Design of UWB snowflake slot antenna based on Koch fractal

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Abstract. There are many forms of wide-slot aperture printed antennas. This paper presents a new type of ultra-wideband antenna with compact structure from the fractal field. The slot structure of the antenna is composed of the third iteration of the Koch curve, and the tri-band is achieved by etching the snowflake slot on the side of the Rogers RT/duriod 5880 dielectric substrate with a relative dielectric constant of 2.2 and a thickness of 1.6 mm. On the other side, a hexagonal adjustment branch is used to enhance the coupling between the slot and the feeder to widen the bandwidth. The test results show that the antenna's operating frequency band covers 2.2 to 13.4GHz. The H-plane radiation is omnidirectional, and the gain peak up to 10dB, which is suitable for ultra-wideband wireless communication.

1. Introduction

Recently, the research and application of ultra-wideband (UWB) technology have emerged endlessly, and the design of ultra-wideband antennas as the RF front-end of the system has become a subject attracting worldwide attention [1-2]. In order to achieve the desired UWB characteristics, researchers have established a series of models from regular shapes to complex shapes, and tried to improve it in various ways to get the desired waveband [3-4], such as fractal [5-6]. The fractal design of the antenna can be used to study the relationship between the antenna structure parameters and its multi-frequency and broadband performance [7]. There are currently proposed some geometric fractals, such as Koch curve, Weierstrass, Cantor, Sierpinski triangle, etc [8]. Reference [9] improved some features of Euclidean geometry based on the introduction of fractal structures at the edges of polygons. The results show that the application of Koch fractal in antenna design helps to achieve its miniaturization, compactness and broadband. And compared with other geometric fractal antennas, Koch fractal-based antennas have wider bandwidth and stable gain. Reference [10] introduced a second-iteration snowflake slot on the back of the substrate, and designed a broadband slot antenna with an impedance bandwidth of 2.5~6.6GHz. The antenna has a higher gain and can be applied to various C-band applications, but the bandwidth is relatively narrow due to the overall structural design of the antenna and the large dielectric constant of the substrate. Reference [11] designed a slot antenna that can work in two frequency bands of 2.38~3.03GHz and 4.45~5.06GHz. The antenna is small and suitable for dual-frequency communication, but the slot structure is composed of Koch snowflake slot loop with third iteration, and the manufacturing process is relatively complicated.

Drawing on the theory and experience of the above references, this paper designs a compact ultra-wideband slot antenna. The antenna etched the third iteration of Koch snowflake slot on the square radiation patch, which can effectively increase the electrical length and reduce the antenna area. Hexagonal adjustment of the branch end enhances the coupling between the slot and the feeder, which can widen the antenna bandwidth. Based on a comprehensive analysis of the number of iterations,
microstrip line structure and size, gain, current distribution and radiation performance, the optimal size of the antenna was determined.

2. Antenna design

Figure 1 shows the geometrical structure of the proposed antenna. Square snowflake slot radiation patch and the loaded hexagonal microstrip feeder are printed on both sides of the Rogers RT/duroid 5880 dielectric substrate, with relative dielectric constant \( \varepsilon_r = 2.2 \) and thickness \( h = 1.6 \text{mm} \).

![Figure 1](image)

Figure 1. The geometry of the proposed antenna: (a) Top view (b) Back view (c) Sectional view.

Koch snowflake slot structure is based on the equilateral triangle shown in Figure 2 (a). Each side of the triangle is equally divided into three sections, and the middle section is replaced by two polylines with the same length and an included angle of 60°. At this time, the first iteration is completed and the result is a hexagon, as shown in Figure 2 (b). Then do the same operation for each side of the hexagon, and complete the second iteration, as shown in Figure 2 (c). So set the number of graphics sides as \( N_n \), the length of one side as \( l_n \), the circumference as \( L_n \), after the \( n \)th iteration,

\[
N_n = 3(4)^n \tag{1}
\]

\[
l_n = \left(\frac{1}{3}\right)^n l_0 \tag{2}
\]

\[
L_n = N_n l_n = 3\left(\frac{4}{3}\right)^n l_0 \tag{3}
\]

![Figure 2](image)

Figure 2. Slot structure: (a) Basic graph; (b) First iteration; (c) Second iteration; (d) Third iteration.

Through HFSS simulation optimization and comprehensive consideration, the optimal values of the antenna parameters are finally determined as shown in Table 1.
Table 1. Optimized antenna parameters.

| Parameter | Value (mm) | Parameter | Value (mm) | Parameter | Value (mm) |
|-----------|------------|-----------|------------|-----------|------------|
| \( l_0 \) | 13.8       | \( h \)  | 1.6        | \( d \)  | 16         |
| \( w \)  | 32.8       | \( f \)  | 3          | \( s \)  | 2          |

3. Result analysis

The antenna reflection coefficients of Koch fractal slot structure with three different iteration levels are shown in Figure 3.

![Figure 3. Simulated of the snowflake slot antenna with different iteration levels.](image1)

Simulations show that the maximum antenna bandwidth in the second iteration is 10.5GHz, which is nearly 3.5GHz more than the bandwidth of the first iteration. When \( n = 3 \), the antenna meets the condition of \( S_{11} < -10 \text{dB} \) in the range of 3.1–13.4GHz, and its standing wave characteristics can completely cover the 3.1–10.6GHz band width assigned to UWB by IEEE802.15.a standard [12]. The return loss reaches below -20dB at 3.4–3.8GHz in the low frequency band and 9.4–11.4GHz in the high frequency band, and has better impedance matching characteristics than the slot structure of the second iteration.

The structure and size of the microstrip line have a crucial impact on the bandwidth and impedance matching of the antenna. As shown in Figure 4, when the antenna is fed with a conventional rectangular microstrip line, tri-band characteristics can be achieved. The resonance points are 3.9GHz, 7GHz, and 10.7GHz. After the hexagon is loaded, the frequency band is effectively extended and the impedance is matched significantly increased. Figure 5 shows the influence of the size of the hexagon on the reflection characteristics of the antenna. It can be found that as the side length of the hexagon increases, the antenna operating frequency band gradually shifts to the left, and when \( s = 3 \), the antenna no longer has ultra-wideband characteristics.
Figure 5. Effect of parameter s on reflection characteristics.  

Figure 6 illustrates the simulated gain of the antenna. The two peaks are located at 8GHz and 12GHz with gains of 7dB and 10dB, respectively.

Figure 6. The gain of antenna.

Figure 7. Current distribution on the antenna surface: (a) 3.1GHz; (b) 7GHz; (c) 10.7GHz.

Figure 7 shows the simulated current distribution of the Koch snowflake slot antenna in three iteration levels at different frequency bands. It can be seen that the maximum current on the antenna surface is concentrated along the fractal edge, and as the frequency increases, the current density at the fractal edge increases, which reduces the radiation of electromagnetic energy.

4. Processing and testing of antenna

Figure 8 shows the photograph of the fabricated antenna. After welding is completed, using vector network analyzer to test, and the result is shown in Figure 9. It can be seen that the actual measurement results are more ideal than the simulation. The main reason for the smaller error is that the short distance between the surface of the patch and the SMA pin. The slot structure is easy to damage during welding, and the test equipment and environment will also affect the final result.

Figure 8. Photograph of the fabricated antenna.

Figure 9. Simulated and measured reflection coefficients.

The far-field radiation patterns of the antenna at the frequency points of 3.1GHz, 7GHz, and 10.7GHz are shown in Figure 10. The results show that the antenna is nearly omnidirectional on the H-plane, and the E-plane shows the bidirectionality of 8-shape, which can effectively radiate electromagnetic energy. (The solid line represents the H-plane and the dashed line represents the E-
plane.)

Figure 10. Antenna radiation patterns: (a) 3.1GHz; (b) 7GHz; (c) 10.7GHz.

5. Conclusion
By using the Koch snowflake structure with inherent self-similarity, an ultra-wideband slot antenna with overall size 32.8mm×32.8mm×1.6mm was designed. The test results show that the reflection coefficient of this antenna is less than -10dB in the range of 2.2~13.4GHz. The H-plane radiation is omnidirectional and the overall gain is stable. It can be used in various C-band and X-band applications, and has broad development prospects.

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