A Penta-Band Planar Inverted-F Antenna for Mobile Phone Application Using LC-Tank-Stacked Network

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Abstract—In this paper, a penta-band antenna design using matching network for mobile phone application is proposed. This design is composed of a planar inverted-F antenna (PIFA) and a LC-tank-stacked network. The LC-tank-stacked network consists of two pairs of stacked chip-LC tank, which combine in parallel with the microstrip line feeding to the antenna. The PIFA can excite dual bands, and each pair of chipLC tanks can effectively widen the lower and upper bandwidth, respectively. According to measured results, the bandwidth can cover 824–960 MHz/1710–2170 MHz band for WWAN application (VSWR = 3 : 1). The peak antenna gain is better than 0.5 dBi and 3.4 dBi for lower and upper operating band, respectively. And the measured radiation efficiency is about 40–60% and 40–70% for lower and upper operating band, respectively.

1. INTRODUCTION

Recently, the rapid progress of wireless communication technologies increases the difficulty of dual-band antenna design toward compact, slim profile and broadband for portable devices. In order to achieve dual-broad bands, some designs have been proposed such as active components (pin diode or varactor) to switch or tune the frequency configuration or the passive chip components (inductor or capacitor) called matching network to match the bandwidth. Therefore, there are some designs such as a dual-feed switching L-shaped or triangular radiator fed by pi-shaped matching network to cover different bands [1, 2], loop radiator shorting to ground plane fed by chip-LC-tank series matching network to cover two operating bands [3], two-path radiator and a strip protruded from ground fed by chip-LC-tank band-stop matching network to cover dual bands [4], slotted radiator fed by chip-LC band-stop matching network to cover dual bands [5], loop radiator with an inductively branch strip to cover two operating bands [6], and stacked inverted-F antenna with parallel chip-LC-tank matching network to cover dual bands [7]. Here, an antenna design fed by a particular LC-tank-stacked matching network is presented. The antenna is a PIFA without clearance region that can produce the dual bands. However, the LC-tank-stacked matching network consisting of two pairs of chip-LC tanks can add the parasitic mode close to original lower band and upper band, respectively. Especially, one pair of chip-LC tanks near the feeding microstrip line can widen the lower band, and the other pair of chip-LC tanks near the ground plane can widen the upper band. Hence, the proposed antenna can achieve the desired dual operating bands 824–960 MHz/1710–2170 MHz for WWAN application (VSWR = 3 : 1). Moreover, the PIFA lower/upper bandwidth can be improved by the LC-tank-stacked matching network form 10%/13% to 17%/26% to cover the WWAN operating band 15%/23%.

2. ANTENNA CONFIGURATION AND DESIGN

The proposed antenna configuration is composed of a PIFA for producing dual bands and a LC-tank-stacked network for dual-band bandwidth enhancement. Figure 1 shows the complete structure. The

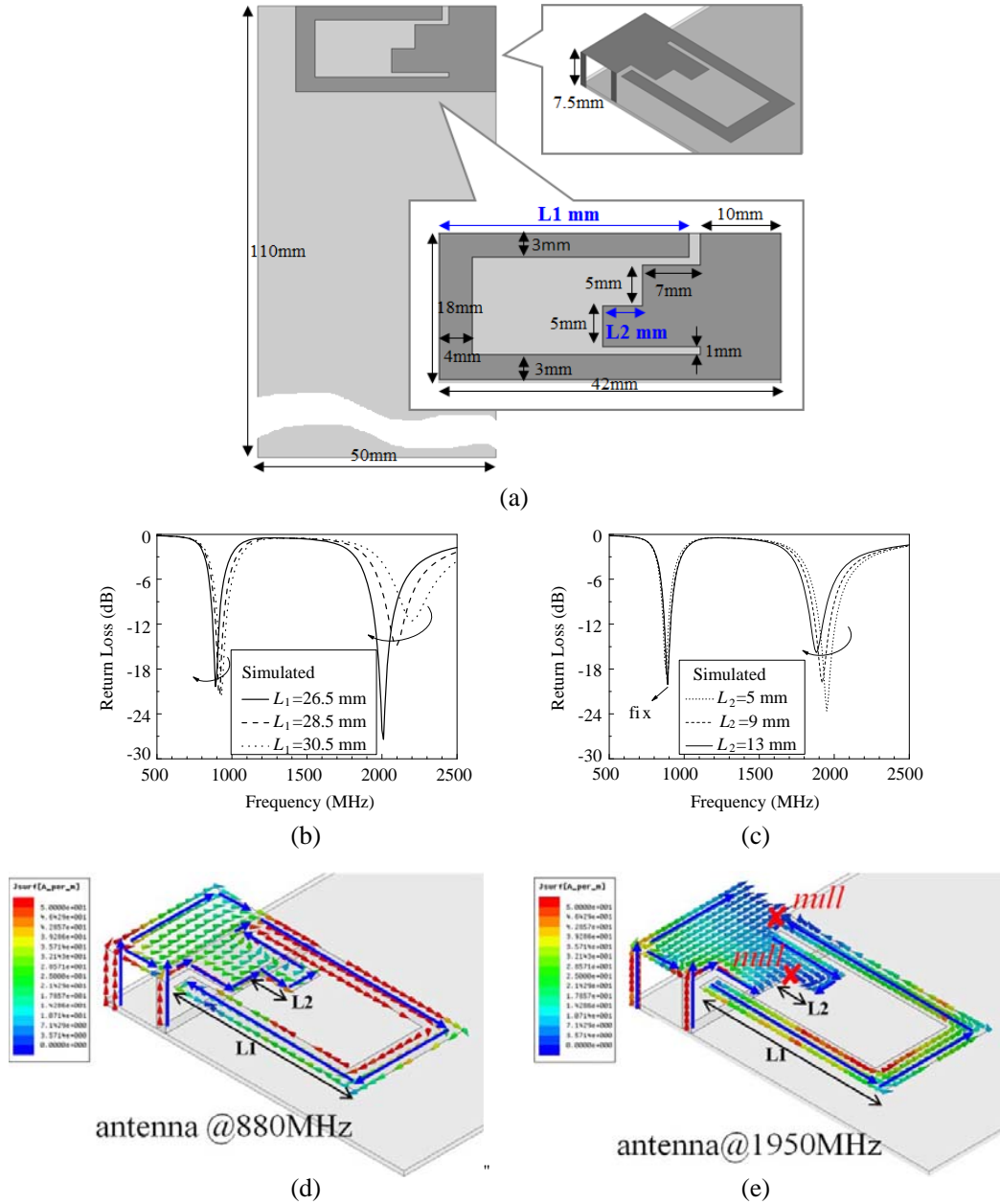**Figure 1.** The implement of the proposed antenna.

Figure 2. (a) Proposed antenna dimension and structural parameters denotation. (b) The simulated return loss as a function of L_1. (c) The simulated return loss as a function of L_2. (d) The antenna current distribution at 880 MHz. (e) The antenna current distribution at 1950 MHz.
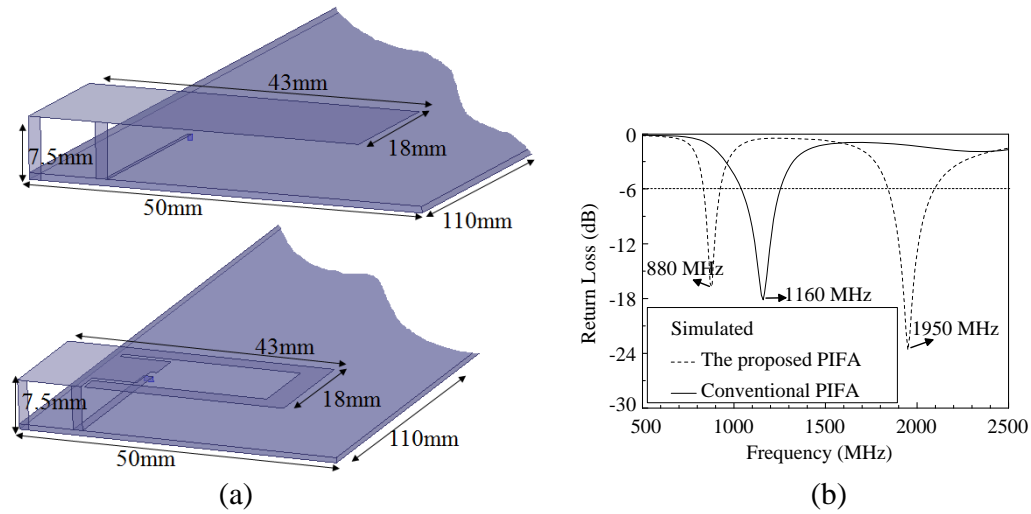
Figure 3. Comparison between proposed PIFA and conventional PIFA. (a) Top for conventional PIFA and bottom for proposed PIFA. (b) The simulated return-loss result.
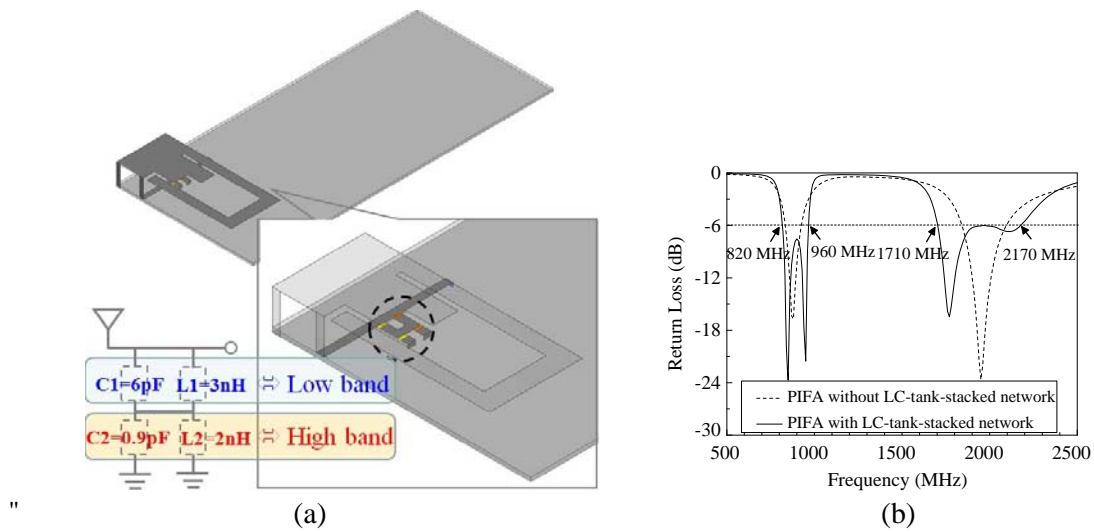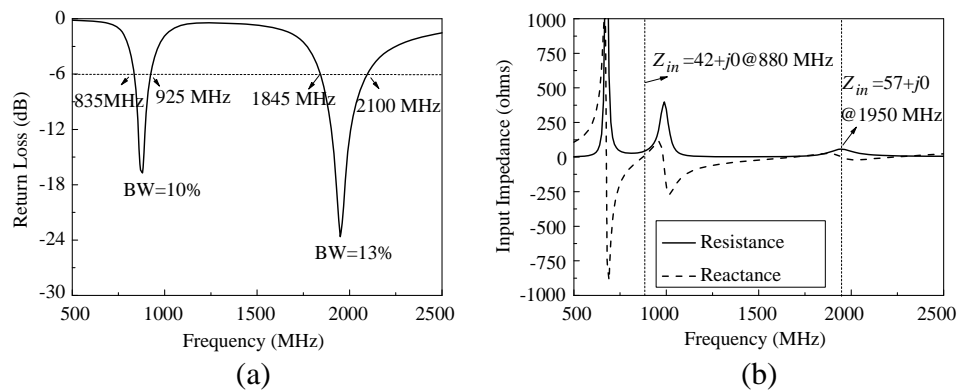

Figure 4. (a) The implement of the proposed antenna with LC-tank-stacked network. (b) The simulated return loss of PIFA and PIFA with network.
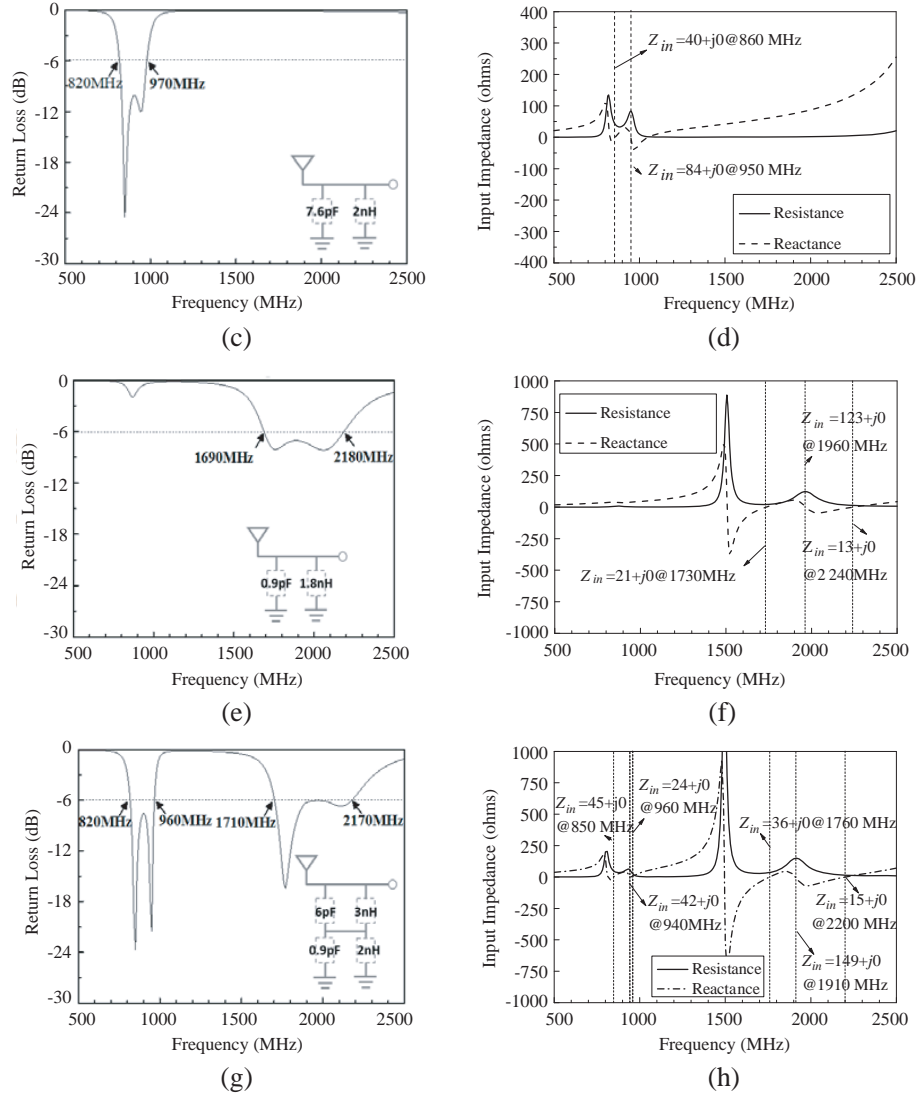
Figure 5. (a) The simulated return loss result of the PIFA. (b) The simulated input impedance result of the PIFA. (c) The simulated return loss result of the PIFA with chip-LC tank for lower band. (d) The simulated input impedance result of the PIFA with chip-LC tank for lower band. (e) The simulated return loss result of the PIFA with chip-LC tank for upper band. (f) The simulated input impedance result of the PIFA with chip-LC tank for upper band. (g) The simulated return loss result of the PIFA with LC-tank-stacked network for dual-band matching. (h) The simulated input impedance result of the PIFA with LC-tank-stacked network for dual-band matching.

ground-plane size is $50 \times 110 \times 0.8 \, \text{mm}^3$ using a FR4 substrate with relative permittivity 4.4, and the PIFA size is $42 \times 18 \times 7.5 \, \text{mm}^3$ using metal injection molding. The PIFA consists of a long strip and short ladder-shape strip. The structural parameter L_1 can be used to define the long-strip length, and L_2 can be used to define short ladder-shaped strip length as shown in Figure 2(a). Note that the structural parameters L_1 and L_2 can control the dual-band ratio. L_1 can manipulate the dual-band movement until the lower band arrives at 880 MHz as shown in Figure 2(b), and then L_2 can fix lower band at 880 MHz and manipulate the upper band arriving at 1950 MHz as shown in Figure 2(c). Figures 2(d), (e) show the current distribution at lower-band 880 MHz and at upper-band 1950 MHz. It can be observed that L_1 and L_2 can affect the dual bands. However, L_2 length is not sensitive to affect the lower band because the main length L_1 is not changed. Basically, the proposed long/short strip PIFA can excite

dual bands and reduce the dual bands toward lower frequency compared to the conventional PIFA [8]. Fig. 3(a) shows the conventional PIFA (an entire metal patch) and the proposed PIFA with the same size. Note that Fig. 3(b) shows the simulated return-loss result between conventional PIFA and the proposed PIFA which can explain the lower dual resonances.

PIFA can provide the mechanism of dual-band ratio; however, the LC-tank-stacked network can widen the dual-band bandwidth to cover the WWAN operating band for the $3:1$ VSWR. As shown in Figure 4(a), the pair of chip-LC tanks near the microstrip line can widen the lower band with $C_1 = 6\,\mathrm{pF}$ and $L_1 = 3\,\mathrm{nH}$, and the other pair of chip-LC tanks can widen the upper band with $C_2 = 0.9\,\mathrm{pF}$ and $L_2 = 2\,\mathrm{nH}$. Figure 4(b) shows the return loss of PIFA and PIFA with LC-tank-stacked network. It is obvious that the LC-tank-stacked network can add parasitic mode at lower and upper bands to achieve WWAN operating band. The dual-broad bands can be explained by input impedance as shown in Figure 5.

Figures 5(a), (b) show the simulated return loss and input impedance results of PIFA, and the resonant frequency at $880\,\mathrm{MHz}/1950\,\mathrm{MHz}$ can be observed at lower and upper bands, respectively. When one pair of chip-LC tanks ($L = 2\,\mathrm{nH}$ and $C = 7.6\,\mathrm{pF}$) combines in parallel with microstrip line feeding to the PIFA, there are two resonances at $860\,\mathrm{MHz}/950\,\mathrm{MHz}$ to widen the lower band as shown in Figures 5(c), (d). Similarly, the other pair of chip-LC tanks ($L = 1.8\,\mathrm{nH}$ and $C = 0.9\,\mathrm{pF}$) combines in parallel with microstrip line feeding to the PIFA. There are three resonances at
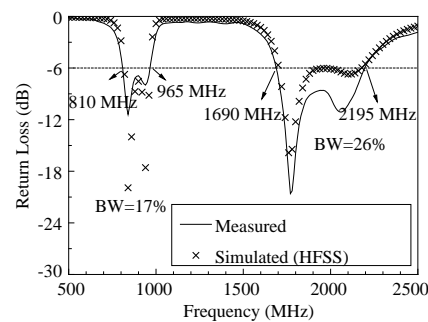
Figure 6. The simulated and measured return loss result of the proposed antenna.
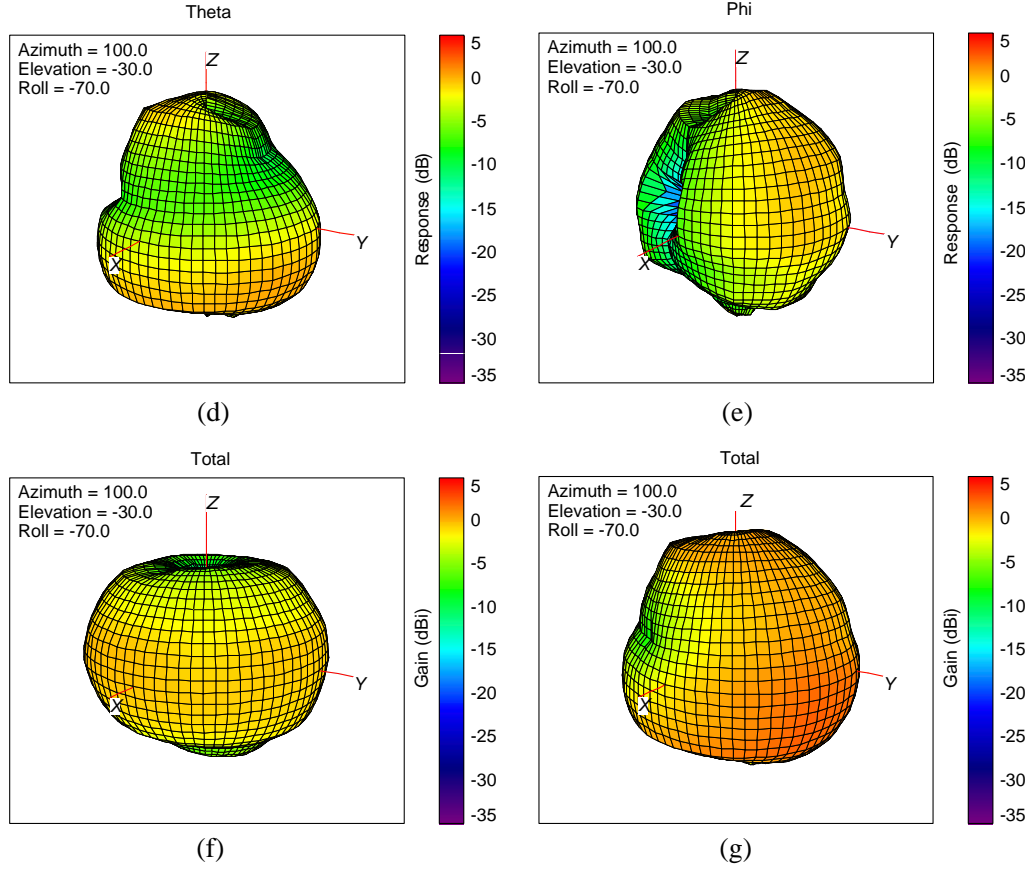
Theta

Azimuth = 100.0
Elevation = -30.0
Roll = -70.0

Phi

Azimuth = 100.0
Elevation = -30.0
Roll = -70.0

(d)

(e)

Total

Azimuth = 100.0
Elevation = -30.0
Roll = -70.0

Total

Azimuth = 100.0
Elevation = -30.0
Roll = -70.0

(f)

(g)
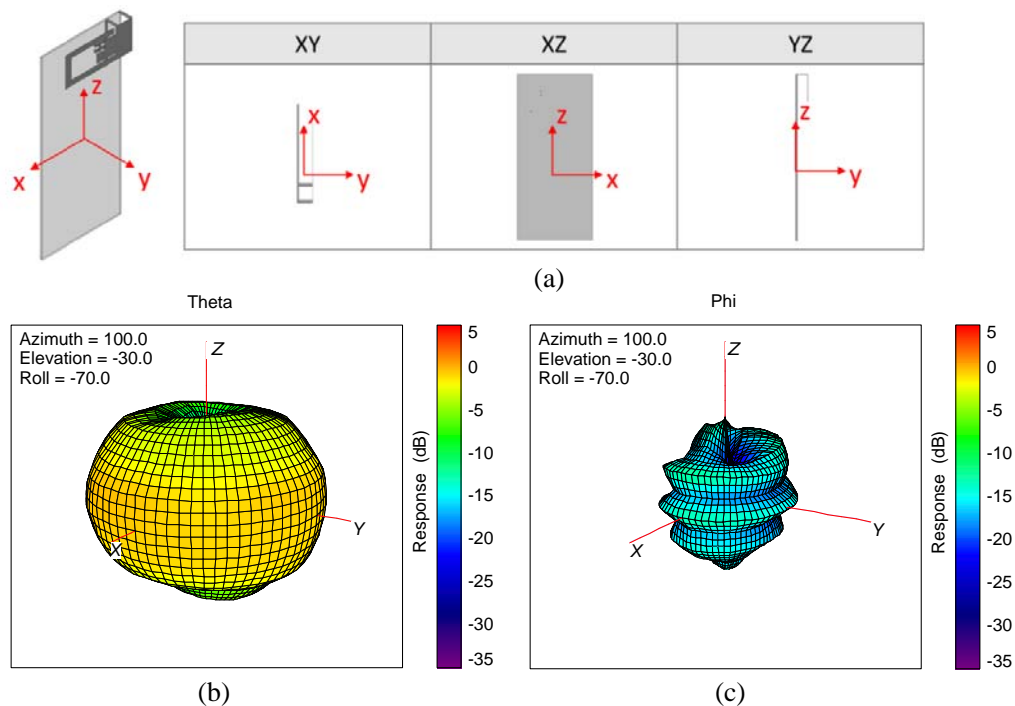
Figure 7. The measured 3-D radiation pattern. (a) The antenna measurement coordination. (b) E-theta polarization at 900 MHz. (c) E-phi polarization at 900 MHz. (d) E-theta polarization at 1900 MHz. (e) E-phi polarization at 1900 MHz. (f) Total gain at 900 MHz. (g) Total gain at 1900 MHz.
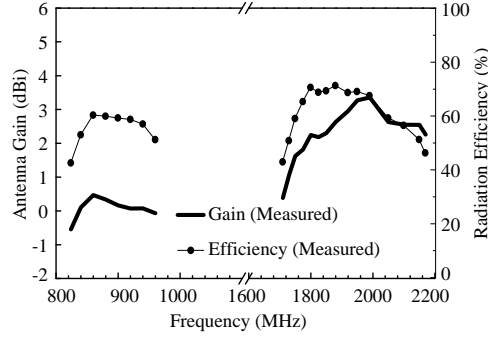
Figure 8. Measured results of the antenna peak gain and the antenna radiation efficiency.

1730 MHz/1960 MHz/2240 MHz to widen the upper band as shown in Figures 5(e), (f). Furthermore, the two pairs of chip-LC tanks combine in parallel with microstrip line feeding to the PIFA and are slightly adjusted, which can simultaneously widen the lower band with three resonances at 850 MHz/940 MHz/960 MHz and upper band with three resonances at 1760 MHz/1910 MHz/2200 MHz as shown in Figures 5(g), (h). Finally, the proposed PIFA with LC-tank-stacked network has a good agreement with the simulated and measured return-loss results as shown in Figure 6. Moreover, the PIFA lower/upper bandwidth can be improved by the LC-tank-stacked matching network form 10%/13% to17%/26% to cover the WWAN operating band 15%/23%.

3. MEASUREMENT ANTENNA RADIATION CHARACTERISTICS

For the antenna radiation pattern, the measured radiation pattern is shown in Figure 7. The coordinate definition is shown in Figure 7(a). Figures 7(b), (c) show the radiation pattern of the E-theta polarization and E-phi polarization at 900 MHz, respectively. Figures 7(d), (e) show the radiation pattern of the E-theta polarization and E-phi polarization at 1900 MHz, respectively. Note that the total gain is mainly distributed on xy-plane at 900 MHz and at 1900 MHz as shown in Figures 7(f), (g). The measured antenna gain and radiation efficiency are shown in Figure 8. For the low band, the peak antenna gain is 0.4 dBi, and the efficiency is between 40–60%. For the upper band, the peak gain is 3.4 dBi, and the efficiency is between 40–70%.

4. CONCLUSION

In this paper, a penta-band antenna design has been proposed. This design is composed of PIFA and a LC-tank-stacked network. By using the LC-tank-stacked network, the dual-broad bands are achieved effectively. According to measured results, the lower-/upperband can cover 824–960 MHz/1710–2170 MHz for WWAN application (VSWR = 3 : 1). The peak antenna gain is 0.5 dBi and 3.4 dBi for lower and upper bands, respectively. And the measured antenna radiation efficiency is between 40–60% and 40–70% for lower and upper bands, respectively.

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