# FRACTAL ANTENNAS: DESIGN, CHARACTERISTICS AND APPLICATION

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**Abstract:** This report will describe the theories and techniques for shrinking the size of an antenna through the use of fractals. Fractal antennas can obtain radiation pattern and input impedance similar to a longer antenna, yet take less area due to the many contours of the shape. Fractal antennas are a fairly new research area and are likely to have a promising future in many applications.

**Keywords:** Numerical integration, Moments Method.

## INTRODUCTION

In today world of wireless communications, there has been an increasing need for more compact and portable communications systems. Just as the size of circuitry has evolved to transceivers on a single chip, there is also a need to evolve antenna designs to minimize the size. Currently, many portable communications systems use a simple monopole with a matching circuit. However, if the monopole were very short compared to the wavelength, the radiation resistance decreases, the stored reactive energy increases, and the radiation efficiency would decrease. As a result, the matching circuitry can become quite complicated. As a solution to minimizing the antenna size while keeping high radiation efficiency, fractal antennas can be implemented. The fractal antenna not only has a large effective length, but the contours of its shape can generate a capacitance or inductance that can help to match the antenna to the circuit. Fractal antennas can take on various shapes and forms. For example, a quarter wavelength monopole can be transformed into a similarly shorter antenna by the Koch fractal.

## FRACTAL DIPOLE ANTENNAS- KOCH FRACTAL

The expected benefit of using a fractal as a dipole antenna is to miniaturize the total height of the antenna at resonance, where resonance means having no imaginary component in the input impedance. The geometry of how this antenna could be used as a dipole is shown in Fig 1.

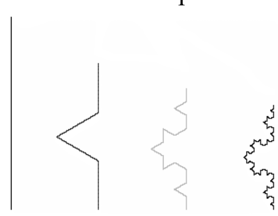

**Fig. 1**- Geometry of Koch dipole

A Koch curve is generated by replacing the middle third of each straight section with a bent section of wire that spans the original third. Each iterations adds length to the total curve which results in a total length that is 4/3 the original geometry:

$$Lenght_{Koch} = h \cdot (\frac{4}{3})^{n} \tag{1}$$

The miniaturization of the fractal antenna is exhibited by scaling each iteration to be resonant at the same frequency. The miniaturization of the antennas shows a greater degree of effectiveness for the first several iterations. The amount of scaling that is required for each iteration diminishes as the number of iterations increase. The total lenght of the fractals at resonance is increasing, while the height reduction is reaching an asymptote. Therefore, it can be concluded that ihe increased complexity of the higher iterations are not advantageous. The miniaturization benefits are achieved in the first several iterations ( Fig. 2).

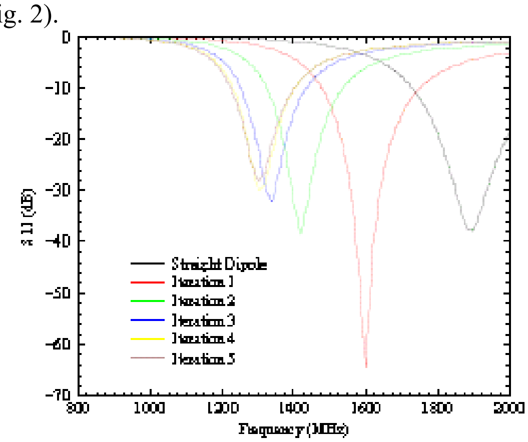


**Fig.2-**Miniaturization benefits

Far field directivity pattern for Koch dipoles of different fractal iterations is shown in Fig. 3.

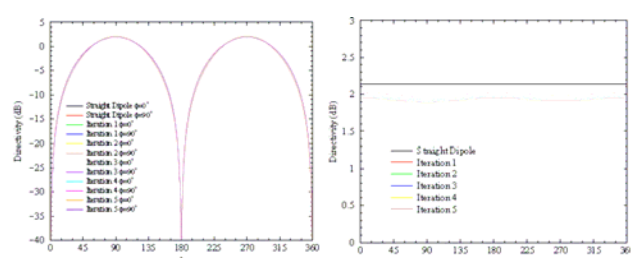


**Fig. 3**- Far field directivity pattern for Koch dipole

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## FRACTAL LOOPS

Loop antenas are well understood and have been studied using a variety of Euclidean geometry. The have distinct limitations, howeever. Resonant loop antennas require a large amount of space and small loops have very low input resistance. A fractal island can be used as a loop antenna to overcome these drawbacks. Two possible fractals fed as loop antennas are depicted in Fig. 4.

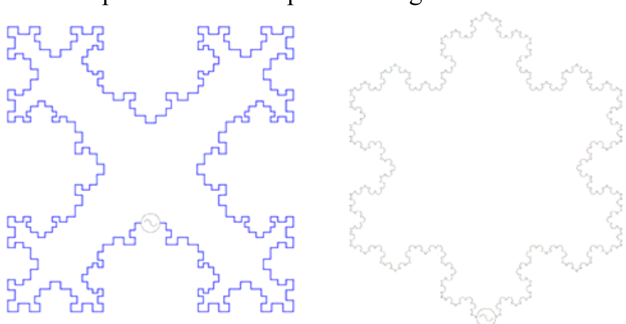

**Fig. 4**-Two possible fractal loop antennas

Fractals loops have the characteristic that the perimeter increases to infinity while maintaining the volume occupied. This increase in length decreases the required volume occupied for the antenna at resonance. For a small loop, this increase in length improves the input resistance. By raising the input resistance, thye antenna can be more easily matched to a feednig transmission line.

## KOCH LOOP

The starting pattern for the Koch loop that is used as a fractal antenna is a triangle. From this starting pattern, every segment of the starting pattern is replaced by the generators. The first four iterations are shown in Fig. 5. The starting pattern is Euclidan and, therefore, the process of replacing the segment with the generator constitutes the first iteration.

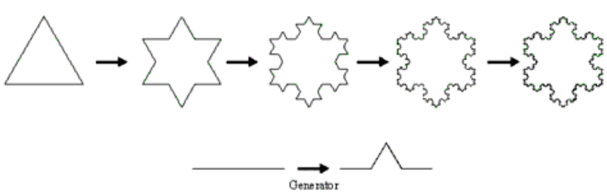


**Fig. 5-** First four iterations of Koch loop

The area of the fourth iteration of the fractal loop, which is a key parameter for small loop antennas, with radius R, is given by,

$$Area_{Koch\ loop} = (1+\frac{3}{9}+\frac{12}{81}+\frac{48}{729}+\frac{192}{6561})\frac{1}{2}\frac{3\sqrt{3}}{2}r^2 = \quad (2)$$

The area of a circle is given by

$$Area_{Circular\ loop} = \pi r^2 \quad (3)$$

Therefore, if the two areas are compared:

$$\frac{Area_{Koch\ loop}}{Area_{Circular\ loop}} = 0.65 \quad (4)$$

It can be seen that the area of the fourth iteration of the Koch loop is 35% smaller than a circumscribed circle. The permiter of the fourth iteration of a Koch loop is given by

$$Perimeter_{Koch\ loop} = 3\sqrt{3}r(\frac{4}{3})^n \quad (5)$$

$$Perimeter_{Koch\ loop} = 16.42r \quad (6)$$

The circumference of a circle is:

$$Perimeter_{Circular\ loop} = 2\pi r \quad (7)$$

Therefore, the perimeter of a fourth iteration Koch loop is 2.6 times longer than a circumscribed circular loop.

$$\frac{Perimeter_{Koch\ loop}}{Perimeter_{Circular\ loop}} = 2.614 \quad (8)$$

Input resistances, with regarding to perimeter, are compared and shown in Fig. 6.

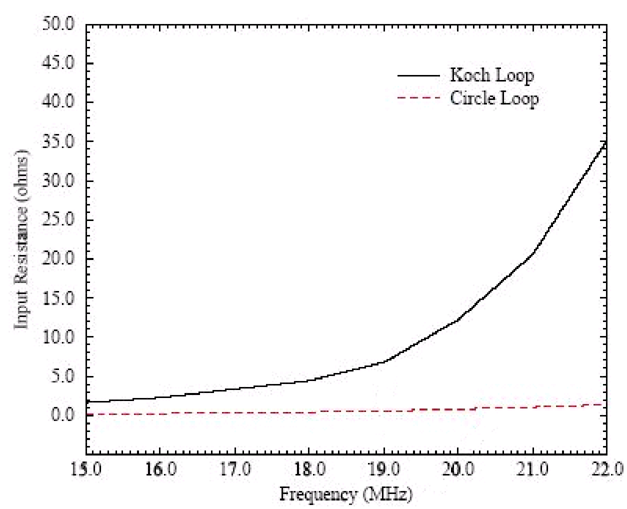


**Fig. 6-** Input resistances, with regarding to perimeter

## MINKOWSKI LOOP

Minkowski loop (Fig. 7) 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 analyzed, where the perimeter is near one wavelength. Several iterations are compared with a square loop antenna to illustrate the benefits of using a fractal antenna.

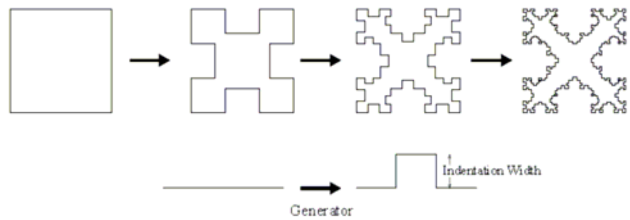


**Fig. 7**- First three iterations of Minkowski loop

Far field patterns for resonant fractal loop antennas for various indentation widths and fractal iterations as computed by the moment method. The pattern cut is orthogonal to the plane of the loop (Fig. 8).

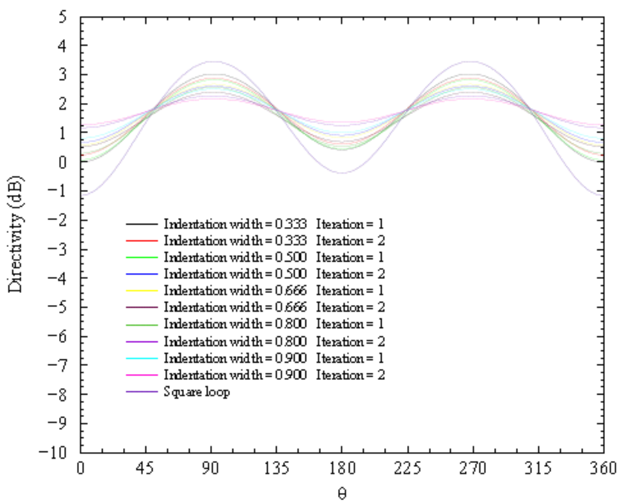


**Fig. 8-** Far field patterns for resonant fractal loop antennas

Fig. 9 shows scaling factor for the various indentation widths versus the fractal dimension.

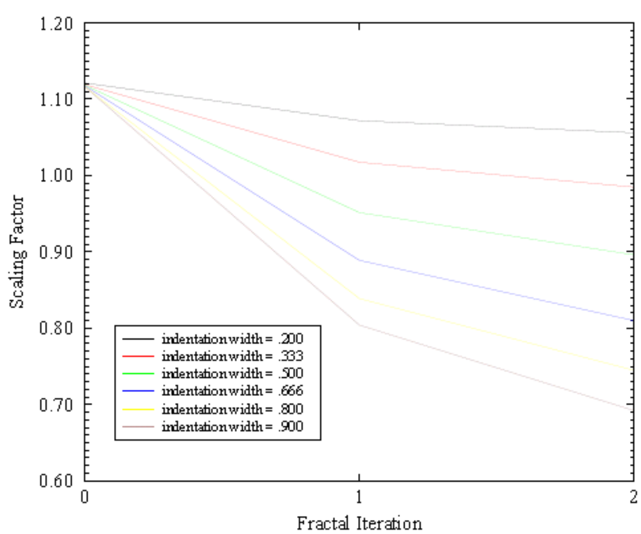


**Fig. 9**- Scaling factor versus fractal dimension

## SIERPINSKI SIEVE

So far, only the space saving benefits of fractal antennas have been exploited. There is another property of fractals that can be utilized in antenna construction. Fractals have self-similarity in their geometry, which is a feature where a section of the fractal appears the same regardless of how many times the section is zoomed in upon. Self-similarity in the geometry creates effective antennas of different scales. This can lead to multiband characteristics in antennas, which is displayed when an antenna operates with a similar performance at various frequencies. The generation of the fractal is hown in Fig. 10. A Sierpinski sieve dipole can be easily compared to a bowtie dipole antenna, which is the generator to create the fractal. The middle third triangle is removed from the bowtie antenna, leaving three equally sized triangles, which are half the height of the original bowtie. The process of removing the middle third is then repeated on each of the new triangles. For an ideal fractal, this process goes on for an infinite number of times.

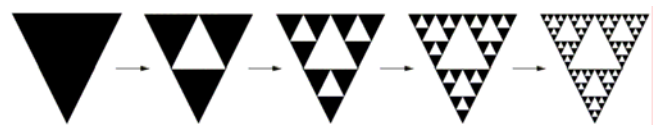

**Fig. 10-** Generation of Sierpinski sieve

The antennas were analyzed using the moment method for computing reflection coefficient (Fig. 11).

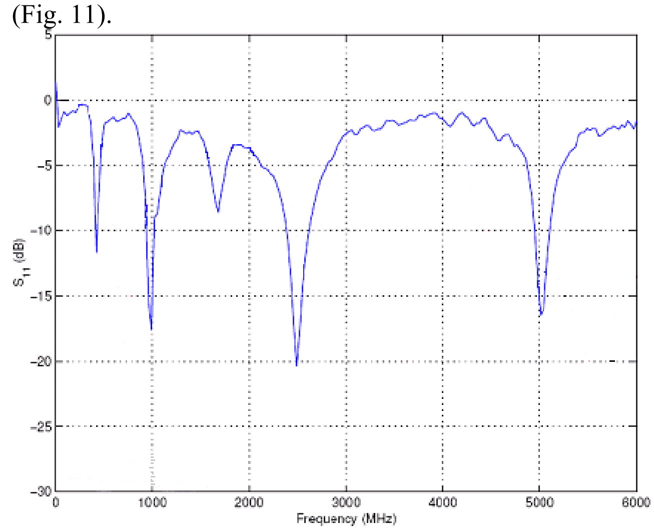


**Fig. 11**- Reflection coefficient compared to frequency

These three resonances relate to the three sizes of the bowtie antennas and the three self-similar sizes inside the Sierpinski antennas. Each resonance is approximately twice that of the one before. This is what would be intuitively expected knowing that the self-similar features of the geometry are scaled by a factor of two for each iteration. The benefits of the multiband behavior can be seen in the far field pattern plots for these antennas. The far field patterns for the antennas at their first, second, and third resonances are shown in Fig. 12, Fig. 13 and Fig. 14.

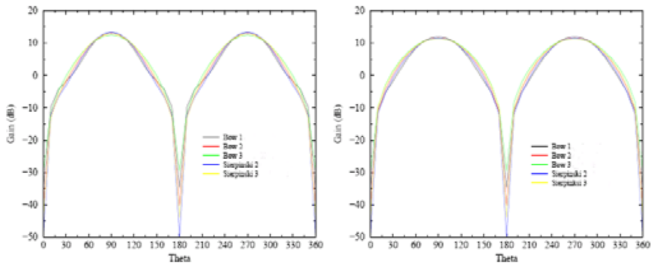


**Fig. 12**- Far field pattern (first resonances)

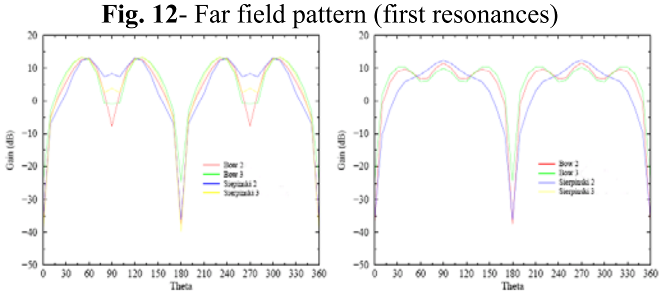


**Fig. 13**- Far field pattern (second resonances)

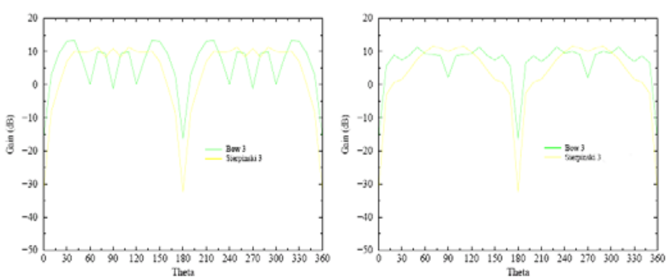


**Fig. 14**- Far field pattern (third resonances)

## APPLICATIONS OF FRACTAL ANTENNAS

There are many applications that can benefit from fractal antennas. Discussed below are several ideas where fractal antennas can make an real impact. The sudden growth in the wireless communication area has sprung a need for compact integrated antennas. The space saving abilities of fractals to efficiently fill a limited amount of space create distinct advantage of using integrated fractal antennas over Euclidean geometry. Examples of these types of applications include personal hand-held wireless devices such as cell phones and other wireless mobile devices such as laptops on wireless LANs and networkable PDAs.

Fractal antennas can also enrich applications that include multiband transmissions. This area has many possibilities ranging from dual-mode phones to devices integrating communication and location services such as GPS, the global positioning satellites. Fractal antennas also decrease the area of a resonant antenna, which colud lower the radar cross-section (RCS). This benefit can be exploited in military applications where the RCS of the antenna is a very crucial parameter.

## ADVANTAGES AND DISADVANTAGES

Advantages of fractal antenna technologie are:

- minituratization
- better input impedance matching
- wideband/multiband (use one antenna instead of many)
- frequency independent (consistent performance over huge frequency range)
- reduced mutual coupling in fractal array antennas

Disadvantages of fractal antenna technologie are:

- gain loss
- complexity
- numerical limitations
- the benefits begin to diminish after first few iterations

## CONCLUSION

Many variations of fractal geometries have been incorporated into the design of antennas. Further work is required to get an understanding of the relationship between the performance of the antenna and the fractal dimension of the geometry that is utilized in its construction. This requires two curses of action. The first course of action requires that many more examples of fractal geometries are applied to antennas. The second crucial course of action is to attain a better understanding of the fractal dimension of the geometries such that correlations can be drawn about this dimension and the performance of the antenna. Also important is that the design of the antenna approaches an ideal fractal as much as possible. Several iterations can be studied to understand the trends that govern the antenna to better understand the physics of the problem.

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**Dr. Mićo Gaćanović** was born in 1952. He is recognized and known internationally as a scientist in the field of applied electrostatics, where he has given his contribution through original solutions, which are patented in 136 countries throughout the world and applied in production. He received many prestigious world-known awards and certificates for his creative work. Hence, he is included in the work of world groups of creativity, research and new technology in Brussels, Moscow, Pittsburgh and other world cities. He is also involved in research projects from the field of theoretical electrical engineering in Germany, Belgium and Russia.