Progress In Electromagnetics Research, Vol. 129, 469–483, 2012

BANDWIDTH ENHANCEMENT OF LTE/WWAN PRINTED MOBILE PHONE ANTENNA USING SLOTTED GROUND STRUCTURE

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Abstract—In this article, a coupled-fed planar printed antenna mounted on the compact no-ground portion of the system circuit board of a mobile phone with a low profile of 10 mm is proposed and studied. The presented antenna is formed by a double-branch feeding strip, a shorted coupling strip with two open-ended loops of different lengths, and a slotted ground structure consisting of two monopole slots, yet it has a size only $15 \times 50\,\text{mm}^2$. Two wide operating bandwidths of 698–960 MHz and 1710–2690 MHz can be achieved by these radiating strips, which provide multiple resonant modes at about 750, 1000, 1750, 2300 and 2900 MHz. In addition, with the presence of the two narrow slots and a chip inductor ($L = 1.5\,\text{nH}$), in this study, the printed antenna can lead to much widened bandwidths in both the antenna's lower and upper bands to cover LTE700/GSM850/900 and DCS1800/PCS1900/UMTS2100/LTE2300/2500, respectively. Good radiation efficiency and antenna gain for frequencies over the desired operating bands are obtained. Detailed design considerations of the proposed antenna are described, and both experimental and simulated results are also presented and discussed.

Received 12 June 2012, Accepted 2 July 2012, Scheduled 10 July 2012
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1. INTRODUCTION

At present, portable handsets (such as mobile phone) have been used widely and raised concerns. However, with the large-scale laying of the third-generation mobile communication systems and the steady development of long-term evolution, the new LTE mobile terminals, especially for mobile phone applications which will be applied widely in the 3rd generation and even the 4th LTE time, will face compatibility issues in the design, because the new generation LTE mobile communication systems not only meet the new LTE standard's operating bands of LTE700/2300/2500, but also cover the primary operating bands of GSM850/900/1800/1900 and UMTS2100 in the 2nd (for instance GSM) and 3rd (for instance UMTS, CDMA, etc.) generations. Owing to that the theoretically ultimate performances of an antenna are limited for the smaller and smaller overall sizes, realizing antenna in the internal mobile phone operating at various modes and the whole frequency bands (LTE/GSM/UMTS) appears very difficult [1–18].

For the above case, studies have been carried out on how to achieve the LTE/GSM/UMTS multi-band mobile phone antennas with compact sizes by using several wideband techniques. In detail, these wideband techniques mainly include designing matching network [3, 7], loading lumped element [4, 18], and using capacitive coupled-fed scheme [5], distributed element structure [6, 8], and slotted ground structure [2, 9, 14]. By using a high-pass matching network in [3], a printed monopole antenna in the internal mobile phone for GSM850/900/DCS1800/PCS1900/UMTS2100 operation with a small area of $10 \times 60\,\text{mm}^2$ is presented. In fact, the use of a matching network can adjust the desired impedance matching in the lower and upper bands. In [4], with a small size of $15 \times 35 \times 3\,\text{mm}^3$, a planar inverted-F antenna (PIFA) with a loop shorting strip and a chip-capacitor-loaded feeding strip for eight-band WWAN/LTE operation in the internal mobile phone is proposed and studied. From the result comparisons of the proposed antenna and referenced cases (seen in Figure 4 in [4]), the chip-capacitor-loaded can adjust the impedance matching of the desired bands effectively. Another design is a printed coupled-fed scheme [5], which consists of a feeding strip and a coupling strip and has a no-ground area of 15 mm by 45 mm, covering the GSM850/900/DCS1800/PCS1900/UMTS2100/LTE2300/2500 operation. In this design, by employing the coupled-fed structure, two wide operating bands can be obtained, compared with the direct-fed structure. And in [8], formed by a wide radiating patch and a long narrow shorting strip acting as a distributed inductor, a printed compact wireless USB dongle antenna attached to a laptop computer for LTE/GSM/UMTS operation is also achieved. Besides, a new technique, using slotted ground structures, has been proposed and studied [9]. The presented antenna is a meandered loop antenna for GSM850/900/DCS1800/PCS1900 operation, which occupies a small volume of $5.5 \times 6 \times 60\,\mathrm{mm}^3$. And in order to improve the desired impedance bandwidths, especially for the desired lower band, a slotted ground structure forming a straight monopole slot (length of 53 mm and width of 1.5 mm) is embedded at the top edge of the system ground plane.

On the other hand, the antennas in the internal mobile phone with low profile and printed configuration are promising for practical mobile applications [2–8, 11–15, 18], because those planar printed antennas can be easily integrated with RF (Radio Frequency) and MMIC (Monolithic Microwave Integrated Circuit) modules, with ease of fabrication and low cost. Of course, considering the overall size of a mobile phone, the antennas need to be compact or have small sizes (smaller than $15\times\ 50\,\mathrm{mm}^2$ or $750\,\mathrm{mm}^2$).

In this paper, based on the use of slotted ground structure [2, 9] and these promising designs [3–21], a new planar coupled-fed antenna for eight-band LTE/GSM/UMTS WWAN operation in the internal mobile phone is proposed. With a printed size of $15 \times 50\,\mathrm{mm}^2$ on the top of a 0.8-mm thick FR4 substrate, the presented antenna consists of a double-branch feeding strip, a long coupling strip with two open-ended loops, and a slotted ground structure formed by two monopole slots. For the desired upper bands of DCS1800/PCS1900/UMTS2100/LTE2300/2500 (1710–1880 MHz/1850–1990 MHz/1920–2170 MHz/2300–2400 MHz/2500–2690 MHz), the double-branch feeding strip can provide three resonant modes at around 1700, 2300 and 2900 MHz to cover 1710–2690 MHz. While for the desired lower bands of LTE700/GSM850/900 (698–787 MHz/824–894 MHz/880–960 MHz), the long coupling strip can generate a double-resonance mode at about 750 and 1000 MHz to cover 698–960 MHz. The antenna geometry and design methods are described in Sections 2 and 3. Measured radiation characteristics of the proposed antenna are presented in Section 4, followed by a conclusion of this design.

2. PROPOSED ANTENNA CONFIGURATION

Figure 1 shows the proposed antenna's configuration. The proposed planar broadband internal antenna for application in the mobile phone is printed on the top of a 0.8-mm thick FR4 substrate of size 50

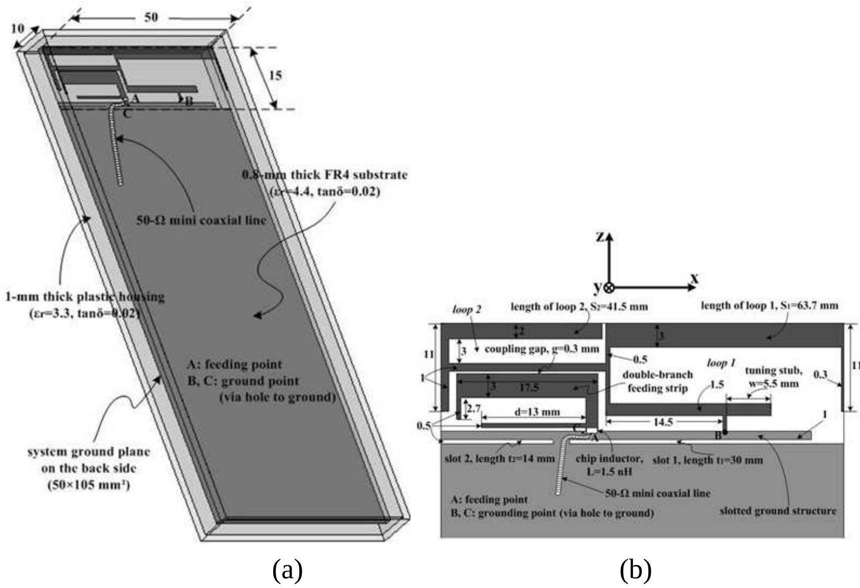


Figure 1. Proposed antenna configuration: (a) Geometry of the wideband antenna for eight-band LTE/WWAN operation in the internal mobile phone. (b) Detailed dimensions of the metal pattern in the antenna area (unit: mm).

$\times$ 120 mm^2, relative permittivity 4.4, and loss tangent 0.02. The system ground plane studied here is chosen to have dimensions of length 105 mm and width 50 mm, which does not cover the whole PCB and leaves a no-ground area (size of 15 $\times$ 50 mm^2) for designing the proposed antenna. A 50-Ω coaxial feed line is employed to excite the antenna. To simulate the practical case, a 1-mm thick plastic housing (with height 10-mm, relative permittivity 3.3, and loss tangent 0.02) is used in the study. There is a gap of 1 mm between the plastic housing and the edge of the used PCB.

According to its inherent functions, in Figure 1(b), the proposed design can be divided into four parts: a double-branch feeding strip, a long coupling strip (or called a parasitic strip) with two open-ended loops, a slotted ground structure formed by two monopole slots, and a chip inductor of 1.5 nH. Firstly, the longer branch of the double-branch feeding strip has a length about 25 mm (0.24-wavelength at 2900 MHz), which can provide a quarter-wavelength resonant path at 2900 MHz. Secondly, the slots 1 and 2 have a uniform width 0.5 mm but different lengths. In the slot's design, the length of slot

1 is $t_1 = 30$ mm (an open-ended monopole slot, 0.23-wavelength at 2300 MHz), generating another resonant mode at about 2300 MHz. For the double-resonance mode in the desired lower band, two fundamental resonant modes at 750 and 1000 MHz can be achieved by loop 1 and slot 1 ($s_1 + t_1 = 84$ mm, about 0.21-wavelength at 750 MHz), and loop 2 and slot 1 ($s_2 + t_1 = 80$ mm, about 0.26-wavelength at 1000 MHz), respectively. Then, a half-wavelength high-order resonant mode at around 1750 MHz can also be obtained by loop 2 (0.48-wavelength at 1750 MHz). Besides, by adjusting the chip inductor ($L = 1.5$ nH in the design) and the tuning stub at the end of loop 1, the desired impedance matching and resonant modes' shift at the lower and upper bands can be improved effectively. From the above analysis, the proposed slotted ground structure can not only provide a resonant mode at about 2300 MHz but also decrease the desired resonant paths at 750 and 1000 MHz, broadening the bandwidths of 698–960 and 1710–2690 MHz to cover all the eight-band LTE700/GSM850/900/DCS1800/PCS 1900/UMTS2100/LTE2300/2500 operation.

Note that the coupling gap between the feeding strip and coupling strip is selected to have a narrow width of 0.3 mm, which is helpful in obtaining wide bandwidths for the excited resonant modes, especially for the lower band. In this configuration, a 50-Ω mini coaxial feed line is employed to excite the proposed antenna at the feeding point A, and the end of the long coupling strip and t external conductor of the used coaxial line are connected to the slotted ground structure of the mobile phone at grounding points B and C. With proper structure and dimensions, the presented design can be easily printed on a thin PCB. Hence, the proposed antenna not only shows a simple configuration but also has a compact size, allowing it to be fabricated at low cost for practical mobile applications.

3. DESIGN PROCESS AND PARAMETRIC STUDY

To study the design process of the proposed antenna, including the presence of the coupling strip and slotted ground structure, Figure 2 shows a comparison of the simulated return loss and input impedance of the proposed antenna and the reference antenna (Ref. 1: monopole only; Ref. 2: without slots). In Figure 2(a), it is clearly seen that with the use of the monopole only, there is no resonant mode generated at the lower band of 698–960 MHz. This case can be explained in Figure 2(b), where the simulated input impedance of the proposed antenna and Ref. 1 is plotted. Compared with the proposed antenna, the real (Re) and imaginary (Im) parts of the input impedance are greatly lowered for the desired operating band. The trend indicates

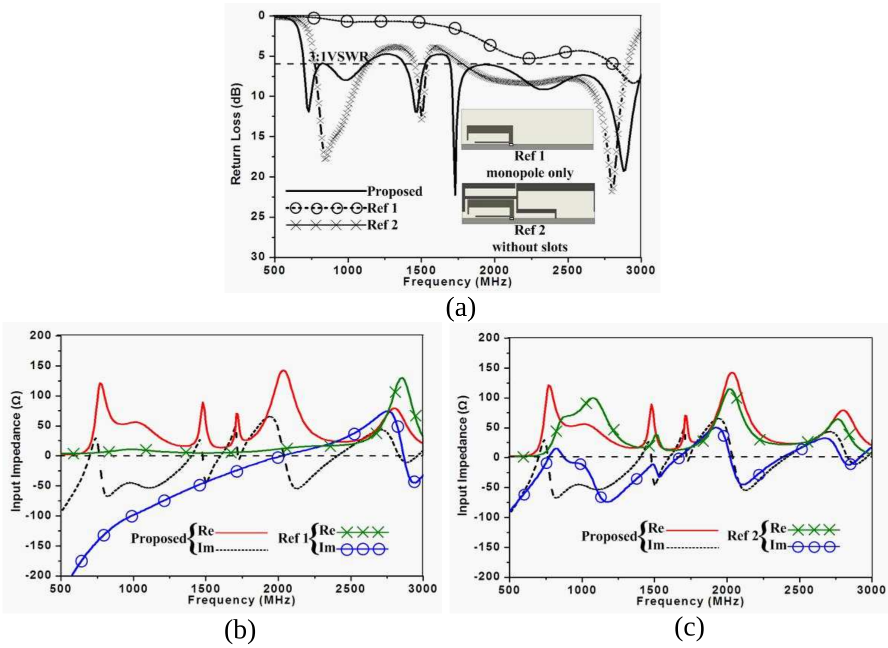


Figure 2. (a) Simulated return loss for the proposed antenna, the corresponding antenna monopole only (Ref. 1) and the corresponding antenna without slots (Ref. 2), (b) comparison of the simulated input impedance for the proposed antenna and Ref. 1, and (c) comparison of the simulated input impedance for the proposed antenna and Ref. 2 (other dimensions are the same as given in Figure 1).

that the desired band of 698–960 and 1710–2690 MHz cannot be obtained for the case of the use of the monopole feed strip only.

Besides, for the case of Ref. 2 (without slotted ground structure), only one resonant mode is obtained at about 800 MHz over the lower band, while another resonant mode at about 1750 MHz is not obtained over the upper band. The results lead to the desired lower and upper bands not covered completely, mainly for LTE700 (698–787 MHz) and DCS1800 (1710–1880 MHz). Also, it can be seen from Figure 2(c) that the impedance matching of the Ref. 2 is poor at around 700 and 1750 MHz. In detail, the real (Re) part is increased to about 50 Ω at 700 and 1750 MHz. From the comparison, the fundamental (lowest) resonant mode of the proposed antenna indeed has a much lower resonant frequency (at about 750 MHz) than that of the corresponding conventional coupled-fed antenna (Ref. 2), and a double-resonance mode at the lower band can be realized to cover the desired

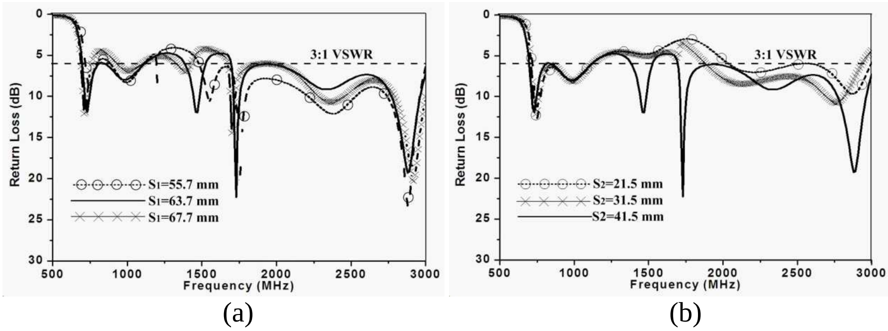


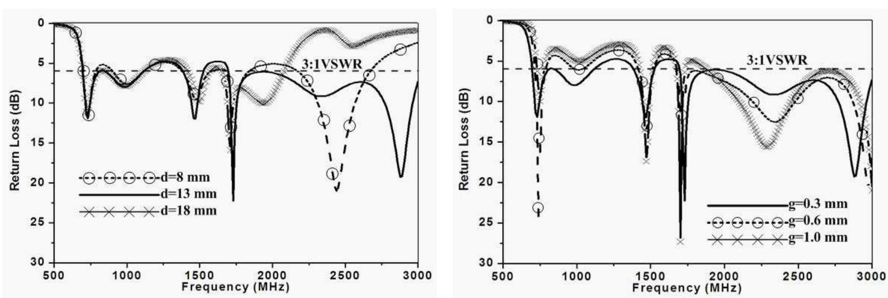
Figure 3. Simulated return loss as a function of (a) the length S_1 of the loop 1 and (b) the length S_2 of the loop 2 (other dimensions are the same as given in Figure 1).

LTE700/GSM850/900 operation. Thus, with the presence of the proposed slotted ground structure (formed by two slots), the desired resonant length of the lower resonant modes and impedance matching of the upper band can be adjusted and improved, respectively, to achieve the eight-band LTE/WWAN operation in the practical mobile phone applications.

Several main parameters, in this design, are also studied. In these studies, only one parameter is varied, whereas other parameters have no variations. Figure 3(a) shows the simulated return loss as a function of the length S_1 of loop 1. Results for the length S_1 varied from 55.7 to 67.7 mm indicate that three resonant modes at 750, 1000 and 1700 MHz shift down with increasing the length, which results in poor impedance matching over the LTE700/GSM850/900 and DCS1800 bands. Similar results can be found from Figure 3(b) that the length S_2 of loop 2 also affects the input impedance matching of the proposed antenna. For the lower band, the effects are small, and good impedance matching can also be obtained for various lengths of S_2. For the upper band, the effects are relatively large. And the improved impedance matching can be achieved at the band of DCS1800 (1710–1880 MHz) when the length S_2 equals 41.5 mm in the study. From the results in Figures 3(a) and (b), it can be concluded that adjusting the lengths of loop 1 and loop 2 can shift up or down the resonant modes to improve the desired impedance matching of the 698–960 and 1710–2690 MHz.

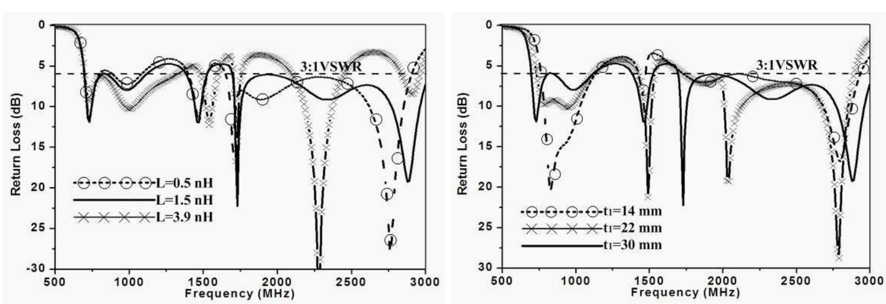
Effects of varying the length d of the shorter branch in the double-branch feeding strip are studied in Figure 4(a). Results for length d varied from 8 to 18 mm are presented. The two $\lambda/4$ modes at about 2300 and 2900 MHz are seen to be affected strongly by length d. By selecting a proper length d ($d = 13$ mm in the design), good impedance matching over the desired upper band of the antenna can be obtained. Figure 4(b) plots the simulated return loss as a function of width g of the coupling gap (seen in Figure 1(b)). In this case, relatively stronger effects on the two excited resonances forming the antenna's lower band are observed. For the upper band, only the operating band of DCS1800 is affected strongly, because varying the coupling gap can adjust the coupling strength between the feeding strip and coupling strip, which leads to improved impedance matching bandwidth in the lower and upper bands for the proposed printed antenna to cover eight-band LTE/WWAN operation.

Figure 5(a) shows the influence of varying the chip inductor L in



(a) (b)

Figure 4. Simulated return loss as a function of (a) the length d of the shorter branch of the double-branch feeding strip and (b) the width g of the coupling gap between the feeding strip and the coupling strip (other dimensions are the same as given in Figure 1).



(a) (b)

Figure 5. Simulated return loss as a function of (a) the chip inductor L and (b) the length t_1 of the slot 1 in the slotted ground structure (other dimensions are the same as given in Figure 1).

the feeding point A. Strong effects on the impedance matching of the frequencies over the upper band are seen when inductor L is varied from 0.5 to 3.9 nH. For $L = 0.5$ nH, the impedance matching over the upper band is improved. However, the impedance matching at about 790 MHz is poor. Moreover, for $L = 3.9$ nH, the trend is inverse. The effects of length t_1 of the slot 1 on the simulated return loss are also given in Figure 5(b). As shown in the figure, all the excited resonant frequencies are affected by varying the length t_1. With increasing the length t_1 from 14 to 30 mm (other dimensions are the same as given in Figure 1), the double-resonance mode at the lower band is lowered further to cover the band of LTE700. And the upper band's operating bandwidth is also improved. In this scheme, the use of the slotted ground structure is helpful for shortening the desired resonant lengths at the lower band. Moreover, consisting of the feeding strip, coupling strip, slotted ground structure, and the system ground plane, which form an entire structure of the proposed antenna, the upper resonant frequencies will also change when the length is increased slightly.

The simulated surface current distributions on the printed metal portion of the proposed antenna at 0.75, 2.3 and 2.9 GHz are also given in Figure 6. At 0.75 GHz shown in Figure 6(a), the relatively strong current distributions are observed on the coupling strip, slotted ground structure, and system ground plane of the mobile terminal, which indicates that the resonant mode of the lower band is mainly

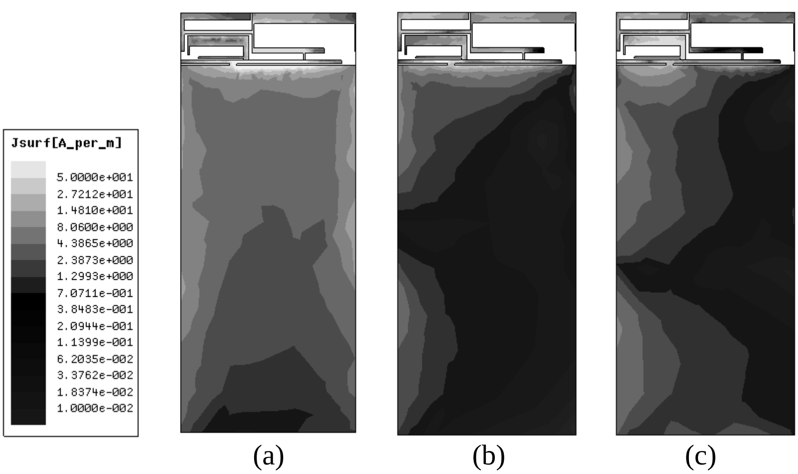
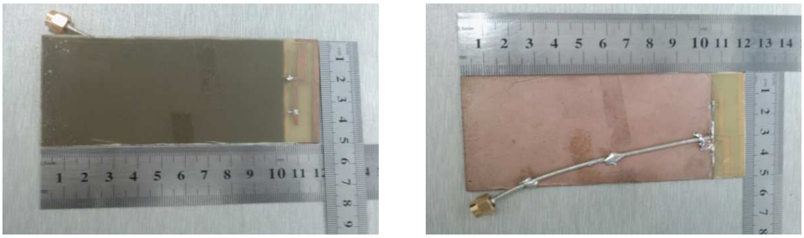


Figure 6. Simulated current distributions on the radiators and system ground of the mobile phone at (a) 750 MHz, (b) 2300 MHz, and (c) 2900 MHz.

contributed by the coupling strip and system ground plane of the mobile terminal. The surface currents of the upper band seen in Figures 6(b) and (c) are different from those shown in Figure 6(a). For the upper band at 2.3, and 2.9 GHz, there are strong current distributions on the feeding strip and partial system ground plane. Of course, since the proposed printed antenna is an entire structure formed by the radiating strips and the system ground plane, the whole antenna configuration makes an effective radiating system to cover the two wide bands of the 698–960 MHz and 1710–2690 MHz.

4. MEAUSURED RESULTS AND DISCUSSION

The proposed antenna is fabricated and tested. Figure 7 shows photos of the fabricated printed antenna. The simulated results are obtained by HFSS 12.0 and the measured results tested by an Agilent N5247A vector network analyzer. Figure 8 shows the measured and simulated return losses for the fabricated prototype. For the desired lower



(a) (b)

Figure 7. Photos of the manufactured printed antenna for eight-band LTE/WWAN operation in the internal mobile phone: (a) top side and (b) back side.

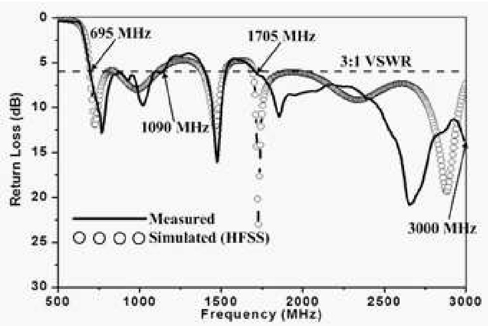


Figure 8. Simulated and measured return loss against frequency for the proposed antenna.

band of LTE700/GSM850/900 (698–960 MHz), two resonant modes at about 750 and 1000 MHz are obtained to cover the bandwidth. For the desired upper band of 1710–2690 MHz, a wide operating bandwidth reaches 1300 MHz (1705–3000 MHz), which is large enough for DCS1800/PCS1900/UMTS2100/LTE2300/2500 operation. In the design, 3 : 1 VSWR is used as the impedance matching bandwidth, which is generally acceptable for practical mobile phone antennas [2–

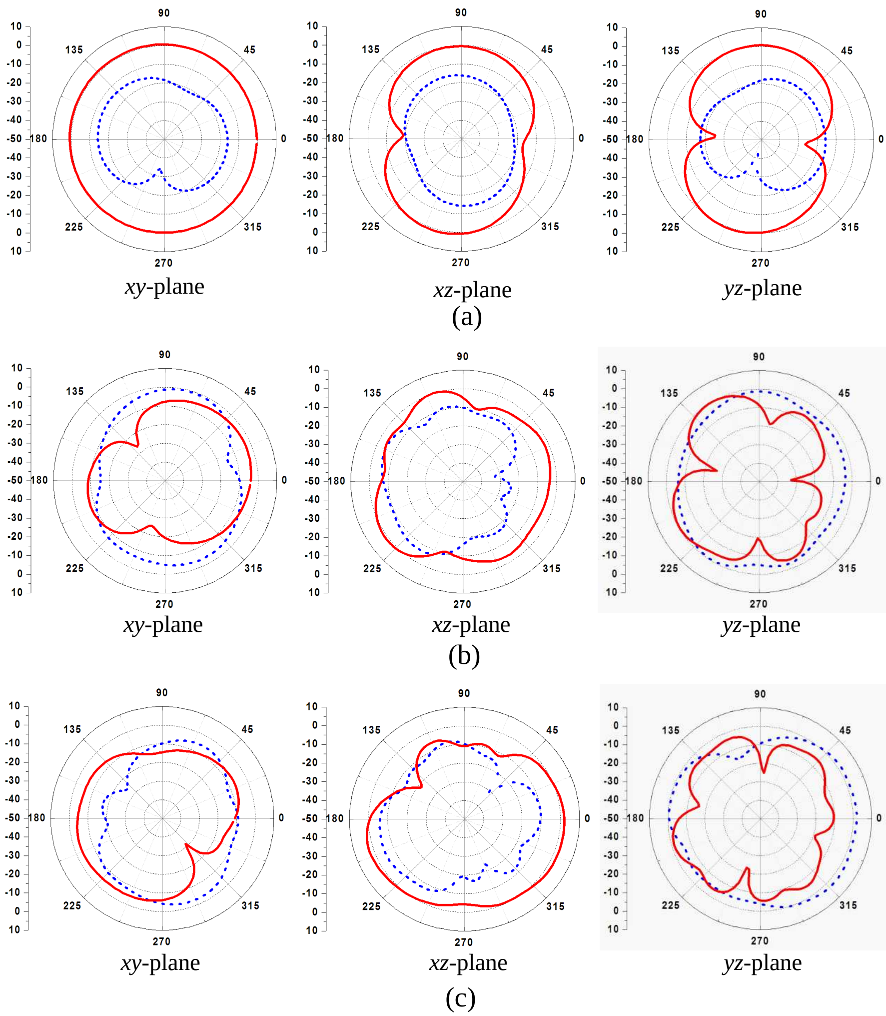


Figure 9. Measured 2-D radiation patterns at (a) 830 MHz, (b) 1960 MHz and (c) 2520 MHz for the proposed antenna (dotted line is E_φ, solid line is E_θ).

9, 12–14]. There are some disagreements between the measurement and simulation of return loss, mainly because of errors in fabrication (properties of used FR4 substrate, size errors of fabrication) and testing (effects of coaxial cable introduced for testing).

The radiation characteristics of the fabricated antenna are also measured. Figure 9 shows the measured 2-D radiation patterns for the proposed antenna. For lower frequency at 0.83 GHz (centre frequency of the lower band 698–960 MHz), the radiation patterns are close to those of the half-wavelength dipole antenna, and omnidirectional radiation is seen in the azimuthal plane (xy-plane) of the mobile handset. For upper frequencies at 1.96 and 2.52 MHz, the measured radiation patterns show several nulls in the azimuthal plane, close to those of the conventional dipole antenna owing to its higher-order resonant modes. In fact, the system ground of the mobile handset is also an effective radiator, which strongly affects the radiation patterns of the internal mobile antenna, especially for the lower band of LTE700/GSM850/900.

Figure 10 shows the measured antenna gain and radiation efficiency of the fabricated antenna. In Figure 10(a), results for the lower band are given, where small variations of the antenna gain in the range of about 0.5–1.3 dBi are seen, and the measured radiation efficiency varies from about 58 to 76%. For the upper band shown in Figure 10(b), the antenna gain varies from 1.8 to 3.9 dBi, while the radiation efficiency is better than 60%. Obviously, the above results of the obtained radiation characteristics indicate that the proposed antenna is a good solution for practical internal mobile applications.

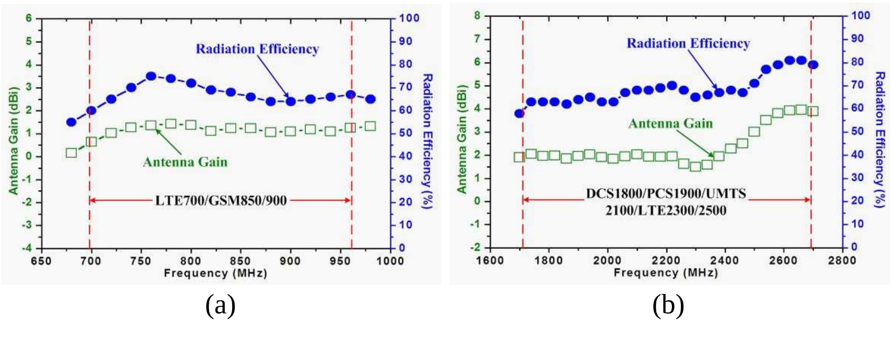


Figure 10. Measured antenna peak gain and radiation efficiency across the operating band for the proposed antenna: (a) The lower operating bands LTE700/GSM850/900. (b) The upper operating bands DCS1800/PCS1900/UMTS2100/ LTE2300/2500.

5. CONCLUSION

This paper presents a new coupled-fed mobile phone antenna, using a slotted ground structure to improve the desired impedance matching bandwidths, which can obtain two VSWR≦3 impedance bands of 698–960 and 1710–2690 MHz. With a planar printed structure, the proposed antenna has a compact size of $15 \times 50\,\text{mm}^2$. The main design parameters of the coupled-fed antenna are studied and discussed, and a practical structure is fabricated for testing in the experiment. The measured parameters, including return loss, radiation patterns, antenna peak gain, and radiation efficiency, are given to validate the proposed antenna. With the presence of wideband features and good radiation efficiency higher than 55% over the desired operating bands, the proposed antenna is attractive for the practical mobile phone applications.

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