Design and Performance Analysis of a Dual-Band Fractal Antenna for Millimeter-Wave 5G Applications

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Abstract. This article presents the design of a dual-band antenna operating at 28 GHz and 39 GHz. The antenna is structured in the form of a Cantor set fractal with a ground plane featuring a strategically placed slot, which lowers the frequency of the first band to 28 GHz and introduces a second band at 39 GHz. The antenna dimensions are compact, measuring 5 × 6 × 0.508 mm³, and it achieves a maximum gain of 7 dBi with a high radiation efficiency of 99%. The antenna maintains a stable radiation pattern across both frequency bands, making it suitable for millimeter-wave 5G applications, where high data rates and reliable connectivity are crucial.

1 Introduction

The rapid advancement of 5G wireless technology necessitates the development of highly efficient antennas capable of supporting millimeter-wave frequencies. Among the emerging solutions, dual-band fractal antennas have garnered significant attention due to their compact size, multifrequency operation, and enhanced performance characteristics [1], [2], [3], [4].
In the realm of 5G technology, a diverse array of antenna designs has been employed to meet the complex demands of high-speed, high-frequency communication. Patch antennas, offer a compact and low-profile solution, making them ideal for portable devices [5], [6], [7], [8], [9]. Fractal antennas, with their unique geometric properties, provide multifrequency operation and enhanced bandwidth, addressing the need for versatile and efficient performance [10], [11], [12], [13], [14]. Additionally, Multiple-Input Multiple-Output (MIMO) antennas play a crucial role in 5G networks, significantly improving data throughput and reliability by utilizing multiple antennas at both the transmitter and receiver ends [15], [16], [17], [18]. Each of these antenna types brings distinct advantages, collectively pushing the boundaries of 5G technology towards faster, more reliable, and more efficient wireless communication.
This article explores the design and performance analysis of a novel dual-band fractal antenna tailored for 5G applications. By leveraging Cantor Set fractal geometry, the proposed antenna achieves superior bandwidth at 28 and 39 GHz, gain, and radiation efficiency, addressing the stringent requirements of next-generation wireless networks. Detailed simulation results validate the antenna's efficacy, marking a significant step forward in the evolution of 5G communication systems.

2 Antenna Configuration Design

The design of the proposed antenna is illustrated in Figure 1. It features a radiating plate with a Cantor set fractal shape. This configuration is constructed on a low-loss Rogers RT5880 substrate. The substrate boasts a dielectric constant (εr) of 2.2. The entire assembly is mounted on a ground plane that features an etched eight-pointed star slot. The antenna configuration is notable for its compact size, measuring just 5×6×0.508 mm³. The precise values for the additional parameters are presented in Figure 1. It is important to note that the designed antenna was crafted with precision, and every parameter was carefully adjusted to ensure peak performance. This was accomplished using the renowned electromagnetic simulation software, CST (Computer Simulation Technology).

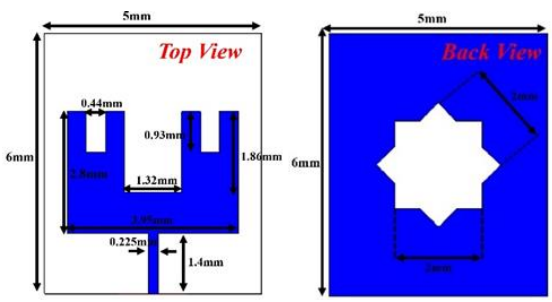

Fig. 1. Proposed antenna configuration.

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Figure 2 illustrates the design and evolution process of the proposed antenna. The S11 responses corresponding to the proposed antenna's evolution stages are depicted in Figure 3.

Antenna a is a simple rectangular antenna with dimensions of 2.88 × 3.395 mm². It operates at frequencies of 31.5 GHz, which do not cover the desired bands, as shown in Figure 3. Antenna b is created by cutting a rectangular slot from the antenna a as first iteration of the Cantor Set fractal configuration, with dimensions of 1.32 × 1.86 mm². As a result, antenna b operates solely at 30.8 GHz. Antenna c is obtained by applying the second iteration of the cantor set fractal structure. Antenna c features a bandwidth ranging from 30.3 to 32.3 GHz. To achieve the desired band of 5G applications an eight-pointed star slot was cut from the ground plane. The proposed antenna exhibits two bands resonating at 28 and 39 GHz.

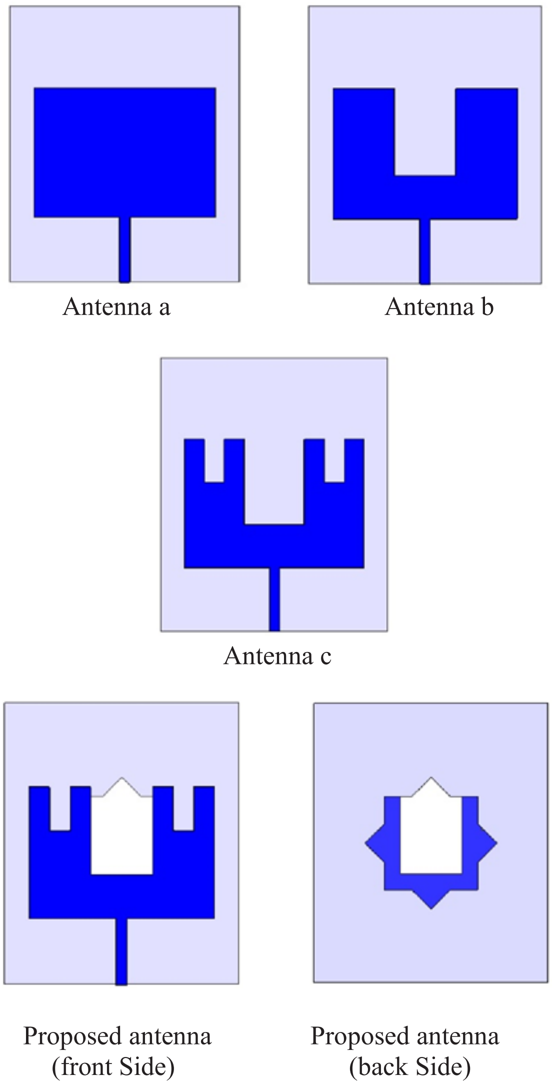


Fig.2. Development Stages of the Proposed Antenna

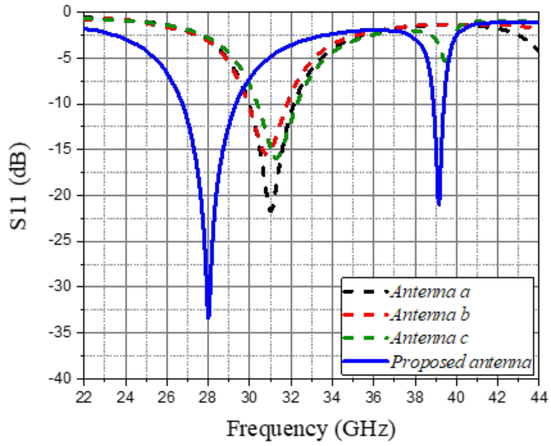


Fig.3 Proposed antenna development stages' S11 responses

3 Results and Discussions

Figure 3 displays the S11 of the proposed design, obtained through simulations using CST software. The antenna resonates at primary frequency bands of 28 and 39 GHz, with bandwidths of 2.7 GHz (ranging from 26.7 to 29.4 GHz) and 0.7 GHz (ranging from 38.8 to 39.5 GHz), respectively.

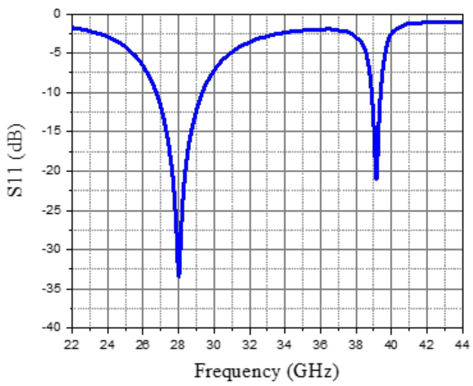
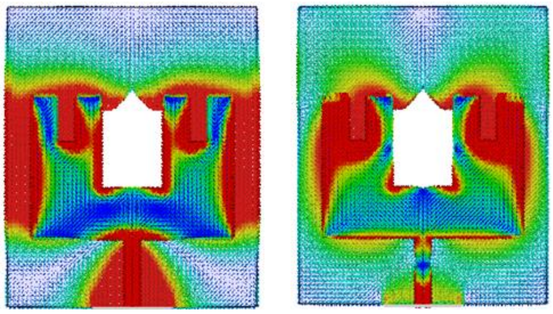


Fig.4. Proposed antenna S11 simulation Results

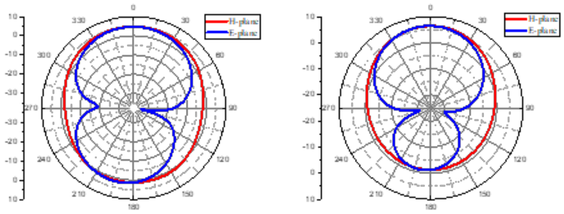
To delve deeper into the antenna's behavior, Figure 5 illustrates the electrical current distribution of the proposed cantor set fractal shape antenna at 28 and 39 GHz. It can be noticed from the figure that the electric current is concentrated in the radiating cantor Set fractal shape. As shown, engraving the slot in the ground plane causes the current to intensify along the slot edges, facilitating edge propagation. This additional edge path increases the antenna's electrical length, thereby reducing its resonant frequency.



28 GHz 39 GHz

Fig.5. Current distribution of the proposed Cantor Set fractal antenna.

As demonstrated in figure 6, the proposed antenna exhibits strong radiation performance in both cutting planes at 28 and 39 GHz. Notably, the antenna maintains a bidirectional pattern in the E plane and an omnidirectional pattern in the H plane, which demonstrates that the radiation performance has a uniform and stable behavior.



28 GHz 39 GHz

Fig.6. Polar radiation pattern of the proposed Cantor Set fractal antenna.

Figures 7 and 8 illustrate the variations in gain and radiation efficiency as a function of frequency. The antenna exhibits excellent radiation characteristics throughout its operating band, with a gain of 6.5 and 7 dBi and radiation efficiency of 99% and 87% at the operating frequencies.

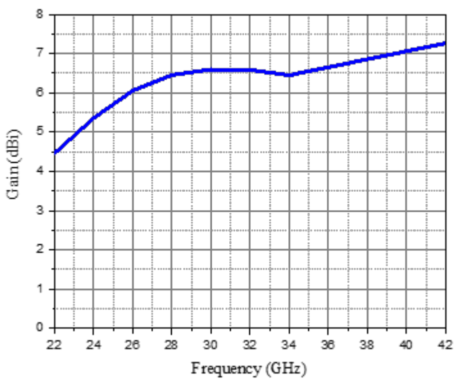


Fig.7. Gain of the proposed Cantor Set fractal antenna.

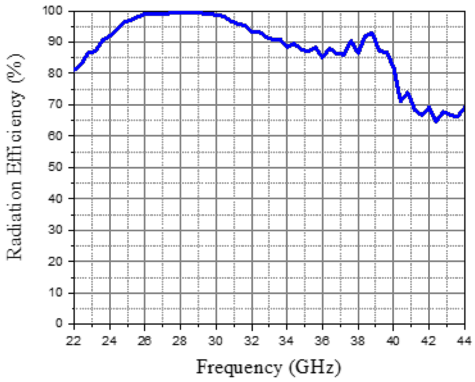


Fig.8. Radiation efficiency of the proposed Cantor Set fractal antenna

4 Conclusion

In this study, we introduced a dual-band antenna design operating across two distinct frequency bands: a broader band spanning 2.7 GHz (from 26.7 to 29.4 GHz) and a narrower band of 0.7 GHz (from 38.8 to 39.5 GHz). The antenna utilizes a Cantor set fractal structure and incorporates a ground plane with a strategically placed slot. This configuration effectively lowers the frequency of the first band to 28 GHz while introducing a second band at 39 GHz. the antenna achieves an excellent gain and high radiation efficiency of 99%. The stable radiation pattern and high efficiency of the antenna make it particularly suitable for millimeter-wave 5G applications,

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