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Minkowski Island Fractal Monopole Antenna with CPW-Feed for Wide-Band Wireless Systems

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ABSTRACT: This paper presents a CPW-fed Minkowski island fractal monopole antenna with wideband characteristics. The Minkowski island fractal geometry is applied on the radiating patch of the monopole antenna to make it compact and enhance bandwidth performance. The measured return loss values indicate a fractional bandwidth of 114% from 2 GHz to 7.3 GHz. The simple structure and wideband characteristics make this antenna suitable for various wireless communication applications, including WLAN, Wi-Fi, Wi-Max, 5G, and sub-6 GHz band services.

1. INTRODUCTION

The rapid growth in wireless communication systems demands low-profile antennas capable of supporting wideband or ultra-wideband (UWB) operations. Wideband characteristics are necessary for high-speed data transmission. It also facilitates the integration of multiple wireless standards within a single platform. Researchers have explored various techniques to meet these shifting demands. These techniques are primarily based on altering surface current distribution or incorporating additional resonant paths within the antenna structure. Such modifications contribute to multiband and wideband operations, which makes these antennas well suited for modern wireless applications.

Monopole antennas are attractive because of their straightforward design, low production cost, and omnidirectional radiation characteristics [1]. While conventional monopole antennas typically exhibit narrow bandwidth, planar monopole antennas offer wide bandwidth. Bandwidth can be enhanced using numerous techniques like geometry modification, ground plane modification, feeding techniques, adding slots or stubs in the radiator, etc. A simple, electrically small, wideband monopole antenna for WLAN application is presented in [2]. This antenna has a simple monopole with a modified ground structure. Modification of the shape of the monopole antenna has resulted in bandwidth enhancement as reported in [3–5]. A printed monopole antenna employing the bounding box technique for bandwidth enhancement and size reduction is illustrated in [6].

The use of coplanar waveguide (CPW) feeding is popular due to its uniplanar structure, easy fabrication, and convenient integration with other components [7–10]. The antenna proposed in [7] is a CPW-fed monopole design that achieves ultra-wideband performance. By strategically embedding a rectangular notch at the corners of each ground plane, the design achieves enhanced impedance bandwidth and compactness, while maintaining good radiation performance across the entire operating frequency range. In [8], a CPW-fed rectangular monopole antenna is proposed, where bandwidth enhancement is accomplished through modifications to both the radiating patch and CPW ground structure. The work presented in [9] uses a CPW-fed planar monopole antenna supporting three operating bands used in WiMAX and WLAN applications. A compact fractal antenna with two different feeding techniques — microstrip line feed and CPW feed — has been demonstrated in [10]. The CPW-fed antenna maintains a return loss below -10 dB over a broader frequency range, indicating enhanced bandwidth. The agreement between simulated and measured results is also more consistent in the CPW-fed design, suggesting better fabrication tolerance.

The application of fractal geometry in antenna designs is a good solution to obtain wideband and multiband characteristics without increasing the size of the antenna. Fractal geometries, characterized by self-similarity and space-filling properties, introduce multiple current paths and resonances, enabling miniaturization and enhanced bandwidth. Common fractal shapes like Koch, Sierpinski, and Minkowski have been widely used to improve antenna performance for wireless and broadband applications. Werner and Ganguly [11] reviewed various fractal antenna geometries, highlighting their multiband, wideband, and miniaturization capabilities. Several researchers have demonstrated the advantages of fractal geometries in antenna design. For example, the antenna in [12] employs a slotted circular monopole with fractal design to achieve UWB performance in a CPW-fed configuration. In [13], a CPW-fed Koch fractal antenna, implemented up to the second iteration

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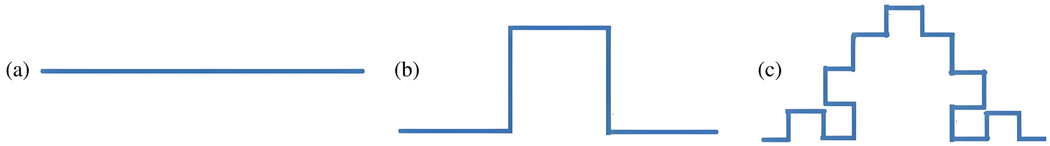

FIGURE 1. The generation of Minkowski fractal. (a) Initiator. (b) First iteration. (c) Second iteration.

FIGURE 2. The generation of Minkowski island fractal structure: (a) Initiator. (b) First Iteration. (c) Second Iteration.

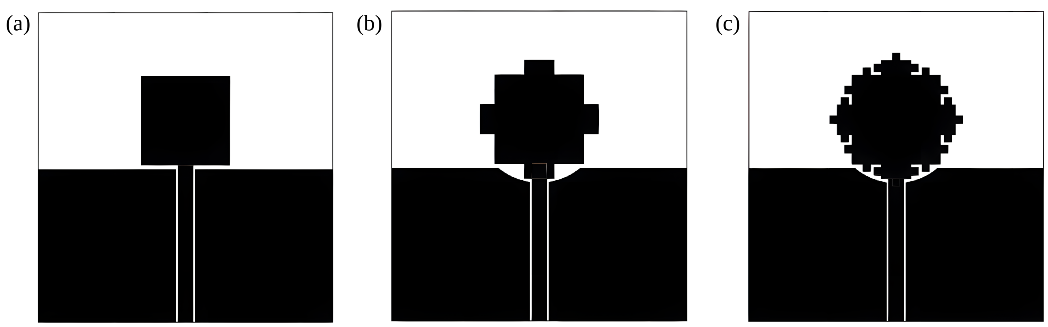

FIGURE 3. The evolution of the design stages. (a) Initiator. (b) First iteration. (c) Second iteration.

with a partial ground configuration, is proposed for multiband wireless applications. Ref. [14] introduces a super wideband antenna utilizing a third-order hexagonal fractal structure, operating in the S, C, and partial X bands.

Recent studies have also explored the use of defected ground structure (DGS) to enhance microstrip and CPW-fed antenna performance. DGS involves deliberately modifying the ground plane to alter current distribution, leading to enhanced bandwidth and radiation characteristics. Notable works have demonstrated that introducing defects in the ground plane improves bandwidth and enhances radiation characteristics [15–17].

In the continuation of fractal-based antenna designs, several fractal geometries — such as Koch, Sierpinski, Hilbert, and Minkowski have been employed in antenna engineering to achieve miniaturization and multiband performance [11–14, 18]. Among them, Minkowski fractal has been less explored than Koch and Sierpinski, but it is gaining growing interest. The Minkowski structure has also been utilized in dielectric resonator antennas, slot antennas, and other configurations [19–22]. In most of these works, Minkowski structure has been used till the 2nd iteration with microstrip line feed. Notably, Minkowski island fractal design, characterized by inward cuts, has been more extensively investigated in prior studies. This work attempts to incorporate a Minkowski fractal island structure with outward cuts into a CPW-fed antenna configuration to enhance performance. While our earlier work [23] focused on a monopole antenna embedded within a Minkowski island slot, the current study presents a fundamentally different approach by utilizing a complementary structure, a Minkowski patch monopole within the CPW-fed configuration. This transition from a slot-based structure to a patch-based design highlights a distinct change in antenna geometry and operating mechanism, underscoring the novelty of the proposed work.

2. GENERATION OF MINKOWSKI ISLAND STRUCTURE

Fractals are geometric shapes created by repeating a basic pattern in progressively smaller scales. A key characteristic of fractals is self-similarity, meaning that their structure looks similar at different levels of magnification. In antenna design, this property is utilized to support multiple resonant frequencies

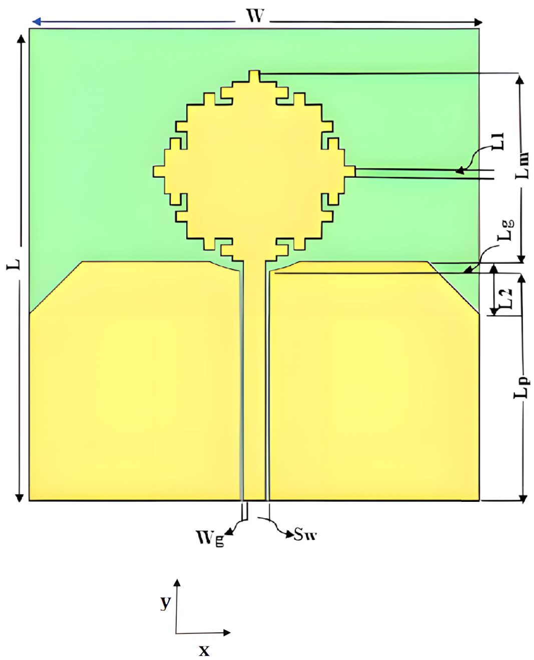

FIGURE 4. Schematic diagram of the proposed Minkowski island fractal monopole antenna.

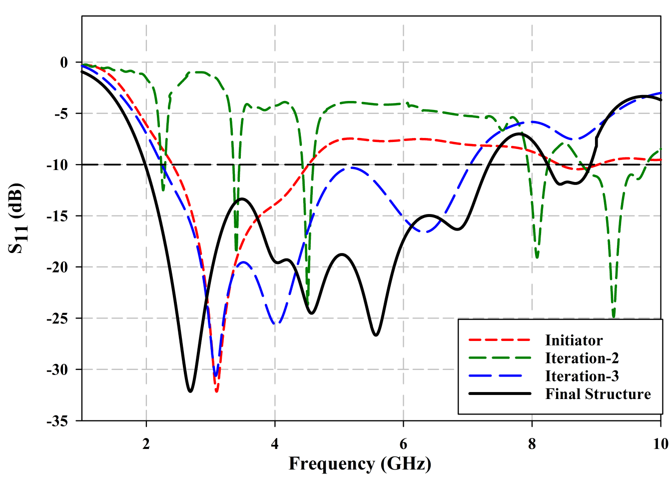

FIGURE 5. Simulated variations of S_{11} with frequency for different iterated levels of Minkowski island fractal monopole antenna.

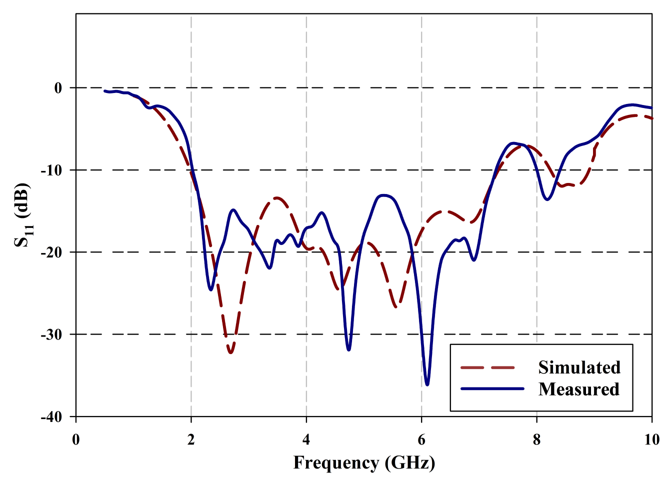

FIGURE 6. Variations of S_{11} with frequency of the proposed Minkowski fractal monopole antenna.

within a compact area, enabling wideband or multiband performance without increasing the overall size of the antenna.

Minkowski fractal structure is generated through a recursive geometric process that enhances antenna compactness and bandwidth. Starting from a simple line segment (initiator), each iteration replaces the middle third of every line with a stepped pattern (protruding outwards or inwards), increasing the effective electrical length. As shown in Figure 1, this iterative method results in a complex, self-similar shape that supports multiple resonant paths. In antenna design, this feature is useful for creating multiple resonant frequencies, which helps in achieving a wide bandwidth.

This principle is applied on a closed figure to develop a Minkowski island fractal structure. The design starts with a square patch as the base structure. By applying the Minkowski transformation through two successive iterations, the final antenna geometry is achieved. Figure 2 depicts different stages in the development of the Minkowski island fractal structure.

3. ANTENNA DESIGN

The design and simulation of the Minkowski island fractal monopole antenna is performed in Computer Simulation Technology (CST) Microwave Studio Software. This antenna has been designed using an FR4 substrate whose relative permittivity $\varepsilon_r = 4.3$, loss tangent $= 0.025$, and thickness $= 1.6$ mm. The initial design, depicted in Figure 3(a), features a simple rectangular monopole radiator with a dimension of $18\,\text{mm} \times 18\,\text{mm}$ fed by CPW feed. Minkowski transformation is applied to the initial design to enhance the antenna's

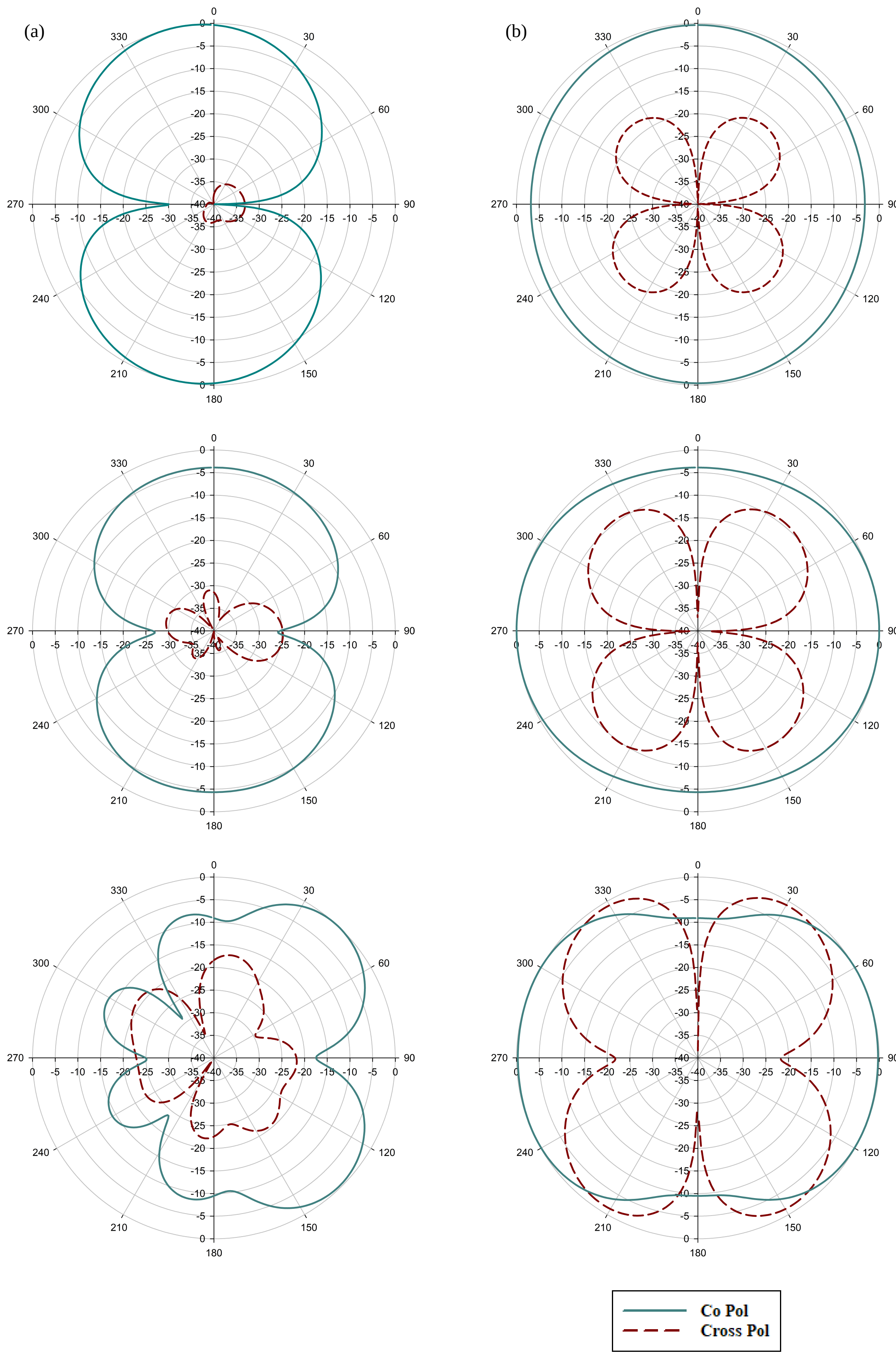

FIGURE 7. Normalized radiation pattern measured at 2.3 GHz, 4.7 GHz & 6.1 GHz on (a) E-plane & (b) H-plane.

TABLE 1. Optimized parameter values of the proposed antenna.

Parameters	W	L	W_g	S_w	L_1	L_2	L_m	L_p	L_g
Values in (mm)	60	63	0.5	3	1.5	7	32	25	1.25

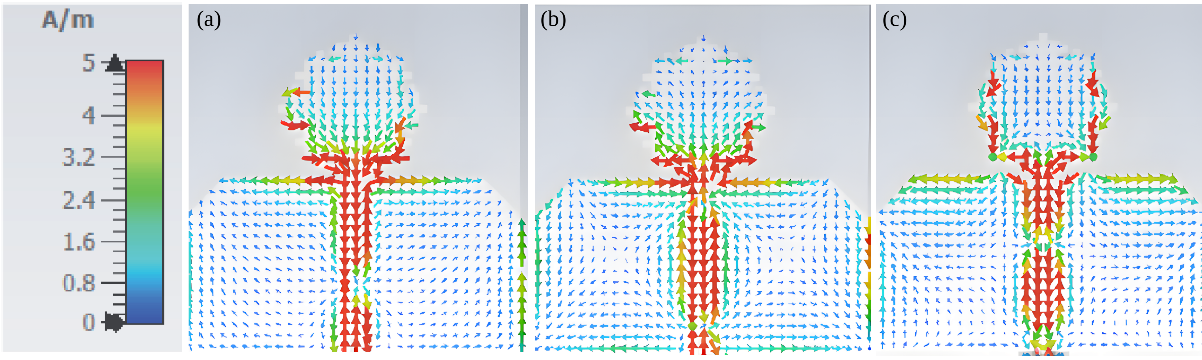

FIGURE 8. Surface current at 0° for different frequencies. (a) 2.3 GHz, (b) 4.7 GHz, (c) 6.1 GHz.

performance. This process involved dividing each side of the square patch into three equal segments and replacing the central segment with a stepped pattern that extends 3 mm outward, as shown in Figure 3(b). Modification of the ground plane was necessary to accommodate the updation. It has been observed that the incorporation of curved necks provides smooth current distribution [24]. Therefore, this approach was adopted. Further application of the Minkowski transformation to this design resulted in the stepped edges that enhance the effective electrical length and bandwidth. This structure is depicted in Figure 3(c). To enhance the bandwidth, the structure has been slightly modified by chamfering the ground plane and adjusting the space between the monopole neck and ground plane. The antenna is excited using a coplanar waveguide (CPW) feed line with a width of 3 mm and a gap of 0.5 mm on each side, providing efficient impedance matching. The final Minkowski island fractal monopole antenna geometry after incorporating chamfered ground plane edges is shown in Figure 4. The optimized parameter values are shown in Table 1.

4. EFFECT OF ITERATION LEVELS ON THE REFLECTION COEFFICIENT

Figure 5 shows variations of S_{11} with frequency at different iteration levels of the proposed antenna. The initial antenna structure exhibited a single-band response with an operational bandwidth spanning from 2.4 GHz to 4.5 GHz, corresponding to a fractional bandwidth of 60.86%. Upon applying the first iteration of the Minkowski transformation, the antenna evolved into a multiband configuration, resonating at 2.26 GHz, 3.39 GHz, 4.5 GHz, 8.06 GHz, and 9.27 GHz. Further enhancement in bandwidth (2.2 GHz to 7 GHz) was observed with the second iteration, where the fractional bandwidth increased from 60.86% to 104%. However, the S_{11} parameter near the 5 GHz region remained close to the -10 dB threshold. The structure was slightly modified to address this issue by chamfering the ground plane edges and adjusting the space between the monopole neck and ground plane. Geometrical modifications such as chamfering and adjusting the space between the monopole neck and ground plane are critical in refining antenna performance. Chamfering smoothes sharp edges to help the surface current flow evenly and avoid unwanted resonances. These modifications led to a notable improvement in bandwidth (1.98 GHz–7.32 GHz), achieving a fractional bandwidth of approximately 115%.

5. RESULTS AND DISCUSSION

The prototype of the proposed antenna was fabricated on a substrate of relative permittivity $\varepsilon_r = 4.3$ and thickness 1.6 mm with the dimensions listed in Table 1.

Frequency domain measurements were conducted using Anritsu MS 46122B Vector Network Analyzer. The variation of S_{11} with frequency of the proposed antenna is shown in Figure 6. The measured result closely matches the simulated value. Return loss measurement indicates a wide bandwidth ranging from 2 GHz to 7.3 GHz, yielding a fractional bandwidth of 114%.

The normalized radiation patterns at various frequencies are shown in Figure 7. The antenna shows a figure of eight patterns in the E-plane and an omnidirectional co-polarization pattern in the H-plane. Cross-polarization is significantly lower than co-polarization across most directions. The distortion in the shape at higher frequency is due to the excitation of higher order mode.

Figure 8 presents the surface current distributions of the proposed antenna at three resonant frequencies: 2.3 GHz, 4.7 GHz, and 6.1 GHz. The gradual change in current path and distribution across these three frequencies confirms the multimode operation of the antenna. The excitation of fundamental and higher-order modes enables the antenna to efficiently cover a wide bandwidth or multiple bands. Furthermore, the observed

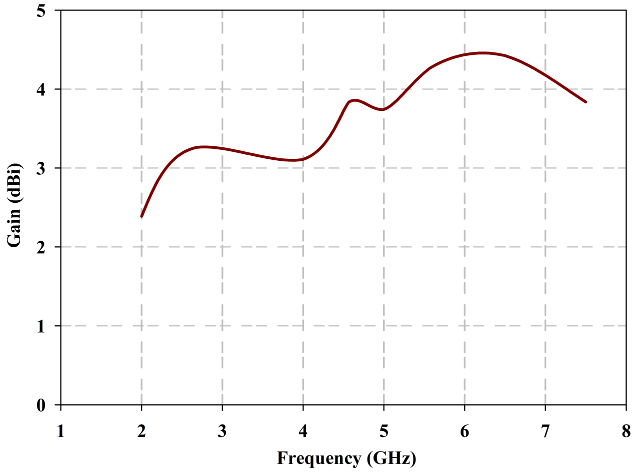

FIGURE 9. Variation of measured gain with frequency for the CPW fed Minkowski island fractal monopole antenna.

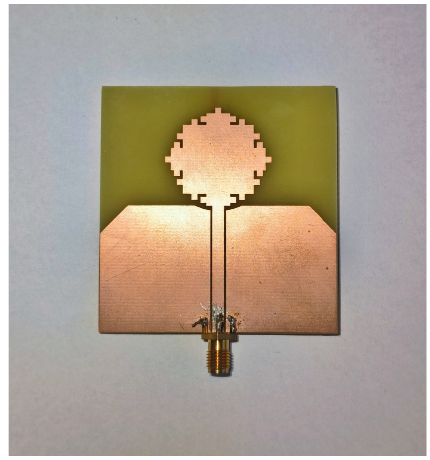

FIGURE 10. Photograph of the fabricated CPW fed Minkowski island fractal monopole antenna.

TABLE 2. The comparison of the proposed antenna with various reported wideband/UWB antennas.

Antenna	Size (mm)	Frequency Range (GHz)	Fractional Bandwidth
Ref. [4]	60 × 20	4 to 10	85%
Ref. [5]	60 × 42	2.78 to 9.78	111%
Ref. [6]	200 × 120	0.28 to 2.27	156%
Ref. [15]	60.4 × 98.1	0.79 to 2.06	89%
Ref. [17]	33.5 × 34.5	2 to 6.2	103%
Proposed Antenna	60 × 63	2 to 7.3	114%

surface current paths validate the design's suitability for wideband applications.

The measured gain of the antenna in the operating band is plotted in Figure 9. The gain remains consistently above 2.5 dBi in the operating band. The increase in the gain at high frequencies is owing to the non-ideal omnidirectional pattern at higher frequencies, which slightly boosts gain. The proposed antenna attains a maximum radiation efficiency of 93.3% within the operating band. Table 2 summarizes the performance comparison of the proposed antenna with various reported wideband and ultra-wideband (UWB) antennas. Figure 10 shows a photograph of the fabricated antenna.

6. CONCLUSION

This work presents a CPW-fed wideband fractal antenna incorporating a Minkowski island monopole for wireless communication systems. The antenna integrates a monopole configuration with Minkowski fractal geometry to enhance bandwidth. The Minkowski fractal monopole introduces multiple resonant modes, significantly extending bandwidth. The antenna achieves wideband operation from 2 GHz to 7.3 GHz, corresponding to a fractional bandwidth of 114 %. This broad frequency coverage makes this antenna suitable for various wireless technologies such as WLAN, WiMAX, Wi-Fi, 5G and emerging sub-6 GHz applications. Additionally, the antenna offers a stable radiation pattern and moderate gain across its operational band. Its uniplanar configuration, omnidirectional characteristics, and compact size make it ideal for modern multi-standard wireless devices requiring seamless connectivity.

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