

Research Article

Miniaturized Dual-Band Antenna for GSM1800, WLAN, and Sub-6 GHz 5G Portable Mobile Devices

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Miniature devices are becoming increasingly demanded as fifth-generation (5G) technology is been deployed. This has necessitated the need to miniaturize all the various components of 5G enabling systems. It is a well-known fact that without the antenna, there is no wireless communication as it forms the link between the space and the wired network. Hence, the miniaturization of the antenna will contribute to the miniaturization of the entire wireless system. In this work, a miniature dual-band ultracompact antenna based on an opened-B-shaped (OBS) patch, a partial ground, and a ground protruding stub is presented. The antenna size is $0.14 \times 0.07\lambda_o$ (λ_o @1.85GHz). The proposed antenna is etched on a rogers (RT5880) substrate and fed with a 50 Ω asymmetric microstrip feedline. The proposed OBS antenna is fabricated and measured. In addition, the equivalent circuit of the proposed OBS antenna is designed and analyzed using AWR®. The antenna operates at a center frequency of 1.85 GHz and 5.89 GHz with an impedance bandwidth of 10.41% and 36.29%, respectively, which means that the first and second bands are narrow and wide bands, respectively. Furthermore, the mean peak gain of the proposed OBS antenna at lower and upper bands are 4.1 dB and 3.95 dB, respectively. More so, the radiation pattern antenna shows a quasiomnidirectional at E-plane and omnidirectional at H-plane. There is a good agreement between simulated and measured results. Therefore, the proposed OBS antenna is a suitable candidate for future portable mobile devices.

1. Introduction

The design of a miniaturized multiband antenna has become a necessity in this era of miniature mobile devices and accessories especially as 5G technology is being deployed which is said to enable the Internet of Things (IoT). A miniaturized antenna contributes to the realization of the miniaturized portable mobile devices while the multiband applicability of the antenna enables the devices to be suitable in the heterogeneous situation. These two properties are of great importance now and much more in the future of portable devices with the advent of 5G technology. One of the major problems of a miniaturized antenna is a reduction in gain and efficiency. Notwithstanding, with proper design, suitable gain and efficiency can be achieved without much complexity. The majority of the Multiband antennas reported in the literature are all narrowband and with bigger sizes. Many researchers such as [1–10] have worked in multiband antennas. First, a multiband antenna can be achieved by enabling the higher-order resonant mode of the resonant antenna. This can be achieved by the radiating patch configuration. For instance, the authors in [1] explore a meandering technique to design a quad-band antenna operating at 2.5 GHz, 4.2 GHz, 5.5 GHz, and 6.8 GHz with a respective bandwidth of 70 MHz, 90 MHz, 350 MHz, and 710 MHz. The meandering patch was etched on a $40 \times 40 \text{ mm}^2$ FR4 substrate. In the same light, the authors in [2] explore the use of hexagonal complimentary ring resonators to achieve resonance at 3.33 GHz, 5.01 GHz, 5.28 GHz, 7.46 GHz, and 9.48 GHz. The design was etched on FR4 of size 15×15 mm². The radiation efficiency was not reported by the authors, the antenna does not cover the sub 6 GHz 5G technology and the bands are narrow. Secondly, the slotting technique is one of the major ways of creating multiple resonances [4, 6-10]. For example, the authors in [4] investigate the application of arc-shaped slits on a Semi-Vitis vinifera leaf-shaped to achieve a Hexa-band antenna. The proposed antenna was developed on a Roger substrate and fed using an asymmetric microstrip feeding technique. Thirdly, the multiple resonators technique is another way of achieving a multiband antenna. In this method, each resonator operates in a unique frequency. For instance, the authors in [11] use multiple resonators connected using a diode for multiband application. The proposed antenna was built on a polyamide of size $24 \times 19 \text{ mm}^2$. The operating frequencies of the proposed antenna are 2.4 GHz, 3.8 GHz, and 5.6 GHz with a bandwidth of 140 MHz, 240 MHz, and 370 MHz, respectively. Apart from wireless mobile communication, the multiband antenna also finds its application in fields such as medical [6, 8, 10]. For example, the authors in [6] presented a multiband antenna for an Ingestible Capsule Endoscope application. The proposed antenna which is based on a meander line slot on the radiating patch and the shorting pins was built on an ultraslim roger ULTRALAM substrate of a thickness of 0.1 mm. The proposed antenna is said to be operating at the 402 MHz, 915 MHz, and 1200 MHz with an impedance bandwidth of 38.6%, 19.6%, and 8.1%, respectively.

It is worth noting that the majority of multiband antennas presented in the literature are narrowband in all the operating frequencies. Although, narrowband has the benefit of interference avoidance but normally has a lower data rate. On the contrary, the wideband antenna has a higher data rate compared to the narrow band antenna [12]. In addition, an antenna with a wider bandwidth can simultaneously be used in wider applications. In other to optimize the communication channel, the two (narrow and wide bands) can be combined in a single antenna to form a narrow- and wideband multiband antenna.

In this work, a miniature dual-band ultracompact antenna based on an opened-B-shaped (OBS) patch, a partial ground, and a ground protruding stub is presented. The antenna size is $0.14 \times 0.07\lambda_o$ (λ_o @1.85*GHz*). The rest of this work is organized as follows: the design formulation and analysis of the proposed antenna are presented in Section 2; Section 3 presents the results and discussion; in Section 4, the design and analysis of the proposed OBS antenna equivalent circuit are presented; in Section 5, parametric study results are presented; Comparative analysis of the proposed antenna with the recent works in the literature is presented in Section 6 and Section 7 is the conclusion.

2. Design Formulation and Analysis

In this design, an open-B-shaped (OBS) is been explored for the design of an ultracompact antenna for miniature mobile devices. The proposed antenna is etched on a rogers (RT5880) substrate with a thickness of 1.57 mm with a footprint of 12×22 mm². The OBS radiating patch design is achieved through the use of two sectorial circles having equal radii but different sectoral angles (\emptyset_1 and \emptyset_2), respectively, and a rectangular shape as shown in Figure 1(a). Figure 1 shows the 3-D view of the proposed antenna. The choice of the sectoral angle is to achieve a standard B-shaped. An asymmetric microstrip feeding (AMF) technique was used hence, the antenna structure serves as a quarter wavelength strip and its resonant frequency can be predicted by using the following equation [13, 14]:

$$l_s$$
 = Lenght of arc of Circle A

 $f_r = \frac{c_o}{4l_s \sqrt{\varepsilon_{reff}}},$

+ lenght of arc of circle B

+ length of rectangular strip

 $l_s = \left(\frac{\pi}{180} \times R\right) \left(\varnothing_1 + \varnothing_2 \right) + L.$

where

where

$$R = r + w. \tag{3}$$

(1)

(2)

The AMF width (w_f) is calculated using the standard microstrip line Equations (4)–(10) [15, 16].

$$Z_{0} = \begin{cases} \frac{120\pi}{\sqrt{\varepsilon_{eff}} \left\{ w_{f}/h + 1.393 + 0.677 ln \left(w_{f}/h + 1.444 \right) \right\}} \text{ for } \frac{w_{f}}{h} \leq 1, \\ \frac{60}{\sqrt{\varepsilon_{eff}}} ln \left(\frac{8h}{w_{f}} + \frac{w_{f}}{4h} \right) \text{ for } \frac{w_{f}}{h} \geq 1, \end{cases}$$

$$(4)$$

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \left(\frac{1}{\sqrt{1 + 12(h/w_f)}} \right).$$
(5)

Since the value of the characteristic impedance is known in this case to be 50 Ω , the width of the microstrip line can be calculated by using the following equation:



FIGURE 1: The proposed antenna (a) radiating patch (b) Radiating patch with the AMF-line (c) Back-view (d) feeding port (e) 3-D view.

$$w_{f} = \begin{cases} \frac{2h}{\pi} \left[B - 1 - \ln(2B - 1) + \frac{\varepsilon_{r} - 1}{2\varepsilon_{r}} \left\{ ln(B - 1) + 0.39 - \frac{0.61}{\varepsilon_{r}} \right\} \right] \text{for } \frac{w_{f}}{h} > 2, \\ \frac{8he^{A}}{e^{2A} - 2} \text{for } \frac{w_{f}}{h} < 2, \end{cases}$$
(6)

where

$$A = \frac{Z_0}{60} \sqrt{\frac{\varepsilon_r + 1}{2}} + \frac{\varepsilon_r - 1}{\varepsilon_r + 1} \left(0.23 + \frac{0.11}{\varepsilon_r} \right),\tag{7}$$

$$B = \frac{377\pi}{2Z_0\sqrt{\varepsilon_r}},\tag{8}$$

where w_f is the width of the microstrip feedline, h is the thickness of the dielectric, Z0 is the line characteristic impedance (50 Ω), ε_r is the permittivity of the substrate, and ε_{eff} is the effective permittivity.

The value of the optimal parameters of the proposed antenna shown in Figure 1 is as shown in Table 1. The predicted resonant frequency is approximately 1.8*GHz*. The simulation of the proposed OBS antenna is done using a Finite Element based simulator called HFSS by Ansys[®] [17] and fabricated using LPKF S105 and measured using Rohde and Schwarz ZVA 50 vector network analyzer.

The procedures for developing the open-B-shaped and the corresponding resonance response is presented in this section. First, the first arc which is as shown in Figure 2(a)was simulated to investigate its lone resonance response. The

I) first arc (Ant. has а length of $l_s = (\pi/180 \times R)(\emptyset_1) = 13.41mm$ which means the expected fundamental resonant frequency is 4.4 GHz. Secondly, the second arc is introduced as shown in Figure 2(b) which makes the radiator patch length becomes $l_s = (\pi/180 \times R)(\emptyset_1 + \emptyset_2) = 28.80mm$. Finally, the rectangula strip of length L and widht w is introduced as shown in Figure 2(c) to achieve the open-B-shaped antenna proposed in this work. It is worth noting that the length of the ground plane (l_a) , and the ground-protruding strip length are determined through parametric studies.

Figure 3(a) shows that Ant. I has two resonant frequencies with the fundamental frequency at 4.4 GHz as predicted and higher resonance at 6.45 GHz having a |S11| of -4 dB and -33 dB, respectively. The introduction of the second arc (Ant. II) shifted the fundamental resonance to be 2.7 GHz with a |S11| of -13.6 dB and the two higher-order modes are excited at 5.5 GHz and 7.4 GHz with a |S11| of -4 dB (shown with a dotted ova in Figure 3(a)) and -14.4 dB, respectively. Finally, the introduction of the rectangular strip (Ant. III) leads to three resonances with a fundament resonant frequency of 1.9 GHz having a |S11| of -21.3 dB and two other resonances 4.9 GHz and 6.4 GHz but with an

Parameter	l_{sub}^{\prime}	l_g'	\mathbf{l}_{g}	$l_{\rm f}$	L	\varnothing_1	\varnothing_2
Value (mm)	19	5	3	7.5	9.75	128°	147°
Parameter	Wg	w _f	w	w _s	r	g	
Value (mm)	12	3	1	1	5	0.75	

TABLE 1: Optimized parameters of the proposed antenna.



FIGURE 2: The Design Procedures(red dot represents the feeding point using lumped port).



FIGURE 3: (a) |S11| Response of the Design Procedure and (b) the Input impedance of the antenna.

overlapped -10 dB bandwidth to form a wideband as shown in Figure 3(a). Figure 3(b) shows the input impedance of the Proposed antenna (ANT. III). It can be observed that the input impedance of the proposed antenna is within the acceptable range at the operating bands.

3. Result and Discussion

The prototype of the proposed antenna is fabricated as shown in Figure 4 and measured to validate the simulated results. As seen in Figure 4, a 50 Ω SMA connector was used during measurement which is the port impedance used during simulation. The feeding terminal is connected to the

feedline of the proposed open-B as seen in Figure 4(a) and the ground terminal of the connector is connected to the ground plane of the antenna as seen in Figure 4(b).

3.1. Reflection Coefficient [S11]. Figure 5 shows the simulated and measured reflectance response of the proposed antenna. It can be seen that there is a good agreement between measured and simulated reflection coefficients. It can be observed that the proposed antenna operates at a center frequency of 1.85 GHz and 5.89 GHz with an impedance bandwidth of 10.41% and 36.29%, respectively. It can be observed that the center frequency of the lower band is in



FIGURE 4: The proposed antenna (a) Top-view (b) Back-View.



FIGURE 5: Reflection Coefficient response of the proposed OBS antenna.

agreement with the analytical result presented in Section 2. It can also be observed that the first and second bands are narrow and wide bands, respectively. This shows that the proposed antenna covers GSM1800, 5 GHz WLAN, and Sub-6 GHz 5G bands.

3.2. Current Distribution. In order to understand the workings of the proposed OBS antenna, the surface current distribution is used. As can be observed in the reflectance response graph, the upper resonance is fundamentally two bands that eventually formed a wideband through an overlap. Therefore, in this section, three resonance frequencies are considered and examined as shown in Figure 6. It can be observed in Figure 6(a) that the OBS patch is responsible for the fundamental resonant frequency (1.85 GHz) as predicted in Section 2. The parts of the antenna responsible for the two upper resonances are as shown in Figures 6(b) and 6(c). It is worth noting that the ground plane, as well as the protruding stub, greatly contribute to the resonances of the proposed OBS.

3.3. The FAR-FIELD Response of the Proposed Antenna. The far-field pattern of the proposed OBS antenna presented as shown in Figure 7 shows that the E-plane radiation patterns are quasiomnidirectional in all the frequencies except at 1.85 GHz where the radiation pattern is directional at the broadside of the antenna with a small back lobe and omnidirectional in H-plane. This is the desired pattern for the antenna in mobile user equipment. In other to show the peak gain in each of the sampled frequencies, a 3D radiation pattern was used as shown in Figure 8. It can be observed that the peak gain at 1.85 GHz, 4.75 GHz, 5.2 GHz, 5.8 GHz, 6.45 GHz, and 6.75 GHz is 4.1 dB, 2.9 dB, 3.3 dB, 3.8 dB, 4.6 dB, and 5.15 dB, respectively. The radiation efficiency of the proposed OBS antenna is as shown in Figure 9. It can be seen that the proposed antenna shows a suitable radiation efficiency across all the operating frequencies. The high radiation efficiency is due to the proper choice of the antenna substrate as well as the good matching between the 50 Ω feed line and the antenna structure. This shows that the proposed OBS antenna is a suitable candidate for future portable devices operating at GSM1800, 5 GHz WLAN (5.2 GHz and 5.8 GHz), and Sub-6 GHz 5G bands.

4. Equivalent Circuit

The equivalent circuit of an RF circuit helps backend RF designers in designing the matching circuit between the antenna and other communication subsystems. The equivalent circuit (EC) of the proposed OBS antenna is presented in Figure 10. The EC of the proposed OBS antenna is designed and simulated in AWR® software. The EC is fed with a 50 Ω feedline as used in the full-wave (HFSS) simulator. The lump element parameters are predicted using equations (9)–(11) [7, 18]. The predicted value serves as the initial lump element design which is afterward tunned using the tuning tool of the simulator to achieve a good agreement between the results of the full-wave simulator and the equivalent circuit simulator. The optimized value after



FIGURE 6: The surface current distribution of the OBS antenna.



FIGURE 7: Radiation Pattern of the proposed OBS antenna.

appropriate tuning is shown in Table 2. Figure 11 shows the resonance response of the EC and the HFSS simulator. It can be observed that there is good agreement between the |S11| of EC and that of HFSS.

$$C = \frac{w_c}{2Z_o (w_o^2 - w_c^2)},$$
(9)

$$L = \frac{1}{w_o^2 C},\tag{10}$$

$$R = \frac{2Z_o}{\sqrt{1/|S_{11}(w_o)|^2 - (2Z_o(w_oC - 1/w_oL))^2 - 1}},$$
 (11)

where C, L, and R are the capacitance, inductance, and resistance, respectively, w_o is the angular resonant frequency, w_c is the angular cutoff frequency, Z_o the input impedance of the port which is 50 Ω in this work.

5. Parametric Analysis

The effect of the length of the Open-B shaped (by parametrically varying L) and the ground-stub length on the resonant frequencies were performed and reported in this section.

5.1. Effect of the Open-B Shaped Length (Using L). Figure 12 is the reflection coefficient response variation with respect to the Open-B shaped length. It can be observed that as L increases, the resonance frequency of the lower band decreases as expected using the mathematical modeling presented in (1) but with equal bandwidth, as shown in Figure 12. At the upper band, it can be observed that the -10 dB bandwidth keeps increasing as L increases as shown in Figure 12. This shows that apart from the lower resonance frequency response, the length of L also affects the bandwidth of the upper band resonance.

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FIGURE 8: Gain of the proposed OBS antenna.



FIGURE 9: Radiation efficiency (simulated) of the proposed OBS Antenna.



FIGURE 10: Proposed OBS antenna EC.

TABLE 2: Optimized Value of the Lumped parameters. ($R_0 = 0.5$ and $L_0 = 0.73nH$).





FIGURE 11: |S11| of the EC and HFSS.



FIGURE 12: Effect of OBS patch length on resonance response.

5.2. Effect of Protruding Ground-Stub Length ($\mathbf{L}_{s} = \mathbf{l}'_{g} - \mathbf{l}_{g}$) on the Reflection Response. It can be observed that L_{s} has a visible effect on the upper band as shown in Figure 13. So, it majorly contributed to the upper band resonance. The only value of L_{s} that shows a wider upper band bandwidth is $L_{s} = 2mm$. So, it is used as the optimized value of L_{s} as stated in Table 1.

5.3. Effect of Ground Plane Length (l_g) on the Reflection Response. Figure 14 shows the effect of the ground plane length on |S11|. As seen in Figure 14, all the values of l_g meet the criterial of the fundamental frequency at 1.85 GHz as evaluated mathematically in section 2 which shows that the



FIGURE 13: Effect of protruding stub length on the reflectance response.



FIGURE 14: The effect of the ground plane on |S11| response.

ground plane does not have a significant effect on the resonant frequencies of the monopole antenna. Notwith-standing, it affects the return loss of all the resonant frequencies. It can also be observed that only $l_g = 3mm$ gives a wide bandwidth at the upper band. Hence, it is the optimal value which achieve the focus of this work as stated in Table 1.

6. Comparative Analysis

A comparative study of the OBS antenna with the previous works in the open literature is presented in Table 3. It can be observed that the proposed antenna is the most compact antenna with the lowest lower band resonant frequency

References	Size $(\lambda_o \times \lambda_o)$	Substrate	FREQ (GHz)	Imp. Bandwidth (MHz)	Gain
[19]	0.2×0.18	FR4	2.48/3.49	340/390	2.4/3.5 (dB)
[20]	0.23×0.18	FR4	2.49/4.2/7.4	300/1000/800	2.92/4.13/5.85 (dB)
[7]	0.25×0.10	RT5880	2.45/2.97/3.52/4.07/ 4.65/5.71/6.67	30/10/180/130/60/1970/1970	2.3/2.61/2.44/2.46/3.21/3.14/3.15 (dBi)
[1]	0.33×0.33	FR4	2.5/4.2/5.5/6.8	70/90/350/710	0.7/0.5/1.8/4.3 (dBi)
[9]	0.21×0.16	FR4	2.5/3.5/5.5	760/964/800	1.5/1.7/3.05 (dBi)
[11]	0.19×0.15	Polyamide	2.4/3.8/5.6	140/240/370	2.26/3.14/3.73 (dBi)
This work	0.14 imes 0.07	RT5880	1.85/5.9*	190/2290	4.1/3.95 ⁺ (dB)

TABLE 3: Proposed OBS antenna and other works in the literature Comparative Analysis.

* center frequency; ⁺average gain.

(1.85 GHz). It can also be observed that OBS proposed in this work demonstrates a suitable bandwidth at the lower band and the widest bandwidth at the upper band compared to other works in the literature. The proposed OBS also demonstrates a higher gain as seen in Table 3.

7. Conclusion

An ultracompact dual-band antenna is presented in this work. The antenna proposed in this work is an ultracompact antenna that is based on an open-B-shaped patched structure, ground-stub, partial ground, and an asymmetric microstrip feedline. The antenna operates at a center frequency of 1.85 GHz and 5.89 GHz with an impedance bandwidth of 10.41% and 36.29%, respectively. The proposed antenna demonstrated a dual-band which is the combination of a narrowband and a wideband compared to all narrowband multiband antenna reported in the literature. The impedance bandwidth of the narrowband is 10.41% while that of the wideband is 36.29%. The proposed antenna demonstrates high Gain and good radiation frequency at both frequencies. Hence, it is suitable for future heterogeneous miniature mobile devices, especially in IoT applications.

Data Availability

The data used to support the study are included in the manuscript.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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