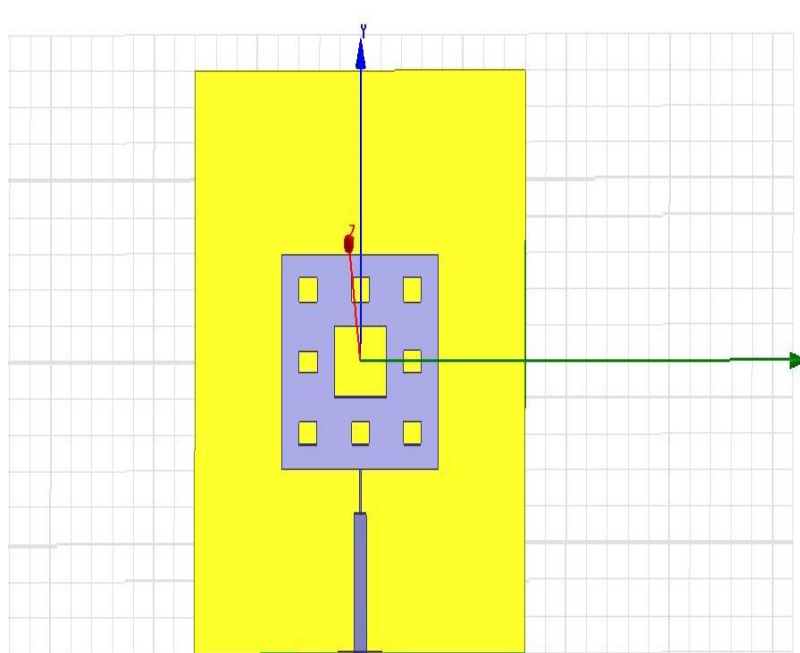
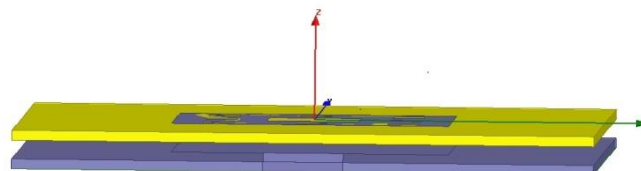
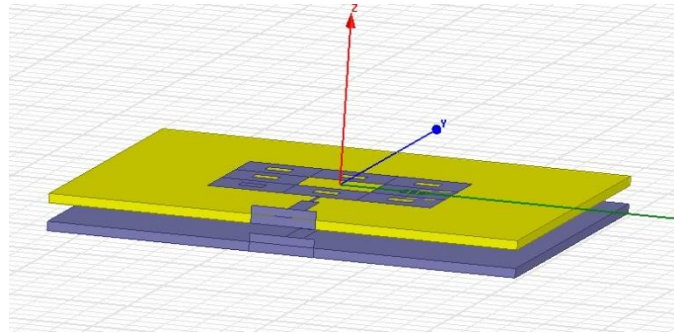


Figure 22: Sierpinski Carpet First iteration microstrip antenna (top view).

shown below.



(1)



(2)

Figure 23: Stacked Sierpinski carpet With (1) NO FEED for parasitic patch and (2) FEED for parasitic patch

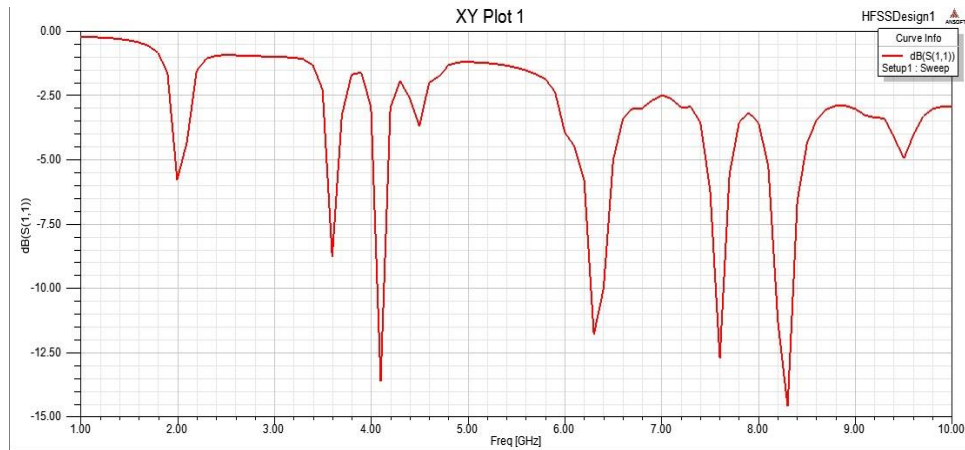
Table 5: Dimensions used for stacked configuration.

| Parasitic patch(mm by mm) | Driven Patch(mm by mm) | Impedance matching line(mm by mm) | Substrate height(mm) |
|---------------------------|------------------------|-----------------------------------|----------------------|
| 38.04 by 29.46 | 38.04 by 29.46 | 6.034 by 0.52 | 1.57mm |

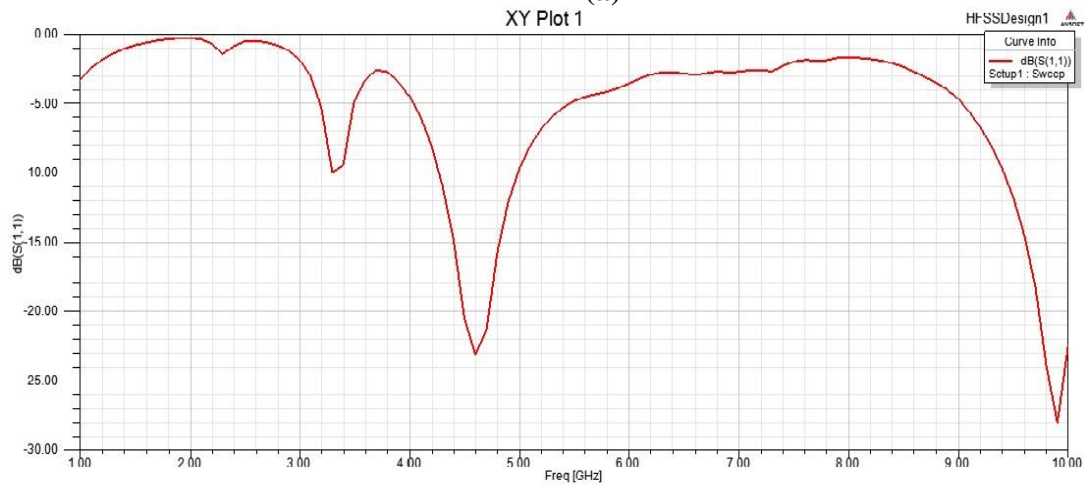
The designed antennas are simulated with the help of simulation software Ansoft HFSS. The Stacked configuration is having a sandwiched layer of air in between the upper and lower models. The return loss and radiation pattern is shown below in Fig.5. This antenna is showing resonance at frequencies 4.1, 6.3, 7.6 and 8.3 GHz. The return loss and the radiation pattern of stacked configuration is shown in Fig.6. for with feed and without feed respectively. From Fig.7.1, it is clearly shown that the frequency resonance is from 4.4 to 4.8 GHz i.e a bandwidth of 400 MHz.

Return Loss

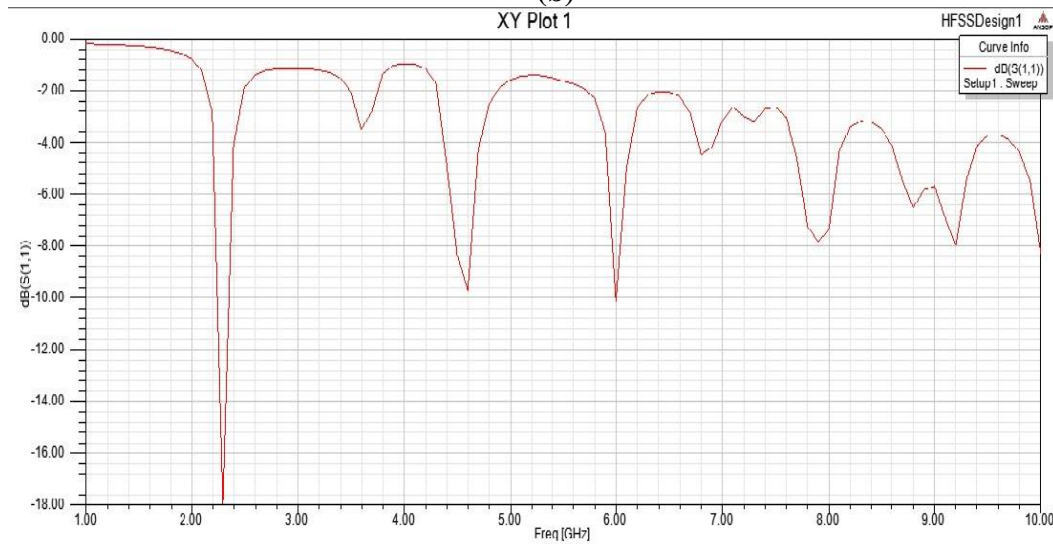
A return loss of generally less than -10 dB is required to achieve good performance at resonant frequency bands. In the first configuration, four bands in UWB band are covered in the results, whereas in case of stacked configuration, the antenna is resonating at 2 bands but with higher bandwidth. The results are obtained using Ansoft HFSS 13 version. The plots are shown below.



(a)



(b)



(c)

Figure 24: Return Loss. (a) for simple iterated sierpinski carpet, (b)for stacked sierpinski carpet with electromagnetically coupled parasitic patch, (c) for stacked sierpinski carpet with feed for parasitic patch.

Radiation Pattern:

The things to be measured in radiation patterns are HPBW(half power beam width) and FNBM(first null beam width). In order to be realised as a practical antenna, radiation pattern and efficiency should be excellent.

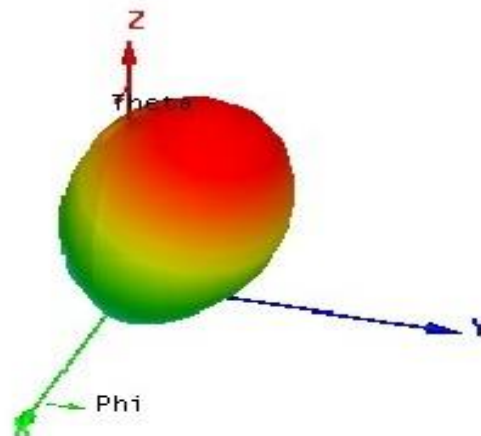
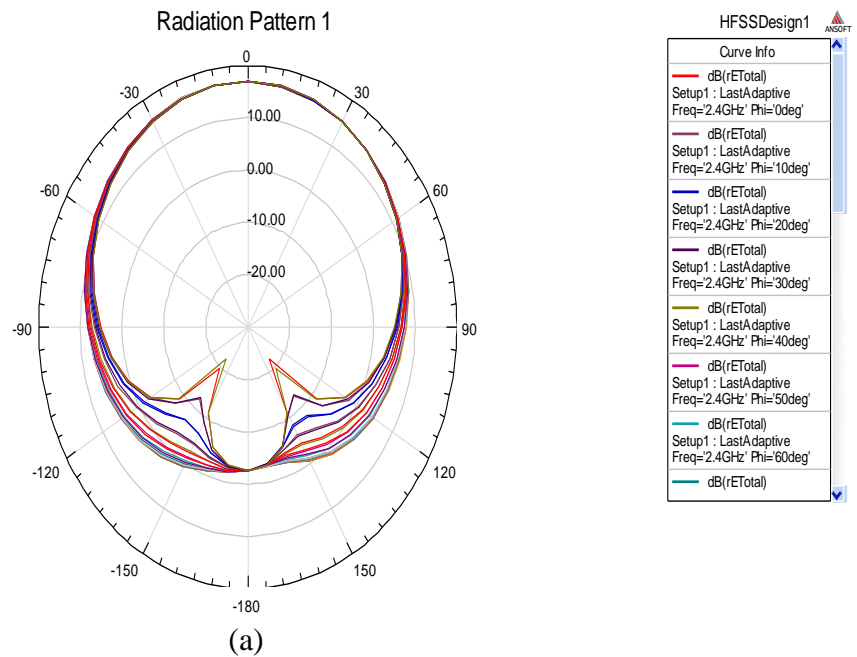


Figure 25 : Radiation patterns(a) 2 D Radiation pattern for different sweep frequencies (b) 3 D polar Plot

Stacking of the antennas, keeping the dielectric constants of the parasitic and driven substrates to a suitable value, increases the resonance frequency and the bandwidth of the antenna. The air gap sandwiched between the upper and lower models is also a factor determining the important characteristics of the antenna.

Table 6. Resonant frequencies and Bandwidth.

| | Resonant frequencies (in GHz) | Bandwidth(in MHz) |
|---------------------------------------|-------------------------------|----------------------|
| Sierpinski carpet | 4.1, 6.3, 7.6 and 8.3 GHz | 400 for 6.3 GHz band |
| Electromagnetically stacked | 4.5 and 9.9 GHz | 790 for 4.5 GHz band |
| Stacked with feeding for both patches | 2.3 and 6 GHz | 80 for 2.3 GHz |

5.2 NOVEL FRACTAL ANTENNA DESIGN

Fractals are generally self-similar curves. I have tried to generate a fractal which is self-similar in nature. Its characteristics are studied using the simulation software Ansoft HFSS. The design of the antenna is shown below

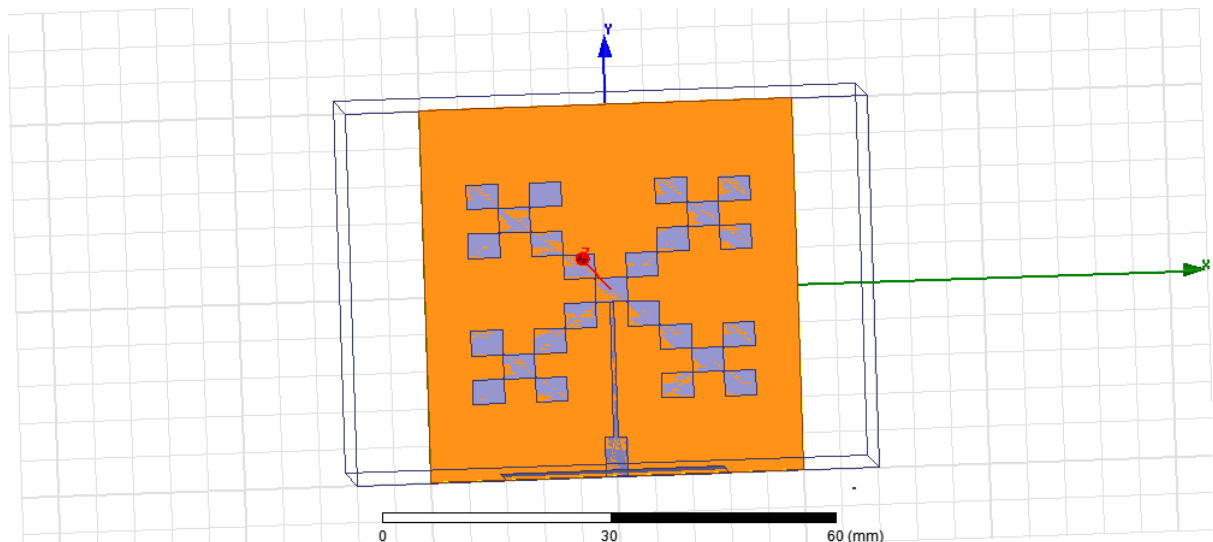


Figure 26 : A novel fractal antenna

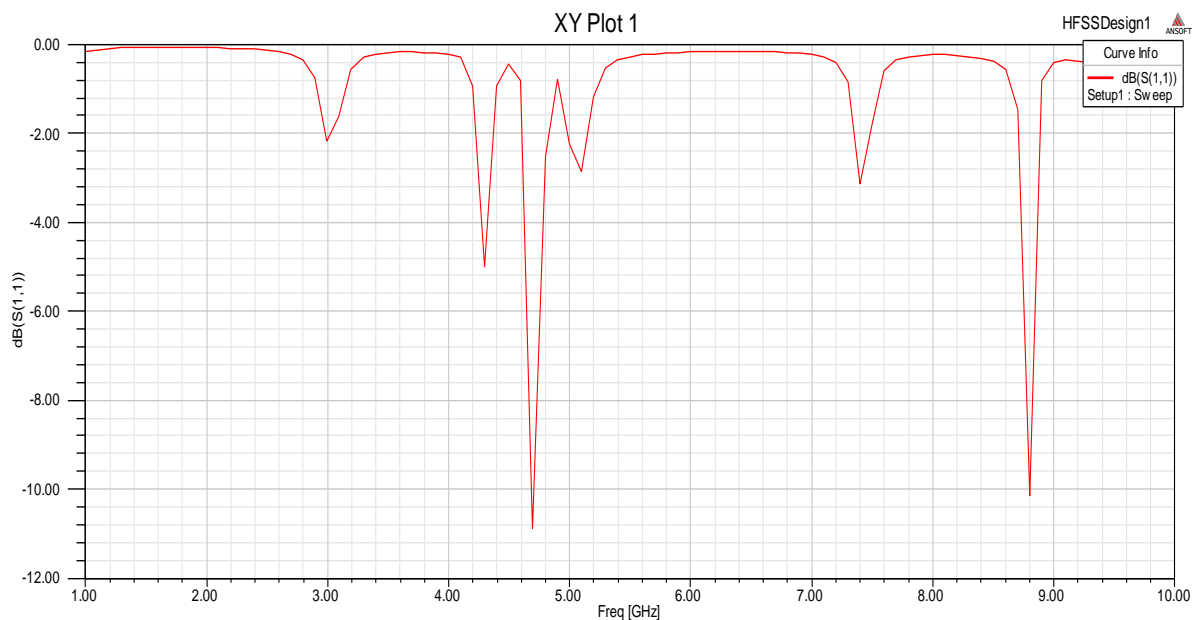
The design parameters for this antenna is listed below in Table 6

Table 6: Design parameters

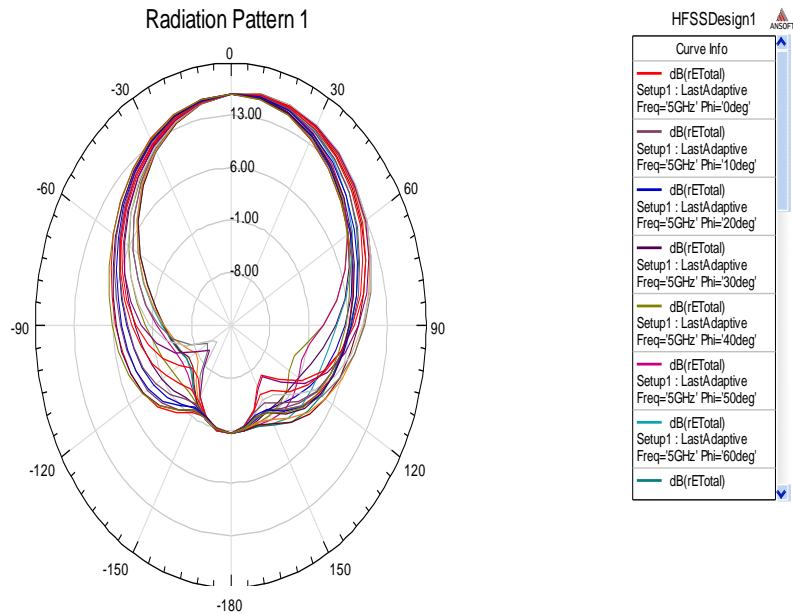
| PARAMETERS | VALUE |
|-------------------------------------|--------------------|
| Patch dimensions | 50.71mm by 39.44mm |
| Feed dimensions | 24.14mm by 0.524mm |
| Substrate used(dielectric constant) | FR 4 (4.4) |
| Port dimensions | 15.7mm 15mm |
| Substrate height | 1.57mm |

The design parameters above given are basically intended for use at 1.8 GHz (GSM 1800). The design is constructed from the rectangular microstrip patch antenna design equations. But as the patch we were working upon was fractal, the exact design equations are missing from the literature. So the resonant frequency is different as expected. This may be a problem occurring due to the improper impedance matching as there is no formulae or methodology to calculate the edge impedance of the fractal structures. The return loss and the radiation pattern of the above design is shown below.

Return Loss & Radiation Pattern



(a)



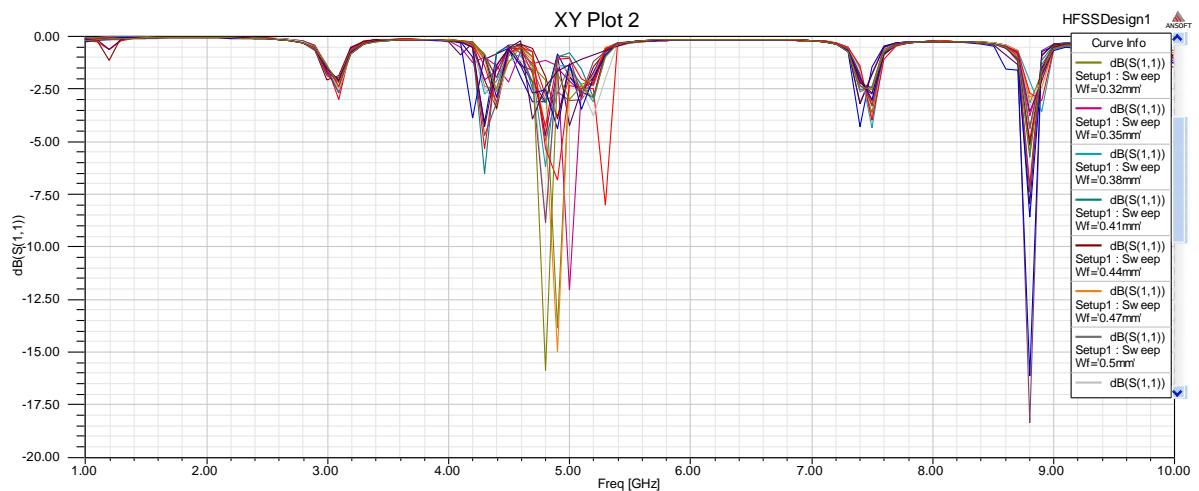
(b)

Figure 27 : Return loss & Radiation Pattern

As shown from the above results, the antenna is radiating at frequencies 4.7 GHz and 8.8 GHz. The radiation pattern is also showing good response for different values of frequency angle (theta). It is measured in terms of dBs.

Matching the impedance is done by taking different values of the width of the quarter wave transformer used in the model. It was easy to do with using the software simulation. A sweep sweep defined below is followed.

WIDTH OF QUARTER WAVE TRANSFORMER: 0.2 mm to 0.7mm and the results (return loss and radiation pattern is observed).



(a)

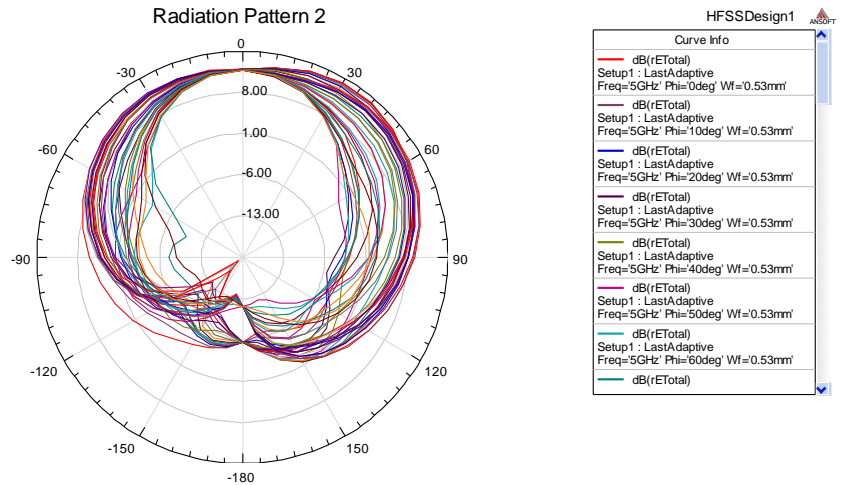


Figure 28: (a) Return loss and (b) Radiation pattern for different values of feed width

It is observed above that the antenna is more effective at X-Band, when the feed width is from 0.2mm to 0.7mm.

CHAPTER 6

CONCLUSION AND FUTURE WORK

6.1. CONCLUSION

Stacking of the patch is studied for the case of Sierpinski Carpet Fractal (SCF) . The simple antenna with patch as second iteration sierpinski carpet is showing a maximum bandwidth of 490 MHz, but the same structure when stacked with simple rectangular patch as driven patch and the parasitic patch as the Sierpinski Carpet, which is electromagnetically coupled to the driven patch, is giving a total bandwidth of 790 MHz. Thus use of the antennas stacking is justified in this case. When the parasitic patch is feeded also, there is a dramatic change in the return loss characteristics. More harmonics are present, that is possibly due to the height of the air sandwiched layer between both the designs. The results are as follows:

| Antenna type | Resonant frequencies (in GHz) | Bandwidth(in MHz) |
|---------------------------------------|-------------------------------|----------------------|
| Sierpinski carpet | 4.1, 6.3, 7.6 and 8.3 GHz | 400 for 6.3 GHz band |
| Electromagnetically stacked | 4.5 and 9.9 GHz | 790 for 4.5 GHz band |
| Stacked with feeding for both patches | 2.3 and 6 GHz | 80 for 2.3 GHz |

Next, in the case of novel fractal shaped antenna, the antenna is found to be resonating at frequencies at 4.7 and 8.8 GHz. This antenna can be used at frequency at frequency centered at 8.8 GHz in X-Band.

6.2. FUTURE WORK

- The proposed antenna will be fabricated and measured result will be compared with simulated results.
- After fabrication it will be operated in the given conditions and the radiation pattern will be analysed.

- The errors will be minimized by using given tools.

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