A Review Analysis of Different Geometries on Fractal Antenna with Various Feeding Techniques

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Abstract— Fractal antennas have the unique property of self-similarity, generated by iterations, which means that various copies of an object can be found in the original shape object at smaller scale size. A fractal is a rough or fragmented geometric shape that can be divided into smaller parts, each of which is (approximately) a reduced size copy of the whole. Fractal antenna is capable of performing operation with good-to-excellent performance at many different frequencies simultaneously at the same time. Normally standard antennas that have to be "cut" for the frequency for which they are to be used and thus the standard antennas only work only well at that the frequency they are given. This paper represents a basic study of a simple fractal antenna with a different shape and there iterations. And I have also discussed the basics of Fractal Antenna, various feeding techniques, design model, advantages and applications.

Key words: Fractal Antenna, Multiband, Space Filling, Self-similar

I. INTRODUCTION

In modern telecommunication systems antennas are require with wider bandwidths and smaller dimensions as compared to the conventional standard antennas. This was beginning of antenna research in various different directions; use of fractal shaped antenna elements was one of them. Some of these geometries have been particularly useful in reducing the size of the antenna, while some others exhibit multi-band characteristics. Antenna configurations based on fractal geometries have been reported in recent years. These are very low profile antennas with moderate gain and can be made operative at multiple frequency bands and hence are multi-functional. According to Webster's dictionary, a fractal is defined as being "derived from the latin fractus which means broken, irrespective of various extremely irregular curves or shapes that repeat themselves at any scale on which they are examined. The word "Fractal" means "broken" or "fractured" from the Latin "fractus." The word was coined by Benoit Mandelbrot, a French mathematician about 20 years ago in his book "The fractal geometry of Nature"[4]. Names like G. Cantor (1872), G. Peano (1890), D. Hilbert (1891), Helge von Koch (1904), W. Sierpinski (1916) Gaston Julia (1918) and other personalities played an important role in Mandelbrot's concepts of a new geometry. Nathan Cohen, professor at Boston University built the first known fractal antenna in 1988. Cohen's efforts were first published the first scientific publication about fractal antennas in 1995, since then a number of patents have been issued. Fractal is a geometrical shape that has the property of self-similarity, which means, each part of the shape is a smaller portion of the original shape. Fractals can be classified as natural and mathematical fractals.

A. *What Are Fractals?*

This question is a simple with a very complicated (and very long) answer. An accurate answer, doesn't help much because it uses other fractal speak jargon that few people understand, so the simple answer of a fractal is a shape that, when you look at a small part of it, has a similar (but necessarily not identical) appearance to the shape of basic initiator. Take, for example, a rocky mountain. From a distance, you can see that how rocky it is; up close, the surface is very similar. Little rocks have a similar surface to big rocks and to the overall mountain.

B. *Why Fractals Are Used?*

Small antennas are of prime importance because of the available space limitations on the devices and the oncoming deployment of diversity and multiple input and multiple output (MIMO) systems. Fractal geometry provides the way solution by designing compact as well as multiband antennas in a most efficient and sophisticated way with better antenna performance. Fractals can be used in two ways to enhance the antenna designs. The first method is the design of miniaturised antenna elements. The second method is use self-similarity in the geometry.

C. *Fractals in Antenna Engineering*

The primary motivation of fractal antenna engineering is extend antenna design and synthesis concepts beyond Euclidean geometry. 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. Fractal and random fractal arrays have been found to have several novel features. Variation in fractal dimension of the array distribution has been found to have effects on radiation characteristics of such antenna arrays. The uses of random fractals reduce the fractal dimension, which leads to a better control of side lobes. It may be concluded that fractal properties such as self-similarity and dimension play a key role in the design of such arrays.

D. *Working Principle*

In fractal antenna coupling between sharp angles produce different current paths achieving multi band operation. Most of the miniaturization benefits of the Fractal Antenna occur within the first five iterations with very little changes in the characteristics. In the fractal antenna higher iterative geometries exhibits lower resonant frequencies. The graph of resonant frequency versus fractal iteration is given below.

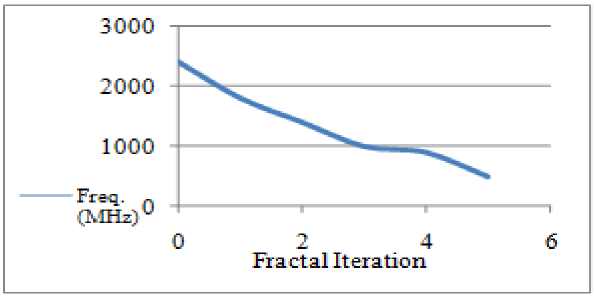


Fig. 1: Fractal Iteration versus Resonant Frequency

E. Iterated Function Systems: Language of Fractal

Fractals have some infinitely repeating pattern. Instead of using the word "repeat" can we use a mathematical synonym "iterate" and the process is called iteration. Iterative function system (IFS) is versatile tool for the convenient generation of fractal geometries. The iterative function system (IFS) is a collection of self-affine transformations as given below,

$$W(x) = A(x) + t = \begin{bmatrix} a & b \\ c & d \end{bmatrix} \begin{bmatrix} x1 \\ x2 \end{bmatrix} + \begin{bmatrix} e \\ f \end{bmatrix} \quad (1.1)$$

The matrix A is given by:

$$A = \begin{bmatrix} (1/s)\cos(\theta) & -(1/s)\sin(\theta) \\ (1/s)\sin(\theta) & (1/s)\cos(\theta) \end{bmatrix} \quad (1.2)$$

The parameters that are used a, b, c and d are defined by scaling and rotation of basic geometry and e and f denote the translation.

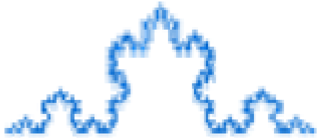
Fractal design has two stages:

- Initiator (0th stage): the very basic shape of the geometry.
- Generator: the shape which gets repeated by cutting in a pattern on the initiator in subsequent stages of different dimensions.

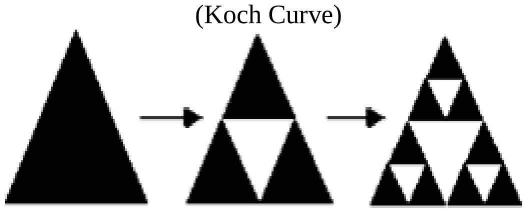
F. Fractal Dimensions

The term fractal was coined by the French mathematician named 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 geometry. The term has its roots in the latin word fractus which is related to the verb fangere (meaning: to break). These geometries were generally discarded as formless, but Mandelbrot discovered that certain special features can be associated with them. Many of these curves were recognized well before him, and were often associated with mathematicians of yesteryears. 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. Some examples of fractals are given in Fig. 2. Most of these geometries are infinitely sub-divisible, with each division a copy of the parent. This special nature of these geometries has led to several interesting features uncommon with Euclidean geometry.

(Cantor Set)



(Koch Curve)



(Sierpinski Gasket)

Fig. 2: Some Basic Fractal Antennas

Mandelbrot defines the term fractal in several ways. These rely primarily on the definition of antennas dimension. A fractal is a set for which the Hausdorff Besicovich 3 dimension strictly exceeds its dimension. Every set having non-integer dimension is a fractal. But fractals can have integer dimension. Alternately, fractal is defined as set F such that:

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

$$D = \frac{\log n}{\log \frac{1}{s}} \quad (1.3)$$

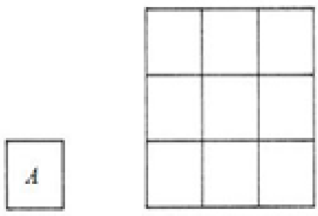
Where n is the number of self-similar copies and s is the scale factor.

1) Dimension Of A Line

Fig. 3: Simple line

$$D = \frac{\log n}{\log s} = \frac{\log 2}{\log 2} = 1 \quad (1.4)$$

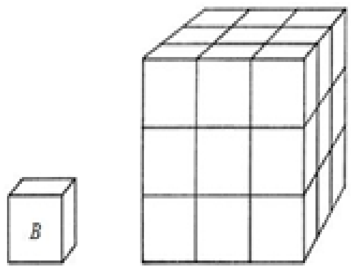
2) Dimension of A Square



$$D = \frac{\log n}{\log s} = \frac{\log 9}{\log 3} = 2 \quad (1.5)$$

Fig. 4: Simple Square

3) Dimension of A Cube



$$D = \frac{\log n}{\log s} = \frac{\log 27}{\log 9} = 3 \quad (1.6)$$

Fig. 5: Simple Cube

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

Table 1. Fractal dimension of some geometry

For example, a square can be divided into 4 copies of ½ scale, 9 copies of ⅓ scale, 16 copies of ¼ scale, or n2 copies of 1/n scale. The same approach can be followed for determining the dimension of several fractal geometries. The dimension of geometries shown in Fig.2 is listed in Table 1.

G. *Function Iteration In The Complex Domain*

The generator is used to add or subtract from the area of the initiator n from each subsequent iteration stage in a fixed pattern culminating in the fractal structure.

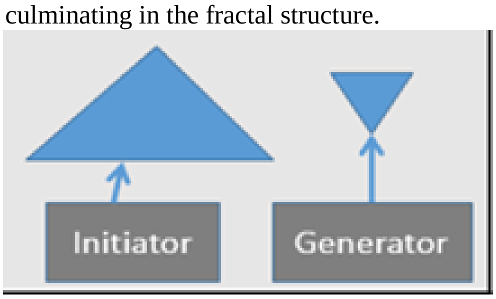


Fig. 6: Initiator and Generator of a Sierpinski Gasket Fractal

Any random processes can be used to generate random fractals.

H. *Fractals as Space Filling Geometries*

Hilbert curve is widely used in the miniaturization of antenna element because of its space-filling property. A line can meander in such a way as to effectively almost fill the entire sheet. The space-filling property lead to the curves that is electrically long but fit into a compact space and lead to the miniaturization of the antenna elements. Due to this space filling property, the fractal antennas occupy space in more effective manner as compared to the traditional Euclidean antennas and hence results in miniature antennas.

I. *Fractals as Multiband Antennas*

Fractal show multiband or log periodic behaviour that has been attributed to self-similar scale Factor of the antenna geometry. When an object is composed of smaller copies of the original geometry, it is said to be self-similar. A self-similar object can be described as a cluster, which is again made up of smaller clusters that are identical to the entire geometry. Thus, within the whole geometry, an infinite number of similar copies can be found. Hence, fractal geometries are said to have no characteristic size.

II. ANTENNA CONFIGURATION

A. *Fractal Geometries*

Many patterns in the nature are so irregular and fragmented that they exhibit not only a higher degree, but also a high level of complexity. Hence, Mandelbrot proposed a new geometry and its use in various fields. The geometry describes many of the irregular and fragmented patterns of nature around us.

1) *Natural Antenna Shapes*

As the name suggests, the fractals which are found in nature all around us are natural antennas. These are also random fractals. These geometries have been used to characterize the structures which are difficult to define with the other Euclidean geometries. Most of these geometries are infinitely further divisible, each division being copy of the initiator. Some of the ex. of natural antennas length of coastline, branches of trees and plants, rivers, galaxies etc [3].

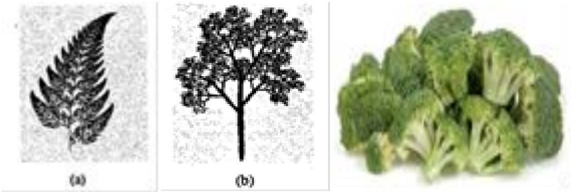


Fig. 7: Some natural shapes (a) Leaf, (b) Tree, (c) Vegetable

B. *Mathematical Antenna Shapes*

The mathematical antennas are those which undergo iterations based on equations. They are also called as deterministic shape fractals. The deterministic shape fractals are visual. The two-dimensional fractals are made of a broken line called the generator. Each segment which forms the broken line is replaced by broken line generator at corresponding scale for a step of algorithms. And by repeating the steps infinitely results in geometrical fractals. The examples of mathematical antennas are given below,

1) *Sierpinski Carpet shape*

Sierpinski carpet shape fractal is realized by the successive iterations on a simple square patch shape, which is called as the zero order iteration. A iteration of dimension equal to one third of the main patch is subtracted from the centre of the patch to obtain the first order iteration. This process is repeated continuously further to next order iterations.

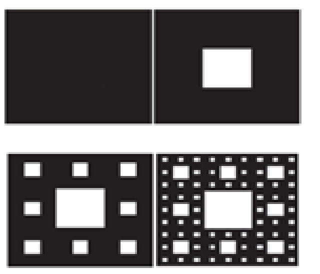


Fig. 8: Sierpinski Carpet shape Antennas up to 3rd iterations.

2) *Koch Curve Shape*

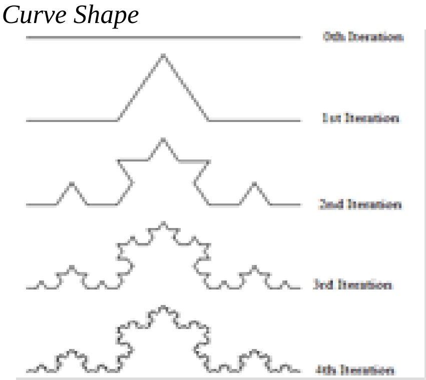


Fig. 9: Koch Curve shape Fractal Geometry

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

3) Minkowski Curve Shape

The Minkowski curve is known as Minkowski Sausage and was dated back to 1907 where a German mathematician, Hermann Minkowski, investigated this quadratic forms and continued fractions. A Minkowski fractal is analysed, where the perimeter is near one wavelength.

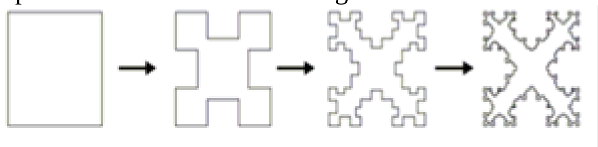


Fig. 10: Iterations of Minkowski curve shape

The proposed antenna is applicable for Satellite, Wi-Fi, Bluetooth, Cellular Phones and Radar etc

4) Hilbert Curve Shape

The first few iterations of Hilbert curves are shown in Fig. 11 It may be noticed that each stages consists of four copies of the previous, along with the additional line segments. The geometry so obtained is a curve that is with the large number of iterations the entire area it occupies will be filled. Apart from this the geometry also has the following properties: self-avoidance, Simplicity and self- Similarity.

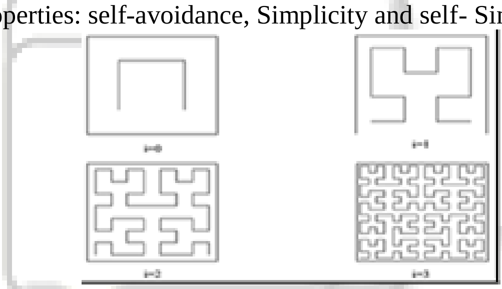


Fig. 11: Generation of Iterations of Hilbert Curve shape

The miniaturised IFA antenna can be easily built in a wireless sensor network (WSN).

5) Circular Microstrip Antenna Shape

In Fig. 12 a circular metallic patch is designed and then pointed star shaped fractal geometry is subtracted from the original circular patch with some sharpness factor and appropriate dimensions.

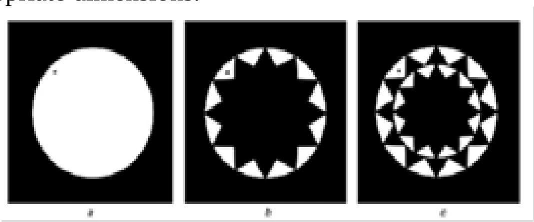


Fig. 12: Circular Microstip Patch shape

Thakare and rajkumar (2009) proposed a novel design of star-shaped fractal patch shape for miniaturisation and backscattering radar cross-section (RCS) reduction. RCS reduction is important for many defence and civilian applications

6) Pythagoren Tree Fractal Shape

The construction of a Pythagoras tree begins with a square. Two other squares are constructed upon this square, each scaled down by a linear factor. The same procedure is then applied recursively to the smaller two squares Fig. 13 shows.

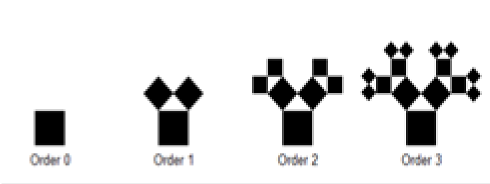


Fig. 13: Iterations of Pythagoren Tree shape

Pourahmadazar.et.al. (2011) a novel modified Pythagorean tree fractal (MPTF) based antenna using multi fractal technique for UWB application.

III. Feeding Techniques

There are various feeding techniques used for fractal antenna that are shown below,

A. Microstrip Line Feeding Technique

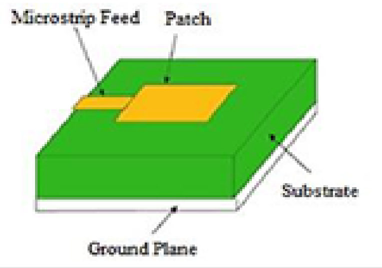


Fig. 14: Microstrip Feed line with Rectangular Patch

B. Coaxial Probe Feeding Technique

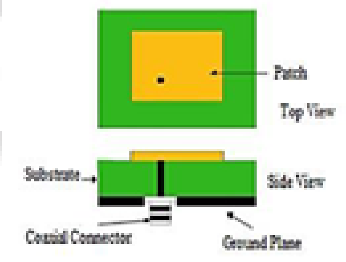


Fig. 15: Coaxial Feed Line

C. Proximity Coupled Feed

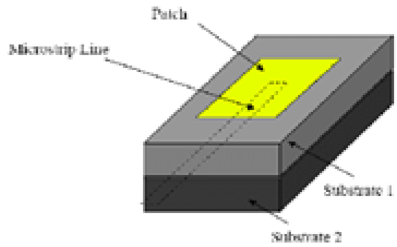


Fig. 16: Proximity Coupled feed

D. Aperture Coupled Feed

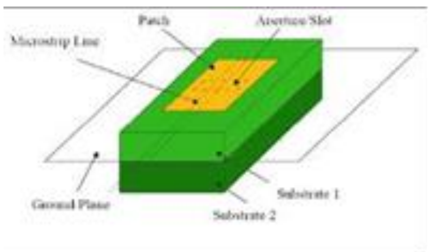


Fig. 17: Aperture Coupled feed

IV. ADVANTAGES OF FRACTAL ANTENNAS

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

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

V. APPLICATIONS OF FRACTAL ANTENNAS

Sudden growth in wireless communications arise need of fractal geometry. Examples of fractal antenna include handheld cell phones and mobile devices like laptops on wireless LAN. Following are applications of fractal geometry.

- Very compact
- Uses for multiband or wideband
- Higher bandwidth and antenna gain
- Light weight
- Mobile Application
- Computer science
- RFID

VI. CONCLUSION

In this paper we can review the geometries, basic geometries, feeding techniques and applications of the various fractal antennas. Fractal antenna represents a uniquely new field of research that combines the attributes of fractal geometry in antenna theory. Research in this field has recently yielded a rich class of new designs for antenna arrays as well as in antenna elements. Fractals are space filling geometries that can be used to effectively fit for long electrical lengths into smaller areas. All through characterizing the fractal geometries and performance of the fractal antennas, it can be summarised that increasing the dimension of the fractal antenna leads to higher degree of miniaturization. Among the given topics in this paper, the fractal antenna geometries, applications and advantages of the fractals have been discussed.

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