International Journal of Advance Research in Science and Engineering
Volume No.08, Issue No.05, May 2019
www.ijarse.com
IJARSE
ISSN: 2319-8354

A Review Paper on Fractal Antennas and Its Applications

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ABSTRACT

Fractals are geometric shapes that repeat itself over a variety of scale and sizes so that the shape looks the same when viewed at different scales. This type of antennas can meet the requirements of designing miniaturized, multiband and wideband antenna with high gain and low profile for modern wireless communication services and applications. The fractal antenna arrays are another division in fractal antenna engineering. In this review paper a comprehensive review of recent developments in the field of fractal antenna array engineering has been presented. Firstly, a brief introduction about fractal antenna, its different shapes and structures has been discussed. Then, the concept of fractal antenna array has been presented. Finally, the recent work done in the area of fractal antenna array and its applications for ultra-wide band frequency range has been discussed.

Keywords: Fractal geometry, fractal antenna, applications.

I. INTRODUCTION

With the advent of wireless communication in today's world, there has been an increased need for more compact and portable multiband and multi service antennas with wider band width. These requirements are fulfilled by fractal antennas. Fractals are geometric shapes which cannot be defined using Euclidean geometry. They are self-similar and repeating themselves on different scales. Clouds, mountains, plant leaves, lightning and coastlines are the inspiration for fractal geometries.

II. FRACTAL ANTENNA

The term "Fractal" comes from the Greek word "fractus" which means "broken" or "fractured". This term was coined by Dr.B.B.Mandelbrot in the year 1974. He has defined mathematically definite structures whose dimensions cannot be limited to whole numbers but can be applied to fractal numbers. These geometries have been used to characterise different objects available or not available in nature to define with equilidean geometries.The fractal geometry has been applied in many fields like medicine, astronomy, volcanology and meteorology. Fractal geometry has also been used in the field of electromagnetics.

Fig1.Different types of fractal shapes in nature.

III. CLASSIFICATION OF FRACTAL ANTENNAS

The classification of fractal antennas has three different domains of classification:

1. **Indentations dependent**

   Since fractal geometries are repeating patterns i.e. they are self-affinity geometry, iteration methods can be used to mathematically create such geometries.

   A generator can be used to create fractals. A predefined generator can create fractals by repeatedly substituting certain part of a pattern at each iteration.

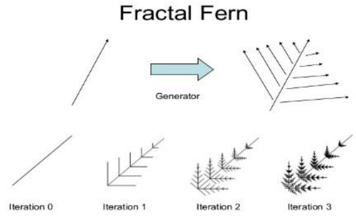

Fig 2. Fractal fern iterations

Iterated function system (IFS) is a finite family of contradictions S={S_1,S_2,…….,S_m}, where S_m is a contradiction that transforms set into geometrically similar sets with probability P={P_1,P_2,……..P_m}. P_i is the relative weight for each contradiction S_i and P_i needs to satisfy the following expression $\sum_{i=1}^{n} P_i$=1.

A unique fractal can be determined by one IFS. The transformation includes several functions such as rotation, move and reflection.

Some "irregular" shapes can also be defined using non- uniform probability distribution. These structures are also called as 'randomized fractal' with statistical self-similarity.

Infinite summation of mathematical expression is used to create fractal structure which usually leads to non- smooth curve due to infinite summation.

2. Based on basic design shape

- Fractals as wire antenna elements: The main idea of symmetrically bending wire in a fractal way, so that the overall arc length remains the same, but the size is correspondingly reduced with the addition of each successive iteration which leads to a standard dipole or loop antenna.
- Fractal patch antenna element: Fractals can be used to minimize patch elements as well as wire elements. The same concept of increasing the electrical length of a radiator can be applied to a patch element so that it can be viewed as a microstrip transmission line.

3. Based on design method

- Linear: based on iteration of linear equations (HILBERT, SIERPINSKI, DRAGON, KOCH, …...).
- Non-Linear: based on the iteration of complex numbers (MANDELBROT, JULIA, ……)
- Random: based on the introduction of random parameters in the iteration to obtain irregular shapes such as mountains and clouds.

IV. TYPES OF FRACTAL ANTENNAS

1. The KOCH Structure

The Koch structure was invented by Swedish mathematician HELGE VON KOCH in 1906 even before the term "fractal" had been coined. There are several variations of this structure:

a) The Koch curve

- The segment is divided into three parts of equal length.
- In the first iteration, an equilateral triangle whose base is the middle segment of the first stage is constructed. Segment which was the base of the triangle of the second step is eliminated.
- These steps are repeated for further iterations to get the Koch curve.

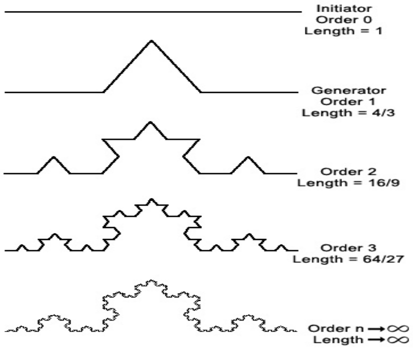

Fig3. Iterations of Koch structures.

International Journal of Advance Research in Science and Engineering
Volume No.08, Issue No.05, May 2019
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ISSN: 2319-8354

b) The Koch snowflake

The procedure to generate a Koch snowflake is the same as to create Koch curve except that the base is a triangle, which means that the procedure isrepeated three times for every iteration.

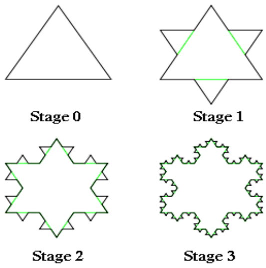

Fig4. Iterations ofKoch snowflake structures.

2. The sierpinski structure

a) This structure was invented by Polish mathematician SIERPINSKI. There are several variations of this structure:

- A solid equilateral triangle is built and will be taken as the base.
- Now, subdivide this into three smaller equilateral triangles and remove the centre one.
- Then, repeat step 2 for the remaining smaller triangles.

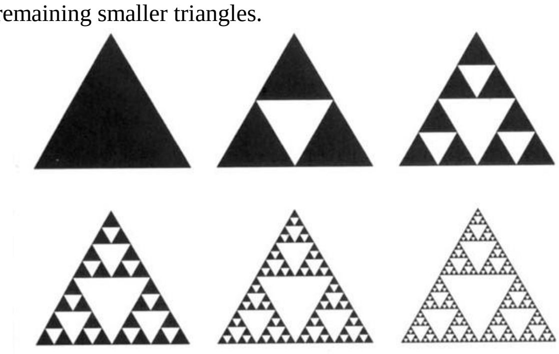

Fig5. Iterations of Sierpinski gasket structures.

a) The Sierpinski carpet

- A solid square is taken as the base for construction.
- The square is cut into 9 congruent sub-squares in a 3 by 3 grid.
- The sub square in the centre is removed.
- The above steps are repeated for the remaining sub squares for further iterations.

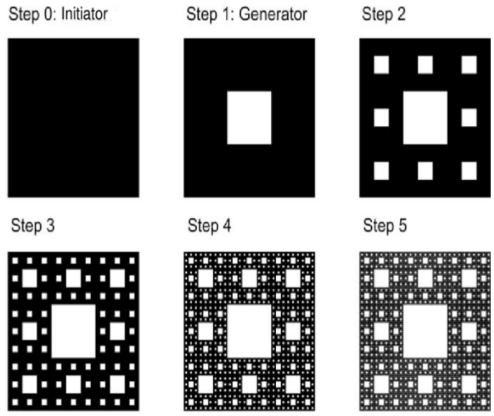

Fig6. Iterations of sirpinski carpet structures.

3. The Dragon structures

The shape of this structure is close to that of a dragon, Hence its name implies.

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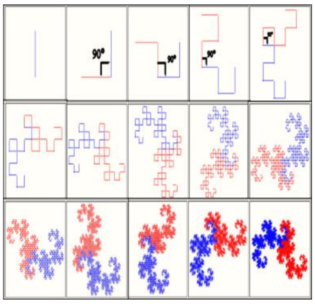

Fig7. Iterations of the dragon structures.

4. The Tree structure

This structure has the shape of a tree. There are several kinds of each structure.
At each iteration, the same shape is generated with a reduction factor.

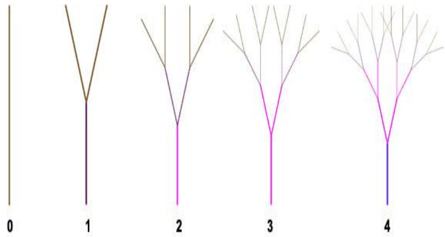

Fig8. Iterations of tree structure.

a) The H-Tree

The H-Tree geometry is based on the same concept of tree structure except the initiator here is the letter "H". In each iteration we create four copies of the previous iteration with reduction factor "R".

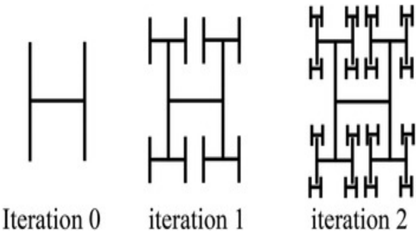

Fig9. Iterations of H-Tree structure.

b) Pythagore Tree

This structure is created using squares. Each triple square in touch creates a right triangle. Hence named as "PYTHAGORE".

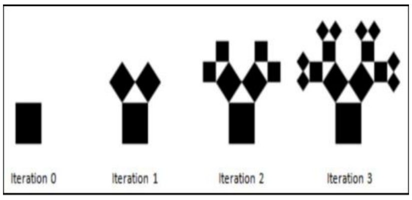

Fig10. Iterations of pythagore tree structures.

5. The circular structure "APPOLLONIUS circle"

- This structure was invented by the Greek mathematician APPOLLONIUS of Perga. These circles are tangents to one over other.

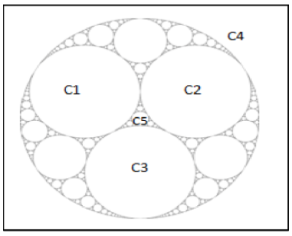

Fig11. The Appollonius circle.

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6. Cantor set

Cantor set was invented by the German mathematician George CANTOR. It is built iteratively from segment[0,T] by removing a central portion. Then the operation is repeated for the remaining two segments, and so on.

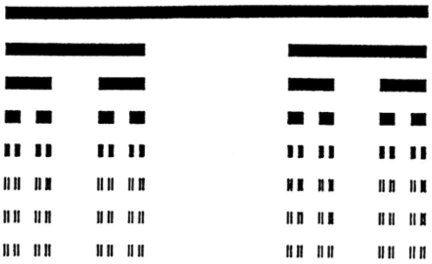

Fig12.Iterations of the cantor set.

7. The Hilbert curve

The Hilbert curve was given by the German mathematician David Hilbert in 1891. The Hausdorff dimension is 2 and the method of construction is described.

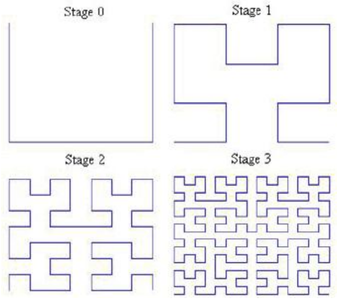

Fig13. Iterations of the Hilbert curve.

8. The MINKOWSKI curve

This curve was given by German mathematician Hermann MINIKOWSKI.

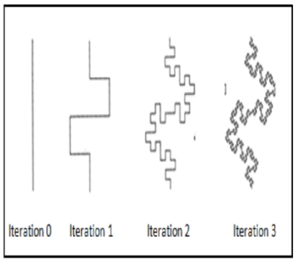

Fig14. Iterations of the minikowski curve.

V. APPLICATIONS OF FRACTAL ANTENNAS

There are wide ranges of applications of fractal antennas. Some of them are discussed below:

1. Anti-radar fractals and/or multilevel chaff dispersers

Chaff is a form of countermeasure employed against radar. It usually consists of a large number of electromagnetic dispensers and reflectors, arranged in the form of strips of metal foil packed in a bundle. When released by an aircraft gets dispersed by the effect of wind and becomes highly reflective clouds. Chaff is usually employed to foil or to confuse surveillance and tracking radar. New geometries of the dispersers are presented with the help of fractals.

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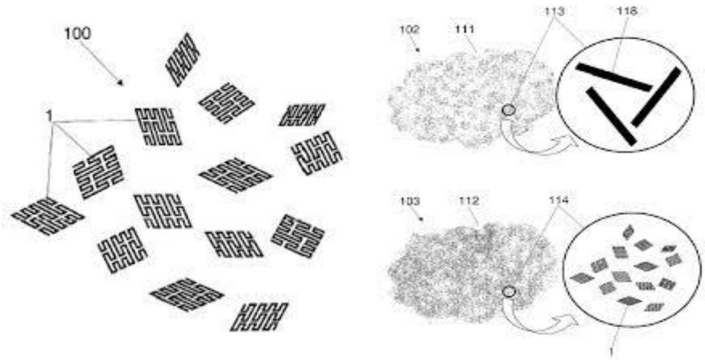

Fig15. Comparison between a conventional chaff cloud with regards to a fractal or multilevel structure chaff cloud.

2. **Fractals in medicine and biology**

   The applications of the fractal principle is very valuable for measuring dimensional properties and spatial parameters of irregular biological structures, for understanding the architectural or morphological organisation of living tissues and organs, and for achieving an objective comparison among complex morphogenetic changes occurring through the development of physiological, pathological, and neoplastic processes.

3. **Fractals in astronomy**

   Fractals may revolutionize the way universe is seen. Cosmologists usually assume that matter is spread uniformly across space. Astronomers agree with that assumption on "small" scales, but most of them think that the universe is smooth at very large scales. Some scientists claim that the structure of the universe is fractals at all scales.

Advantages of fractal antennas

- Miniaturisation.
- Better matching of input impedance.
- One antenna is sufficient to take care of multiple bands both wideband and narrowband.
- It provides consistent performance over huge frequency range. Hence fractal antennas are said to be frequency independent.
- There will be reduced mutual coupling in array antennas made using fractal geometrical approach.

Disadvantages of fractal antennas

- Numerical limitations.
- Gain loss
- Complexity involved in the design and manufacturing.
- After few iterations in the fractal antenna design, the benefits begin to diminish.

VI. CONCLUSION

This review work provides an insight to the various types of fractal antennas and its applications. From the paper we conclude that the fractal geometries enhance the bandwidth of the antenna up to a great extent. The different properties of fractal antennas result in small size, high efficiency and high gain antenna. The resonant frequency increases with the increase in the number of iterations of fractal geometry which results in lower return losses. Fractal antennas have a wide range of applications. It is used in radar, medical imaging, telecommunications, weather forecasting and satellite communications etc. Fractal antenna reduced the size of the conventional antenna which is the prime requirement for the modern wireless system.

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