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# Design of Sub-6GHz and Sub-7GHz Dragon Fractal Antenna for 5G Applications with Enhanced Bandwidth

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**Abstract:** This paper presents the design and development of a novel DRAGON fractal antenna optimized for 5G applications, specifically targeting the sub-6 GHz N77 (3.3-4.2 GHz), N78 (3.3-3.8 GHz), N79 (4.4-5 GHz), and sub-7 GHz N96 (5.9-7.1 GHz) frequency bands. The compact antenna, with dimensions of 50 × 45 × 1.6 mm³, features a sixth-iteration DRAGON fractal radiator, which is an innovative approach to antenna design due to its recursive, self-similar geometry that enhances bandwidth and miniaturization. This design, combined with a coplanar waveguide (CPW) feed technique, ensures efficient impedance matching and reduces physical size without compromising performance. Fabricated on an FR-4 substrate with copper ground and radiating planes, the antenna was validated using both simulation and experimental datasets. The simulation results were obtained using FEKO software, while the experimental results were derived from S11 measurements using an HP 8719C network analyzer. The antenna achieves a wide operational bandwidth of 3.67-6.7 GHz, a peak gain of 5.5 dBi, and demonstrates excellent agreement between simulated and measured results. These findings highlight the antenna's novel application of the DRAGON fractal structure, which distinguishes it from traditional antenna designs by offering compactness, wideband capabilities, and performance optimization, making it suitable for next-generation 5G communication systems.

**Keywords:** 5G applications, Dragon fractal structure, Fractal antenna, Sub-6GHz, Sub-7GHz.

## 1. Introduction

The rapid advancements in 5G technology have transformed modern communications, particularly within the sub-6 GHz and sub-7 GHz frequency bands. These frequency ranges serve as the cornerstone for initial 5G deployments, offering an optimal balance between coverage, capacity, and data speed compared to higher-frequency millimeter-wave bands [1-4].

The sub-6 GHz spectrum is especially valuable for urban and suburban environments due to its superior ability to penetrate obstacles such as buildings and other physical barriers [5-7]. The sub-7 GHz spectrum provides enhanced capacity and flexibility, supporting a wider array of applications and improving network performance. Together, these bands underpin critical advancements in domains such as the Internet of Things (IoT), autonomous vehicles, and smart cities [8-10].

Research efforts in sub-6 GHz and sub-7 GHz 5G antenna design have yielded a variety of solutions. For instance, planar rectangular antennas have demonstrated simplicity and ease of fabrication, while ellipse-shaped ring patches and dipole designs offer promising bandwidth and gain characteristics. Other innovative designs include multislotted antennas for bandwidth enhancement, compact reconfigurable antennas for flexible operation, and metamaterial-based antennas for improved gain. Despite these advancements, challenges remain in achieving compactness while maintaining broad bandwidth and high performance.

Research efforts in sub-6 GHz and sub-7 GHz 5G antenna design have yielded a variety of solutions. For instance, planar rectangular antennas have demonstrated simplicity and ease of fabrication [11], while ellipse-shaped ring patches [12] and dipole designs [13] offer promising bandwidth and gain characteristics. Other innovative designs include multislotted antennas for bandwidth enhancement [5], compact reconfigurable antennas for flexible operation [14], and metamaterial-based antennas for improved gain [15]. Flexible and transparent Coplanar Waveguide (CPW) antennas have also been proposed to address design challenges in sub-6 GHz applications [16]. A square slot antenna for sub-6 GHz has been proposed [17], and an ultra-wideband (UWB) patch antenna with a defected ground structure (DGS) has also been introduced [18].

Multiple Input Multiple Output (MIMO) antennas have been extensively developed and utilized for sub-6 GHz and sub-7 GHz 5G applications [19-21]. Despite these advancements, challenges remain in achieving compactness while maintaining broad bandwidth and high performance.

Fractal-based antennas have garnered significant attention due to their unique geometric properties, which enable compact designs with wideband capabilities. Among the various fractal geometries explored, including Sierpinski and tree patterns [22-23], the DRAGON fractal curve offers untapped potential in antenna design due to its recursive, self-similar structure. This geometry allows for the creation of compact radiators that can achieve performance optimization across multiple scales.

This paper introduces a novel broadband compact antenna design that integrates the DRAGON fractal geometry with a Coplanar Waveguide (CPW) feed technique, specifically tailored for sub-6 GHz and sub-7 GHz 5G applications. The proposed antenna offers a wide operational bandwidth of 3.67-6.7 GHz, effectively covering the N77, N78, N79, and N96 frequency bands. Compared to traditional antenna designs, the DRAGON fractal structure enables a compact size while enhancing performance through additional current paths that increase the effective aperture without expanding the physical dimensions. The CPW feed technique further improves impedance matching, ensuring low return loss and high efficiency. These combined features result in a stable radiation pattern, low side lobes, and superior multi-band operation, making the proposed antenna an attractive solution for modern 5G communication systems. Conventional antenna designs often face limitations such as restricted bandwidth, larger physical dimensions, and poor performance at higher frequency bands, making them less suitable for modern 5G communication systems. For example, antennas presented in the references above may achieve either compact size or wide bandwidth, but rarely both simultaneously. Other designs show promising performance improvements but suffer from issues such as high return loss or insufficient impedance matching. In contrast, the proposed antenna integrates the DRAGON fractal geometry with a CPW feed technique, achieving superior bandwidth efficiency (3.67-6.7 GHz) while maintaining a compact structure. This dual advantage of miniaturization and wide frequency coverage makes the design highly suitable for 5G applications.

The remainder of this paper is organized as follows: Section 2 presents the principles of the DRAGON fractal structure. Section 3 the design methodology and discusses the simulation results, providing a detailed analysis of the antenna's performance across the desired frequency bands. Section 4 offers the experimental validation of the proposed design, including fabrication and measurement results. Finally, Section 5 concludes the paper by summarizing the key findings and suggesting potential directions for future research.

## 2. Theoretical background

Fractal geometry, introduced by B. Mandelbrot, characterizes complex patterns that exhibit self-similarity across different scales. Unlike traditional Euclidean geometry, which focuses on regular shapes such as lines, circles, and polygons, fractal geometry captures irregular and fragmented structures found in natural phenomena, including coastlines, mountains, and clouds. A defining feature of fractals is that magnification of any part reveals finer details that replicate the overall structure. This property makes fractals particularly useful in antenna design, as they enable the creation of compact structures that maintain performance across multiple frequency scales.

The DRAGON curve is a recursive fractal structure generated through iterative transformations. It is constructed by folding a strip of paper in half repeatedly to form a right-angle pattern. Each iteration introduces increasing complexity, doubling the number of segments and refining the geometric details.

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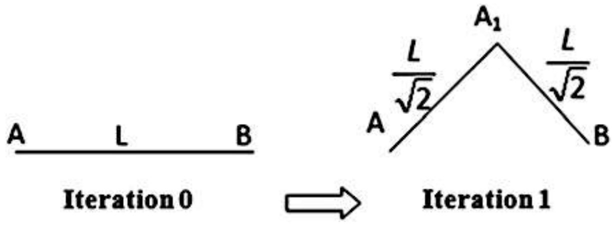


Figure. 1 Creation of the iteration 1 of the DRAGON fractal

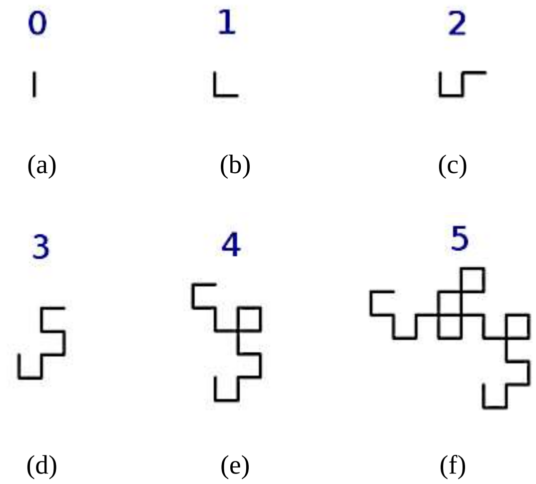


Figure. 2 The iterations 0 to 5 for DRAGON fractal structure: (a)Iteration 1, (b)Iteration 2, (c)Iteration 3, (d)Iteration 4, (e)Iteration 5, and (f)Iteration 6

In mathematical terms, the DRAGON fractal is described as a series of geometric transformations involving scaling and rotation.

Fig. 1 illustrates the iterative process of creating the DRAGON fractal. The figure shows the steps involved in the first iteration, where a strip of paper is folded and then unfolded to form a right-angle pattern. The key steps include:

- The first fold at center point A, followed by scaling and rotating the line segment.
- The second fold and rotation at center point B to create the recursive structure.
- This iterative process results in the self-similar geometric shape that forms the DRAGON fractal pattern.

Fig. 2 shows the DRAGON fractal structure from iteration 0 (the starting line) to iteration 5. Each iteration builds upon the previous one, introducing more detail and complexity. This figure visually demonstrates how the DRAGON fractal curve evolves through iterations, with increasing complexity and finer detail visible in each successive iteration.

Its HAUSDORFF dimension, which quantifies the fractal's complexity structure is provided by

$$\dim = \frac{\ln(n)}{\ln(R)} = \frac{\ln(2)}{\ln(\sqrt{2})} = 2 \quad (1)$$

While widely used fractals like Sierpinski and tree patterns have been explored in antenna design, the DRAGON curve remains relatively unexplored, presenting a novel opportunity for innovation in compact broadband antennas.

## 3. Design methodology

The proposed DRAGON fractal antenna is designed on an FR-4 substrate with a dielectric constant of 4.4, ensuring suitable electrical properties for efficient antenna operation. The substrate has a thickness of 1.6 mm, and the antenna's compact dimensions are 50 × 45 mm$^2$, making it suitable for applications with spatial constraints. The fractal radiator is fed using a coplanar waveguide (CPW) technique, which enhances impedance matching and simplifies the integration with other components.

Fig. 3 illustrates the geometry of the antenna design based on the DRAGON fractal structure. It shows the first iteration of the fractal antenna.

Table 1 provides the optimized design parameters, which were fine-tuned using FEKO simulation software to achieve the desired operational performance.

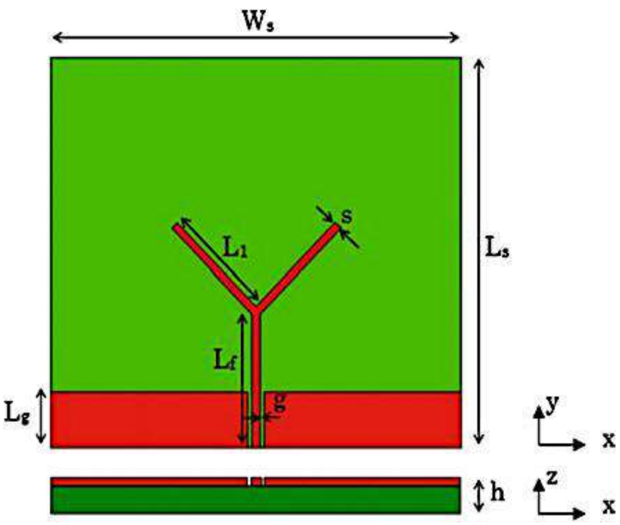


Figure. 3 The first iteration of the proposed DRAGON fractal antenna's geometry

Table 1. Dimensions of the proposed design in "mm"

| | | | |
|---|---|---|---|
| $W_s$ | 50 | s | 1 |
| $L_s$ | 45 | $L_f$ | 16 |
| h | 1.6 | $L_g$ | 6.55 |
| g | 0.5 | $L_1$ | 13.57 |

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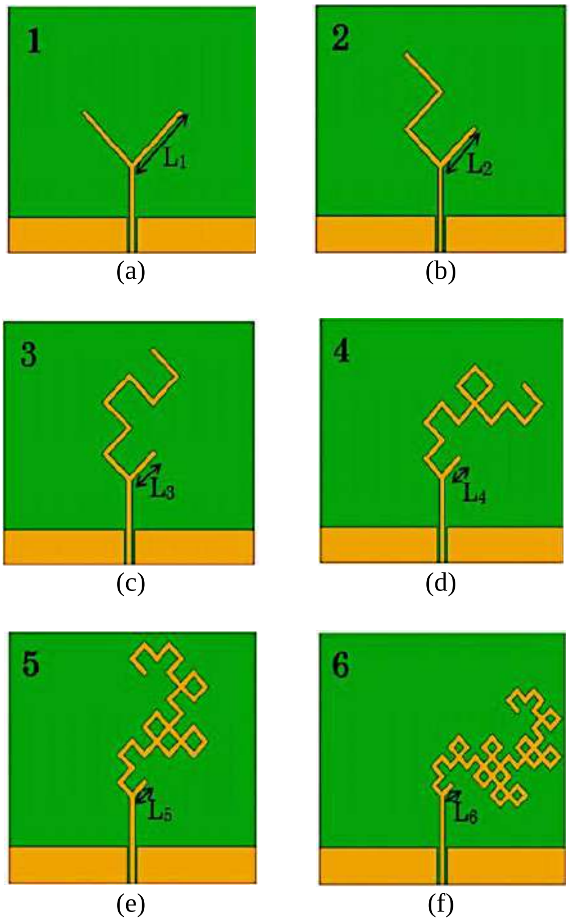


Figure. 4 Proposed DRAGON fractal antennas' six iteration: (a) Iteration 1, (b) Iteration 2, (c) Iteration 3, (d) Iteration 4, (e) Iteration 5, and (f) Iteration 6

Fig. 4 displays iterations 1 to 6 of the DRAGON fractal antenna design. Each iteration represents a refinement of the geometry, which is designed to enhance the antenna's bandwidth and performance: Iteration 1 to Iteration 6 show how the antenna geometry changes with each step, with increasing complexity and better impedance matching. Each iteration is represented with a visual breakdown of the $L_k$ parameters (lengths) that define the antenna's structure.

For the iteration k, the length $L_k$ is determined by the equation:

$$L_k = \frac{L_1}{(\sqrt{2})^{k-1}} \tag{2}$$

Fig. 5 displays the variation of the simulated S11 against frequency for the different iterations of the studied antenna. The performance characteristics of the antenna through six iterations show notable differences in both resonant frequencies and bandwidths. The antenna displays a resonance frequency of 7.56 GHz with a bandwidth of 660 MHz in the first iteration, covering the frequency range of 7.2 to 7.86 GHz. The second iteration has a wider bandwidth of 1.3 GHz, extending from 8 to 9.3 GHz, as well as an increase in resonant frequency to 8.43 GHz. During the third iteration, the resonant frequency shifts to 4.13 GHz, with a narrower bandwidth of 210 MHz, covering 4.04 to 4.25 GHz. Dual resonant frequencies of 2.95 and 5.4 GHz are shown in the fourth iteration, together with corresponding bandwidths of 600 MHz (2.7 to 3.3 GHz) and 1 GHz (5 to 6 GHz). With a broad bandwidth of 2.47 GHz, spanning from 3.75 to 6.22 GHz, the fifth iteration resonates at 5.26 GHz. Finally, the sixth iteration exhibits resonant frequencies of 4 GHz and 4.4 GHz, with a combined bandwidth of 3.03 GHz, ranging from 3.67 to 6.7 GHz.

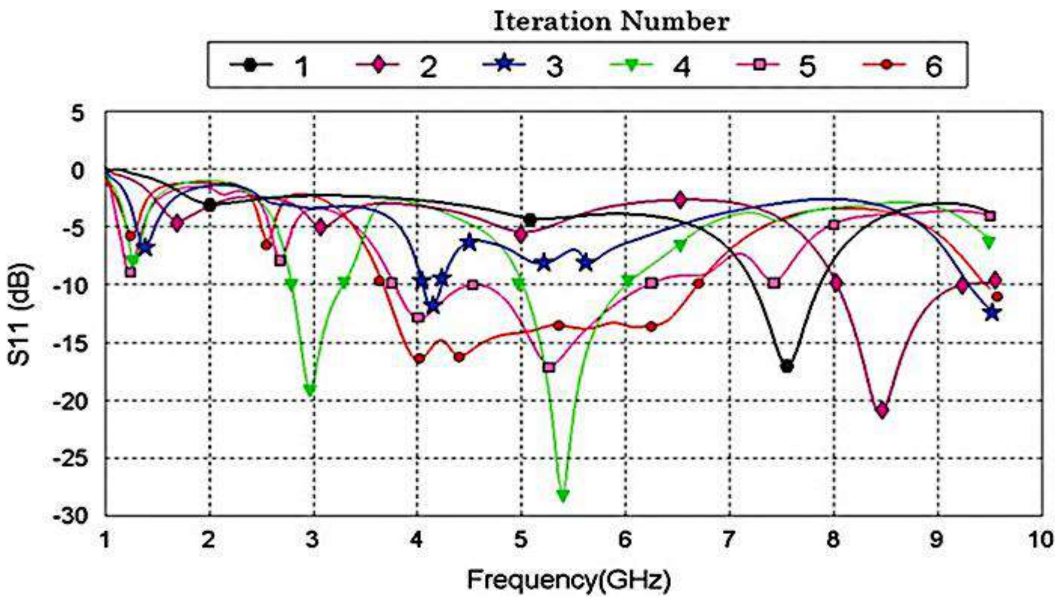


Figure. 5 Simulated S11 for Different Iterations

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This configuration aligns with sub-5G applications, particularly those operating around 6 GHz.By passing from Iteration 1 to Iteration 6, the proposed antenna achieves a significant increase in effective electrical size due to its self-similar recursive DRAGON fractal structure, which allows for broad frequency operation without increasing the physical dimensions.

## 4. Results and discussions

The six iterations of the DRAGON fractal structure antenna were fabricated as illustrated in Fig. 6.

The S11 was measured using an HP 8719C to experimentally validate the simulated results. Fig. 7 displays the variation of the S11 obtained from both simulation and measurement versus frequency for the six iterations. The simulation and measurement results agree well overall. The measured results show slight shifts in the bands, which may be due to factors like manufacturing tolerances and the influence of soldering the SMA connectors. Each iteration of the antenna design results in more resonant frequencies and wider bandwidths with improved gains. The first iteration produces an antenna that operates over a 660 MHz band (7.2-7.86 GHz). By the sixth iteration, an ultra-wideband antenna with a 3.03 GHz bandwidth (3.67-6.7 GHz) is achieved. This final version could be an effective solution for sub-6 GHz frequency bands N77 (3.3-4.2GHz), N78 (3.3-3.8 GHz), N79 (4.4-5 GHz), and Sub-7 GHz N96 (5.925-7.1 GHz). The superior performance of the DRAGON fractal antenna is attributed to its ability to create multiple current paths through its self-similar recursive structure. This unique feature allows the antenna to increase its effective electrical size, resulting in a wide operational bandwidth of 3.67-6.7 GHz. Importantly, this improvement is achieved without increasing the antenna's real size, demonstrating the efficiency and innovation of the fractal-based design.

The 3D gain patterns for the six iterations of the DRAGON fractal configuration, shown in Fig. 8, demonstrate stable radiation behavior with consistent main lobes and low side lobes across resonant frequencies. The recursive nature of the DRAGON fractal enhances performance by creating new current paths, increasing the antenna's effective aperture without increasing its physical size. This results in improved directivity and radiation stability, as seen in Iteration 1 at 7.56 GHz with a focused pattern and Iteration 6 at 4.4 GHz with broadened beamwidth for better coverage. These findings highlight the fractal antenna's suitability for compact and efficient in 5G applications.

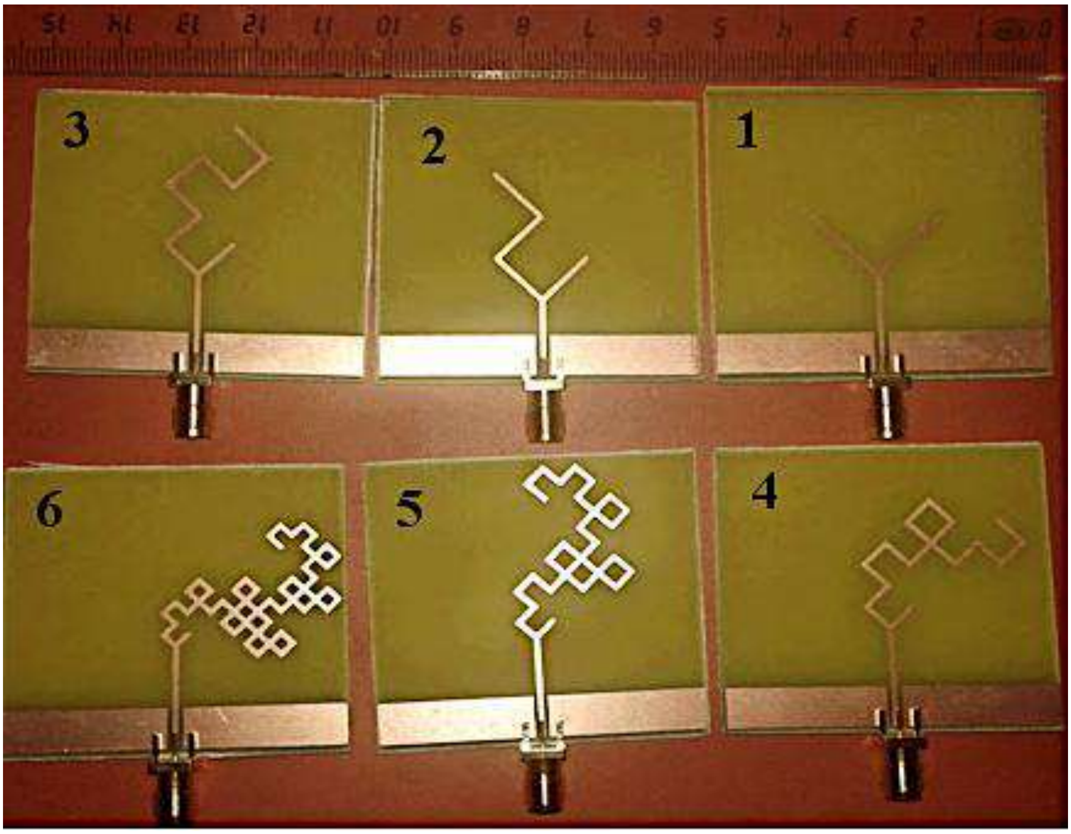

Figure. 6 The prototype for the six different iterations of the proposed DRAGON fractal antenna

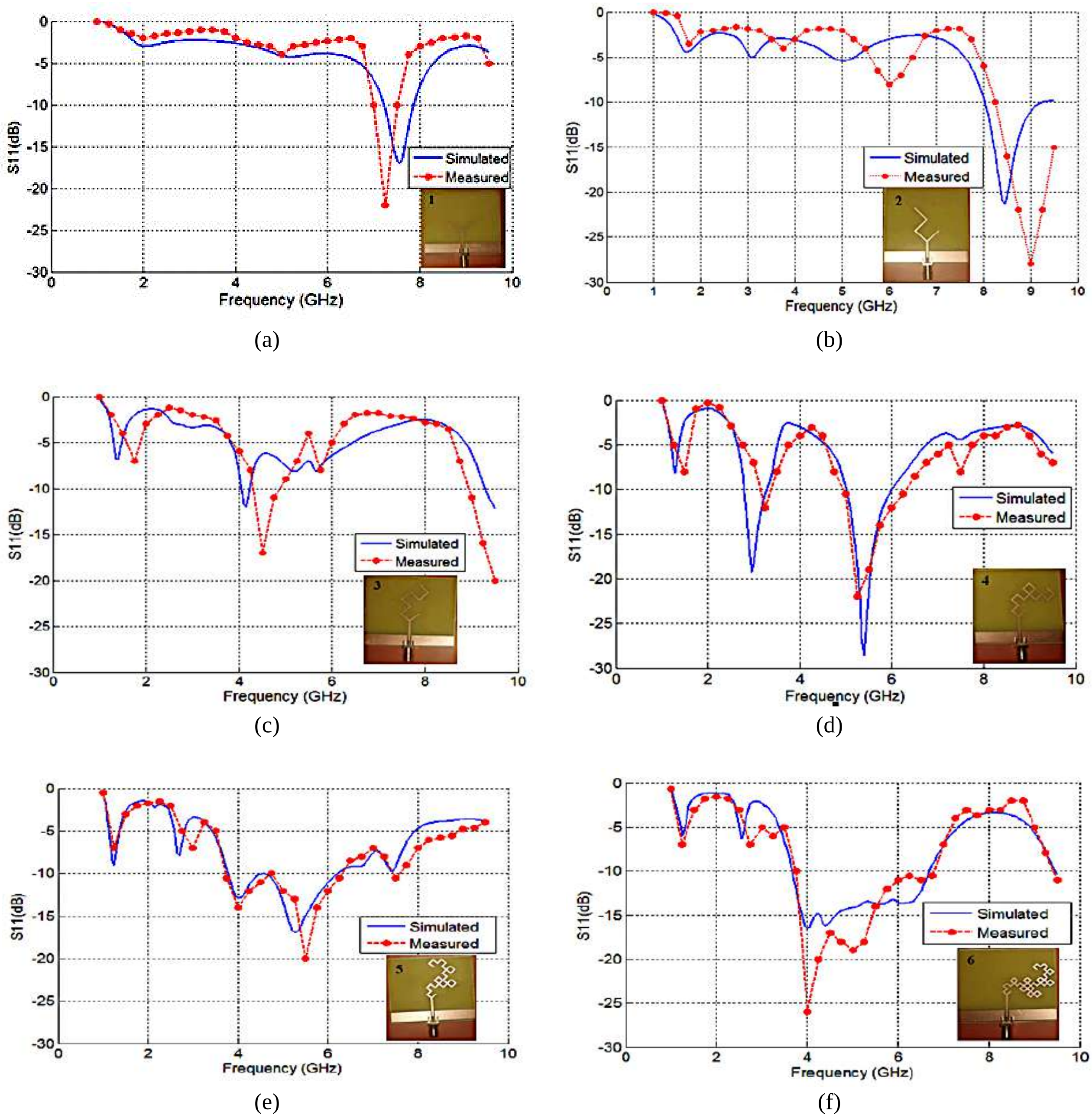


Figure. 7 Simulated and measured S11: (a) Iteration 1, (b) Iteration 2, (c) Iteration 3, (d) Iteration 4, (e) Iteration 5, and (f) Iteration 6

Table 2 table presents a comparison between the antenna developed in this work and several previously published designs. Key performance metrics such as antenna size, substrate material, operating band, bandwidth, and gain are considered to assess the relative advantages and limitations of each design. The proposed DRAGON fractal antenna offers a compact size of 50 × 45 × 1.6 mm³, making it smaller than most designs, including Ref [4] (150 × 80 × 0.035 mm³), Ref [13] (150 × 150 × 21 mm³), and Ref [20] (150 × 75 × 1.6 mm³). It also provides a wide bandwidth of 3.03 GHz, outperforming designs like Ref [4] (1.56 GHz), Ref [13] (1.38 GHz), and Ref [24] (0.23 GHz). While Ref [18] achieves a comparable bandwidth (2.92 GHz) with a low-loss Teflon substrate, and Ref [25] uses a premium ROGERS3003 material, these designs result in higher complexity and cost. The proposed antenna balances performance and cost-effectiveness by using an FR-4 substrate. Additionally, the design is simpler and more practical than the reconfigurable antenna in Ref [25] and the MIMO antenna in Ref [24], which increase design complexity. Overall, the DRAGON fractal antenna combines compactness, wideband operation, and stable performance, making it a superior solution for 5G applications compared to the referenced designs.

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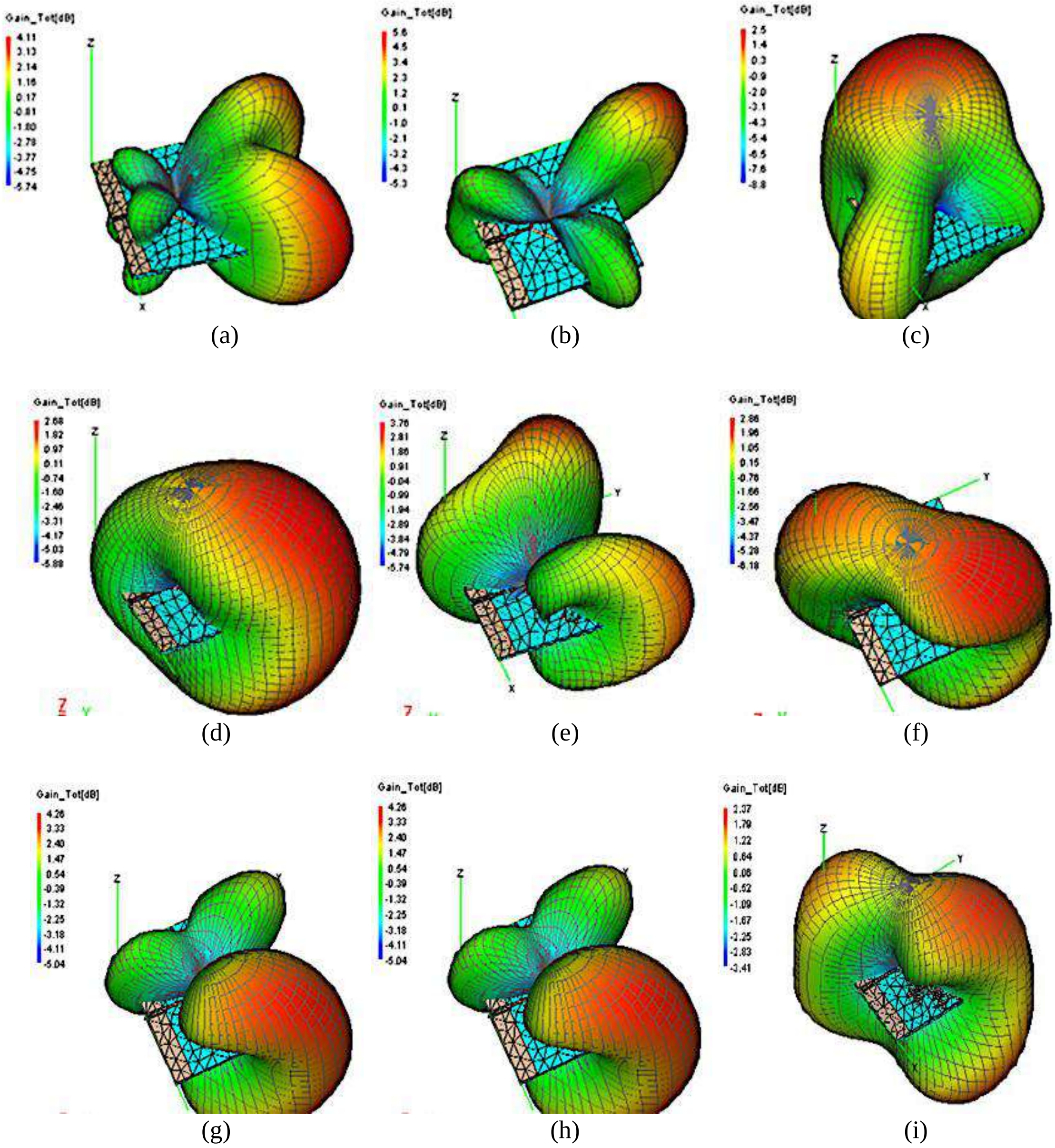


Figure. 8 3D simulated radiation pattern: (a) Iteration 1 (at 7.56 GHz), (b) Iteration 2 (at 8.43 GHz), (c) Iteration 3 (at 4.13 GHz), (d) Iteration 4 (at 2.95 GHz), (e) Iteration 4 (at 5.4 GHz), (f) Iteration 5 (at 4 GHz), (g) Iteration 5 (at 5.26 GHz), (h) Iteration 6 (at 4 GHz), and (i) Iteration 6 (at 4.4 GHz)

Table 2. comparison of the referenced and proposed DRAGON fractal antennas

| Refs | Size (mm3) | Substrate | Operating Band (GHz) | Bandwidth (GHz) | Gain (dBi) |
|---|---|---|---|---|---|
| [4] | 150 × 80 × 0.035 | FR-4 | 3.34-5.0 | 1.56 | 4.25- 6.0 |
| [12] | 180 × 60 × 1.6 | FR-4 | 3.28-3.78 | 0.5 | 2.4 - 6.1 |
| [13] | 150 × 150 × 21 | Not specified | 3.05-4.42 | 1.38 | 7.09 - 9.36 |
| [18] | 80 × 50 × 0.508 | Teflon | 2.32-5.24 | 2.92 | 3.04 - 4.31 |
| [20] | 150 ×75× 1.6 | FR-4 | 3.2-4 | 0.8 | 3.3-4 |
| [24] | 100 × 100 × 5.7 | FR-4 | 3.39-3.62 | 0.23 | 5-6.8 |
| [25] | 66 ×66 × 0.13 | ROGERS3003 | 3-4.12 | 1.12 | 4 |
| This Work | 50 × 45× 1.6 | FR-4 | 3.67-6.7 | 3.03 | 2-5.5 |

## 5. Conclusion

This study presents the design and implementation of a compact DRAGON fractal antenna optimized for 5G applications. With dimensions of 50 × 45 × 1.6 mm³, the proposed antenna demonstrates exceptional performance, achieving a wide operational bandwidth of 3.67-6.7 GHz and a peak gain of 5.5 dBi. These results confirm its suitability for sub-6 GHz and sub-7 GHz communication systems, particularly for 5G frequency bands N77, N78, N79, and N96.The use of the coplanar waveguide (CPW) feed technique, combined with the recursive DRAGON fractal radiator, enabled the realization of a compact design without compromising bandwidth or gain. Experimental validation shows strong agreement with simulations, highlighting the robustness of the design process. This work contributes a cost-effective and scalable solution for next-generation 5G communication systems, where compactness and performance are critical. Future research could explore further miniaturization and integration into multi-functional communication systems.

## Conflicts of Interest

The authors declare no conflict of interest.

## Author Contributions

"Conceptualization, AR, OB and AOS ; methodology, AR; software, AR, OB and AEA; validation, AR, OB, AOS and AEA; formal analysis, AR; investigation, AR, and AOS ; resources, AR; data curation, AR; writing—original draft preparation, AR, and OB; writing—review and editing, AR, OB, and AJAAG; visualization, AR, AOS, and AJAAG; supervision, AOS, AEA, and AJAAG; project administration, AEA; funding acquisition, AJAAG".

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