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Research Article

A Small Planar Antenna for 4G Mobile Phone Application

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The analysis and design of a small planar multiband antenna operating in the 4G frequency bands are presented. The numerical and experimental results demonstrated that the proposed antenna satisfies the requirement of 6 dB return loss for the impedance bandwidth of the LTE700/LTE2300/LTE2500 and WiMAX3500 bands. The gains at 750 MHz/2.3 GHz/2.6 GHz/3.5 GHz are 2.1 dBi/4.9 dBi/4.7 dBi/4.3 dBi, respectively. The measured radiation patterns verify the suitability of the antenna to be employed in mobile phones. The dimensions of the radiant patch are $49 \times 10\ \mathrm{mm}^2$. The proposed antenna can be easily fabricated and customized to various 4G mobile phones as a compact internal antenna.

1. Introduction

With the rapid development of the fourth-generation (4G) mobile communication technologies, the mobile phone antennas have received substantial attention because of the wide applications made available in such systems [1–4]. In fact, these antennas, which are an important part of mobile phone terminals, affect the overall performance of these communication systems. The usual mobile phone antennas have been proved unable to meet the 4G wireless communication requirements of the multiband and broadband applications [5–7]. In the last few years, a variety of small Long Term Evolution (LTE) mobile phone antennas have become the hot topic of the communication industry research [8–11]. To address the difficulties of integrating antennas in 4G mobile phones, many efforts have been made to expand the performance of the antennas in the LTE bands [12–16]. However, these design solutions generally require large size or volumes, which may be not compatible with the new generation of mobile phone applications. Because of the extremely limited volume of a mobile terminal, it is very important to synthesize compact multifunctional and broadband antennas. In the near future, these consumer electronic devices will be capable of integrating multibands protocols (LTE, WiMAX, etc.) into one single communication system. Thus, the antenna for 4G mobile phones must be compact size and low profile.

In this paper, a multiband antenna for a 4G mobile terminal application is proposed. The antenna is made by means of compact multiresonator planar elements that occupy a size of $49 \times 10 \times 1.6\ \mathrm{mm}^3$. It covers multibands which include the LTE700 (698–787 MHz), LTE2300 (2305–2400 MHz), LTE2500 (2500–2690 MHz), and WiMAX3500 (3390–3600 MHz) operations. Good radiation characteristics within the operative antenna frequency band are obtained. Details of the proposed antenna design and of the related parametric analysis are presented and discussed in the next sections. With the attractive features described above, the proposed antenna is a promising candidate for wireless devices.

2. Antenna Configuration

The geometry of the proposed LTE-printed antenna is depicted in Figure 1. The antenna has a planar structure and a simple configuration consisting of two horizontal-U rings, a feed, a shorting line, and a ground plane. It is fed by a $50\ \Omega$ minicoaxial line connected between the feeding point (point A) of the driven monopole and the phone-display ground point (point B). The proposed antenna is fabricated on a commercially available FR4 substrate having thickness of 1.6 mm, relative permittivity of 4.4, and loss tangent of 0.024.

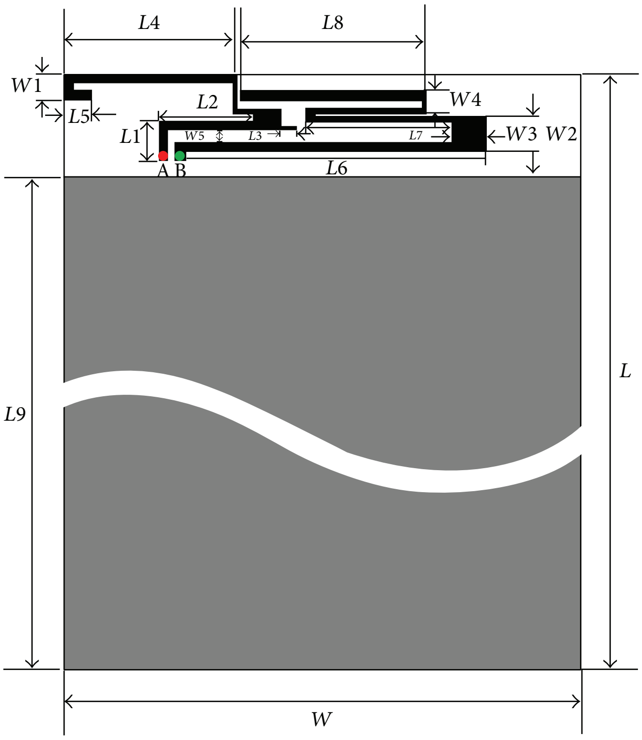


FIGURE 1: Geometries of the proposed antenna.

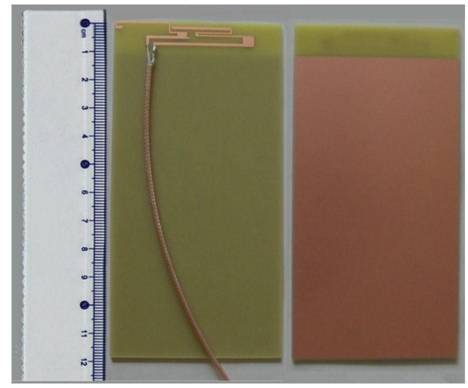


FIGURE 2: Photograph of the fabricated antenna with short feeding cable.

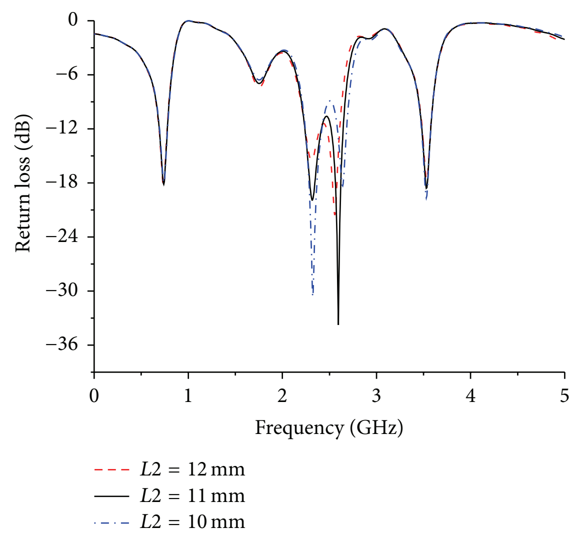


FIGURE 3: Simulated return loss characteristics for the proposed antenna for various values of $L2$.

The system ground plane of the antenna has dimensions of $108 \times 60\,\text{mm}^2$. The area where the ground plane is not present has dimensions of about of $49 \times 10\,\text{mm}^2$. Thus, the size of this antenna is suitable for mobile phone applications.

The values of the design parameters shown in Figure 1 were evaluated by means of an extensive parametric analysis performed using the commercial software HFSS. After completing the optimization process the dimensions of the proposed antenna have been set as follows: $L = 120$ mm, $L1 = 4.5$ mm, $L2 = 11$ mm, $L3 = 2$ mm, $L4 = 20$ mm, $L5 = 3$ mm, $L6 = 34$ mm, $L7 = 16$ mm, $L8 = 20$ mm, $L9 = 108$ mm, $W = 60$ mm, $W1 = 3$ mm, $W2 = 4$ mm, $W3 = 4$ mm, $W4 = 2.5$ mm, and $W5 = 1.5$ mm. Based on the optimized design dimensions, a prototype of the proposed antenna depicted in Figure 2 was realized and tested.

3. Parameters Study

Figure 3 shows the frequency behavior of the antenna reflection coefficient for different lengths of the geometrical parameter $L2$ when the other parameters are kept constant to their optimized values. From Figure 3 it appears that the length $L2$ mainly controls the second antenna resonance frequency f_2. In particular, it is found that as the length $L2$ increases, the second resonance frequency f_2 moves upward. From the figure, one can also see that the resonant frequency is of 2.6 GHz and the impedance bandwidth is 2.148~2.697 GHz, thus covering the LTE2300/LTE2500 frequency band, when the length $L2$ is of 11 mm. Therefore, the length of the parameter $L2$ is set to 11 mm.

Figure 4 illustrates the frequency behavior of the antenna reflection coefficient when the length of the parameter $L7$ varies from 15 mm to 17 mm when the other parameters are kept constant. From this figure it appears that the third resonance frequency f_3 moves downward as the length of the parameter $L7$ is increased. The length of $L7$ mainly controls the third resonance frequency f_3 for the 3.5 GHz WiMAX band. As is shown in Figure 4, when $L7$ is equal to 16 mm, the resonant frequency is of 3.53 GHz while the antenna bandwidth is in the frequency range 3.392~3.632 GHz. Therefore, the length of the parameter $L7$ is set to 16 mm so as to assure a resonance frequency at f_3.

A different behavior of the reflection coefficient with respect to the variation of the geometrical parameter $L8$ is observed in Figure 5. In fact, when this parameter increases from 18 mm to 22 mm, while maintaining the other structure parameters to the values of the optimized design, both the first resonance frequency f_1 and the third resonance frequency f_3 move downward. In particular, when $L8$ is of 20 mm, the first resonance frequency f_1 and impedance

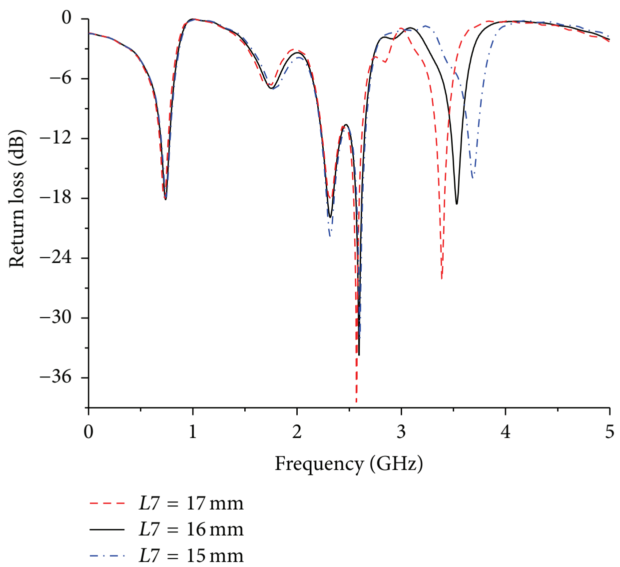


FIGURE 4: Simulated return loss characteristics for the proposed antenna for various values of $L7$.

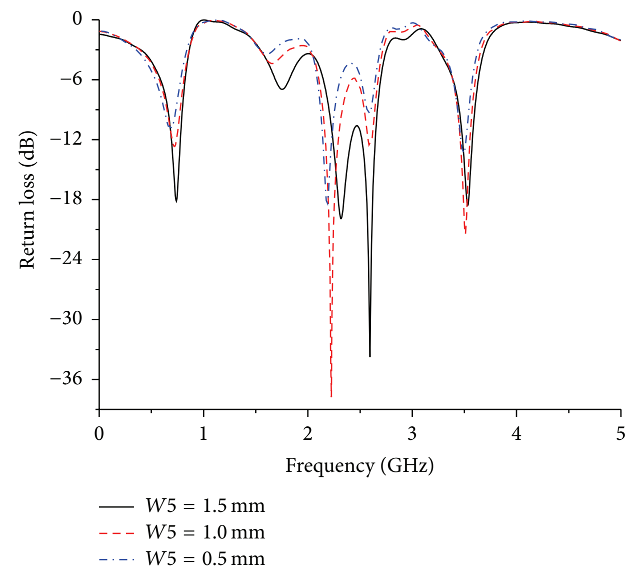


FIGURE 6: Simulated return loss characteristics for the proposed antenna for various values of $W5$.

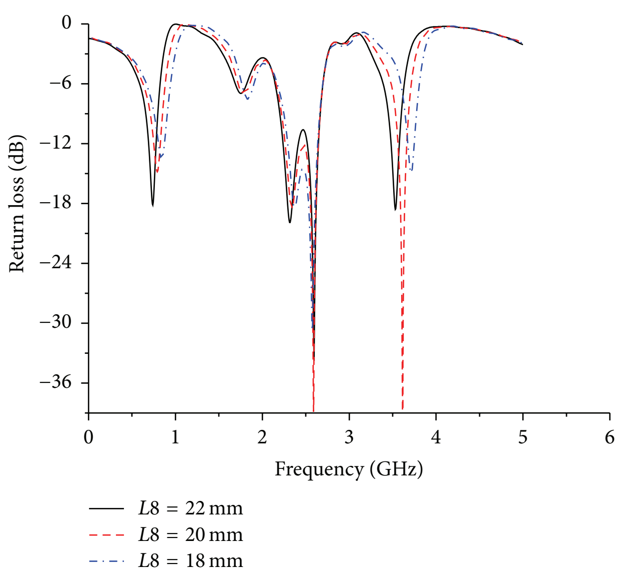


FIGURE 5: Simulated return loss characteristics for the proposed antenna for various values of $L8$.

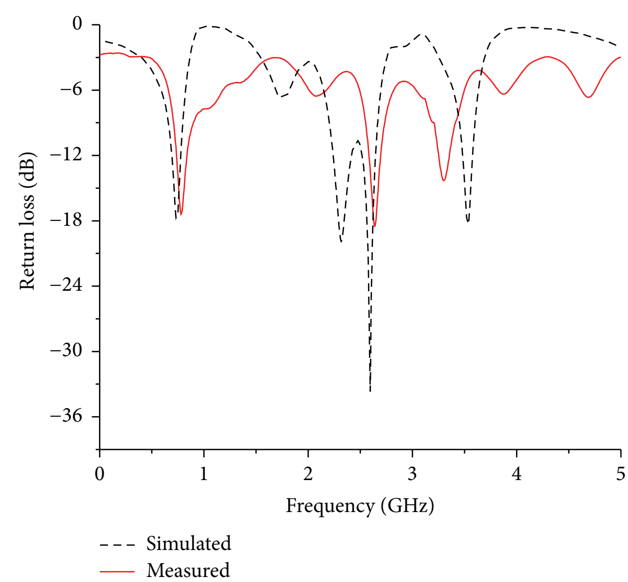


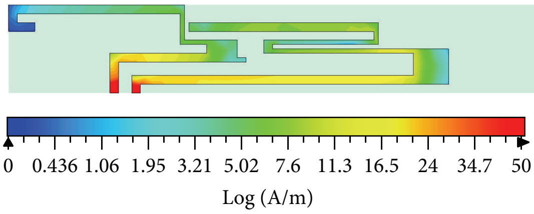
FIGURE 7: Simulated and measured return loss versus frequencies of the proposed antenna.

bandwidth are 0.74 GHz and 0.590~0.823 GHz covering LTE700, respectively. Thus, the parameter $L8$ is set to 20 mm.

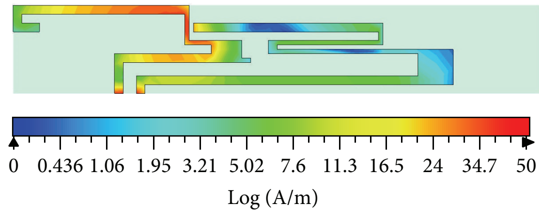
Finally, in Figure 6 the simulated return loss of the proposed antenna for the different values of the widths $W5$ is shown. As in the other cases the other antenna geometrical parameters are kept constant. From Figure 6 it can be seen that both the first resonance frequency f_1 and the third resonance frequency f_3 move upward as the width $W5$ increases. In particular, when the width of $W5$ equals 1.5 mm, the first resonance frequency is 0.74 GHz and the impedance bandwidth defined by 6 dB return loss is 0.590~0.823 GHz, thus covering the LTE700 frequency band. At the same time, the third resonance frequency is 3.5 GHz and the impedance bandwidth is 210 MHz (3.39~3.60 GHz) at the 3.5 GHz WiMAX band. Therefore, the parameter $W5$ is chosen to be $W5 = 1.5$ mm.

4. Results and Discussions

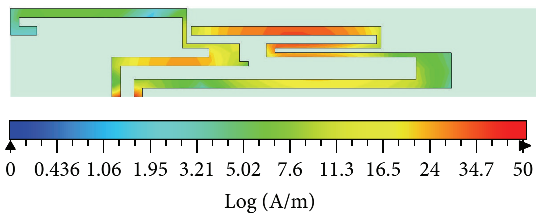
An antenna prototype (see Figure 2) designed using the geometric parameters obtained by means of the parametric analysis presented above has been realized and measured. The proposed antenna has been measured using an Agilent PNA 8362B Network Analyzer in a frequency range from 45 to 5000 MHz. Figure 7 compares the frequency behavior of the simulated and measured return loss (reflection



(a) $f = 0.75$ GHz

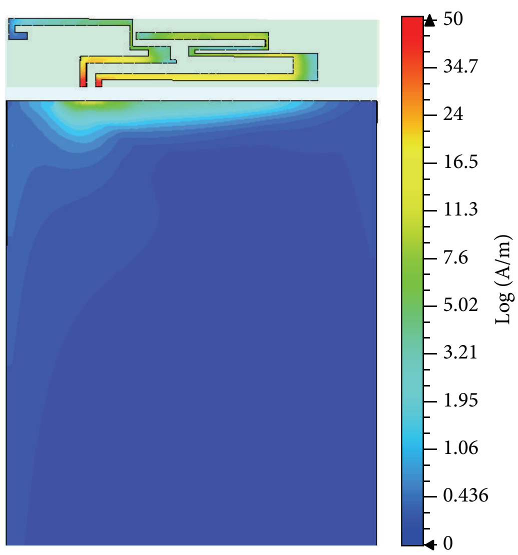


(b) $f = 2.6$ GHz

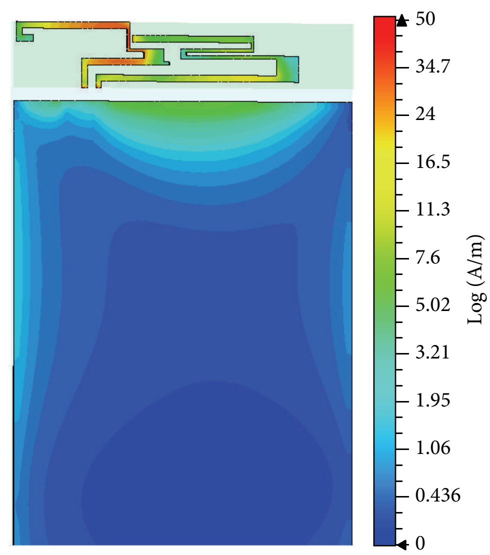


(c) $f = 3.5$ GHz

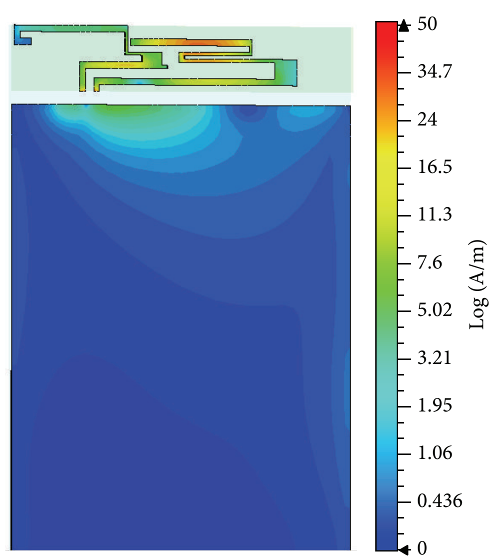
FIGURE 8: Surface current distributions on the radiating patch at (a) 0.75 GHz; (b) 2.6 GHz; and (c) 3.5 GHz.



(a) $f = 0.75$ GHz



(b) $f = 2.6$ GHz



(c) $f = 3.5$ GHz

FIGURE 9: Surface current distributions on the proposed antenna at (a) 0.75 GHz; (b) 2.6 GHz; and (c) 3.5 GHz.

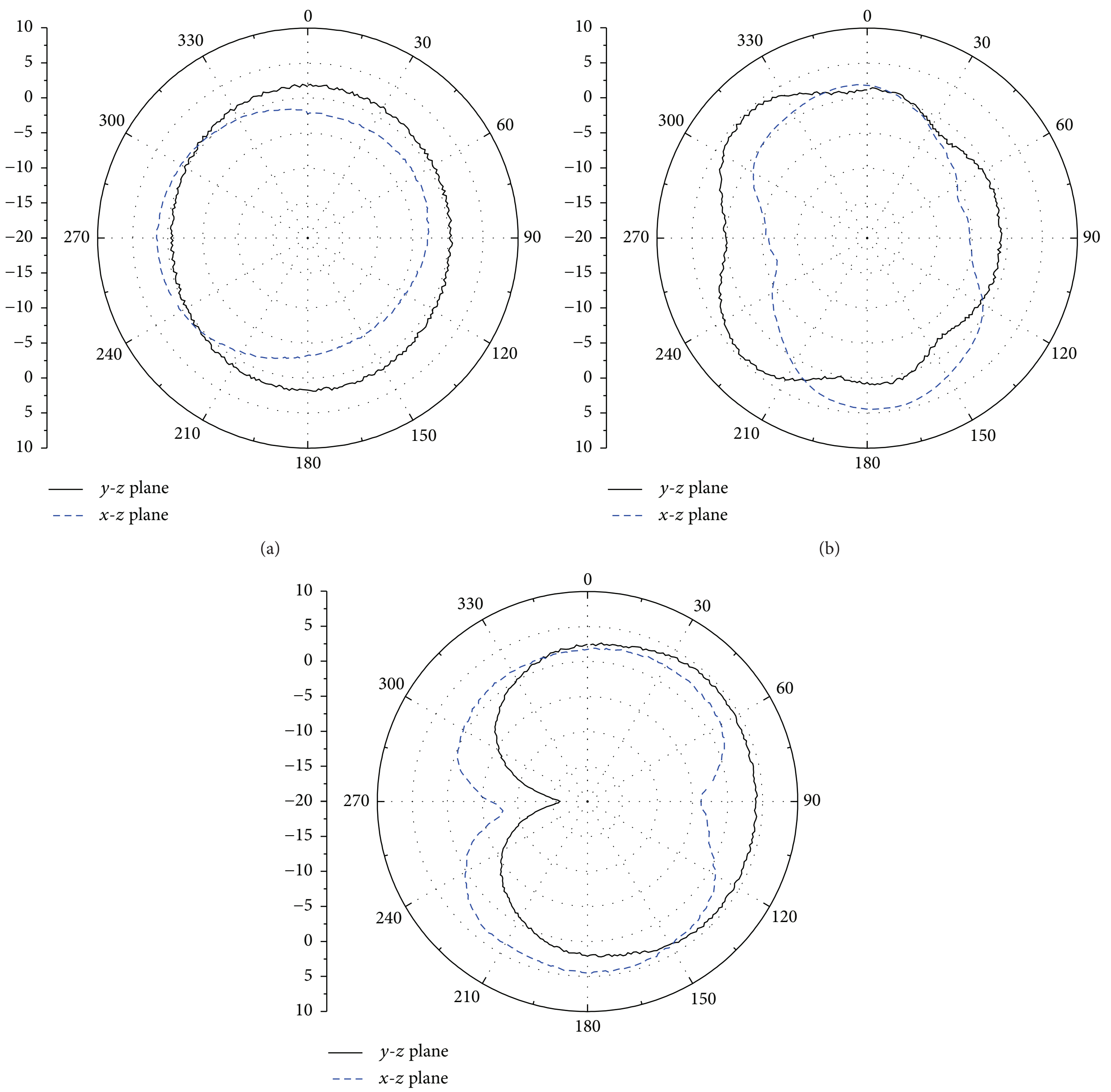


Figure 10: Measured radiation patterns of the proposed antenna for the LTE operation frequencies at (a) 0.75 GHz; (b) 2.6 GHz; and (c) 3.5 GHz.

coefficients) of the proposed antenna. All frequency bands are covered within the 6 dB of return loss, which is a widely used standard in the mobile phone antennas. The discrepancy observed between the computed and measured values of the reflection coefficient is due to the substrate and realization tolerances, as well as to the effect of the SMA connector and of the soldering points. When the antenna is carefully realized the measured impedance bandwidth is of 230 MHz (0.59 GHz~0.82 GHz, 32.6%) for the LTE 700 (698–787 MHz), of 550 MHz (2.15 GHz~2.70 GHz, 22.68%) for the LTE2300 (2305–2400 MHz) and the LTE2500 (2500–2690 MHz), and of 230 MHz (3.40 GHz~3.63 GHz, 6.54%) for the 3.5 GHz WiMAX.

The numerical simulations were performed using the full-wave commercial software HFSS. This software was used to evaluate and verify the three resonant frequencies 0.75, 2.6, and 3.5 GHz, which mainly depend on the lengths of the different current paths along the two horizontal-U rings. Figures 8(a)–8(c) show the surface current density excited along the two horizontal-U rings antennas at the three resonant frequencies 0.75, 2.6, and 3.5 GHz, respectively. In Figure 8(a), the lowest band surface current density distribution along the two input antenna ports at the resonant frequency of 0.75 GHz is shown. A larger surface current density flows along the first horizontal-U ring when the resonant frequency is 2.6 GHz as it is observed in Figure 8(b). However, larger surface current densities flow along the second horizontal-U ring when the resonant frequency is 3.5 GHz as is shown in Figure 8(c). Figures 9(a)–9(c) show the surface current density excited along the radiating patch and on the ground plane at the three resonant frequencies 0.75, 2.6, and 3.5 GHz, respectively. The emission phenomena take place along the U rings, at the patch corners, and at the substrate truncations where the conversion of surface waves into volume waves occurs [17]. In conclusion, the maximum amplitude of the surface current distribution excited on the antenna at the three resonant frequencies is located in different parts of the radiating structure.

Figure 10 shows the measured far-field radiation patterns in the E plane (x-z plane) and H plane (y-z plane). Figures 10(a)–10(c) show the radiation patterns at 0.75 GHz, 2.6 GHz, and 3.5 GHz, which are the resonance centre frequencies, respectively. That is to say, the proposed printed antenna covers three LTE bands and one WiMAX band. As evidenced by the radiation patterns it appears that the proposed antenna displays nearly omnidirectional radiation characteristics in the H plane, and monopole-like radiation pattern characteristics in the E plane at the considered frequencies. Moreover, since the planar radiating structure is realized on a single side printed circuit board is easy to manufacture.

5. Conclusions

A planar antenna for 4G mobile communication systems has been presented, realized, and tested experimentally. The obtained impedance bandwidth across the operating bands can reach about 356/413/237 MHz for the LTE bands and 210 MHz for the WiMAX band while the peak gains are about 2.1/4.7/4.3 dBi and 4.3 dBi, respectively. Good radiation characteristics across the operative bands have been also confirmed. The proposed antenna has a planar structure so it is easy to fabricate at low cost by printing it directly on the flexible printed circuit board of the mobile phone. Therefore, the proposed antenna meets the challenging requirements of the modern mobile phone communications.

Competing Interests

The authors declare that they have no competing interests.

Acknowledgments

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