Study of A 28-GHz Tree-shaped Fractal Millimeter Wave Antenna

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Abstract. In this study, a tree-shaped fractal antenna is designed. The antenna uses a finite ground plane with a rectangular structure. By increasing the number of iterations of the tree fractal structure, optimizing the size of the priority ground plane and the size of the dielectric substrate, the antenna can obtain good impedance matching. And through electromagnetic simulation of HFSS. The antenna's working frequency band is 26GHz-30.2GHz (relative bandwidth is 15%), and the maximum gain is 4.72dB at the center frequency of 28GHz, which can be used for future 5G communication.

1. Introduction
In recent years, antennas designed with fractal structures have been continuously proposed. Typical fractal structures are Koch [1], Sierpinski [2], Minkowski [3], Hilbert [4] and Cantor [5]. Because the fractal structure has self-similarity and space filling characteristics, using fractal structure to design the antenna can improve the performance of the antenna [6]. The self-similarity of the fractal antenna can realize multi-band or ultra-wideband characteristics, and the space filling can realize the miniaturization of the antenna [7]. This paper uses the self-similarity and space filling characteristics of fractal theory to design a tree-like fractal antenna that can be used in future 5G mobile communications.

2. Antenna Design and Analysis
2.1. Proposed Tree Fractal Antenna Structure
The basic unit of the tree-like fractal structure is an isosceles trapezoid (zero-order iteration). The width of the upper bottom surface is \(c=0.8\)mm, the width of the lower bottom surface is \(d=2.5\)mm and the height is \(e=0.8\)mm. The basic unit is \(S_0\). The structure obtained by performing the basic unit with the factor \(a=0.8\) is denoted as \(S_1\), and the structure obtained by reducing the factor \(a\) with the factor \(a\) is denoted as \(S_2\). As shown in Fig. 1, the first-order tree fractal structure is composed of \(S_0\) and \(S_1\); the second-order tree fractal structure is composed of \(S_0\), \(S_1\), and \(S_2\); the third-order tree fractal structure is composed of \(S_0\), \(S_1\), \(S_2\), and \(S_3\); The fourth-order tree fractal structure is composed of \(S_0\), \(S_1\), \(S_2\), \(S_3\), and \(S_4\). The obtained tree-like fractal structure is sequentially rotated around the center by 60°, 120°, 180°, 240°, and 300° to obtain a zero-order six-array structure, a first-order six-array structure, and a second-order six, respectively, as shown in Fig. 2. Array structure, third-order six-array structure, fourth-order six-array structure.
2.2. Impact of Different Order Typing Structures on Antenna Performance

The fig. 3 shows the return loss curve of the first fifth order tree fractal antenna. The size of the ground plane is 4mmX8mm. As can be seen from the figure, the zero-order six array antenna has a resonance point at 27.6GHz, and the corresponding return loss is -15dB, -10dB bandwidth is 26.4GHz-29GHz, the impedance matching of the antenna is not ideal. The first-order six-array antenna has a resonance point at 28 GHz, and the corresponding return loss is -32dB, and the -10dB bandwidth is 26.2GHz-30GHz. The second-order six-array antenna has a resonance point at 28GHz and the corresponding return loss is -48dB, The -10dB bandwidth is 26GHz-30.2GHz, and the impedance matching of the third-order six-array antenna is poor. The fourth-order six-array antenna also has a resonance point at 28GHz. The corresponding return loss is -40dB, and the -10dB bandwidth is 26.2GHz-30.2GHz. The impedance matching between the zero-order six-array antenna and the third-order six-array antenna is poor. The first-order six-array antenna, the second-order six-array antenna, and the fourth-order six-array antenna all have resonance points at 28 GHz. The integrated bandwidth and impedance matching characteristics, the second-order six-array antenna performs well and the antenna structure is relatively simple.
2.3. Effect of Height of Finite Ground Plane on Antenna Performance

The fig. 4 shows the return loss curves corresponding to different ground plane heights. It can be seen from the figure that the antenna impedance matching is poor when the ground plane height is h=3mm. The return loss of the antenna shows ultra-wideband characteristics when 3.4mm and h=3.6mm. The center frequency is higher than the target frequency. When h=3.8mm, the antenna resonates at 28.8GHz, and the corresponding return loss is -43.1dB, -10dB bandwidth is 27GHz-32.5GHz, when h=4mm, the antenna has a center frequency point at 28GHz, the corresponding return loss is -48dB, and -10dB bandwidth is 26GHz-30.2GHz. When h changes from 3.6mm to 4.2mm, the center frequency of the antenna gradually changes to low frequency. Since the impedance matching of the antenna is optimal when h=4mm and the center frequency point is consistent with the target frequency point, h=4mm is selected here.

![Figure 4. S11 curves corresponding to different ground plane heights](image)

2.4. Influence of Different Ground Plane Width S11

The fig. 5 shows the return loss curves corresponding to different ground plane widths. At this time, the radiating elements are all second-order six arrays. As can be seen from the figure, the antenna impedance matching is poor when w=6mm, and the antenna is when w=6.5mm. The return loss of the antenna exhibits ultra-wideband characteristics. When w=7mm, the antenna resonates at 29.1GHz. The corresponding return loss is -28.6dB, the -10dB bandwidth is 27.4GHz-30.9GHz, and the antenna is at w=7.5mm. The resonance point appears at 28.6GHz, the corresponding return loss is -32.8dB, the -10dB bandwidth is 26.8GHz-30.5GHz, when w=8mm, the antenna resonates at 28GHz, and the corresponding return loss is -48.2 dB, The -10dB bandwidth is 26GHz-30.2GHz. When w=8.5mm, the antenna resonates at 27.4GHz, the corresponding return loss is -29dB, and the -10dB bandwidth is 25.2GHz-30.1GHz. In the process of w changing from 7mm to 8.5mm, the center frequency of the antenna gradually becomes lower. Among them, the antenna obtains the best impedance matching when w=8mm, and the best broadband characteristics when w=8.5mm. We choose w=8mm.
3. Antenna Simulation Results

The tree-shaped fractal antenna is composed of a tree-shaped fractal structure, a feeding microstrip line, a dielectric substrate, and a finite ground plane. The feed microstrip line is a 0.5mm X 4.2mm rectangle, and the finite ground plane is an 8mmX4mm rectangle. The dielectric substrate is a Rogers4350 sheet with relative dielectric constant of $\varepsilon = 3.66$ and loss tangent of $\delta = 0.004$. The overall size of the antenna is 8mmX13mmX0.6mm. This article uses HFSS simulation software to simulate and optimize the antenna model. The order of the tree-like fractal array antenna, the height of the finite ground plane, and the size of the dielectric substrate are optimized through the foregoing. The geometry size of the antenna structure is shown in Fig. 6.

From Fig. 7 we can see that the antenna's -10db bandwidth is 26GHz-30.2GHz, Fig. 8 is the two-dimensional gain curve of the center frequency of the antenna at 28 GHz, Fig. 9 is the three-dimensional gain pattern of the antenna at the center frequency of 28 GHz.
4. Conclusion
In this paper, a self-similarity of the fractal structure and space filling characteristics are used to design antenna with a tree fractal structure. By increasing the number of iterations of the tree fractal structure, optimizing the size of the priority ground plane and the size of the dielectric substrate, the antenna can obtain good impedance matching. The antenna's working frequency band is 26GHz-30.2GHz (relative bandwidth is 15%), and the maximum gain is 4.72dB at the center frequency of 28GHz, which can be used for future 5G communication.

Acknowledgments
This project was supported by National Natural Science programs (51267021) and College students' innovative entrepreneurial training programs (2019).

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