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Review
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An Overview of Fractal Antennas

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Abstract

Wireless communication for wireless applications is growing at a faster rate these days. There is a greater need for low-profile, multiband or wideband antennas. With the elevated low-profile antennas are in high demand due to advancements in antenna technology. The fractal antenna's self-similarity and self-repetitive characteristics enable it to satisfy this requirement. This paper provides a thorough overview of fractals, going on to discuss their dimensions and various applications successfully. The idea of a fractal antenna and its various geometries is explained in this project. Beginning with the basic idea of fractals and their mathematical underpinnings, such as fractal dimensions and scaling features, this review paper provides a thorough introduction to fractal geometry. Beginning with the basic idea of fractals and their mathematical underpinnings, such as fractal dimensions and scaling features, this review paper provides a thorough introduction to fractal geometry. It also looks at how these ideas are used in antenna engineering to improve compactness, gain, and bandwidth. A thorough discussion is given of the idea of fractal antennas and their several geometries, including Sierpinski, Koch, Minkowski, and Hilbert structures, emphasizing their design processes and functionalities. This study also looks at the benefits and drawbacks of fractal antennas, such as their potential losses and difficulty of construction. Lastly, it highlights their important uses in satellite communication, wireless communication, military systems, and new research fields, illustrating their increasing significance in contemporary antenna technology. This paper also discusses the advantages and disadvantages of fractal antennas, as well as their highly beneficial uses in research and related sectors.

Keywords: Antenna performance optimization, dimensions, Euclidean iterations, self-similarity, wideband/multiband

INTRODUCTION

The term "fractal" is derived from the Latin word fractus, meaning broken or irregular fragments, and is also associated with the Greek word fringe. Fractals describe complex geometric shapes that exhibit irregular yet patterned structures like those precisely found in nature. The relationship between fractal geometry and natural patterns has been widely studied, revealing how repetitive and self-similar forms occur in various natural phenomena [1–3].

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The first practical fractal antenna was developed in the late 1980s, marking the beginning of a new approach in antenna engineering. Antennas are available in a wide range of configurations, including wire antennas, aperture antennas, reflector antennas, and several other types designed for different applications. Among these, fractal antennas represent a relatively recent advancement in antenna design and have gained significant attention in both commercial and military sectors [4, 5].

Fractals are characterized by their self-similarity and self-repetitive properties, meaning that their geometric patterns repeat at different scales. These characteristics make fractal structures efficient in achieving compact size, multiband operation, and improved performance. Additionally, fractal geometries are relatively straightforward to design and implement, making them attractive for modern wireless communication systems that demand miniaturization and enhanced functionality [6].

Fractal Antenna

Fractal antennas are small antenna combinations that operate at several frequencies. It is a geometrical shape, which means that every component is a replica of the original form. Antennas with a small size, high gain, and excellent performance are necessary for wireless communication, navigation, and military communication. To fulfill these criteria, a smaller, non-deterministic fractal antenna is required. Fractal antennas exhibit broad behavior due to their self-similar features. The fractal's ability to fill spaces was utilized to reduce the antenna's size and create a low-profile, highly useful antenna for the communication system. A single fractal antenna can operate at numerous resonant frequencies [7–9].

The Use of Fractals

These days, a tiny antenna is the primary and necessary requirement for any application, due to the devices' limited area, diversity deployment, and multi-input, multi-output (MIMO). By constructing compact size and multiband antenna efficiency, fractal antennas offer a superior solution and provide an efficient method with better antenna performance than others. There are two ways to employ fractals to improve the antenna design. The first is the use of fractals in the construction of small antenna elements, and the second is the application of self-similarity in the geometry. Fractal dimensions are a special characteristic of fractal geometry.

Topological dimension, Hausdorff dimension, box counting dimension, and self-similarity dimension are the various forms of fractal notation found in fractal geometry. The most crucial characteristic for characterizing fractal geometries among these notations is the self-similarity dimension [10].

The dimension of self-similarity is defined as:

$$D_s = \frac{\log(N)}{log\frac{1}{s}}$$

Where,
N = duplicates that are self-similar,
S stands for scale factor.

Geometry Fractal

The geometries of a fractal antenna can be described and built in an iterative process. A small, wideband antenna can be created using fractal geometry.

There are several versions of the same fundamental shape. Iterations are small and accommodate multiband frequency because they can go on indefinitely while taking up a small amount of space. There are two categories of fractal geometries. They are as follows.

Natural

Fractals that surround us in nature serve as natural antennas. They are also known as random antennas. This kind of geometry has been employed to describe the various structures that constitute challenging Euclidean geometries. The random geometry is shown in Figure 1.

The majority of these infinitely divisible geometries are further divided. Every division is duplicate of the original. Coastlines, plant or tree branches, rivers, and galaxies are examples of natural fractal geometries. A few examples of natural fractal antennas are shown in Figure 2.

Figure 1. Satellite image illustrating the distribution of sea ice floes along the ocean surface.

Figure 2. Natural fractal antenna.

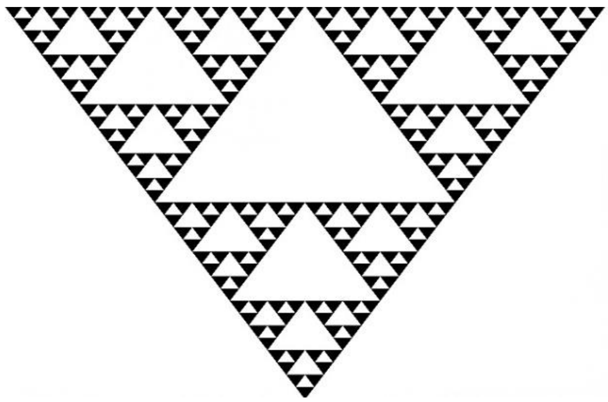

Figure 3. A mathematical or deterministic geometry.

Mathematically

Deterministic geometries are another name for mathematically fractal geometries. The geometries subjected to these equations are mathematically fractal. These were determined by iterations. This fractal can be observed [8].

An example of mathematical or deterministic geometry is shown in Figure 3. Two broken lines, referred to as generators, make up this geometry. Every section that makes up a broken line is swapped out because the initial line generator was broken. Geometric fractals are created by repeating these processes. Sierpinski gaskets, Koch curves, Mandelbrot curves, Minkowski curves, and others are examples of mathematical geometry.

FRACTAL GEOMETRY TYPES

Sierpinski Curve

Sierpinski, A. The Polish mathematician is honored by the name Gasket Sierpinski. Sierpinski. In 1961, he explained this fractal's characteristics [6].

Subtracting the central triangle from the main triangle yields a Sierpinski geometry. Three identical triangular geometries emerge on the structure following the subtraction from Figure 4. Each shape represents half of the primary triangle [1].

The Sierpinski curve iteration process, which yields geometry by subtracting the central triangle from the main triangle, is depicted in Figures 4 and 5. Repeating the same procedure of the ideal Sierpinski gasket is obtained by subtraction an infinite number of times. This fractal is a deterministic one. It shares characteristics with all fractals, such as reappearance, which indicates that if we magnify any portion of the triangle, we will have an identical triangle. In the Sierpinski gasket, equilateral triangles are created using the midpoints of each side as the vertices of a new triangle that is separated from the original triangle. Proceed with each of the remaining triangles in the same manner. The three smaller triangles remain after the central triangle is removed [8]. The ideal Sierpinski gasket is obtained by performing the same subtraction process an unlimited number of times. This is a deterministic fractal. It features characteristics shared by all fractals, such as reappearance, which indicates that if we magnify any portion of the triangle, we will obtain an identical triangle. In the Sierpinski gasket, equilateral triangles are created using the midpoints of each side as the vertices of a new triangle that is separated from the original triangle. The three smaller triangles are left behind when we remove the middle of each surviving triangle [8].

Sierpinski Carpet

Similar in construction to Sierpinski gasket, the Sierpinski carpet structure uses square forms rather than triangles. To activate this type of fractal antenna, it is included with a square in the plane, then the open central square is removed, and the square is divided into nine smaller squares, as shown in Figure 5. Additionally, nine smaller congruent squares are created from the remaining eight squares [7].

Figures 5(a)–(d) shows the iteration process of the Sierpinski carpet, in which the main square is divided into nine smaller squares, where the central square is removed.

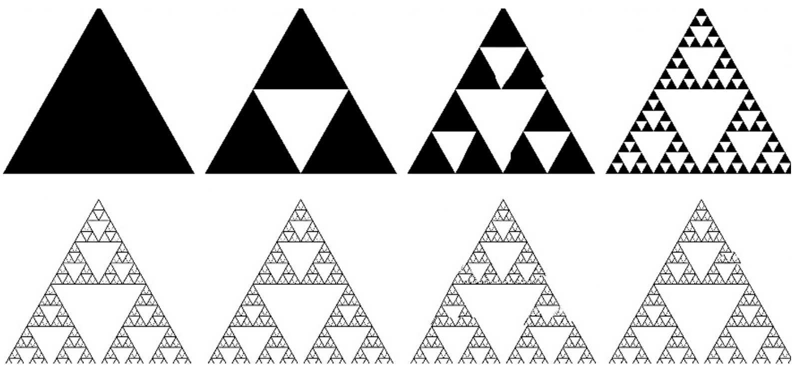

Figure 4. Three identical triangular geometries emerge on the structure.

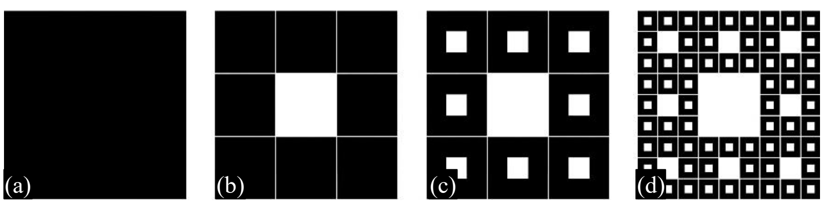

Figure 5. (a)–(d) Sierpinski carpet structure uses square forms rather than triangles.

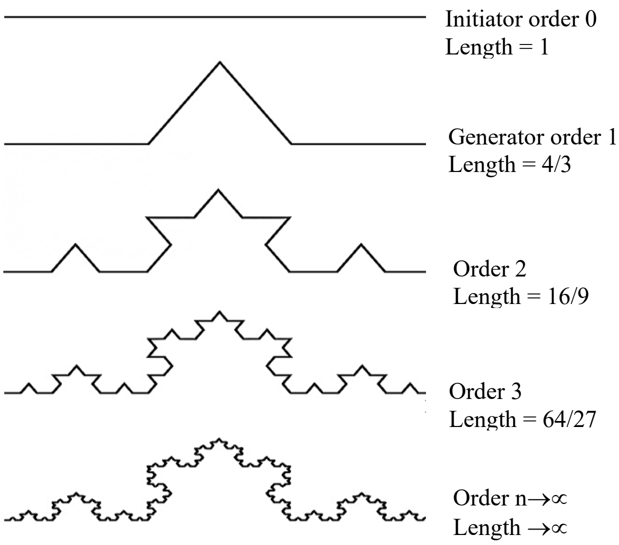

Figure 6. Minkowski curve.

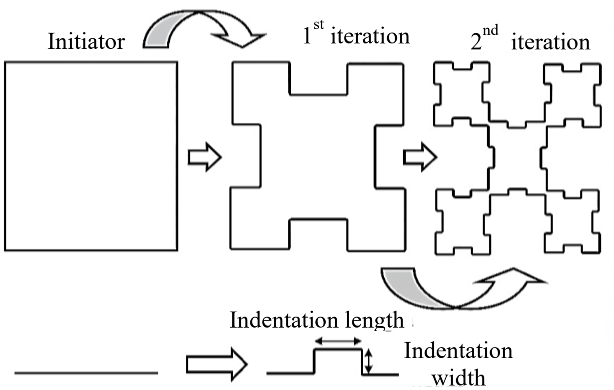

Figure 7. Evolution of a square-based fractal geometry through successive iterations using edge indentations.

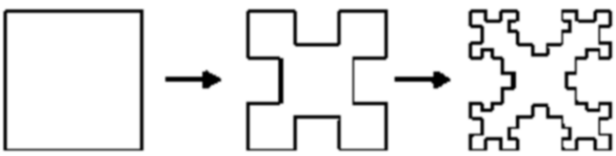
Figure 8. Successive iterations in the generation of a square-based fractal geometry.

Koch Curve

Koch curves have a straightforward design and are easy to construct. First, a straight line is assumed by the researcher. This is then split into three sections, each of which is the same length as in Figure 6. Two others take the place of the middle. The generator is the initial iteration of the geometry. Higher iterations are created by reusing the process. It creates a triangle and splits it into smaller triangles [10, 7].

Minkowski Curve

The Minkowski Sausage is another name for Minkowski. The German scientist Hermann Minkowski is credited with creating this antenna in 1907. He successfully created quadratic forms and continued with fractals. Minkowski loops are used to increase an antenna's efficiency while reducing its size, as shown in Figures 7 and 8. The Minkowski curve is similar to the Koch curve. In addition, triangles are used instead of equilateral triangles [10].

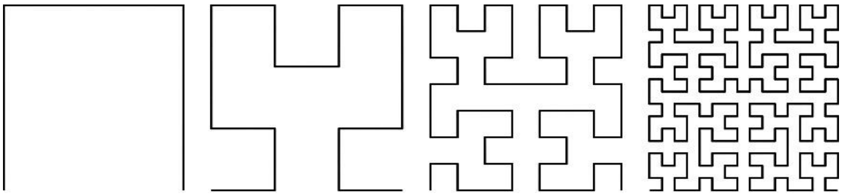

Figure 9. Evolution of a square fractal geometry through successive recursive iterations.

Minkowski Curve

Assume that Hilbert curve geometry is attempting to fill the area it occupies since it has a space-filling quality and involves many iterations from Figure 9. Furthermore, geometry possesses qualities of self-similarity, simplicity, and self-avoidance. Because it encompasses the space it occupies, this geometry is simpler than the others. Because the line segments of this Hilbert curve do not overlap, there will be less complexity [10].

Merits of Fractal Antenna

The size of fractal antennas is small. Because of their small size, they are ideal for military use.

- The input impedance was superior to that of other antennas.
- Wideband/multiband frequencies can be supported by fractal antennas, allowing for the utilization of a single antenna rather than multiple antennas.
- These antennas are compatible with a wide range of frequencies.
- The likelihood of obtaining potent solutions increased significantly while using fractal antennas.
- Inductance and capacitance can be added to fractal antennas without the need for any additional components.
- The fractal antenna offers an advantage over some antennas that function poorly in hostile environments due to their size. Fractal antennas are made to withstand the most extreme circumstances.
- These antennas have instantaneous spectrum access; they are closely packed. Antenna arrays are uniquely improved by fractal antennas.
- They can make the best smart antenna technology possible.
- Less expensive.
- More dependable.

Fractal Antenna Demerits

- High gain loss
- Numerical constraints
- Complexity
- After the initial iterations, performance begins to decline.

Fractal Antenna Applications

- Fractal antenna for ultra-wideband (UWB) devices.
- Fractal antennas can be utilized as UWBs with inscriptions for circular antennas with a triangular shape. UWB is necessary for devices that require ultra-wideband frequencies.
- The frequency range of the ultra-wideband is 2.25 GHz to 15 GHz. Fractal geometries have been used to attain this feature.

Applications in the Military

Antenna designers now face new challenges in the modern military. The requirement for small and compact sizes is increasing daily. For navigation and targeting, a wideband frequency is required. Fractal antennas are compact, low-profile devices with several widebands. Owing to these benefits, fractal antennas are frequently employed in military settings.

Developing dialog for building communications, Fractal offers universal wideband antenna technology that is perfect or helpful. This antenna operates at frequencies between 150 MHz and 6 GHz and provides omnidirectional coverage.

To maximize the diverse, functional possibilities of wireless communication systems like ZigBee, WiMAX, and MIMO, fractal antennas are extremely useful. Fractal antennas have applications in signal intelligence and are highly beneficial in the universal technique of communication.

- A unique application
- Welfare via electronic
- Mobile gadgets

Fractional antennas have limitations, and after a few iterations, the advantages disappear.

CONCLUSION

The fundamentals of fractal antennas, including their dimensions, geometries, benefits, drawbacks, and applications, involve the development and benefits of fractal antennas.

Antennas can be miniaturized using various fractal geometries. The many fractals that can be used to construct an antenna are discussed in this study. Fractals are crucial for minimizing the size of the antenna and achieving the best or most effective gain, possessing the property.

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