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A Review on Fractal Geometry and UWB Applications

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Abstract

In today's telecommunication, people demand more but at the time they want it should be cost effective and also compact in size. For that new concept of fractal antenna introduced which is useful to make multiband antenna and also compact in size. In this paper the basics of fractal geometry has been described. Due to the rapid development in the field of wireless communications there is an increasing demand for higher data rate and large bandwidth. The Ultra Wideband (UWB) is a promising technology for satisfying these demands. This paper also described the range and some of its application.

Keywords:*Fractal, UWB,multiband, IFS*

1. Introduction

Today's telecommunication system demand for wider bandwidth antenna and smaller in dimension rather than conventional ones. These demands are satisfied by fractal antenna. As the fractals are self-similar this leads to multiband and space filling capacity leads to increase the electrical length [2].

Development of components for ultra wideband (UWB) communication band has attracted a lot of attention with the opening up of the UWB bands for 3.1-10.6 GHz by FCC in 2002[1] which is used for high data-rate wireless communication, high-accuracy radar, and imaging systems. The UWB antenna has drawn heavy attention from researchers which displays desirable characteristics such as compact size, low cost, and good Omni-directional radiation pattern.

First we see the basics of fractal geometry and later discuss about UWB application.

2. FRACTAL GEOMETRY

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 term "Fractal" means linguistically "broken" or "fractured" from the Latin "fractus." The term was coined by Benoit Mandelbrot, a French mathematician about 20 years ago in his book "The fractal geometry of Nature" [3].

Fractal is a geometrical shape that has the property of self-similarity, which means, each part of the shape is a smaller version of the parent shape or original shape. Fractals can be classified as:

1) Natural and
2) Mathematical fractals

2.1 Natural fractals:

These fractals are found in nature all around us. These are also called as random fractals. Most of these geometries are infinitely further divisible, each division being copy of the parent. Some of the examples of natural antennas are length of coastline, branches of trees and plants, rivers, galaxies etc.

2.2 Mathematical fractals:

These are those which undergo iterations based on equations. They are also called as deterministic fractals. The deterministic fractals are visual. The two-dimensional fractals are made of a broken line called the generator. Each of the segments which form the broken line is replaced by broken line generator at corresponding scale for a step of algorithm. And repeating the steps infinitely results in geometrical fractals. The examples of mathematical antennas are Koch, Sierpinski gasket, Mandelbrot sets etc. The number of iterations is based on iterated function systems [4].

2.3 FRACTAL DIMENSION

Generally, we can think of objects that are zero dimensional (0-D) i.e. points, 1-D i.e. lines, 2-D i.e. planes and 3-D i.e. solids. We are known with zero, one, two and three dimensions. But for fractal antenna, we will talk about fractal dimensions i.e. non-integer dimensions, such as 2.12D, 1.14D, 3.79D, etc.

There are different notations of the dimension of fractal geometries, such as topological dimension, Hausdorf dimension Box counting dimension, and self-similarity Dimension. Among these, the self-similarity dimension is one of the most important parameters for the characterization of the fractal geometries.

The self-similarity dimension of the fractal geometry is defined as[5]:

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

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

2.4 ITERATIVE FUNCTION SYSTEM (IFS)

Iterative function schemes (IFS) represent an extremely versatile method for conveniently generating a widevariety of useful fractal structures. These iterated function systems are based on the application of a series of affine transformations, w, defined by [6]

$$w\begin{pmatrix} x \\ y \end{pmatrix} = \begin{pmatrix} a & b \\ c & d \end{pmatrix}\begin{pmatrix} x \\ y \end{pmatrix} + \begin{pmatrix} e \\ f \end{pmatrix} \ldots(2)$$

Or

w(x,y)=(ax+by+e, cx+dy+f) …(3)

Where a, b, c, and d control rotation and scaling, while e and f control linear translation [5].

Fractal antenna design has two things:

1) Initiator (0th stage): It is basic shape of the geometry. It can be any shape either triangle, rectangle or any other quadrilateral.

2) Generator: It is the shape which is obtained by scaling the initiator and will be repeated either inside or outside on the initiator to obtain subsequent stages to reach final fractal geometry. Generator is obtained from the initiator itself.

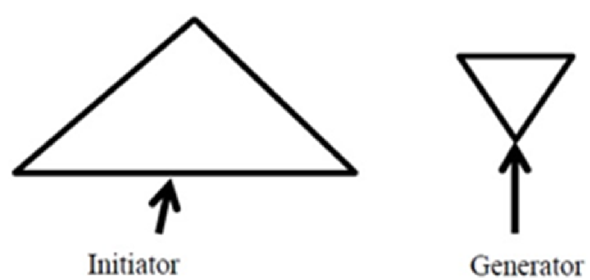

Fig1. Initiator and Generator

Some of the basic fractal geometries are as under:

1. Koch Curve:

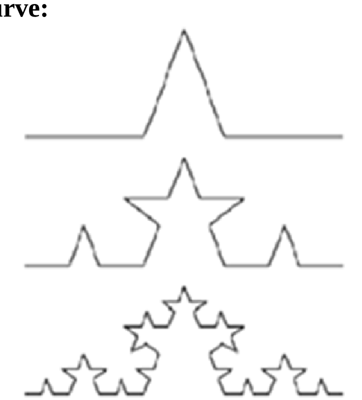

Fig2. Koch curve

It starts with a straight line, which is the initiator. Then partitioned into any number of equal, say three parts, and the segment at the middle is replaced with two others of the same length. This results in the first iterated version of the geometry and is called the generator. The higher iterations of the geometry can be obtained by further repeating this process. Each segment in the first iterated curve is ⅓ the length of the initiator [7].

2. Sierpinski Gasket

The first few stages in the construction of the Sierpinski gasket are shown in Fig 3. The procedure for geometrically constructing this fractal begins with an equilateral triangle contained in the plane, as illustrated in Stage 0 of Fig 3. The next step in the construction process (see Stage 1 of Fig 3) is to remove the central triangle with vertices that are located at the midpoints of the sides of the original triangle, shown in Stage 0. This process is then repeated for the three remaining triangles, as illustrated in Stage 2 of Fig. 3. The next stage in the construction of the Sierpinski gasket are also shown in Fig 3.[7]

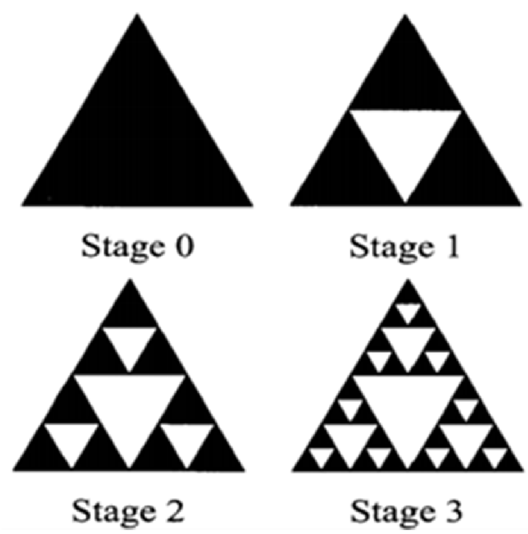

Fig 3 Construction of a Sierpinski gasket fractal.

3. Sierpinski Carpet

Sierpinski carpet fractal is realized by successive iterations on a simple square patch, which is called as the zeroth order iteration. A square 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 obtain next order iterations. The pattern is defined in such a way that each consequent etched square is one third in dimension as compared to the previous one sharing the same centre point [8].

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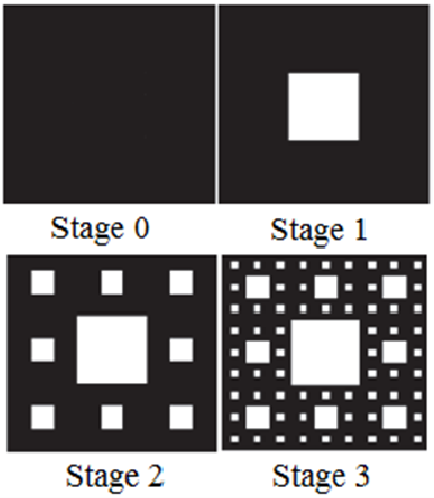

Fig. 4 Construction of Sierpinski Carpet

Sierpinski carpet fractal is realized by successive iterations on a simple square patch, which is called as the zeroth order iteration. A square 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 obtain next order iterations. The pattern is defined in such a way that each consequent etched square is one third in dimension as compared to the previous one sharing the same centre point [8].

4. Minkowski Curve

The Minkowski curve is also known as Minkowski Sausage and was dated back to 1907 where a German mathematician, Hermann Minkowski, investigated quadratic forms and continued fractions. Minkowski loop (Fig. 5) can be used to reduce the size of the antenna by increasing the efficiency with which it fills up its occupied volume with electrical length. A Minkowski fractal is analysed, where the perimeter is near one wavelength. The comparison of several iterations with a square loop antenna is done to illustrate the benefits of using a fractal antenna.

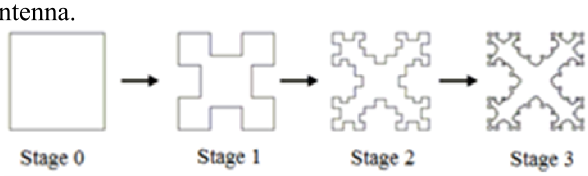

Fig. 5 Construction of Minkowski Curve

Minkowski island fractals can be used to achieve miniaturization in antenna systems while keeping an identical electromagnetic performance to the square loop antenna [9].

3. ADVANTAGES AND DISADVANTAGES

Fractal has many advantages but it has also some disadvantages also they are as under:

3.1 Advantages:

- Compact in size
- Wider bandwidth
- Multiband
- Cost effective
- Improved Reliability
- Frequency independent

3.2 Disadvantages:

- Low gain
- Numerical Limitations
- Complex geometry
- Practically only few iterations are possible to design, after that benefits start to diminish.

4. ULTRA WIDE BAND (UWB)

UWB is one of the most promising technologies for future high data-rate wireless communications, high-accuracy radars, and imaging systems. Compared with conventional narrow-band and wideband wireless communication systems, UWB systems compatible to the emission limit masks regulated by regulation bodies operate with an extremely wide bandwidth in microwave bands. UWB usually refers to a transmission technology for information spread over a large operating bandwidth. Such UWB technology has been developed and employed for decades mostly for military related systems. Since the first Report and Order by the Federal Communications Commission (FCC) authorized the unlicensed use of UWB which must meet the emission masks on February 14, 2002, both industry and academia have paid much attention and effort on R&D of commercial UWB systems [1].

According to the FCC, any transmitting system which emits signals having a bandwidth greater than 500 MHz or 20% bandwidth can gain access to the UWB spectrum.

$$BW = 2\frac{f_H - f_L}{f_H + f_L} \geq 0.2 \text{ and } f_H - f_L \geq 500MHz \quad \ldots..(4)$$

Where fL and fH are the frequencies defining the antenna's operational band.[1]

UWB communication has many advantages over short-distance communication as follows:

1. Higher data rates over large bandwidth (BW) and large channel capacity
2. Better immunity to multipath interference
3. Less complexity and cost
4. Low power consumption

4.1 UWB APPLICATIONS

UWB has many applications in different fields. They are as under:[1]

1. Imaging Systems: Provides for the operation of GPRs and other imaging systems. Imaging systems include:

Ground Penetrating Radar Systems: GPRs must be operated below 960 MHz or in the frequency band 3.1-10.6 GHz. GPRs operate only when in contact with, or within close proximity of, the ground for the purpose of detecting or obtaining the images of buried objects. The energy from the GPR is intentionally directed down into the ground for this purpose.

Wall Imaging Systems: Wall-imaging systems are designed to detect the location of objects contained within a "wall," such as a concrete structure, the side of a bridge, or the wall of a mine.

Through-wall Imaging Systems: Through-wall imaging systems detect the location or movement of persons or objects that are located on the other side of a structure such as a wall.

Surveillance Systems: Although technically these devices are not imaging systems, for regulatory purposes they will be treated in the same way as through-wall imaging systems used by police, fire and rescue organizations and will be permitted to operate in the frequency band 1.99-10.6 GHz. Surveillance systems operate as "security fences" by establishing a stationary RF perimeter field and detecting the intrusion of persons or objects in that field.

Medical Systems: A medical imaging system may be used for a variety of health applications to "see" inside the body of a person or animal.

2. Communications and Measurement Systems: Provides for use of a wide variety of other UWB devices, such as high-speed home and business networking devices. The devices must operate in the frequency band 3.1-10.6 GHz. The equipment must be designed to ensure that operation can only occur indoors or it must consist of hand held devices that may be employed for such activities as peer-to-peer operation.

CONCLUSIONS

This paper described the basics of fractal geometry and from some basic fractal shape like Sierpinski, Minkowski, Koch it is clear that fractal has two main feature i.e. Self-similarity and space filling are two common techniques in designing of Fractal antennas. Self-similarity leads to multiband while the space filling cause the long electrical length. From UWB communication it is clear that it very important for imaging and communication system as it has high speed data rate, low power consumption.

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