Design and Development of Multiband Hybrid Microstrip Patch Antenna for Advanced Wireless Communication Systems

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***Abstract*— This research article present a novel flower-shaped multiband microstrip patch antenna is presented for modern wireless communication systems, including GSM, WiMAX, ISM, and WLAN applications. The antenna is implemented on an FR-4 substrate (tan δ = 0.02, εr = 4.3) with a thickness of 1.6 mm. To achieve improved impedance matching, the design incorporates two symmetrical rectangular slots and one elliptical slot. The antenna is excited using a 50 Ω microstrip feed line and operates efficiently across four distinct frequency bands—band 1 (0.651–1.696 GHz), band 2 (2.76–2.98 GHz), band 3 (3.53–3.97 GHz), and band 4 (4.55–5.92 GHz)—for |S11| ≤ −10 dB. Additionally, the paper presents a comprehensive analysis of the simulated surface current distribution and far-field radiation characteristics.**

Keywords- wireless communication, Microstrip Patch, multiband antenna etc.

I. INTRODUCTION

The rapid growth of wireless communication technologies has driven the need for compact antenna designs that can efficiently utilize multiple operating bands. Various frequency bands are allocated for different communication standards, including GSM (890–960 MHz), PCS (1880–1990 MHz), DCS (1710–1880 MHz), UMTS (1920–2170 MHz), Bluetooth (2400–2484 MHz), WiMAX (3400–3600 MHz), and WLAN (5150–5350 MHz and 5725–5875 MHz). To support these services, numerous compact broadband [1–5] and multiband antennas [22–25] have been proposed for fixed and portable wireless devices. Several designs offering dual-band, triple-band, and multiband operation have been introduced for modern communication requirements [6–10].

Fractal antennas have gained significant attention due to their compact size, low profile, lightweight nature, and inherent wideband or multiband characteristics. Mandelbrot introduced the term fractal in 1983 to describe structures that exhibit self-similarity across different scales, meaning each part resembles the overall shape. Fractals may be regular or irregular in form [12–21]. Examples of irregular fractals include ferns, tree leaves, snowflakes, and coastlines, whereas Sierpinski gaskets, Sierpinski carpets, Koch curves, Minkowski fractals, and Meander fractals represent regular fractal geometries.

Werner [13] explored the use of fractal geometry in antenna engineering and demonstrated several design approaches, including Sierpinski structures, fractal trees, Hilbert and Koch curves, Cantor arrays, and Minkowski curves. These geometries offer advantages such as conformal shapes, compact size, low profile, and the ability to achieve wideband or multiband performance.

In this work, a hybrid fractal-like antenna structure is proposed to achieve a simple and effective multiband design. The antenna is fabricated, measured, and thoroughly analyzed. Simulated and measured S11 parameters are compared graphically, and the surface current distribution as well as the far-field radiation patterns are discussed in detail.

II. ANTENNA GEOMETRY

The two-dimensional planar flower-shaped hybrid fractal structure is shown in Fig. 1. It is fabricated on an FR-4 epoxy substrate with tan δ = 0.02, ε_r = 4.3, and a thickness of 1.6 mm. A 50 Ω microstrip feed line of dimensions $M_1 \times M_2$ is designed on the top layer of the substrate and terminates at one of the leaves of the fractal-shaped structure. A circular slot of diameter D_1 is etched at the center of the antenna, and six smaller circular slots of diameter D_2 are removed from the six petals of the flower to support multiband operation.

On the bottom side of the substrate, a ground plane of dimensions L_g and W_g is printed at $Z = 0$. A semi-elliptical slot with major and minor radii R_1 and R_2, respectively, is etched from this ground plane. Additionally, two small rectangular open slots of dimensions $L_1 \times W_1$, symmetrically placed about the Y-axis, are incorporated into the ground layer to achieve proper impedance matching. All optimized design parameters of the proposed antenna are listed in Table 1.

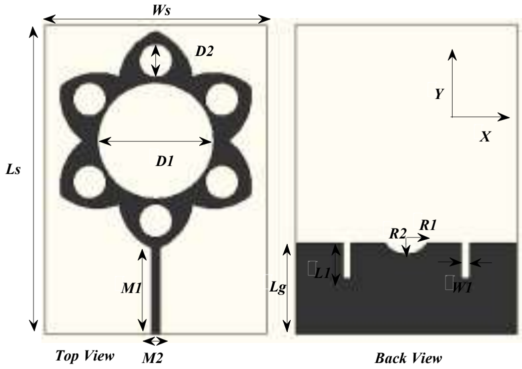


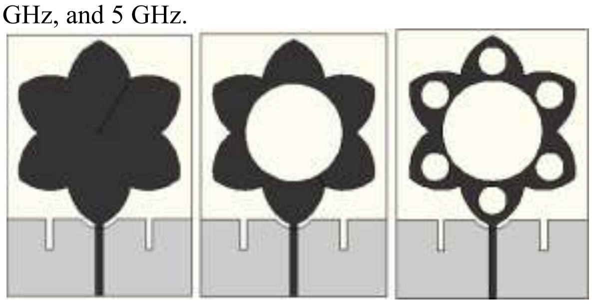
Fig. 1 Geometry of the flower shaped hybrid microstrip patch antenna

Table 1 Optimized dimension of proposed antenna

Parameter	Dimension	Parameter	Dimension
M_1	32.5mm	D_2	11mm
M_2	3.2mm	L_g	34mm
L_s	110mm	R_1	7mm
W_s	75mm	R_2	5.5mm
D_1	40mm	L_1	12mm
W_1	2.8mm		

III. EVOLUTION OF ANTENNA

The evolution of the flower-shaped hybrid fractal antenna is illustrated in Fig. 2, and the comparative frequency responses of Antenna 1, Antenna 2, and Antenna 3 are presented in Fig. 3. When simulated using CST Microwave Studio, Antenna 1 exhibits two resonant frequencies at 0.95 GHz and 3.5 GHz. In the first iteration (Antenna 2), a circular slot concentric with the flower-shaped structure is introduced on the top layer of the substrate. This modification generates additional resonant modes at 1.75 GHz and 5 GHz. The introduction of the slot alters the inductance (L) and capacitance (C) of the structure, thereby reducing the phase velocity $v_p = 1/\sqrt{LC}$, which leads to mode merging and the appearance of new resonant frequencies. As a result, Antenna 2 supports four frequency bands with five resonances at 0.94 GHz, 1.75 GHz, 3.42 GHz, 3.5 GHz, and 5 GHz.



(1) (2) (3)

Fig. 1 Evolution of the flower shaped hybrid microstrip patch 1, 2 and 3

In the second iteration (Antenna 3), six circular slots are etched on the petals of the flower-shaped structure. This further enhances impedance matching between the radiating patch on the top layer and the modified ground plane on the bottom layer. Antenna 3 exhibits four operating bands with resonant frequencies at 0.94 GHz, 1.7 GHz, 3.42 GHz, 4.7 GHz, and 5.4 GHz, along with improved return-loss performance. The corresponding impedance bandwidths for $|S_{11}| \leq -10$dB are 23%, 18%, 16%, and 29% for band 1, band 2, band 3, and band 4, respectively.

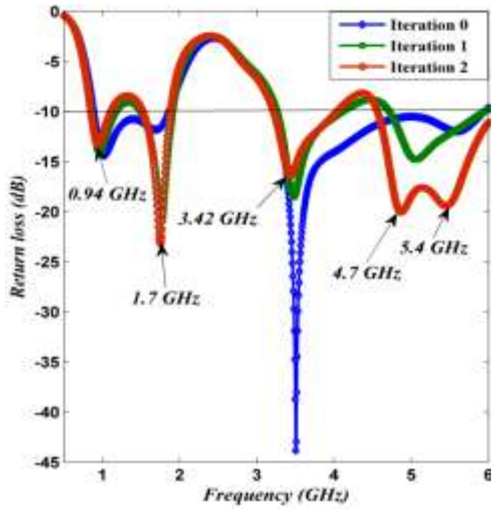


Fig. 2 Simulated frequency response of flower shaped hybrid microstrip patch antenna 1, 2 and 3

IV. EXPERIMENTAL RESULT

The fabricated flower-shaped hybrid fractal antenna is shown in Figure 4. After fabrication, the antenna was tested using a Vector Network Analyzer over the 0.5–6 GHz frequency range. Figure 5 presents a comparison of the simulated and measured results. The variations observed at lower frequencies are primarily attributed to imperfect synchronization between the top radiating structure and the ground plane. Additional factors such as the lossy characteristics of the FR-4 glass-epoxy substrate, differences between practical and ideal measurement environments, and improper soldering of the microstrip connector may also contribute to these discrepancies. To minimize such variations, careful attention must be given to soldering the connector to the microstrip feed.

Fig. 4 Fabricated flower shaped hybrid microstrip patch antenna

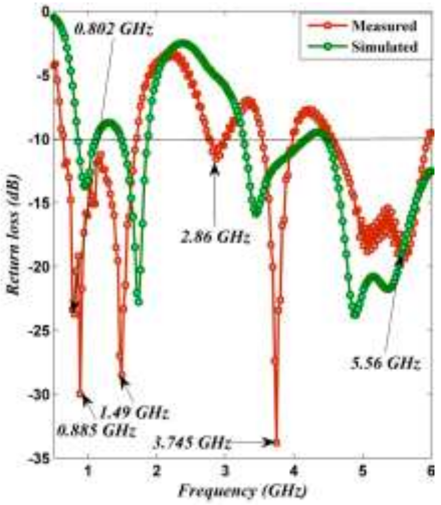


Fig. 5 Measured and simulated frequency response of the proposed antenna

The fabricated antenna successfully covers four frequency bands—band-1 (0.651–1.696 GHz), band-2 (2.76–2.98 GHz), band-3 (3.53–3.97 GHz), and band-4 (4.55–5.92 GHz)—for $|S_{11}| \leq -10$ dB. The corresponding resonant frequencies achieved by the antenna are 0.802, 0.885, 1.49, 2.86, 3.745, and 5.56 GHz. Table 2 summarizes the covered frequency bands along with their fractional bandwidths, calculated using $(BW(\%) = (f_h - f_l) * 200/(f_h + f_l))$.

Table 2 Frequency response characteristic of fabricated antenna

Frequency Band (GHz)	Measured Resonance frequency (GHz)	Bandwidth (%)
0.651-1.696	0.802	89
	0.885	
	1.49	
2.76-2.98	2.86	7.66
3.53-3.97	3.745	11.73
4.55-5.92	5.56	26

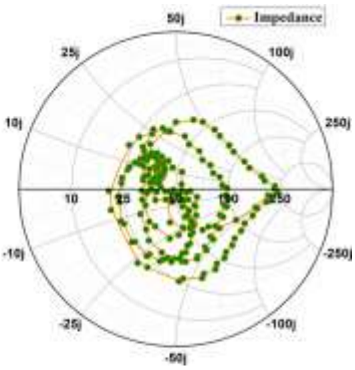


Fig. 6 Normalized input impedance of the proposed antenna

Figure 6 illustrates the variation of the input impedance of the proposed antenna as a function of frequency. The radiation characteristics of the antenna are described using its E-plane and H-plane patterns. Figure 7 presents these radiation patterns for the simulated structure at four resonant frequencies: 0.94, 1.7, 3.42, and 5.4 GHz. At the lower frequencies of 0.94 and 1.7 GHz, the antenna exhibits an eight-shaped omnidirectional pattern in both the E-plane and H-plane. However, at the higher resonant frequencies of 3.42 and 5.4 GHz, the radiation patterns become distorted, which can be attributed to the excitation of higher-order modes.

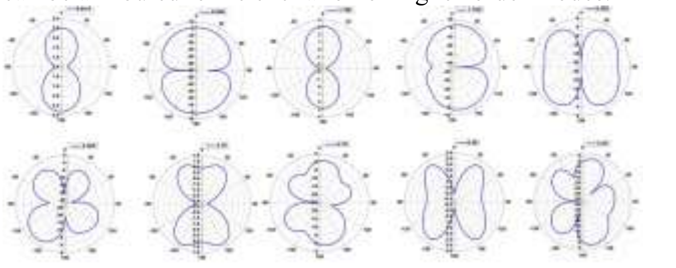


Fig. 7 E and H plane radiation pattern of the proposed antenna 0.94, 1.75, 3.42, 4.7 and 5.4 GHz

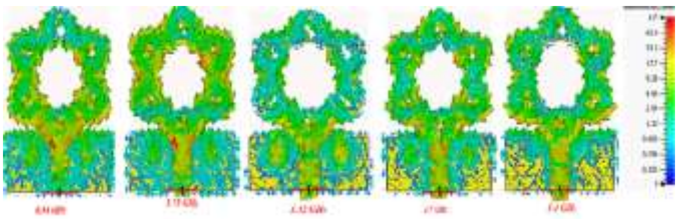


Fig. 8 Surface Current Distribution of the prototype at simulated resonating frequencies 0.94, 1.75, 3.42, 4.7 and 5.4 GHz

Figure 8 represents surface current distribution of the proposed antenna at frequency simulation 0.94, 1.75, 3.42 and 5.4 GHz.

V. CONCLUSION

A novel flower-shaped multiband fractal antenna has been designed, simulated, and fabricated in this work. The multiband behavior is achieved through the incorporation of self-similar circular slots of varying scales within the flower-shaped geometry. The fabricated prototype covers four frequency bands—band-1 (0.651–1.696 GHz), band-2 (2.76–2.98 GHz), band-3 (3.53–3.97 GHz), and band-4 (4.55–5.92 GHz)—for $|S_{11}| \leq -10$ dB. These operating bands make the antenna suitable for GSM, WiMAX, ISM, and WLAN applications in wireless communication. The antenna also exhibits six resonant frequencies at 0.802, 0.885, 1.49, 2.86, 3.745, and 5.56 GHz.

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