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Research Article

Ultra-Compact Slitted Flower-Shaped Dual-Band Monopole Antenna for Modern Portable Devices

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A meanderingly slitted bio-inspired (MSB)-shaped antenna is presented in this work. The footprint of the proposed MSB antenna is $12 \times 10\,\text{mm}^2$ ($0.12 \times 0.10\lambda_g^2$ at $2.1GHz$). The MSB antenna proposed in this operates at 2.1 GHz and 5.2 GHz frequencies with a bandwidth of 70 MHz and 570 MHz and a radiation efficiency of 52.5% and 96%, respectively, which is suitable for UMTS, radio navigation, Long Term Evolution (LTE), and 5 GHz Wireless Local Area Network (WLAN) applications. The proposed MSB antenna demonstrates a peak gain of 2.9 dBi at 5.2 GHz and an omnidirectional radiation pattern at both E-plane and H-plane in both operating bands. The fabrication and measurement of the proposed antenna prototype are presented. The parametric study of the proposed structure is performed and presented. Therefore, the proposed antenna is a promising candidate for modern portable devices.

1. Introduction

Antenna is one of the enabling components of wireless communication systems, and it has evolved over the years. In this era of heterogeneous technologies, the multiband antenna has become an indispensable need [1–3]. In addition, miniaturization of the antenna (electrical) size is another issue confronting the antenna design engineers due to the users' ever-increasing quest for portable mobile devices [4]. Therefore, a modern antenna should not only be suitable for the multifrequency application, but it must also be compact in order to reduce the overall size and weight of the mobile devices. The miniaturization of multiband antennas has been achieved using slotting [5–7], defected ground structure (DGS) [8–11], parasitic loading [8, 12–17], and multiple structures.

In addition, folding and meandering techniques have also been explored for the design of the miniaturized antenna. For example, the authors in [1] presented a ram horn-shaped folded antenna suitable for LTE-A and WLAN with a footprint of $10 \times 15\,\text{mm}^2$ on a rogers substrate. More so, the hexagonally folded antenna was presented by authors in [18] which is suitable in the global positioning system (GPS), LTE, and satellite applications, but the antenna size is $70 \times 45\,\text{mm}^2$ on an FR4 substrate compared with an antenna dimension $12 \times 10\text{mm}^2$ proposed antenna in this work. In addition, a tapered ACS-fed antenna with a split-ring resonator (SRR) slitted ground on a $25 \times 12.2\,\text{mm}^2$ FR4 substrate was reported by authors in [19]. In a similar manner, the authors in [20] presented a shorting pin-based meander line monopole antenna having a footprint of $0.22 \times 0.36\,\text{mm}^2$ which operates as a hexa-band antenna.

Recently, the plant leaf-shaped (bio-inspired) structures are increasingly been explored in antenna design. This is due to its improvement in perimeter, self-repeating, and suppleness capabilities. Although this (leaf shape) has been greatly explored in designing ultra-wideband antennas [21–24], the authors in [25] have explored the same in designing compact multiband antennas. For example, the

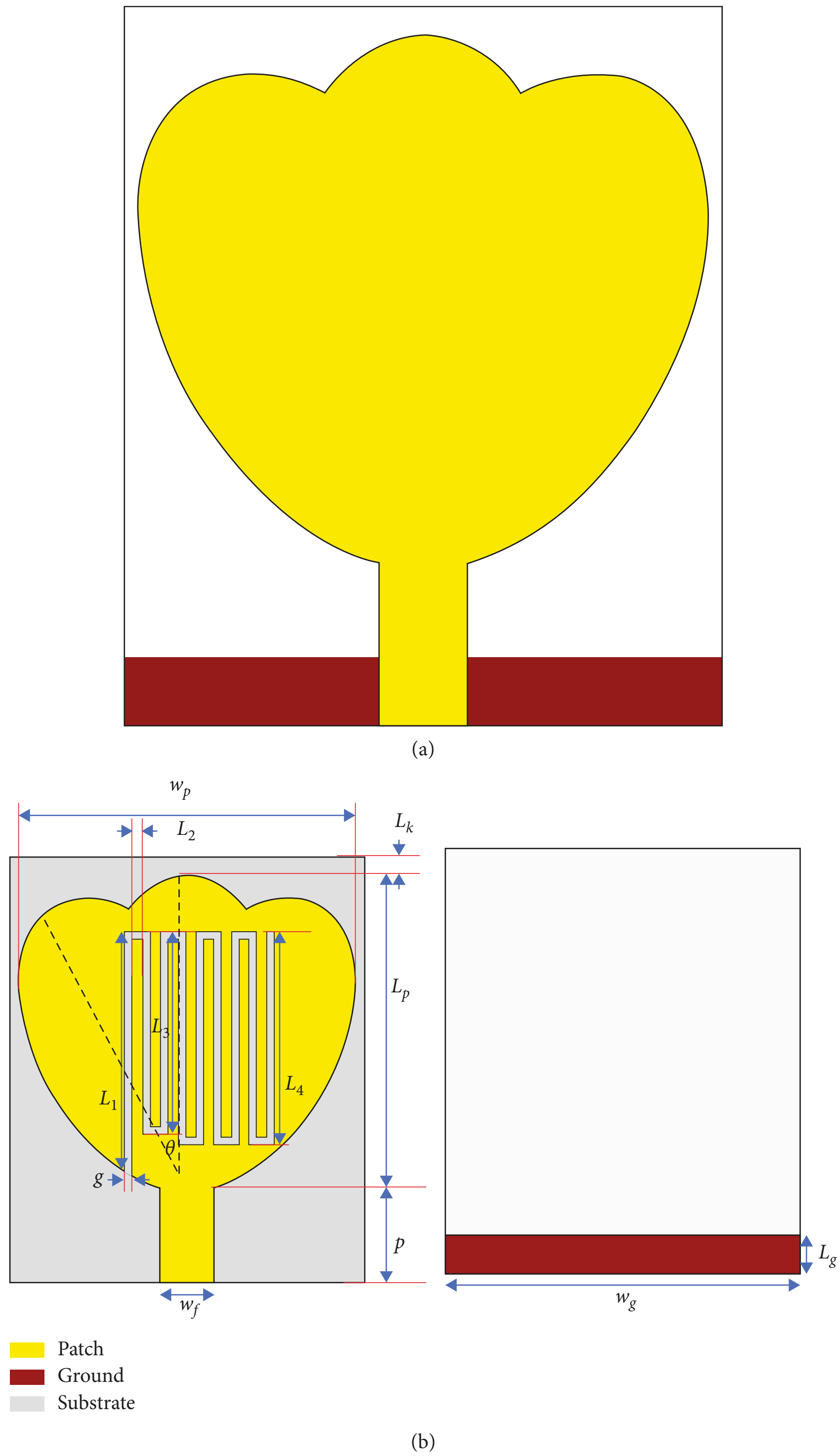


FIGURE 1: (a) Proposed MSB antenna initiator, (b) proposed MSB antenna design.

works presented in [25] are hexa-band bio-inspired antennas with the dimension of $22 \times 12\,\text{mm}^2$, respectively.

In this work, a flower-shaped patch with a meander slit is explored in designing an ultra-compact dual-band monopole antenna having a footprint of $12 \times 10\,\text{mm}^2$ $(0.12 \times 0.10\lambda_g^2$ at $2.1GHz)$ which is the smallest dual-band (LTE and WLAN) antenna size in the open literature as far as we know.

2. Design and Analysis of the Proposed MSB Antenna

The proposed MSB antenna design is a flower-shaped monopole antenna with a meandering slit that is fed with a $50\,\Omega$ microstrip feed line on a $12 \times 10\,\text{mm}^2$ rogers Duroid 5880 substrate having a permittivity of 2.2 and a thickness of

TABLE 1: Bio-inspired MTM backed antenna optimized design parameters.

Parameter	L_p	L_1	L_2	L_3	L_4	L_k	L_g
Value (mm)	8.8	6.7	0.3	5.7	6.0	0.5	1.1
Parameter	w_f	w_p	w_g	g	p	w	θ
Value (mm)	1.5	9.4	10	0.1	2.7	0.5	30°

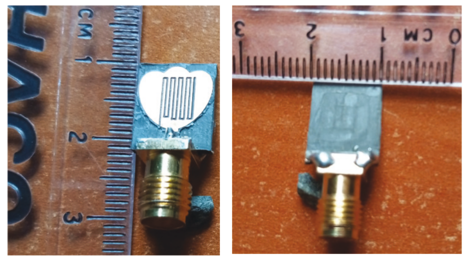
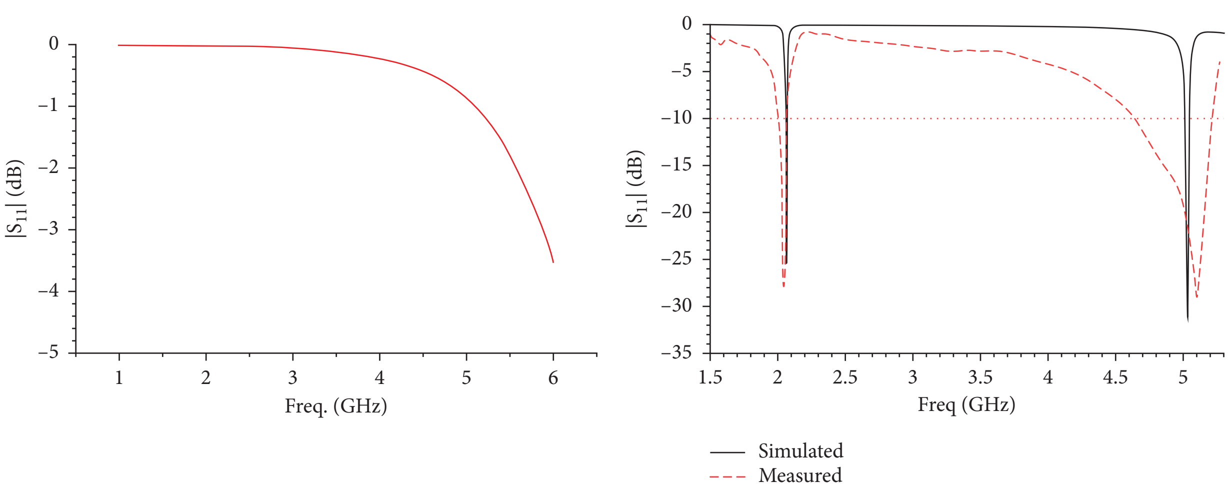


FIGURE 2: The fabricated MSB antenna.



(a) (b)

FIGURE 3: (a) The $|S_{11}|$ response of the initiator, (b) reflective response of the proposed MSB antenna.

1.57 mm as shown in Figure 1. The design begins with the flower patch monopole as shown in Figure 1(a) from which the meander line is slitted as shown in Figure 1(b), and the ground plane is shown in Figure 1(c). Table 1 shows the parametric dimension of the MSB structure. The notch-frequency (f_{rm}) of the meandering slit can be determined by using fundamental resonant frequency of a rectangular waveguide (TM100) as shown in equation (1) [26]. Hence, a notch is expected in 2.3 GHz, thereby leading to a resonance before and after 2.3 GHz, respectively. The finite element method (FEM)-based simulation tool is used for the simulation of the antenna presented in this work.

$$f_{rm} = \frac{c}{2L_m\sqrt{\varepsilon_{\text{eff}}}}, \quad (1)$$

where L_m is the total length of the meander line and defined as shown in equation (2), ε_{eff} is the effective permittivity, and c is the speed of light in the free space.

$$L_m = L_1 + 8L_2 + 2L_3 + 6L_4. \quad (2)$$

3. Results and Discussion

The fabrication of the prototype of the proposed antenna is as shown in Figure 2. The simulated and measured L_p results of the proposed MSB antenna are presented in this section.

3.1. Reflection Coefficient. Figure 3(a) shows the reflection response of the initiator (Figure 1(a)), and it can be observed that the first response of the slitless flower is above 6 GHz. It can be observed from Figure 3(b) that while using the meander slit, there is a notch at 2.3 GHz as predicted in equation (1) which leads to resonances at 2.1 GHz and 5.2 GHz representing the resonances before and after the notch, respectively, as predicted. This shows that the slit is a contributing element in the resonance at 2.1 GHz and 5.2 GHz. The measured bandwidth of the proposed MSB antenna as seen in Figure 3(b) is 70 MHz and 570 MHz at 2.1 GHz and 5.2 GHz, respectively. This implies that the proposed MSB antenna is suitable for UMTS, radio navigation, LTE, and 5.2 GHz WLAN applications. It can be

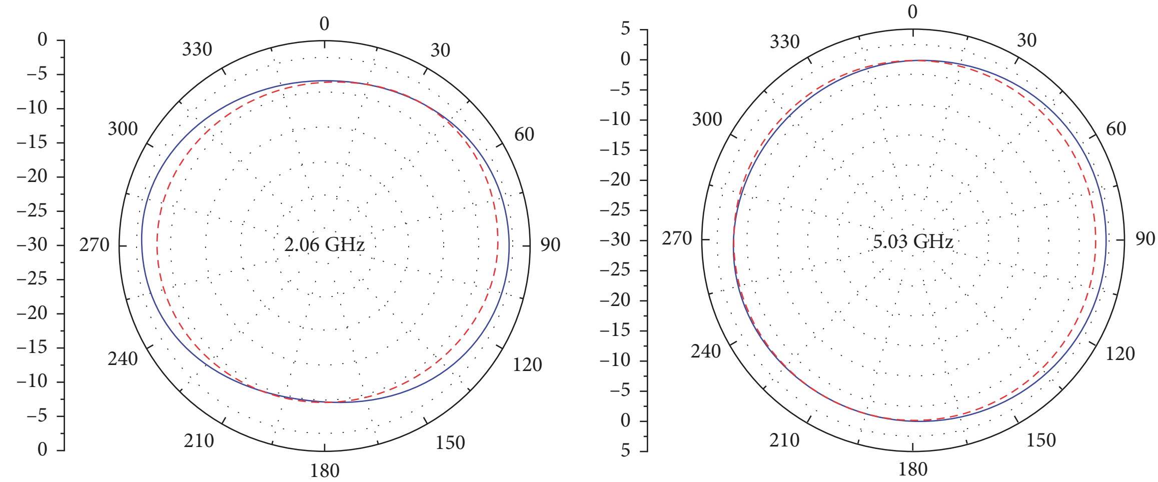


Figure 4: The radiation pattern of the proposed MSB antenna.

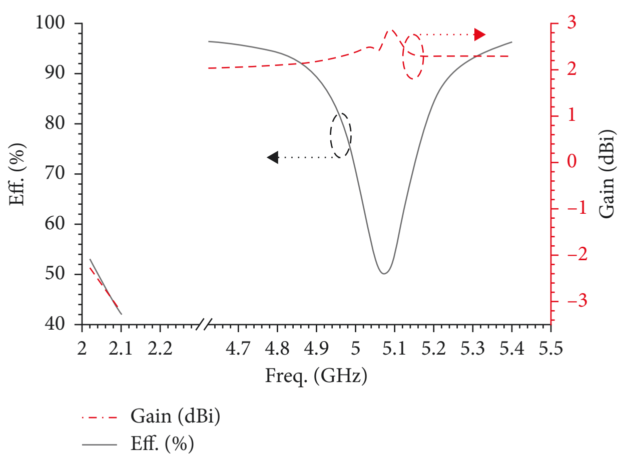


Figure 5: The gain and efficiency of the proposed MSB antenna.

noticed that there is no significant difference in the resonant frequencies of the simulated and measured results. Besides, it can be observed that the proposed MSB design shows good impedance matching at both operating frequencies as the measured reflection coefficient at 2.1 GHz and 5.2 GHz is less than −25 dB, respectively.

3.2. Gain, Radiation Pattern, and Efficiency of the MSB Antenna. The radiation pattern of the proposed MSB antenna is shown in Figure 4. It can be observed that the radiation pattern at both E-plane (denoted by the red short dash) and H-plane (denoted by the blue solid line) at both 2.1 GHz and 5.2 GHz are omnidirectional which is a desirable radiation pattern in mobile user equipment. The gain and efficiency of the proposed MSB antenna are presented in Figure 5. It can be observed that the peak gain is 2.9 dBi, respectively. Besides, the peak radiation efficiency at the lower and upper bands are 52.5% and 96%, respectively. The efficiency of the proposed antenna at 2.1 GHz is low because of the compactness of the proposed antenna, and this is a common phenomenon in electrically small antennas [27]. Therefore, the proposed MSB antenna is a suitable candidate for LTE and WLAN wireless portable devices.

4. Current Distribution

The antenna current distribution (CD) gives a physical operational scenario of the antenna. Hence, the current distribution of the proposed MSB antenna is shown in Figure 6. It can be observed that the current primarily concentrates on the flower patch and around the meandering slit at 2.1 GHz which shows that the meander-line slit increases the current path (antenna electrical length) on the flower-shaped patch and thereby leads to the resonance at the lower frequency (2.1 GHz). In the case of 5.2 GHz resonance, the current is distributed around the slit only unlike the case of 2.1 GHz which shows that the slit also contributed to the resonance at 5.2 GHz. This implies that the slit is one major contributor to the resonance at these frequencies.

5. Parametric Study

The effect of the ground plane, slit width, and slit length on the reflective response of the proposed MSB antenna are studied and presented in this section.

5.1. Effect of L_g on $|S_{11}|$. As seen in Figure 7, the length of the ground plane affects the depth of reflection; that is, it impacts the impedance matching. It can be seen that the optimal value of L_g is 1.1 mm which demonstrates the best reflection coefficient. It can be noted that L_g variation does not affect the resonant frequency at both bands.

5.2. Effect of **g** *on $|S_{11}|$.* It can be observed from Figure 8 that the width of the slit has a significant effect on the resonant frequency at both bands. It can be seen that as the slit width increases, the resonant frequencies increase correspondingly. With a 0.1 mm increase in the slit width, there is an 11.96% increase in resonant frequency at the lower band and

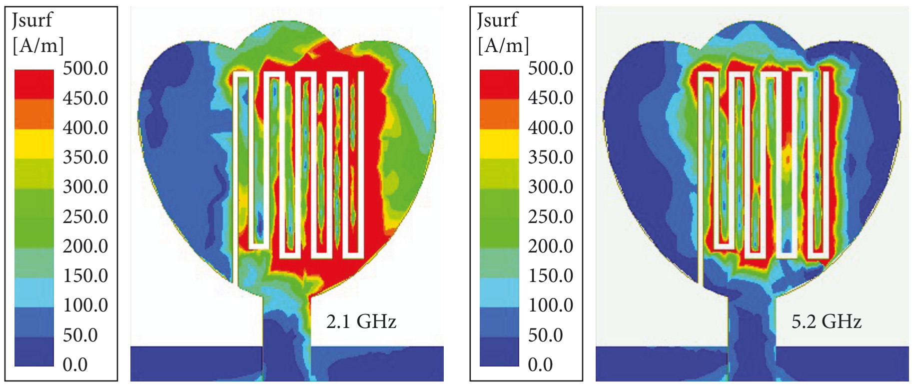


Figure 6: Current distribution of the proposed MSB antenna.

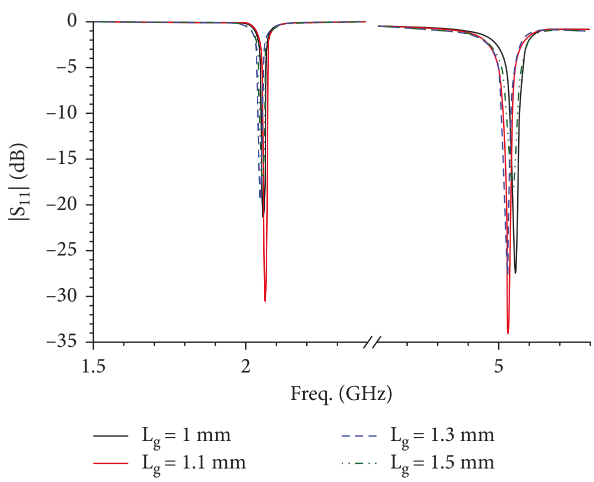


Figure 7: $|S_{11}|$ of the varying L_g.

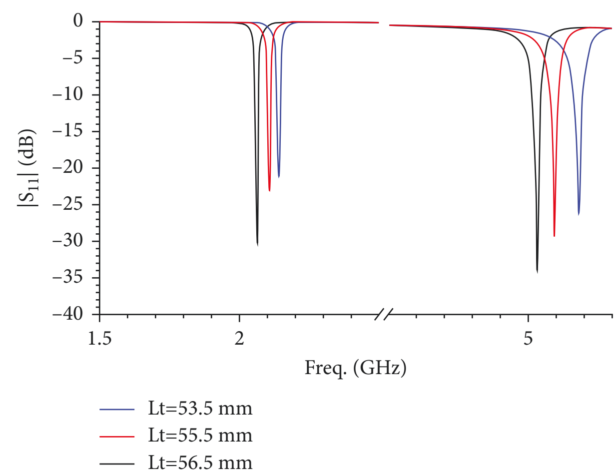


Figure 9: $|S_{11}|$ of the varying L_t.

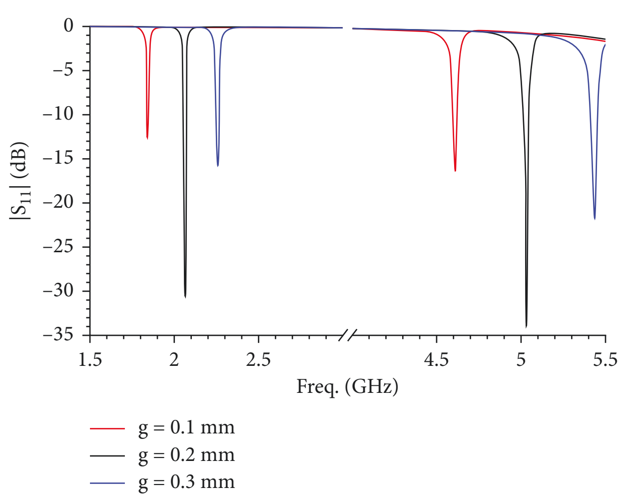


Figure 8: $|S_{11}|$ of the varying g.

a 9.33% increase at the upper band.This scenario is because variation in slit width tremendously affects the equivalent slit length. It can also be noted that the optimal value of the slit width is 0.2 mm in terms of optimum impedance matching as seen in Figure 8. This shows that the slit width can be used to achieve frequency reconfigurability as demonstrated herein. Although the focus of this work is 2 GHz and 5 GHz bands, this case is of importance to the antenna community as it shows that by simply changing the slit width, the operating frequency of both bands can be changed concurrently while maintaining a reflection coefficient below −10 dB at both bands.

5.3. Effect of L_m on $|S_{11}|$. As expected from equation (1), there is a frequency shift with an increase in the slit length at both operating frequencies. It can also be noticed that as the slit length increases, the impedance matching at the upper band increases. It is noteworthy also that the slit length can also be used for small-width frequency reconfigurability purposes as shown in Figure 9.

6. Comparative Analysis

Table 2 presents the comparative analysis results of this work with the existing works in the literature. For normalization purposes, the electrical size of the antennas was used considering the lowest resonance frequency. The results show that the MSB antenna presented in this work is the most compact as seen in the third column of Table 2. Although, in terms of the peak gain, the works presented by authors in [20, 28] outperformed the proposed antenna notwithstanding at a bigger

Table 2: MSB antenna's comparative analysis with the existing works in the literature.

Ref.	Year	GW size (λ_g^2)	Frequency (GHz)	Antenna gain	Efficiency (%)	Techniques
[29]	2019	0.54×0.62	2.4/3.5/5.5	2.25/3.72/2.71	NR	Split ring resonant array
[1]	2021	0.11×0.17	2.3/5.8	0.62/2.2 dBi	93.67/99.87	AMF and GPS
[28]	2020	0.42×0.49	3.59/5.53+	3/3.6 dBi	93/87	C-SRR, H-CRR, and ACGP
[20]	2021	0.99×0.58	1.5/2.45/3.85/5.13/5.8	2.7/4.8/4.1/2.5/4.2 dB	NR	Window grille shape
[30]	2022	1.14×1.14	5.5	2.5	85	L-shaped monopole with J-shaped DGS
[31]	2022	0.86×0.21	1.57/2.4/3.5/5	NA	NA	Slot resonator
This work		0.12×0.10	2.1/5.2	−2.1/2.9 dBi*	52.5/96*	MSB

*Peak value, +extracted from the comparative table; GW-guided wavelength, NR: not reported; NA: not available to the authors; AMF: asymmetric microstrip feeding; GPS: ground protruding stub; C-SRR: complementary split ring resonator; H-CRR: hexagonal closed ring resonator; ACGP: asymmetric coplanar ground plane; DGS: defected ground structure.

antenna size which is not desirable in modern portable devices. Therefore, the antenna proposed in this manuscript is suitable where antenna size reduction is of a greater need, which is the case of mobile portable devices.

7. Conclusion

In this work, an ultra-compact dual-band antenna based on the meanderingly slitted bio-inspired radiating patch is presented. The footprint of the proposed MSB antenna is $12 \times 10\,\mathrm{mm}^2$ and suitable for UMTS, radio navigation, and WLAN applications. The prototype of the proposed MSB antenna is fabricated. The parametric study and comparative analysis of the proposed MSB antenna are carried out and presented. The proposed MSB antenna demonstrates stable omnidirectional radiation, good radiation efficiency, and gain at both operating frequencies which make it a suitable candidate for portable mobile communication devices.The result of the comparative analysis shows that the proposed MSB antenna outperformed the recent works in the open literature.

Data Availability

The data used in this manuscript are all included within the manuscript.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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