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Design of an Antenna with Ground Plane Slots for LTE/WWAN Mobile Phones

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Abstract—In this paper, an antenna composed of an inverted L-shaped feeding strip and a shorting strip with three branches for LTE/WWAN mobile phones is presented. With the help of novel ground plane slots, the proposed antenna can realize miniaturization ($34 \times 15\,\text{mm}^2$) and multiband to cover LTE/WWAN bands. The measured bandwidth (3 : 1 VSWR) of the proposed antenna is 156 MHz (810–966 MHz) at the low band and 1937 MHz (1548–3485 MHz) at the high band. Moreover, the lowest measured radiation efficiency of the fabricated antenna is more than 54% in the whole operation band. The proposed antenna has been successfully fabricated and measured, and there is a good agreement between simulated and measured results.

1. INTRODUCTION

With the diversification of mobile phone functions, mobile terminal should not only cover the operation bands of the second generation GSM850/900/1800/1900 and the third generation UMTS2100 mobile communication systems but also cover the operation bands of the fourth generation LTE2300/2500 mobile communication systems. In addition, the design space of the antenna is becoming smaller and smaller because of the increase of electronic components in mobile phones. Therefore, the miniaturization and multiband of mobile phone antennas is always a hot research topic in recent years.

At present, there are already a lot of researches about the miniaturization and multiband of the mobile phone antennas [1–13]. In order to better achieve miniaturization and multiband, many technologies have been studied. The coupling feed technology [1–3] and loading printed distributed inductance technology [4, 5] can help to achieve the miniaturization of mobile phone antenna. Loading the matching network [6, 7] and reconfigurable technology [8, 9] are helpful in achieving multiband of the mobile phone antenna. The slot loaded technology [10–13] can not only achieve the multiband of the mobile phone antenna, but also improve the impedance matching of the mobile phone antenna. Table 1 lists the dimensions and performance of the antenna for the same frequency bands in recent works. And the bandwidth below -10 dB return loss of the propose antenna is much wider than the reference antennas in Table 1.

Inspired by the above antenna [1, 4, 5, 11, 13], a antenna with ground plane slots for LTE/WWAN mobile phones is proposed in this paper. The proposed antenna is composed of an inverted L-shaped feeding strip, a shorting strip with three branches, and ground plane slots. With the help of the coupled-fed excitation between the feeding strip and the shorting strip branch 1 and branch 2, the proposed antenna can cover the LTE/WWAN bands. The ground plane slots and shorting strip branch 3 can improve the impedance matching of the proposed antenna in low band and high band, respectively. The proposed antenna only occupies a small size of $35 \times 15\,\text{mm}^2$, which can realize the demand of miniaturization and multiband.

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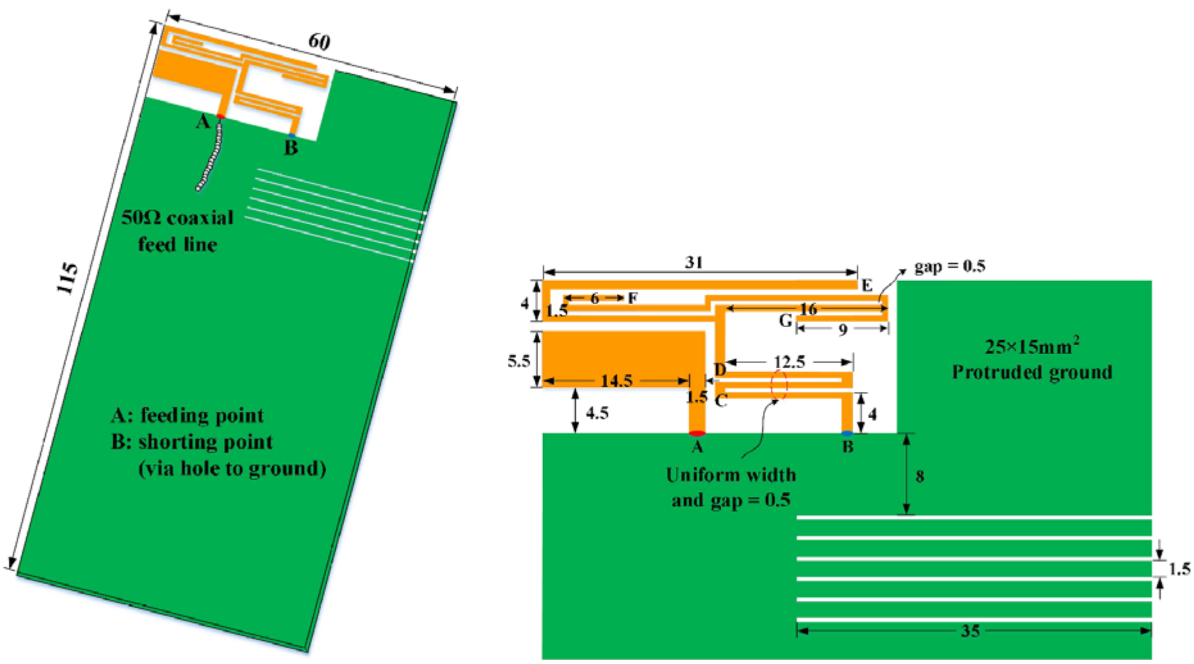
Table 1. Comparison of proposed antenna with reference antennas.

Antenna	Frequency bands covered	Antenna size (mm^2)	Bandwidth (MHz) (Low/High)	Efficiency (%) (Low/High)
Proposed antenna	LTE/WWAN	34×15	156/1937	55-62/54-64
Reference [3]	Same as above	60×8	205/1040	40-50/44-70
Reference [6]	Same as above	60×10	170/1510	50-65/55-65
Reference [8]	Same as above	30×15	169/980	33-52/40-67
Reference [9]	Same as above	34×10	189/1025	47-65/50-65

2. ANTENNA CONFIGURATION

Figure 1(a) shows the geometry of the proposed antenna with ground plane slots for LTE/WWAN mobile phones. The proposed antenna is printed on a 0.8 mm thick FR4 substrate with a relative permittivity of 4.4 and loss tangent of 0.02, and the size of the substrate is $115 \times 60\,mm^2$. The proposed antenna is placed on the bottom edge of the substrate and only occupies a small volume of $34 \times 15\,mm^2$. The system ground planes with six slots are printed on the back side of an FR4 substrate, including a main ground plane of $100 \times 60\,mm^2$ and a protruded ground plane of $25 \times 15\,mm^2$. Point A is the feeding point of the proposed antenna, which is excited by $50\,\Omega$ coaxial feed line. Point B is the shorting point of the proposed antenna, which is directly connected to the ground plane through a via-hole in the system circuit board. The detailed size parameters of the antenna are given in Fig. 1(b).

Figure 1(b) shows detailed dimensions of main parameters of the proposed antenna. The proposed antenna is composed of three parts: an inverted L-shaped feeding strip, a shorting strip with three branches (shorting strip branch 1: BE, shorting strip branch 2: BF, shorting strip branch 3: BG), and six ground plane slots. The strip CD is a printed distributed inductor, which can improve the



(a) (b)

Figure 1. Configuration of proposed antenna. (a) Geometry of the proposed antenna. (b) Dimensions of main parameters of the proposed antenna.

impedance matching of the proposed antenna by compensation for the capacitance caused by shorting the length of the radiation strip. Firstly, the feeding strip and shorting strip branch 1 are resonant at 900 MHz in low band and 1.77 GHz in high band with the help of the coupled-fed excitation. Secondly, adding the shorting strip branch 2 makes the antenna have another resonance point in low band and high band. Finally, the ground plane slots and shorting strip branch 3 improve the impedance matching of the antenna in low band and high band, respectively.

3. DESIGN PROCESS AND PARAMETER ANALYSIS

In order to better analyze the design process of the proposed antenna, the return loss of the proposed antenna and three reference antennas are shown in Fig. 2. The reference antenna 1 (Ref. [1]) only have the feeding strip and shorting strip branch 1, compared with antenna Ref. [1]; the reference antenna 2 (Ref. [2]) adds the shorting strip branch 2; and the reference antenna 3 (Ref. [3]) is the proposed antenna without the shorting strip branch 3. Antenna Ref. [1], with the help of the coupled-fed excitation between the feeding strip and the shorting strip branch 1, can generate a resonance at 900 MHz in low band and a resonance at 1.77 GHz in high band, but its bandwidth is narrow in both high band and low band. So the shorting strip branch 2 is proposed in antenna Ref. [2], which can generate a resonance at 930 MHz in low band and a resonance at 2.15 GHz in high band, and also shift the low resonant mode from 900 MHz to 870 MHz and shift the high resonant mode from 1.77 GHz to 1.85 GHz, but antenna Ref. [2] cannot cover the low band completely. So the ground plane slots are introduced in antenna Ref. [3] to improve the impedance matching of the antenna in low band. The return loss of antenna Ref. [3] in low band becomes better when the ground plane slots are introduced, but in high band, the bandwidth of antenna Ref. [3] cannot cover the whole working band that we need. So the shorting strip branch 3 is introduced to improve the impedance matching of the antenna in high band. All these make the proposed antenna operate in all LTE/WWAN bands successfully.

In order to better understand the structure of the proposed antenna, the main parameters of the proposed antenna have been studied. First, the effects of length $L1$ are analyzed in Fig. 3(a), as length

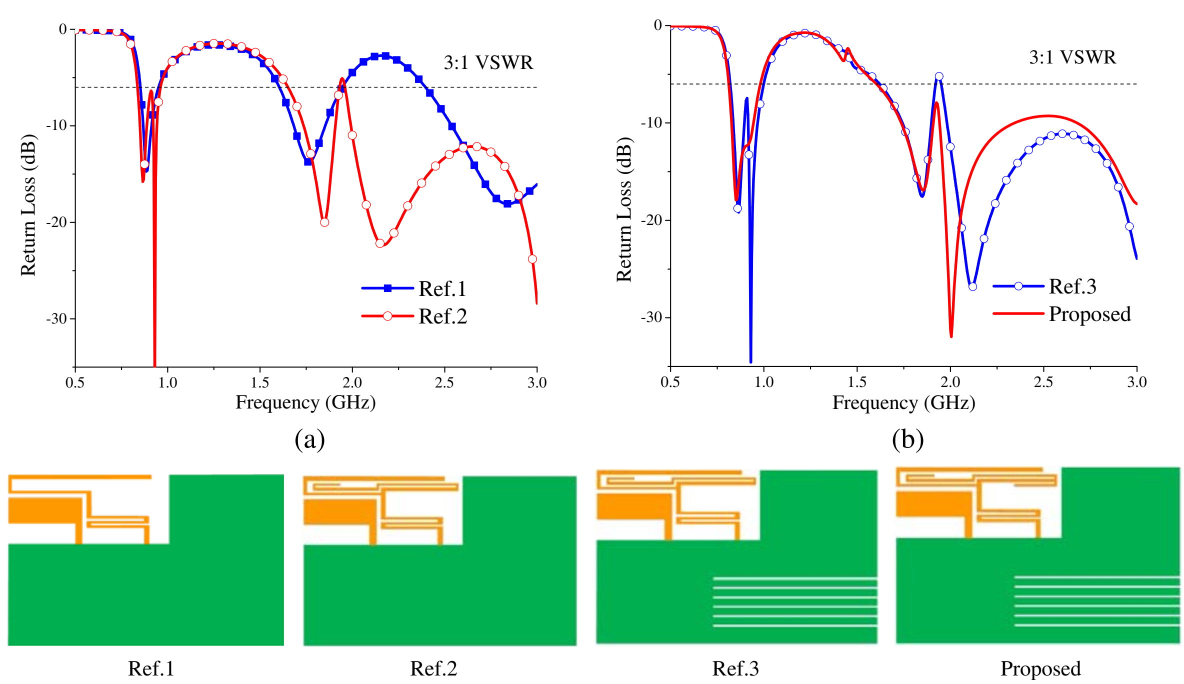


Figure 2. Comparison between the simulated return loss of the proposed antenna and three reference antennas. (a) Simulated return loss for antenna Ref. [1] and antenna Ref. [2]. (b) Simulated return loss for antenna Ref. [3] and the proposed antenna.

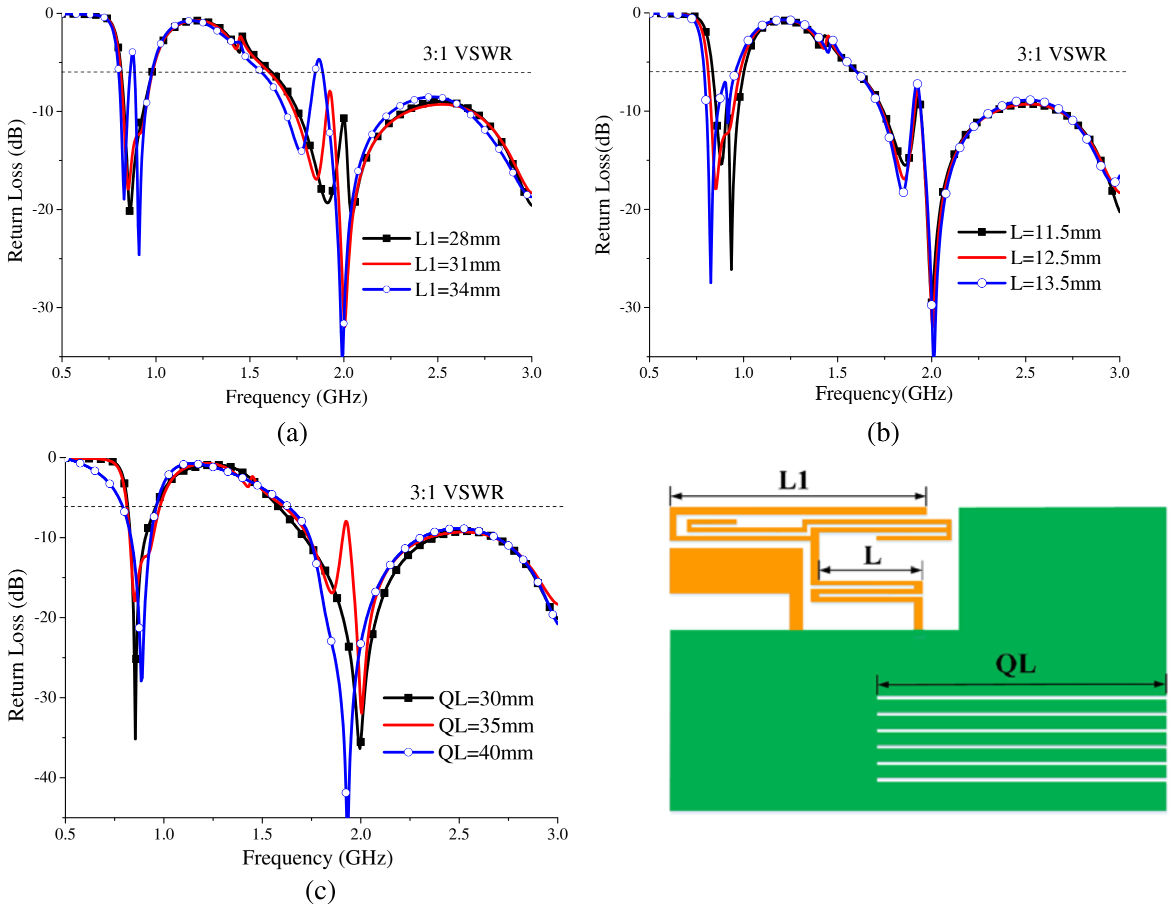


Figure 3. Simulated return loss as a function of (a) The length $L1$ of the end of the shorting strip branch 1. (b) The length L of the printed distributed inductor. (c) The length QL of the ground plane slots.

$L1$ is increased from 28 mm to 34 mm, the first high-frequency resonance point shifts towards low band, and the impedance matching of the antenna becomes worse. Then, Fig. 3(b) shows the return loss curves for different values of length L, as length L is increased from 11.5 mm to 13.5 mm, and the resonances in low-band shift towards high band. When $L = 12.5$ mm, the proposed antenna can completely cover the low-band. Finally, as can be seen from Fig. 3(c), when the length $QL = 35$ mm, the impedance matching of the proposed antenna in low-band is the best.

Figure 4 shows the simulated surface current distribution on the printed metal strip for the proposed antenna at 900 MHz, 2 GHz, and 2.6 GHz. Fig. 4(a) shows the surface current distribution of 900 MHz. It can be seen that strong currents are on feeding strip and the shorting strip branch 1, which means that the resonant mode at 900 MHz is contributed by the shorting strip branch 1. Similarly, Fig. 4(b) shows that the resonant mode at 2 GHz is generated mainly by the coupled-fed structure between the feeding strip and the shorting strip branch 2. The surface current distribution of 2.6 GHz is given in Fig. 4(c), which shows that the resonant mode at 2.6 GHz is generated mainly by the feeding strip. The ground plane slots and the shorting strip branch are mainly used to improve the impedance matching of the proposed small-size coupled-fed antenna.

4. MEASUREMENT RESULTS AND DISCUSSION

The proposed antenna has been successfully fabricated and measured. The proposed antenna was simulated by HFSS (High Frequency Simulator Structure) software and measured by Agilent N5242A.

Fig. 6 shows the simulated and measured return losses for the fabricated antenna (shown in Fig. 5). It can be seen that there is a good agreement between the simulated and measured results. The measured bandwidth with 3 : 1 VSWR of low band is 156 MHz (810–966 MHz), while the bandwidth of high band is 1937 MHz (1548–3485 MHz), which can fully cover the LTE/WWAN bands. When the return loss of the proposed antenna is below −10 dB, the bandwidth of the proposed antenna is 106 MHz (837–943 MHz) in low band and 1584 MHz (1600–1928 MHz and 1976–3232 MHz) in high band. The small discrepancy is mainly due to the fabrication tolerance and welding.

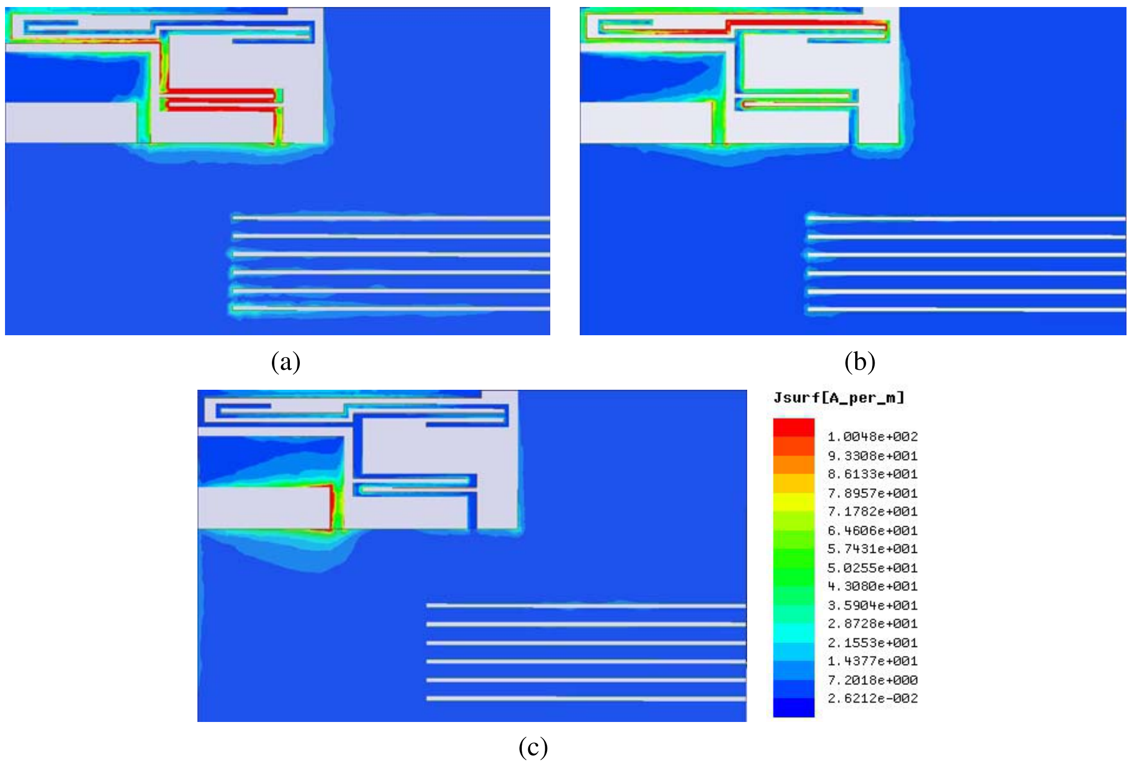


Figure 4. Simulated surface current distribution on the printed metal strip for the proposed antenna. (a) 900 MHz. (b) 2 GHz. (c) 2.6 GHz.

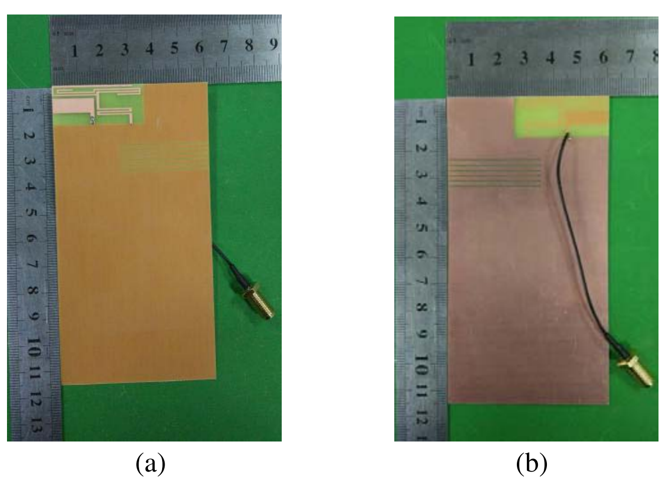


Figure 5. Photographs of the fabricated antenna. (a) Front side. (b) Back side.

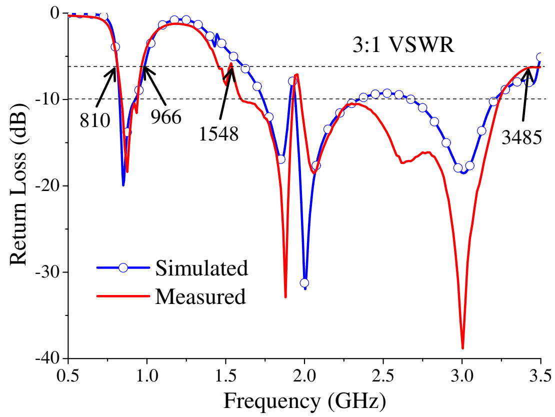


Figure 6. Simulated and measured return loss for fabricated antenna.

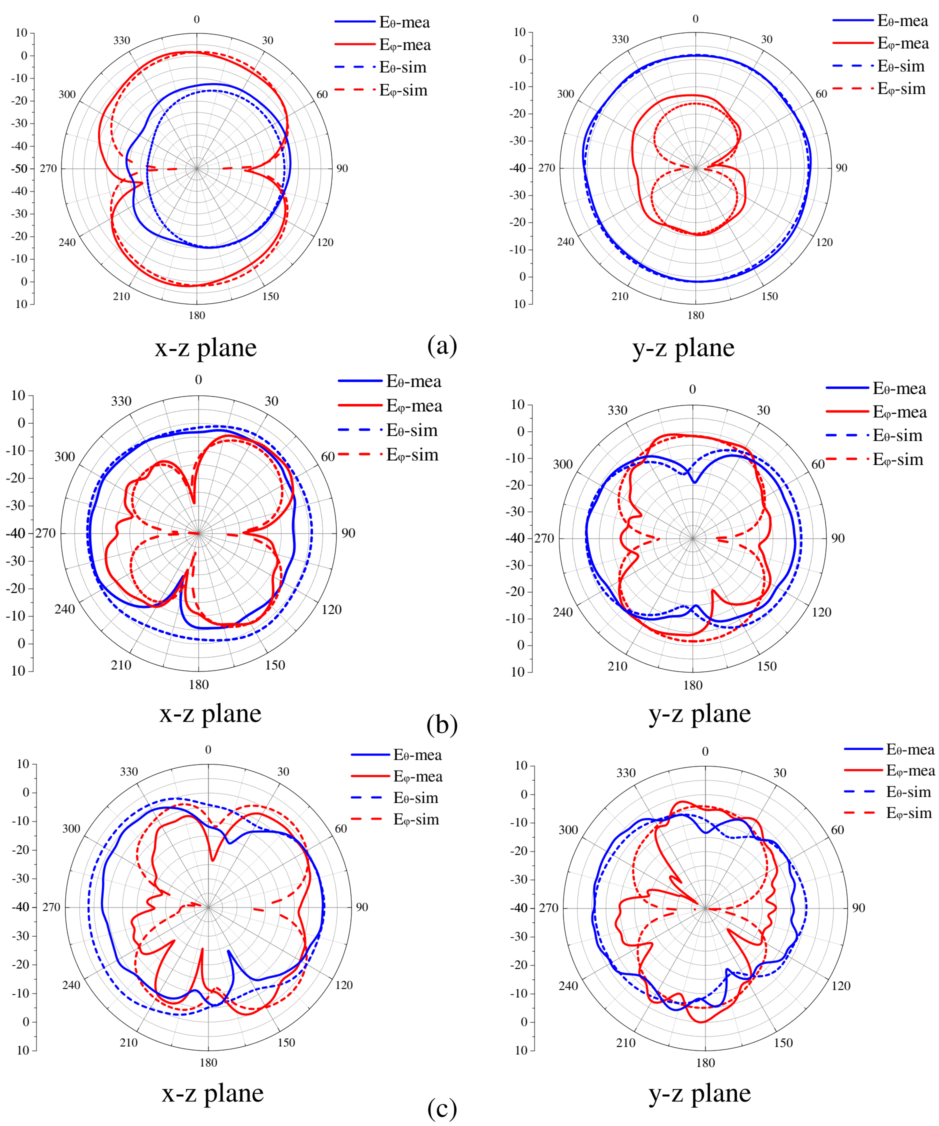


Figure 7. Simulated and measured 2-D radiation patterns for fabricated antenna. (a) 900 MHz. (b) 2000 MHz. (c) 2600 MHz.

Figure 7 shows the simulated and measured radiation patterns of the fabricated antenna at 900 MHz, 2000 MHz, and 2600 MHz. The radiation patterns at 900 MHz shown in Fig. 7(a) are similar to the dipole antenna, which have a good omnidirectional performance, indicating that the radiation characteristic of the proposed antenna at the low band is relatively stable. On the other hand, at 2000 MHz and 2600 MHz, the radiation patterns have some changes, mainly due to the high-order resonance.

Figure 8 shows the measured radiation efficiency and antenna gain for the fabricated antenna. Over the desired 824–960 MHz band, the radiation efficiency varies from about 55% to 62%, and the antenna gain ranges from −0.4 to 0.4 dBi. Over the desired 1710–2690 MHz band, the radiation efficiency varies from about 54% to 64%, and the antenna gain ranges from 1 to 4 dBi. The measured radiation characteristics suggest that the proposed antenna is acceptable for practical mobile communication application.

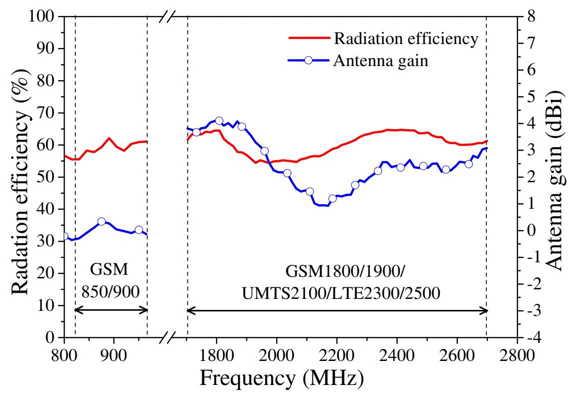


Figure 8. Measured radiation efficiency and antenna gain for the fabricated antenna.

5. CONCLUSION

A novel antenna with ground plane slots for LTE/WWAN mobile phones is presented in this paper. With the help of ground plane slots, the antenna can realize the demand of multiband. The bandwidth with 3 : 1 VSWR of the proposed antenna is 156 MHz (810–966 MHz) in low band and 1937 MHz (1548–3485 MHz) in high band. The proposed antenna has been successfully fabricated, and the performance parameters of the antenna are measured, including return loss, radiation pattern, radiation efficiency, and gain. Measured results show good agreement with the simulated ones. Therefore, the proposed antenna is quite competitive for the practical application.

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