Fractal Antennas: A Novel Miniaturization Technique for Next Generation Networks

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***Abstract*— Emerging applications of wireless communication system demand adaptability and unobtrusiveness in antenna system. Besides this, the main constraints in advanced telecommunication systems are performance, size, weight, cost, ease of installation of antenna. One of the successful approaches is "Fractal Antennas". The reason behind popularity of these antennas is their electrically large structure which adjusts very efficiently into compact areas. This paper describes about a review of fractal antenna, its types, generation process and different geometries already used to design antennas.**

***Keywords*— Antennas, Fractals, Multiband Antennas**

I. INTRODUCTION

The term FRACTAL, coined by Benoit B. Mandelbrot (French Mathematician) in 1970's from a Latin word "fractus", means "fractured" or "broken". Certain geometries, which could not be defined using Euclidian geometry like trees, clouds, mountains, coastlines, lightening etc., were termed as fractal after his research on nature's fragmented and irregular geometries [1]. Most of these phenomena are self-similar at different scales and the dimensions are fractional numbers. Mandelbrot defined these geometries as Fractional or Fractal geometries which were called as formless and discarded by many researchers. This geometry has been applied to many fields and results have been found. Fractals have also been combined with electromagnetic theory. Studies in this field found that the radiation pattern using fractals are much better as compared to the traditional antennas. Traditionally, single antenna could work at a single frequency only, meaning

Multi-band operation could be achieved by using multiple antennas only. Nowadays, a single small fractal antenna can be used for multiband performance because of its self similar structure at different scales [2].

A number of fractal shaped antennas have been developed like Sierpinski gasket, Sierpinski Carpet, Koch loop, Cantor slot patch etc. in past years. Implementation of these fractal geometries to antenna arrays has proved to be very useful. In 1986, the Thinned fractal linear and planar array, the first application of fractals to the antenna design, was studied by Kim. After Kim, Werner worked on the same concept in 1996 [3-6]. In 1995, Cohen designed the first antenna element using the Koch monopole and Koch dipole fractal geometry by bending the wire in a systematic way using the concept of fractals. Sierpinski gasket, fractal shape, named after polish mathematician Sierpinski, was designed as antenna by Puente in 1998 [7-9]. Hohlfeld demonstrated that the positions of frequency bands can be changed by changing the scale factor. Later on, Xu designed the fractal tree which could give better results as compared to Sierpinski gasket [10, 11]. Sindou suggested some of the ways to improve the fractal tree. In 2000, Borja demonstrated a new design methodology for Sierpinski microstrip patch antenna. In 2001, Yeo and Gianvittorio studied some other applications of fractals concepts to patch antenna design [12, 13]. In 2002, Gianvittorio and Samii defined the fractals as small space filling geometries, having electrically large length which easily fits into smaller areas. In 2004, Petko presented new design methodologies for fractal tree-shaped antennas and studied their behaviour [14].

In 2005, the various characteristics of Silicon fabricated Sierpinski dipole antenna was studied by Kikkawa and Kimoto. Lui introduced the printed fractal slot antennas [15, 16]. Sachendra N. Sinha considered a new fractal with self-affinity property in 2007. Ananth Sundaram implemented Koch recursion technique on folded Slot antenna [17, 18]. In 2008, Mahdi used Penta-Gasket-Koch approach to introduce a new planar monopole antenna with third iteration) Wen-Ling Chen successfully reduced the size of microstrip patch antennas by combining Sierpinski and Koch fractal shapes [19, 20]. In 2009, Hatem Rmili designed a two dimensional irregular fractal antenna for multiband performance of the antenna measured over 1-30 GHz frequency range. Wen-Ling Chen enhanced the bandwidth of fractal slot antenna by giving Microstrip-line feed to it [21, 22]. Joaquin used heat sink as a fractal antenna and compared the results with patch antenna [23]. In 2011, Nima Bayatmaku designed a new E-shaped fractal antenna with probe feed for Mobile Communication Applications. Javad proposed a Modified fractal Pythagorean Tree for ultra wideband Applications [24, 25]. In 2012, Daotie Li modified an UWB bow-tie antenna with the help of Koch like curve for better radiation at higher frequencies. Han Byul Kim successfully implemented a two port fractal slot (Spidron based) antenna as a gap filler antenna for multifunctional communication [26, 27].

II. TYPES OF FRACTALS

Fractals are classified among two major categories.

A. Deterministic Fractals

The Deterministic fractals consist of those shapes which contain rotated and self-similar copies at different scales. For example: Sierpinski gasket, Sierpinski carpet, Koch curve etc. they are also called Geometric Fractals.

Fig. 1 Sierpinski gasket

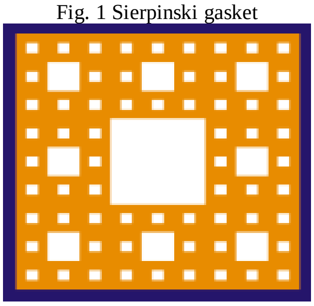

Fig. 2 Sierpinski Carpet

B. Random fractals

The Random fractals consist of those shapes which are statistically self-similar. The natural phenomena like clouds, coastlines, lightening etc falls in this category [28, 29].

Fig. 3 Coastline

Fig. 4 Tree

III. GENERATION PROCESS

Fractal can be defined according to this definition:

A fractal is a set for which the Hausdorff- Besicovich dimension strictly exceeds its topological dimension.

Cohen, the first to design an antenna using fractal concept in 1988, published this work in 1995. Cohen introduced the generation of fractals in a systematic way that the wire should be bent in such a systematic way so that the total length of wire remains same and the size is successively reduced by the implementation of a series of iterations. This concept proved to be very successful for antenna size reduction. It was observed that the multiband property of fractals is due to self-similar nature of these antennas and fractal antennas require very less space as compared to the traditional Euclidian geometry antenna structures. The term Perimeter Compression (PC) is also defined by Cohen.

$$PC = \frac{\text{Full} - \text{size antenna element length}}{\text{Fractal reduced antenna element length}} \quad (1)$$

According to Cohen, the radiation resistance of antennas based on fractals reduces as a small power of perimeter compression and the fractal concept help to improve the antenna efficiency gain [30, 31].

Fractals are generated using successive iteration method. So, the fractals have infinite complexity. As far as, they are zoomed-in it can be found that each small part is the scaled-down copy of the whole structure. Puente studied that the resonant frequency of antenna can be reduced by increasing the fractal iteration and it can also be shifted by increase in fractal iteration [32, 33].

The Hausdorff- Besicovitch formula explains the fractal dimension (D) as:

$$D = \frac{\log(N)}{\log(s)} \quad (2)$$

The formula for total length (l) is as follows:

$$l = h\left(\frac{N}{s}\right)^n \quad (3)$$

Where, N is the number of segments of geometry, s is the no. the segment is divided on each iteration, h is curve height, n is no. of iterations [34].

IV. FRACTAL GEOMETRIES

There are certain fractal geometries which have been successfully applied into antenna design.

A. Koch Fractal curve

The Koch curve was firstly introduced by a Swedish mathematician, H. V. Koch. The main aim was to achieve a continuous curve which does not have a tangent. Koch curve has infinite complexity as well as detail.

Puente also studied the results of Koch Fractal antenna and found that with the increase in total length of the wire, the input resistance of antenna can be increased and resonant frequency can be reduced. Koch curve can be generated by the use of iterated function system [35-37].
Three iterations of Koch fractal are shown in Figure 5.
The fractal dimension (D) for the Koch curve is given by the Hausdorff- Besicovitch formula as:

$$D = \frac{\log(4)}{\log(3)} \quad (4)$$

The formula for total length (l) is as follows:

$$l = h\left(\frac{4}{3}\right)^n \quad (5)$$

Where, h is curve height & n is no. of iterations.

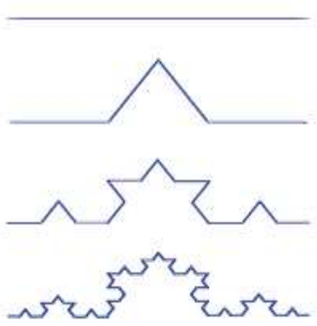

Fig. 5 Koch fractal curve

B. Minkowski Curve

The Minkowski curve was firstly suggested by Hermann Minkowski, a German mathematician. This is based on iterative process. Minkowski curve has very good performance at resonant frequencies. Minkowski curve has eight side generator, because of this Minkowski curve is electrically very long but fits into very compact area [36, 37].

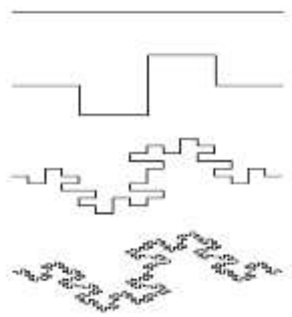

Fig. 6 Minkowski Curve

Figure 6 shows the three iterations of Minkowski curve. Fractal dimension (D) for Minkowki curve is given as:

$$D = \frac{\log(8)}{\log(4)} \quad (6)$$

The formula for total length (l) is as follows:

$$l = h\left(\frac{8}{4}\right)^n \quad (7)$$

Where, h is curve height & n is no. of iterations.

C. Sierpinski triangle

Sierpinski triangle, also known as Sierpinski gasket was first introduced by Sierpinski, a polish mathematician in 1916. The gasket can be obtained by subtracting the scaled down inverted triangle from the main triangle and final gasket is obtained using iterative process. The multiband Sierpinski fractal antenna was firstly introduced by C. Puente in 1996. He demonstrated that by changing the flare angle, scaling factor and total height of antenna the performance of antenna can be improved. Hohlfeld, in 1999, demonstrated that by changing the value of scaling factor the positions of frequency bands can be changed [38,39]. The fractal dimension (D) for Sierpinski triangle is given as:

$$D = \frac{\log(3)}{\log(2)} \quad (8)$$

The formula for total length (l) is as follows:

$$l = h\left(\frac{3}{2}\right)^n \quad (9)$$

Where, h is curve height & n is no. of iterations.

Fig. 7 Sierpinski triangle

D. Cohen- Minkowski Geometry

The first fractal antenna was given by N. Cohen. Cohen worked on various fractal geometries. Cohen-Minkowski is one of those geometries.

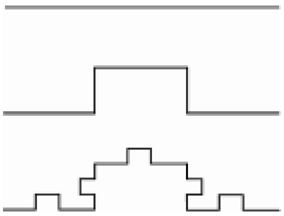

Fig. 8 Cohen- Minkowski Curve

The above figure shows two iterations of Cohen- Minkowski curve.

The fractal dimension (D) for this geometry is given as:

$$D = \frac{\log(5)}{\log(3)} \quad (10)$$

The formula for total length (l) is as follows:

$$l = h\left(\frac{5}{3}\right)^n \quad (11)$$

Where, h is curve height & n is no. of iterations.

V. CONCLUSION

The self-similar structures can be used as multiband antennas. The current density distribution, radiation efficiency, resonant frequency, bandwidth, Radiation resistance and Quality factor of the fractals can be improved by total length of the antenna and hence changing the wavelength. The field of fractals is still in early stages of development and getting advanced day by day. These days, fractal antennas are modified to achieve omnidirectional radiation patterns with high efficiency and good gain.

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