Design and Analysis of Miniature Fractal Antenna

Ying Suo[1,2], Jingyu Han[1], Wei Li[1,2], and Weibo Deng[1]

[1]School of Electronics and Information Technology
Harbin Institute of Technology, Harbin 150001, China
[2]Electronic Science and Technology Postdoctoral Station
Harbin Institute of Technology, Harbin 150001, China

Abstract— Fractal antenna designs can meet most of the needs in size reduction of antenna design. In this paper, Koch iteration technique is applied to a dipole antenna in order to get a miniaturized radar array element. The dipole antenna with 3rd Koch iteration applied to each of its four segments is designed to operate at a resonant frequency of 500 MHz. The four fractal segments of this antenna spin around the center axis with an angle difference of 90 degrees each, which results to an all-four-direction feature. The overall size of this dipole fractal antenna at the resonant frequency is reduced by around 33% compared with conventional dipole antenna meanwhile retaining its band characters. An improved model is also introduced with a better performance in bandwidth, which can reach more than 12% at 500 MHz.

1. INTRODUCTION

The fractal iteration technique has drawn much attention since its first introduction in 1973 by B. B. Mandelbrot. Among these fractal types, Koch curve has a wide application in the design of miniaturized wire antenna due to its unique self-similarity nature [1]. Under the expanding need of size reduction in antenna design, fractal theory can help provide a great number of solutions for miniaturized antenna [2]. This paper presents the calculation and design of a fractal dipole antenna with an operating frequency of 500 MHz. The creation and optimization of this dipole antenna model using proper fractal dimension is carried out and analyzed according to the effects of miniaturization. The results from simulations and analysis are done in FEKO software environment.

2. ANTENNA DESIGN

2.1. Generation of Koch Fractal Curve

Koch curve as shown in Figure 1 is a simple but effective fractal geometry in the application of wire antenna miniaturization [3]. One of the mathematical approaches that contributes to the modeling of Koch fractal antenna is Iterated Function System (IFS). IFS is in fact an affine transformation cluster which can perfectly match the self-similarity character of fractal patterns [4].

In order to generate a mathematical model of Koch fractal curve, we use IFS method to calculate the exact coordinates of those endpoints on the corresponding curve. Matlab is used in this section of the research to help do iteration calculations and draw the figure. It first determines the trisection points, then make a rotation with a certain angle around those points to make one iteration. Repeat these steps and we can finally get an N-iterated Koch curve, of which the dimension also has a great effect on performance of the antenna [5].

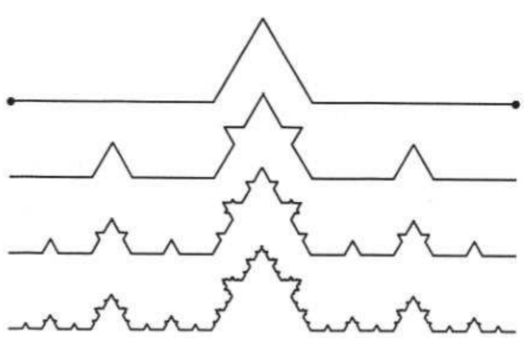

Figure 1: Koch fractal curve.

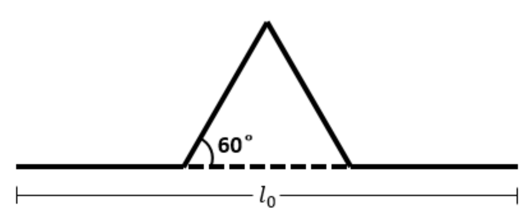

Figure 2: Schematic diagram of single Koch iteration.

2.2. Dimensions of Koch Curve

One of the most significant features of Koch fractal curve is its infinite length. The more iteration applied to the curve, the longer the curve will be. However, when it comes to antenna design, there is always a most suitable dimension of the curve. The relationship between its total length and its initial length is shown below [7].

$$L = (4/3)^n \cdot l_0 \tag{1}$$

L: Total length of the Koch curve.

l_0: Initial length of the Koch curve.

n: Fractal dimension (Iteration times).

This size reduction character of Koch curve helps greatly in the process of antenna miniaturization. According to latest researches, the most ideal iteration times for Koch curve in antenna design is 3rd iteration. When Koch curve is applied iteration three times, it gets a satisfying size reduction feature meanwhile maintain its excellent electrical characteristics [6].

2.3. Antenna Calculation and Modeling

As shown in Figure 3, Koch fractal antenna is composed of two identical wires with pre-designed Koch curve pattern. The feed point is at the connection point between these two parts, which is also the geometric center of the whole antenna.

Considering the unique geometry features of Koch fractal dipole, a transformed Koch dipole antenna is proposed and the diagram is shown in Figure 4.

This Koch fractal dipole antenna design features a four-direction spinning character. The antenna is composed of four identical 3rd iteration Koch curve segments that have a 90 degrees angle between each other, which all spin around the central axis.

The designated resonant frequency of this antenna is 500 MHz. According to equation

$$\lambda = c/f \tag{2}$$

working wave length should be 0.6 m. Then each of the four segments should have an effective length of $0.3\,\text{m}/4 = 0.075\,\text{m} = 7.5\,\text{cm}$. Using Equation (1) we can get the initial length of each segment which is calculated and designed to be around 4.96 cm. The total height of this antenna is 19.845 cm.

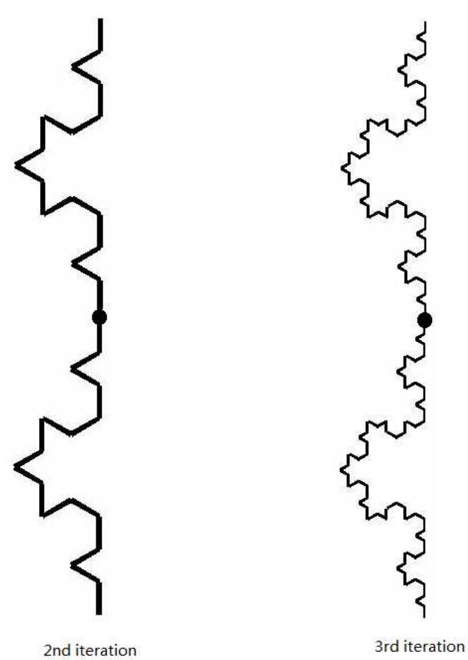

Figure 3: Koch fractal dipole antenna.

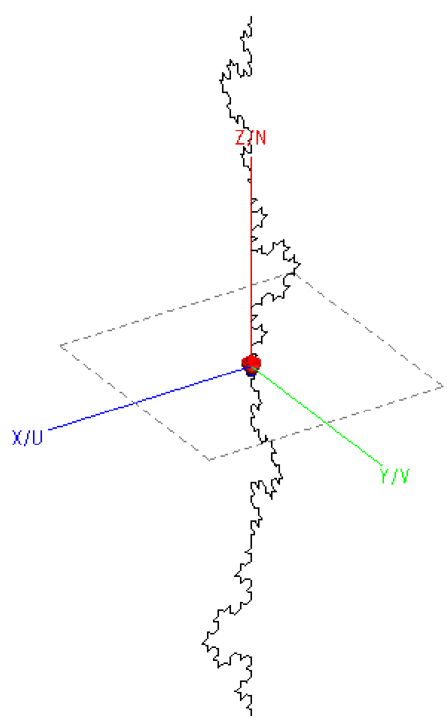

Figure 4: Spinning Koch dipole design.

After the size is decided, the whole antenna model is calculated in MATLAB environment. And the coordinates are imported into FEKO to assemble the wire antenna, after which simulations are done in FEKO environment.

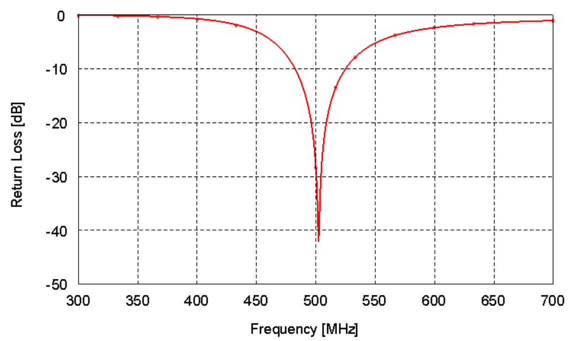

Figure 5: Simulated return loss of designed Koch fractal dipole.

Table 1: Comparison between conventional and Koch dipole.

Antenna	Conventional	Koch Fractal
Length	30 cm	19.845 cm
Resonant Frequency	500 MHz	502 MHz
Return loss	−16 dB	−42 dB
Bandwidth	8%	8.3%
Compactness	-	66.15%

3. RESULTS AND DISCUSSION

3.1. Return Loss

Figure 5 shows the simulation results of return loss for this Koch fractal dipole antenna in the frequency range from 300 MHz to 700 MHz. The measurement at the valley shows that the resonant frequency is at about 502 MHz, where the return loss is at the minimum value of −41.8 dB.

The bandwidth of this antenna is the frequency bandwidth where its return loss is below −10 dB. According to this simulation result, the bandwidth of this antenna is around 8.3%.

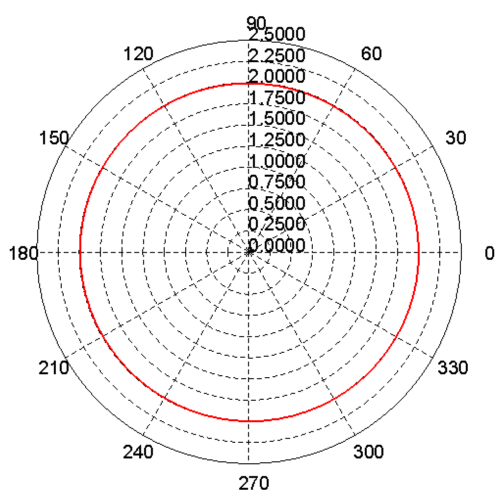

Figure 6: Radiation pattern in Azimuth plane.

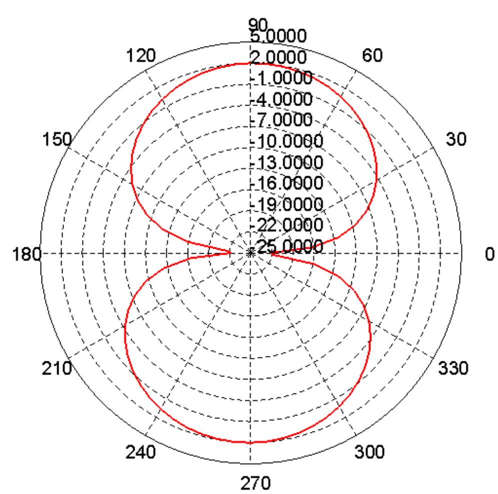

Figure 7: Radiation pattern in Meridian plane.

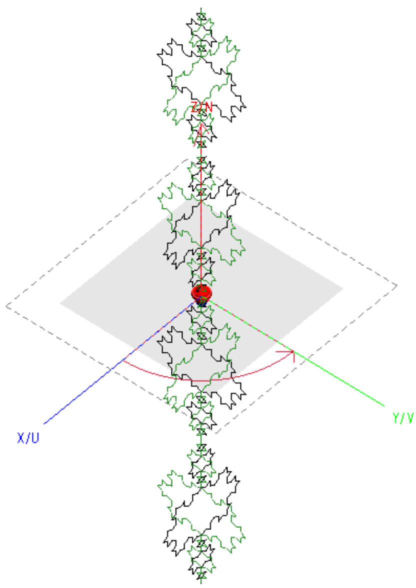

Figure 8: Improved antenna model with better bandwidth.

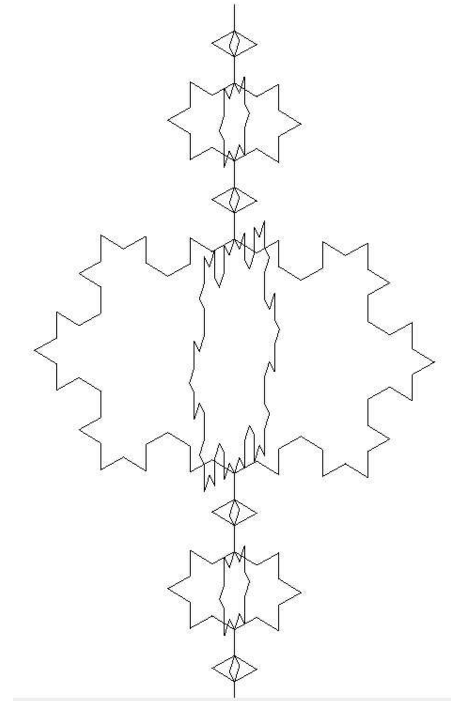

Figure 9: Zoomed structure of improved model.

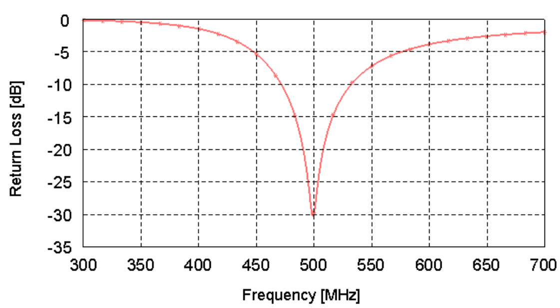

Figure 10: Simulated return loss of improved model.

3.2. Radiation Pattern

Figure 6 describes the radiation pattern of this designed Koch fractal dipole antenna in Azimuth plane. The figure shows a great Omni-directivity character. Directivity of designed Koch fractal antenna is 2 dBi at the resonant frequency of 500 MHz.

Figure 7 provides the radiation pattern of this designed Koch fractal dipole antenna in Meridian plane. It shows a symmetric pattern with the directivity of 2 dBi at the resonant frequency of 500 MHz.

A comparison is also performed between conventional dipole antenna and currently designed Koch fractal antenna. The results are displayed in Table 1.

From the table we can see that the Koch fractal geometry can provide a great miniaturization character. The compactness compared with traditional dipole antenna at 500 MHz can reach 66.15%. That means the size is reduced by 33.85%. The return loss reduces dramatically after Koch fractal is applied. However, the bandwidth only has a slight increase.

4. IMPROVED MODEL

Considering the barely satisfying bandwidth performance of the antenna introduced above, an improved model is proposed and calculated under simulation environment. The diagram of the improved model is shown in Figure 8.

This improved model can be realized by simply rotating and copying the original antenna introduced above three times, making each fractal segment facing all four directions. The zoomed structure of each fractal block is shown in Figure 9.

This improved model shows a great bandwidth boost from the original 8.3% to 12.6%. Simulated return loss is shown in Figure 10.

The radiation patterns show that there is not much differences between the improved and original antenna regarding of radiation patterns.

5. CONCLUSION

Two Koch fractal dipole antennas of 3rd iteration have been designed and simulated successfully in FEKO environment. Antenna size, resonant frequency, return loss and bandwidth are simulated and measured. The antenna's size reduction of 33.85% is the main purpose of this paper. Besides, the rotating shape character of the first antenna can provide better adaptability when it is applied to outdoor or some other certain environments.

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