Design of the Gradually Defect Patch Fractal Array Antenna for Unmanned Aerial Vehicle

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Abstract. This paper creatively proposes a new fractal iterative structure of a gradual defect patch and combines it with a rectangular array structure. Aiming at the performance requirements of the UAV system for multi-band compatible antennas, a gradual defect patch fractal array is designed. The radiation performance of the fractal array antenna was simulated by the method of moments, and antenna samples were made and the radiation performance was tested. Both simulation and actual measurement results show that this antenna has a working bandwidth of 5.5 GHz or more, a minimum return loss as low as -44 dB and excellent omnidirectional radiation capability. This antenna is compatible with the GPS system frequency band, Beidou system frequency band, all working frequency bands of the second to fifth generation mobile communication systems and the three working frequency bands of the RFID system, and is expected to be widely used as an unmanned aerial vehicle system antenna.

1. Introduction
In recent years, UAVs have been widely employed in military and civilian fields with the realization of the miniaturization of racks, multi-functional equipment, remote control, autonomous flight and intelligence. The antenna system must enable data communication between the drone and the ground controller and the cloud data center. The performance of the antenna system directly determines the performance of the drone flight control, wireless data transmission, functional command transmission and execution, among other things.

UAV systems need to use RFID systems for flight control and target detection, GPS systems and Beidou systems for flight positioning and track tracking, and mobile communication systems are used to transmit and synchronize data. Therefore, the UAV antenna needs to work in the GPS system frequency band, the Beidou system frequency band and all the working frequency bands of the second to fifth-generation mobile communication systems. At the same time, it also works in the working frequency band of the RFID system. The working frequency band of the GPS system is 1.164 ~ 1.577 GHz; The working frequency band of Beidou system is 1.204 ~ 1.564 GHz; In China, The second-generation mobile communication frequency bands currently used are GSM standard 0.905-0.915 GHz, 0.950-0.960 GHz, 1.710-1.785 GHz, 1.805-1.880 GHz frequency bands. The third-generation mobile communication frequency bands is TD-SCDMA standard 1.880-1.920 GHz, 2.010-2.025 GHz, 2.300-2.400 GHz frequency band and WCDMA standard 1.920-1.980 GHz, 2.110-2.170 GHz frequency band. The fourth-generation mobile communication frequency band is the TD-LTE standard 2.570-2.620 GHz frequency band. The fifth-generation mobile communication frequency bands are 3.300-3.400 GHz, 4.400-4.500 GHz, and 4.800-4.990 GHz [1-5]. The three main operating frequency bands of the international RFID system are 0.902-0.928 GHz, 2.400-2.4835 GHz, and 5.725-5.875 GHz.
GHz [6-9]. The UAV antenna needs to have multi-band compatibility and be able to fully cover all the working frequency bands. And to ensure that all operating frequency bands have high stable radiation characteristics and greater performance redundancy.

2. Introduction to Fractal Structure of Gradual Defect Patch

"Fractal" was first proposed by French mathematician Mandelbrot in 1983, which is used to describe a class of geometric shapes with self-similar characteristics. At the moment, there are more and more applications of fractal theory in antenna design. The self-similarity of the fractal structure makes the current distribution inside the fractal antenna relatively uniform, the antenna working bandwidth is larger, and the complex folding structure of the fractal structure makes it possible to reduce the size of the antenna.

The gradual defect patch fractal structure is a brand-new fractal iterative structure, and its fractal iterative process is shown in Figure 1. The initial element of the fractal structure of the gradual defect patch is a square, which is divided into 10 rows and 10 columns, a total of 100 small squares. For a total of 25 small square areas with 5 rows and 5 columns in the upper left, cut out 1 small square in the upper left; For a total of 25 small squares in 5 rows and 5 columns at the bottom left, cut out a total of 4 small squares with 2 rows and 2 columns in the top left; For a total of 25 small squares in 5 rows and 5 columns at the bottom right, cut out 9 small squares in 3 rows and 3 columns at the top left; For a total of 25 small squares in 5 rows and 5 columns on the upper right, cut out 16 small squares in 4 rows and 4 columns on the upper left; Finally, a first-order gradual defect patch fractal structure composed of 70 small squares is formed. Similar replacements for each small square of the 1st-order gradual defect patch fractal structure can get the 2nd-order gradual defect patch fractal structure.

![Figure 1. Schematic diagram of the iterative law of the fractal structure of the gradual defect patch.](image)

3. Antenna structure design

The gradual defect patch fractal antenna is used as the array element antenna in the antenna structure design. The whole and part of the gradual defect patch fractal have self-similarity. The radiofrequency current can be distributed very uniformly within the fractal structure. The antenna has excellent broadband working performance when the fractal structure of the gradual defect patch is used to design the radiating antenna patch. The gradual defect patch fractal has multiple defects with different side lengths, "digging holes," forming multiple radiation slits of different lengths, multiple radiation slits working in different frequency bands, and their radiation superposition can form a larger working bandwidth.

A rectangular array structure is used in the antenna design. A single gradual defect patch fractal small antenna has a larger working bandwidth, but the limited radiation energy is dispersed in a larger working frequency band, and the radiation intensity is difficult to meet the requirements. After the
rectangular array structure is used, the radiation superposition of multiple gradual defect patch fractal small antennas can significantly improve the antenna's radiation intensity.

The antenna's dielectric substrate is a low-loss epoxy glass cloth substrate with a relative dielectric constant of 4.4. The shape of the substrate is rectangular with dimensions of 48 mm x 48 mm and a thickness of 1 mm.

The gradient defect patch fractal array antenna includes a substrate, an antenna ground plate pasted on the back of the substrate, and a gradient defect patch fractal array radiation patch pasted on the front of the substrate. The antenna ground plate is a fully conductive ground structure, and the gradient defect patch fractal. The array radiation patch structure is shown in Figure 2. The basic array arrangement structure of the gradual defect patch fractal array antenna is a rectangular array structure, which includes 4 rows and 4 columns, a total of 16 array element areas, the size of each element area is 12 mm x 12 mm, and the center of each element area is placed a small gradual defect patch fractal antenna. Each gradual defect patch fractal small antenna has an antenna feed point at the center of the bottom edge.

Each gradual defect patch fractal small antenna is created by iterating the gradual defect patch fractal in a 10 mm x 10 mm rectangular area. And a 2-stage incremental defect patch fractal structure is used in each gradual defect patch fractal small antenna.

![Figure 2. Schematic diagram of the structure of the gradual defect patch fractal array radiation patch.](image)

4. **Antenna performance simulation and antenna sample test**

We used the method of moments (MOM) to simulate the antenna radiation performance, and the results are shown in Figure 3 and Figure 4.

Figure 3 shows that the working frequency range of this antenna is 0.173-6.406 GHz, the working bandwidth is 6.233 GHz, and the minimum return loss of the antenna is -49.89 dB.

Figure 4 shows that this antenna's E-plane and H-plane patterns have omnidirectional radiation characteristics.
We used the corrosion process to make an antenna sample and tested its radiation performance. The measured results are shown in Figure 5 and Figure 6.

Figure 5 shows that the operating frequency range of this antenna is 0.554-6.118 GHz, the working bandwidth is 5.564 GHz, the bandwidth octave is 11.04, and the minimum return loss of the antenna is -44.21 dB. This antenna completely covers the GPS system frequency band, the Beidou system frequency band, all operating frequency bands of second to fifth-generation mobile communication systems, and the three working frequency bands of the RFID system.

Figure 6 shows that this antenna has the excellent omnidirectional working capability.

Comparing the simulation results and actual measurement results of the antenna radiation performance and pattern, we found that the actual measurement performance of this antenna is basically the same as the simulation performance, which fully demonstrates that the antenna we designed has stable and reliable performance.
5. Conclusion
This paper creatively combines a new gradient defect patch iterative fractal structure with a rectangular array structure, and designs a gradient defect patch fractal array antenna to meet the performance requirements of UAV systems for multi-band compatible antennas. The gradual defect patch fractal antenna is used as the array element antenna in the design, and the working frequency bands of multiple radiation slots with different lengths of the gradual defect patch structure are superimposed to ensure that the array element antenna has a larger working frequency band and a larger bandwidth. The self-similarity of the element antenna uniformizes the internal radiofrequency current distribution, ensuring that the antenna has stable and reliable broadband working performance. The rectangular array structure is used to create an array, which effectively improves the antenna's radiation intensity.

Both simulation and measurement results show that this antenna can completely cover the GPS system frequency band, the Beidou system frequency band, all working frequency bands of the second to fifth-generation mobile communication systems and RFID system frequency bands. The antenna has high stable radiation in all working frequency bands. And it also has greater performance redundancy and excellent omnidirectional radiation capabilities. This antenna's radiation performance is much better than that of existing UAV antennas, and the self-similarity of the fractal structure ensures that the antenna has relatively better anti-destructive properties. This antenna combines the advantages of fractal and rectangular array antennas and has broad application prospects in the field of UAV multi-band antennas.
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