Analysis of Self-Similar Antennas and its Applications

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***Abstract* –** In modern era compactness is one of our greatest necessities. Traditionally each antenna operates at a single frequency band, where a different antenna is needed for different application. This will take more space for occupation. This paper presents a brief study on different techniques of novel fractal antennas and its multiple applications. Fractals have self-similar shapes and space filling properties. This property makes the fractal antenna compact and operating in multiband frequencies. The fractal antenna is formed by applying a generator shape repetitively at a constant scale factor and results in an antenna with log-periodic characteristics which is a multiband antenna and a miniaturization characteristic.

Key Words: Fractal antenna, Self-similar, Miniaturization.

I. Introduction

Antenna is basically a Latin word. It literally means a long pole supported with materials like wood etc. placed transversally for various functions. Though with passage of time there have been some distinct changes in its forms and shapes. Marconi in 1909 coined the word antenna which is used in the present form and taken in the terminology of radio system today. An antenna has various usages in the different field of Telecommunication and allied areas in frequent ways. It has multi-disciplinary application in communication, health science and many more which cannot be countable. From the first decade of the 20th century when Marconi coined the term antenna, till the 40s, the device was primarily concerned with wired arrangements used as radiators. The transformation later saw the antennas evolve in various shapes and sizes, used at numerous frequencies. During the later third quarter of the century there has been great amount of academic development in the field of microstrip and printed antenna research work. With technologies like WLAN, radio Communication etc. There had been a noticeable or rather remarkable growth in the study of antenna design for these applications. This paper presents the study of fractal geometry for multiple usages [1-4].

II. Basic of Fractal

These naturally available geometries were not having any form before Mandelbrot research. So that Mandelbrot research was revolution in the field of antenna design. Mandelbrot coded the mathematical characteristics of these similar isolated shapes that so common features of fractal geometries electromagnetically analyzed for different iterations. The common term is in irregular geometries based on theory. Nature gives number of example of fractal geometries. Fractal geometries found in intricate place of science and engineering for representing unique geometry that occur in nature.

$$D = \frac{\log N}{\log r}$$

Fractal geometries [1] have found a sophisticated place in science as a depiction of particular geometrical structures available in natural environment. It is defined by the leaves of a tree and plants, the clouds, the arbitrary destruction that carves on mountains, the sharpness of seashores etc. The complete dimensional planes such as one dimensional line or two dimensional planes are categorized in the Euclidean structures. These structures have not defined the fractional dimensions. These fractional dimensions are first The complete dimensional planes such as one dimensional line or two dimensional planes are categorized in the Euclidean structures.

These structures have not defined the fractional dimensions. These fractional dimensions are first defined by the Benoit Mandelbrot as the term fractal meaning the geometries having dimensioned that are not complete or whole number [7].

One interesting feature of fractals is its infinite length fitting in a finite volume. Fractal is defined by a set of F such that

1) **F** has an adequate structure repeating with different scales.
2) **F** is too random to be defined by conventional geometry.
3) **F** having some form of self-similarity.
4) **F** can be defined by recursive methods.
5) Dimension of **F** is greater than its topological dimension.

Various ways are available to describe the different structural dimension in geometry such as topological dimension, Euclidean dimension, self-similarity dimension, and Haussdorf dimension. The self-similarity structures are the widely available and simplest to realize the characteristics of dimension. A design is recognized as self-similar structure if it looks comparable or same on different scales. comparable or same on different scales. The expected length, L of the structure is equal to the length of ruler, r multiplied by a number, N; to measure the entire dimensions of the structure or design. For example, if there are n copies of original geometry scaled down by a fraction f, the similarity dimension D is defined as Here, D can be a fractional number and identified as the Haussdorf dimension means like Euclidean geometry, it is not necessary that D must be an integer. These arrangements are useful to describe the natural entities and specifically proven beneficial structures that can be used in fractal antenna design.

Fig. 1. A fern is example geometry in nature that is easily modeled using fractal

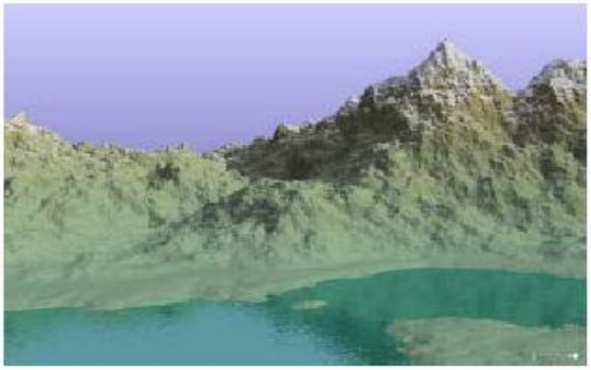

Fig.2. Landscape scene that also be modeled using fractal geometry

Fig. 3. Fractals are geometric forms that can be found in nature

Advantages of Fractal

There are several advantages in applying these natural powerful structures (fractals) for the development of the numerous antenna elements. By applying fractals in antenna configurations:

1. We can achieve compactness in antenna size.
2. Multi-frequency or multiband antenna can be designed.
3. Having more flexibility in gain optimization.
4. Wide band width can be attained

The infinite complexity and features of the fractal is the key to develop a compact and low profile antennas. Fractal antennas are of identical shape but repetitive with reduction in length consecutively [8].

For the most fractal antennas, self –similarity concept is used to achieve multiple frequencies or multiband since the antenna can be resonate from the different parts which are similar to each other at different scales. The combination of these infinite complexity and self-similarity features makes it possible to construct the antennas with very wideband performance. Also these fractional dimensions of fractal structure leads to successfully optimization of gain of the antenna configurations.

There has been an ever-growing demand, in both the military as well as the commercial sectors, for antenna designs that possess the following highly desirable attributes [8].

1) Reduced size

2) Low profile

3) Conformal

4) Multi-frequency or wideband.

III. Concept of Fractal

The word fractal is came from the Greek word “Frangere”, indicating the broken or uneven fragments [1]. It was firstly used to develop in 1975 by Benoit Mandelbrot, a mathematician [2]. Fractal geometry has been applied into several areas with high success rate: implementations of antennas are one of them. Fractal antennas are high gain, low profile and multi-frequency antenna which is generally used for Wi-Fi applications due to its competences and proficiencies [7]. These designs are attributed to the techniques based on an iterative geometry, which splitting a shape into the replicas of itself with smaller dimension [6]. These antennas have following properties such as [7].

a. Self-similarity property

b. Space–Filling property

c. One of the important properties of antenna is frequency independent.

Numerous methodologies have been developed and utilized to achieve one or more of antenna design objectives.

In recent times, antenna designs are developed by exploiting the properties of fractals to achieve several goals related to the various applications requirements. Traditionally the antenna systems are designed and analyzed with the help of their foundation in Euclidean geometry. However, the development of new types of antenna that employ fractal geometry instead of Euclidean geometric concepts in their design has attracted a huge attention from the researchers. The research and development from all over the world has been going on and this new and rapidly growing field is referred as fractal antenna engineering. Since the fractal geometry is an extension of classical geometry, its introduction offers the unprecedented opportunity to explore a nearly limitless number of earlier unattainable arrangements for promising procedure to the development of new and innovative designs.

IV. Fractal Geometry

This section will present a brief overview of some of the more common fractal geometries that have been found to be useful in developing new and innovative designs for antennas.

1. **Sierpinski Gasket:**

The most popular fractal antenna is Sierpinski gasket named after the Polish mathematician Sierpinski who described some of the main properties of this fractal shape in 1916. The original gasket is constructed by removing a central inverted triangle from a main triangle shapes as shown in figure 4.

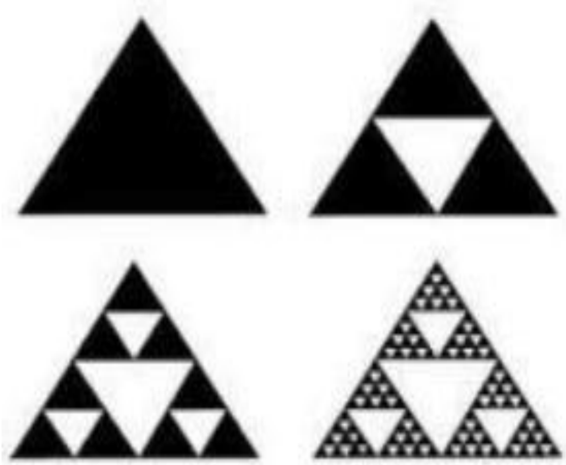

Fig.4.Several stages in the construction of Sierpinski gasket fractal antenna.

2. Crown Square Fractal Antenna

Another popular fractal antenna is Crown *square micro strip fractal antenna. This antenna is shown in figure 5. This antenna is constructed by removing a square shape from an original square as shown in figure. After this a same shape with a scale of is added after (n-1) th iteration. Generally, only two iterations are considered since higher order iterations do not make significant effect on antenna properties

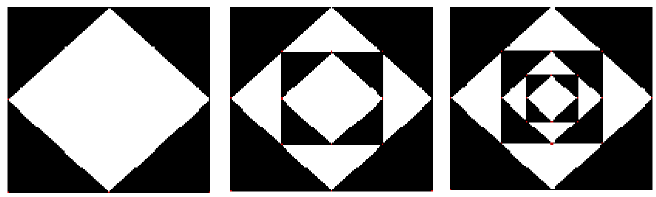

Fig.5. Crown Square Fractal Antenna

3. Sierpinski Carpet fractal antenna:

Next fractal antenna is Sierpinski carpet antenna, shown in figure 6. This fractal shape is constructed with three iterations that are the Sierpinski carpet appears at three different scales within main structure. This patch gave multi resonance frequency that is 1.45 GHz, 3.21 GHz, 5.33 GHz and 7.2 GHz and the achieved percent bandwidth is about 1% at each band.

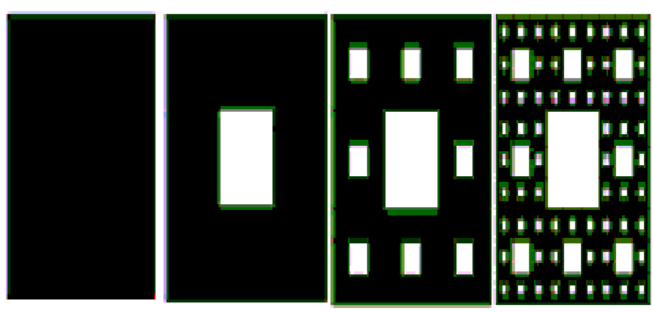

Fig. 6. Sierpinski carpet fractal

4. Hilbert curve fractal antenna

Next fractal antenna is Hilbert curve fractal antenna introduced by K.J Vinoy. Fractal Hilbert curve geometry results in an antenna with low resonant frequency compared to other configurations. This antenna consists of line segments arranged in a predictable fractal order. This can be modeled using wire segments. This antenna is shown in figure 7. It is clear that, as the fractal iteration order increases, the total length of the line segments contributing to the geometry increases in almost geometric progression, as the area it encompasses remain the same.

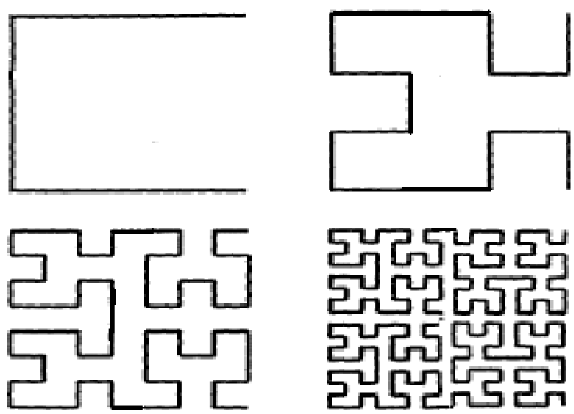

Fig. 7. Several stages in the construction of a Hilbert curve

5. VON KOCH SNOWFLAKE fractal Antenna

6.

Koch snowflake is created by adding smaller and smaller triangles to the original structure in an iterative way. This procedure is clearly established, when the first few stages in the construction of Koch snowflake geometry are shown in below figure 8[2][5].

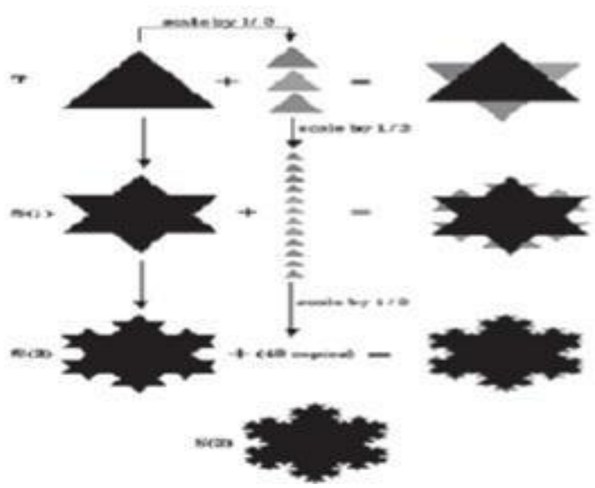

Fig. 8. First few stages in the construction of a Koch Snowflake

6. MINKOWSKI fractal antenna

Minkowski fractal has a square shape in which each of four straight sides of square is replaced with generator and we applied cut of iteration width by scaling 1/3 of each straight sides of square at every iteration and the depth is adjust at optimization to get accurate results. Fe steps in construction of Minkowski geometry is shown in below figure 9.

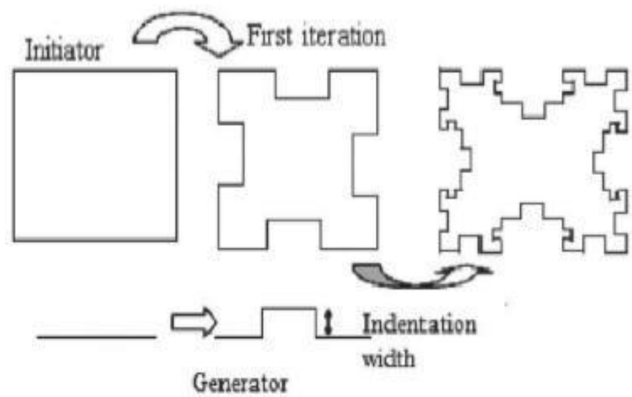

Fig. 9. Several stages in the construction of a Minkowski fractal

V. Historical Review

From the first developed fractal antenna, it's got huge attention form the researchers all over the world due to its enhanced properties such as compactness, multi frequency, wide bandwidth etc. These antennas are highly efficient as per the application requirement. Due to its self-similar structure, it provides better control to play with the parameter to improve the desire properties of an antenna. There are several fractal techniques (discussed above) on which an antenna can be design with required characteristics. Several works has already been done and plenty of development is going on. Table 1 presents the progress and enhancement in the field of fractal antenna.

Table 1: Representation of Progress in Fractal Antenna Design

Author Name	Techniques used	Objective	Advantages	Limitations	Application
N. Cohen [5]	Wireless telecommunication	Fractal Antenna Applications in Wireless Telecommunication	Minimize the effective area	Easy to fabricate but possesses inherent asymmetries which generate higher order modes due to this cross polarization radiation	Compact antennas of multiband/wide- band with optimized gain
J. Anguera [8]	Ground modification	Designing the ground plane of handset antenna	Multiband characteristics are achieved	Gain	Multi-band antennas for handsetphones.
Homayoon Oraiziet. al. [9]	Giuseppe Peano Fractal Geometries	Analysis of Giuseppe Peano fractal structure properties for miniaturization	Enhanced Bandwidth	As the number of fractal repetitions increases, the lowest antenna resonant frequency decreases.	Compact antennas with enhanced bandwidth
JayaramKizhekkePakkath-illam et.al.[10]	Variable distance opposite direction current	To analysis magnetic field of fractal protruded tapered slot antenna	No nulls present in the interrogation area, the ratio of interrogation area to the size of the antenna is large	Gain	Tracking chemicals and pharmaceu-ticalmanagement
Yogesh Kumar Choukiker et.al.[11]	Combination of Minkowski island curve and Koch curve fractals techniques	Multiband characteristics	Compact in size, Reduced Envelope correlation coefficient	Gain	Covering multiple wireless communication bands for handheld mobiledevices
He-XiuXu et.al.[12]	Three- Dimensional Gradient- Index Fractal Metamateri- als	To design metamaterial element in terms of a deep sub wavelength feature by incorporating fractal geometry	Wide bandwidth range of 3 to 7.5 GHz without significantly affecting the crosspolarization patterns and impedance matching.	Uniformity of pattern is broken	C-band Applications

VI. Advantages & Disadvantage

Fractal antenna has some specific properties, which make it more attractive and application oriented as compared to other antennas. It has some limitations too, which need to be take care off, using optimization techniques or trade-off methods. The major advantages and limitations are listed below.

Major advantages:

- Small in size.
- Higher input impedance matching for multi-frequency/broadband applications (use one antenna rather many).
- Frequency unbiased (constant efficiency over huge frequency range)
- Diminished material coupling in fractal array antennas
- Main limitations:
- Reduced Gain and enhanced complexity
- Numerical Confines
- The benefits begin to diminish after first iteration.
- Application Area:

Due to its compactness and wide bandwidth range along with multi frequency characteristics, fractal antenna has been applying in the various fields to enhance the uses and efficiency. Major areas are listed below:

1. **Telecommunication:** In the region of telecommunication fractal antenna have great use. As the compactness getting the necessity of the modern era devices, the requirement of small antennas with enhance properties is highly required. Fractal-shaped helps to reduce the size and the weight of the antennas with improved properties with the help of its self-similar structure. The benefits depend on the fractal applied, frequency of interest, improved gain, multi/wide band etc. In general, the fractal parts produce fractal loading and make 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. Fractal antenna is one of the leading companies in the field of manufacturing fractal antenna.

Fig.10. Fractal antenna used for Telecommunication

2. **Automobile:** The system relates a multi-service antenna integrated in a plastic cover fixed in the inner surface of the transparent windshield of a motor car. The miniaturized This antennas are required in a car for the basic services such as the radio reception preferably within the AM and FM or DAB bands, the cellular telephony for transmitting and receiving in the GSM 900, GSM 1800 and UMTS bands and for instance the GPS navigation system. Therefore, the necessity of such techniques is highly required which design the antenna with substantial reduced size that can be integrated into a vehicle component such as in rear-view mirror, vehicle windshield. Fractal technique based antenna is one of the most suitable candidates for it due to its compactness and compatibility to implant its design on any surface as shown in Figure 11.

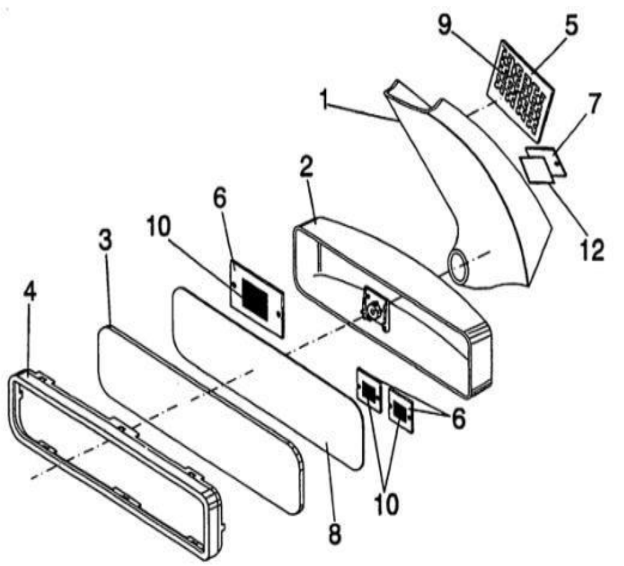

Fig.11. Fractal antenna implanted in rare Glass

3. **Bio-medical:** Fractal antenna plays a major role in bio-medical applications. It helps in identifying major diseases in a human body such as cancer, diabetes etc. and allows transmitting data for testing. Due to its compact size and high gain, it could be implanted with the biomedical instruments easily and sending/receiving the signal uninterruptly.
4. **Satellite communication:** It is highly necessary to use miniaturized antennas for satellites. As the compactness achieved, the antenna performance will be severely affected. Therefore, the techniques, which can able to design compact antenna with enhanced performance is highly required such as fractal techniques. Fractal techniques-based antennas are of miniature in size and light in weight with improved properties such as gain and bandwidth. These techniques are also helpful to make antenna multiband/wideband as per the application requirements.
5. **Military:** The military typically operates in demanding, dynamic, semi-structured and large-scale environments. This reality makes it difficult to detect, track, recognize/classify, and response to all entities within the volume of interest, thus increasing the risk of late (or non-) response to the ones that pose actual threat. Antennas, invented by Fractal Antenna Systems, beat these odds. These antennas are built on repeating scales of size (self-similar), which make it useful for spy related work. It can be easily hides in watches, shoes, cloth etc. due to its compactness and work fruitfully with its improved properties as shown in figure 12.

Fig.12. Fractal antenna implant in cloth

VII. Conclusion

The fractal antenna is a major breakthrough in the field of antenna engineering. It has ability to resonate at multiple frequencies due to its self-similar structure with the different dimension range. It also provides number of iteration as a tool to control or optimized its properties according to the application requirement. The incorporation of fractal geometry in conventional antenna offers many of the improved characteristics with optimal trade-off such as compactness, wideband, multi frequency etc.

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