A New Ultra Wideband Fractal Monopole Antenna

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Abstract **—** Ultra wideband antennas are used greatly in commercial and military communication systems. A reduction in physical size and multi-band capability are very important in the design of ultra wideband antennas. The use of fractal geometry in antenna design provides a good method for achieving the desired miniaturization and multi-band properties.

In this paper, a compact, multi-band, and broad-band antenna based on new fractal geometry is designed, simulated, and measured. The proposed design is achieved by applying the 2nd iteration of a new fractal geometry to a wire monopole antenna. A numerical electromagnetics simulation is performed using SuperNEC electromagnetic simulator software. The results show that the proposed antenna can be used for 6 GHz – 30 GHz frequency range. Radiation patterns are also studied.

Index Terms **—** Bandwidth, fractals, fractal antenna, ultra wideband.

I. INTRODUCTION

One of the essential requirements of wireless systems is a low profile and multi-band antenna. Ultra wideband (UWB) wireless systems require antennas with more bandwidth and smaller dimensions. A fractal geometry is a very good solution to fabricate these antennas. Traditional UWB antennas are based on quarter-wavelength elements, which require different antenna elements for different frequency bands. Applying fractals to antenna elements allows for smaller size, multi-band, and broad-band properties. This is the cause of widespread research on fractal antennas in recent years [1-4].

Fractals have self-similar shapes and can be subdivided in parts such that each part is a reduced size copy of the whole. The self-similarity of fractals makes it possible to design antennas with UWB performance. Fractal geometries have complex and convoluted shapes such that these discontinuities increase bandwidth and the effective radiation of antennas. Also, the space-filling property of fractals leads to curves which have long electrical length but fit into a compact physical volume. This property can be utilized to miniaturize antenna elements [5-10].

Several wire antenna configurations based on fractal geometries have been investigated including Koch, Minkowski, Hilbert, and fractal tree antennas in recent years. These antennas have been simulated using the moment method, as well as fabricated and measured. The simulation and experimental results of these antennas are available in literature to date.

The Koch fractal curve is one of the most well-known fractal shapes. In this paper, a new fractal geometry that looks similar to the Koch fractal geometry is presented. By applying this fractal generator to a wire monopole antenna, we have achieved an ultra wideband antenna. The huge bandwidth is the main advantage of this fractal antenna over conventional fractal antennas.

The moment method based electromagnetic simulator SuperNEC has been used for the design and simulation of the proposed antenna. According to the results, this new fractal monopole antenna is multi-band, and broad-band

and is applicable between 6 GHz - 30 GHz frequency range. Also, the radiation patterns are studied at multi frequencies.

This paper is arranged in four sections. Design of proposed antenna is discussed in Section II. Simulated and measured results are presented in Section III and the conclusions are summarized in Section IV.

II. ANTENNA STRUCTURE

The most well-known fractal antenna is Koch antenna such that the various types of it, are used greatly in telecommunication systems. In initial process of this project, many designs and simulations are performed over fractal antennas. The various types of fractal antennas are considered and finally a new fractal shape is introduced because of its good performances in bandwidth and radiation patterns.

The geometric configuration of this new fractal curve starts with a straight line, called the initiator, which is shown in Fig. 1 (n=0). This is partitioned into four equal parts, and the two centric segments are replaced with four others of the same length with the indentation angle θ = 60° which is shown in Fig. 1 (n=1). This is the first iterated version of the new fractal geometry and is called the generator. The process is repeated in the 2nd iteration which is shown in Fig. 1 (n=2).

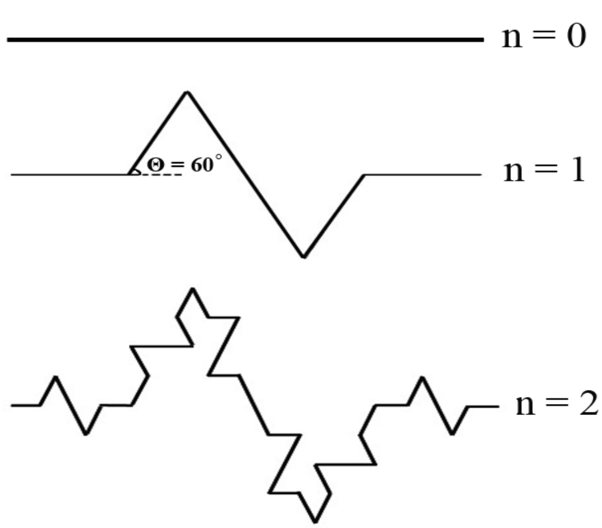

Fig. 1. Iterations of the proposed fractal geometry.

Each segment in the first iteration (generator) is ¼ the length of the initiator. There are six such segments. Thus for the nth iteration, the length of the curve is $(6/4)^n$.

An iterative function system (IFS) can be defined to generate the generator. A 3×3 matrix must be defined for each segments of the generator. The length of each segment is a quarter of straight line and the indentation angle is 60˚. Thus, the transformations to achieve the segments of the generator are:

$$W_1=\begin{bmatrix}\frac{1}{4} & 0 & 0\\ 0 & \frac{1}{4} & 0\\ 0 & 0 & 1\end{bmatrix},$$

$$W_2=\begin{bmatrix}\frac{1}{4}\cos 60^\circ & -\frac{1}{4}\sin 60^\circ & \frac{1}{4}\\ \frac{1}{4}\sin 60^\circ & \frac{1}{4}\cos 60^\circ & 0\\ 0 & 0 & 1\end{bmatrix},$$

$$W_3=\begin{bmatrix}\frac{1}{4}\cos 60^\circ & \frac{1}{4}\sin 60^\circ & \frac{3}{8}\\ -\frac{1}{4}\sin 60^\circ & \frac{1}{4}\cos 60^\circ & \frac{1}{4}\sin 60^\circ\\ 0 & 0 & 1\end{bmatrix},$$

$$W_4=\begin{bmatrix}\frac{1}{4}\cos 60^\circ & \frac{1}{4}\sin 60^\circ & \frac{1}{2}\\ -\frac{1}{4}\sin 60^\circ & \frac{1}{4}\cos 60^\circ & 0\\ 0 & 0 & 1\end{bmatrix},$$

$$W_5=\begin{bmatrix}\frac{1}{4}\cos 60^\circ & -\frac{1}{4}\sin 60^\circ & \frac{5}{8}\\ \frac{1}{4}\sin 60^\circ & \frac{1}{4}\cos 60^\circ & -\frac{1}{4}\sin 60^\circ\\ 0 & 0 & 1\end{bmatrix},$$

$$W_6=\begin{bmatrix}\frac{1}{4} & 0 & \frac{3}{4}\\ 0 & \frac{1}{4} & 0\\ 0 & 0 & 1\end{bmatrix}. \tag{1}$$

The generator is then achieved as:

$$W(A)=W_1(A)\cup W_2(A)\cup W_3(A)\cup W_4(A)\cup W_5(A)\cup W_6(A) \tag{2}$$

This process can be repeated for higher iterations of this fractal geometry. The similarity dimension of this geometry can be calculated as:

$$D = \frac{\log 6}{\log 4} = 1.29248 \ . \quad (3)$$

This is due to the observation that at each iteration there are six equal copies of the original geometry that are scaled down by a factor of 4. Therefore, this amount is more than the similarity dimension of Koch geometry.

The proposed design is based on a loaded 2nd iteration of the new generator to a wire monopole antenna. If the length of monopole is assumed to be *"X"*, by applying the 2nd iteration of this generator, the length will be $X \times (6/4)^2$.

In this paper, we have supposed the length of monopole is 3.2 cm and 1 mm in diameter. Therefore, the length of the fractal curve is $3.2 \times (6/4)^2 = 7.2cm$.

The structure of this fractal monopole antenna is shown in Fig. 2.

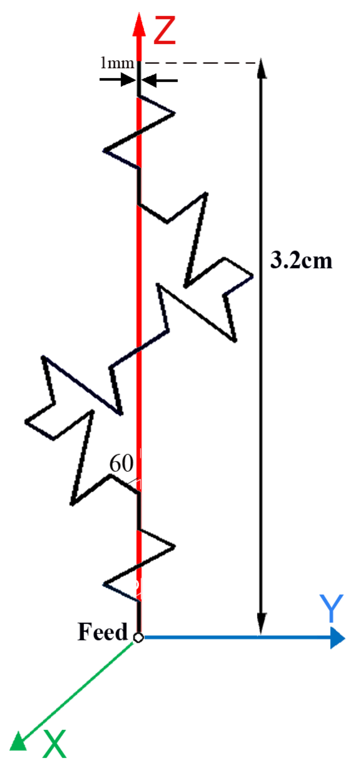

Fig. 2. Antenna structure.

The fractal antenna is made by copper and vertically installed above a ground plane which is from aluminum metal. The proposed structure has a physical dimensions of 32 × 16 mm². The fabricated fractal monopole antenna is shown in Fig. 3.

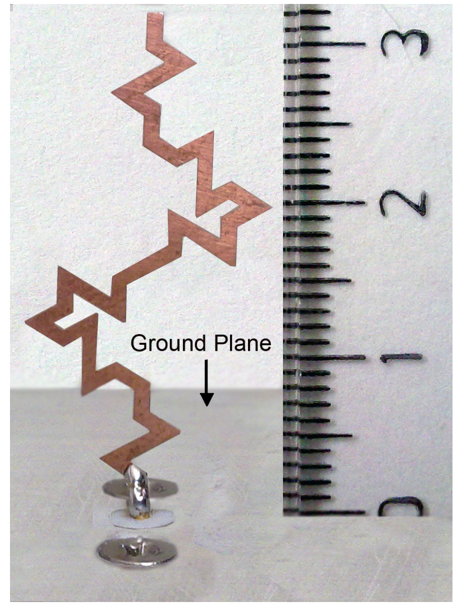

Fig. 3. Photograph of the fractal antenna prototype.

III. SIMULATION AND MEASUREMENT RESULTS

The MoM (method of moments) is a very powerful technique which can be applied to the analysis of complicated geometries such as fractal structures. MoM is used for simulation of this antenna based on the SuperNEC electromagnetic simulator software. One starts with defining the antenna structure for the software, then specifying the feed location. The wire conductivity of all conductors is assumed to be 5.7E7. Also, the ground plane is assumed perfect. The voltage source is 1 volt and the frequency range is from 5 GHz – 30 GHz.

Figure 4 shows the simulated and measured reflection coefficient versus frequency.

According to the input reflection coefficient, this UWB antenna is applied in 6 - 30 GHz frequency range and can be matched with a 50 Ω coaxial cable. So, the bandwidth of this structure is more than the variations of the Koch monopole antennas.

To study the radiation pattern, Figure 5 presents the radiation patterns for three frequencies, including 8 GHz, 15 GHz, and 20 GHz for the *x-y*, *x-z*, and *y-z* planes.

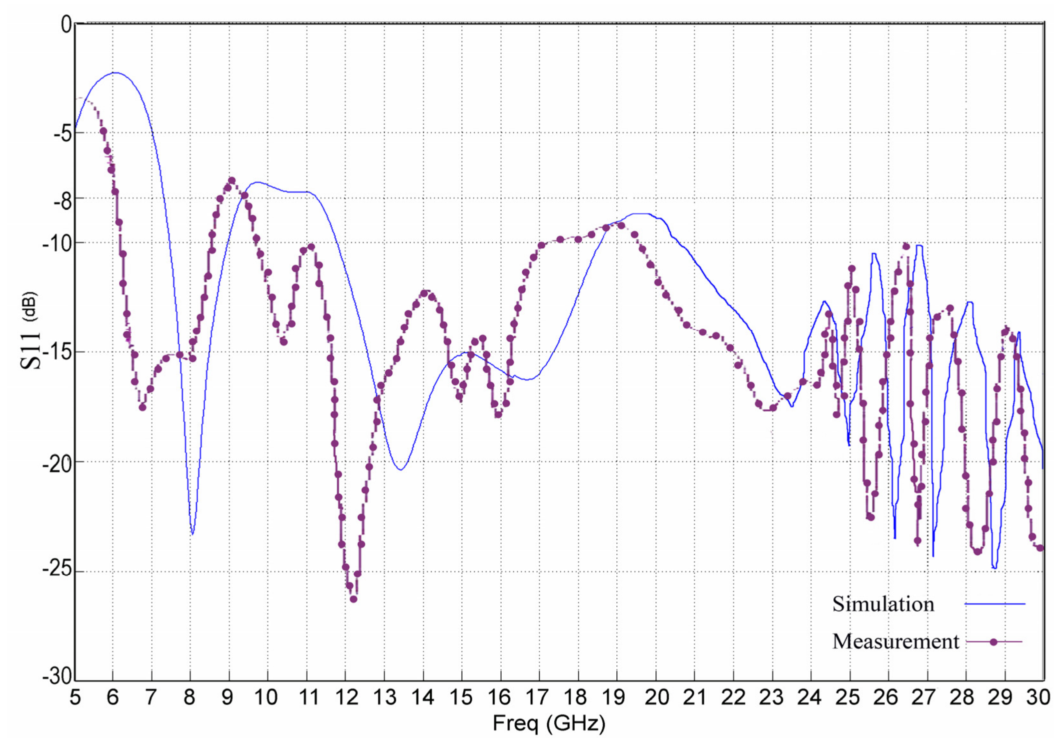

Fig. 4. The simulated and measured S_{11}.

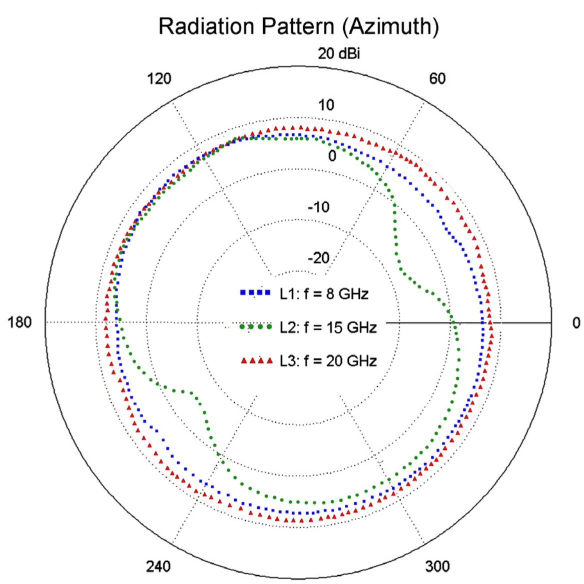

Fig. 5a. Radiation Patterns (x-y plane).

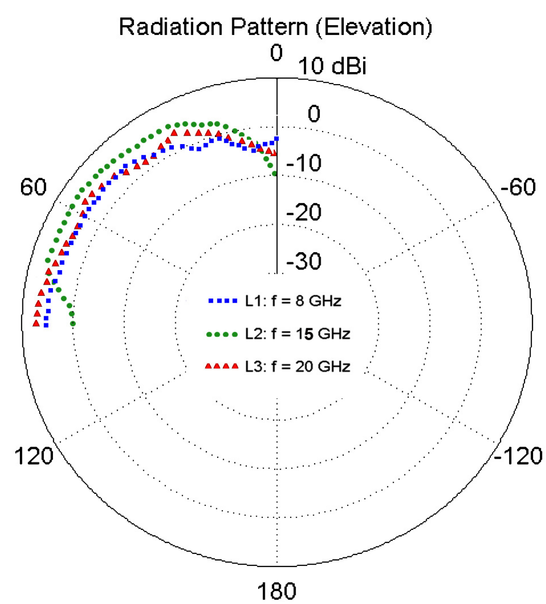

Fig. 5b. Radiation Patterns (x-z plane).

It can be observed that the antenna provides a nearly omnidirectional pattern over the desired frequency bandwidth.

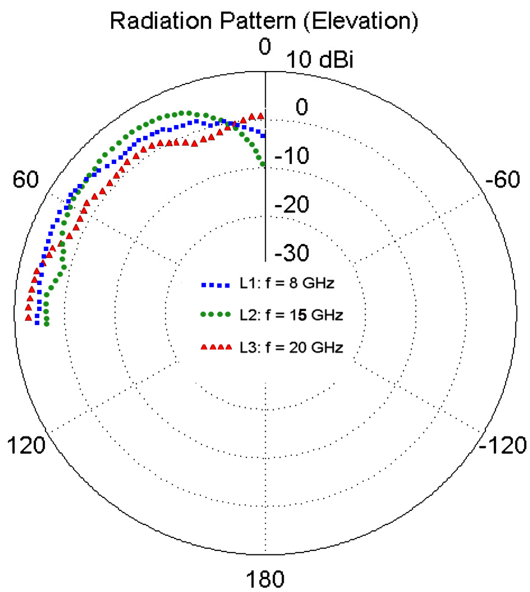

Fig. 5c. Radiation Patterns (*y-z* plane).

IV. CONCLUSION

Fractals have been used to achieve miniaturization and multi-band operation in antenna systems. Fractal geometries have miniaturized antenna elements. It has also been used in the design of multi-band antennas.

The unique fractal monopole antenna was simulated and fabricated, with similar results in the modeled and measured performance. The proposed antenna has a compact structure, a second iteration of a new fractal geometry, and measuring only 3.2 × 1.6 cm^2 when fabricated. Simulations show usable performance from 6 to 30 GHz. Measurements and fabrication show that the antenna works according to predictions, is simple to design, and is relatively easy to construct.

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