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PLANAR MONOPOLE ANTENNA WITH TWO COUPLED STRIPS FOR INTERNAL EIGHT-BAND LTE/WWAN LAPTOP COMPUTER APPLICATION

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Abstract—In this paper, a compact planar monopole antenna with eight-band LTE/WWAN (LTE700/2300/2500/GSM850/900/1800/1900/UMTS) operation for laptop computer application is presented. This design structure comprises a bent driven strip and two coupled strips, which can contribute multiple resonance modes to combine two wide operating frequency bands covering 665–1023 MHz and 1612–2924 MHz. The proposed antenna fed by a 50-Ω coaxial cable occupies a small size of only 65(L) × 11(W) × 0.4(H) mm^3, so it can be flexibly embedded inside the casing of the laptop computer as an internal antenna. A fabricated prototype of the antenna is tested and analyzed. Experimental results exhibit that nearly omnidirectional coverage and stable gain variation across the desirable LTE/WWAN bands can be obtained with the antenna.

1. INTRODUCTION

In recent years, the practical requirements of the WWAN (wireless wide area network) and the LTE (long term evolution) applications are rapidly increased for various modern portable devices, such as mobile phone and laptop computer. To this end, multiband antenna design to cover the WWAN bands (GSM850/900/1800/1900/UMTS) of 824–896/880–960/1710–1880/1850–1990/1920–2170 MHz and the LTE bands (LTE700/2300/2500) of 698–787/2305–2400/2500–2690 MHz have become a promising technology. Regarding the design condition

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of a mobile phone, several multiband antennas capable of achieving LTE/WWAN operation have been investigated in [1–6]. By utilizing a coupled feed structure and an inductive shorting strip, three planar monopole antennas [1–3] could generate a good multiband property for LTE and WWAN applications in a mobile handset. Moreover, the use of a meander shape was an effective way to further reduce the antenna's size. Thus three compact designs [4–6] could function as an internal antenna for a small handset device.

To serve more communication systems for a laptop computer device, on the other hand, numerous antenna designs presented in [7–13] were developed with multiband or wideband features. By properly forming a coupled-fed structure to excite the branch radiator, a monopole antenna [7] and a loop antenna [8] were received high attention due to their eight-band operation characteristics. It was also attractive that bandwidth enhancement for a laptop computer LTE/WWAN antenna could be reached using a bent slot [9, 10]. Based on a parallel resonant circuit [11] or a parasitic shorted strip [12], two printed monopole antennas may successfully achieve not only eight-band LTE/WWAN application but also good radiation performance over the desired bands. For a low-profile laptop computer application, a compact inverted-F antenna working with multiple branch strips to create multiband property has been recently proposed in [13]. According to those previous studies shown in [1–13], a smaller size and multiband operation were two critical design challenges for an internal LTE/WWAN antenna in a portable device.

In this paper, we propose a printed monopole antenna to meet the LTE/WWAN eight-band operation for laptop computer application. It has a two-sided structure that is composed of a bent driven strip and two coupled strips. Comparing to those designs [1–13] used in a portable device, the proposed antenna can achieve not only a multiband property but also a more compact size of $65(\mathrm{L}) \times 11(\mathrm{W}) \times 0.4(\mathrm{H})\,\mathrm{mm}^3$ ($0.286\,\mathrm{cm}^3$). This will make the proposed antenna suitable for integration within a smaller laptop computer device such as ultrabook. Besides, by properly constructing two coupled strips close to the driven strip, two wide operating bands covering 665–1023 MHz and 1612–2924 MHz for LTE/WWAN applications can be attained with the antenna. Details of the antenna design are then described in Section 2. A fabricated prototype of the antenna will be experimentally tested and analyzed in Section 3. Parametric study for further tuning the antenna performance will be performed and discussed as well. Finally, this paper will be concluded with a brief summary in Section 4.

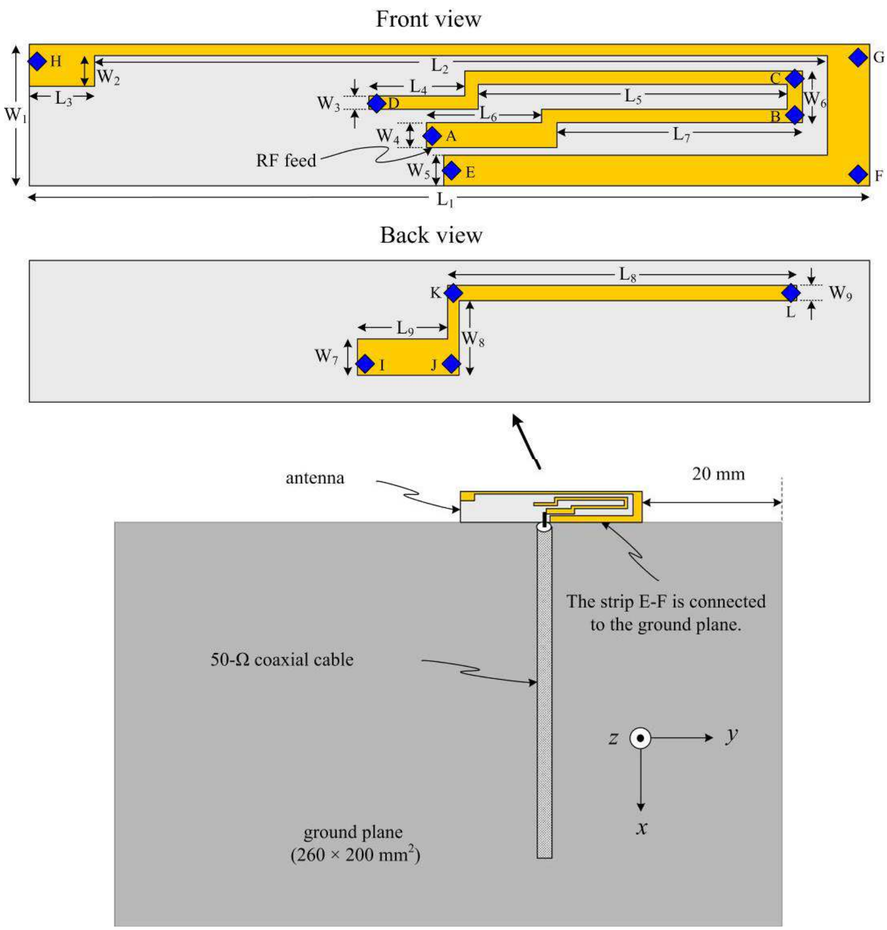

Figure 1. Design structure of the proposed eight-band LTE/WWAN monopole antenna. ($L_1 = 65$ mm, $L_2 = 57$ mm, $L_3 = 5$ mm, $L_4 = 7.5$ mm, $L_5 = 24$ mm, $L_6 = 9$ mm, $L_7 = 19$ mm, $L_8 = 27$ mm, $L_9 = 7$ mm, $W_1 = 11$ mm, $W_2 = 2$ mm, $W_3 = 1$ mm, $W_4 = 2$ mm, $W_5 = 2$ mm, $W_6 = 4$ mm, $W_7 = 2.8$ mm and $W_8 = 5.8$ mm).

2. ANTENNA DESIGN

Figure 1 depicts the whole configuration of the proposed monopole antenna for eight-band LTE/WWAN operation in a laptop computer device. It comes with a two-sided structure, which is consisted of a bent driven strip and two coupled strips. The overall size of the antenna is only about 65(L) × 11(W) × 0.4(H) mm^3 to be flexibly embedded inside a laptop computer device as an internal antenna. This design is fed by a 50-Ω coaxial cable, which is fabricated on a 0.4-mm-thick FR4 substrate with dielectric constant $\varepsilon_r = 4.4$ and loss tangent $\tan\delta = 0.02$. It is mounted on the top edge of the ground plane with a size of 260(L) × 200(W) mm^2, which is made with a 0.8-mm-thick copper plate to model the display panel of the laptop computer. In our design, the strip E-F of the antenna is connected to the ground plane. This means that a gap between the strip E-F and the ground plane is 0 mm for real application. A distance between the antenna and the right edge of the ground plane is reasonably selected to be about 20 mm. Then the antenna's performance can be enhanced due to reduction of the casing effect.

To achieve a good dual-wideband property, two and three resonant modes for producing the antenna's lower and upper bands are respectively designed. In this study, twelve points from A to L shown in Figure 1 and simulated surface current distributions are employed to describe the antenna's operation, where the current distributions are analyzed using an electromagnetic solver, HFSS [14]. The path A-B-C-D on the front side of the antenna functions as not only a driven strip but also a quarter-wavelength monopole. According to such design idea, the path A-B is resonated at about 2600 MHz mode and its extended path A-B-C-D is mainly working for 940 MHz mode. The current distributions at 940 MHz and 2600 MHz are simulated in Figures 2(b) and (e), where strong currents can be excited around the paths A-B-C-D and A-B, respectively. We also find that the length of the path A-B-C-D is calculated around 67 mm, which is shorter than a quarter-wavelength at the frequency of 940 MHz. This is because a capacitive coupling effect occurs between the paths A-B-C-D and E-F-G-H, as shown in Figure 2(b).

In order to further widen the antenna's upper and lower bands, the path E-F-G and its extended path E-F-G-H are designed to be about 36 mm and 106 mm, which are near a quarter-wavelength of 2120 MHz and 720 MHz, respectively. Figure 2(a) indicates intense current distributions along with the path E-F-G-H for generating the 720 MHz mode. It is also obvious that the path E-F-G can provide strong currents for the 2120 MHz mode, as shown in Figure 2(d). To enhance the radiation performance of the antenna, the end of the path E-F-G-H is formed with a rectangular patch, where the design parameters L_3 and W_2 are optimized to be 5 mm and 2 mm, respectively. Moreover, by coupling the energy from the driven strip to the back path I-J-K-L, a resonant mode at 1900 MHz can be successfully excited for the antenna. In Figure 2(c) strong and uniform currents flow along the path I-J-K-L while the 1900 MHz mode is excited for the antenna.

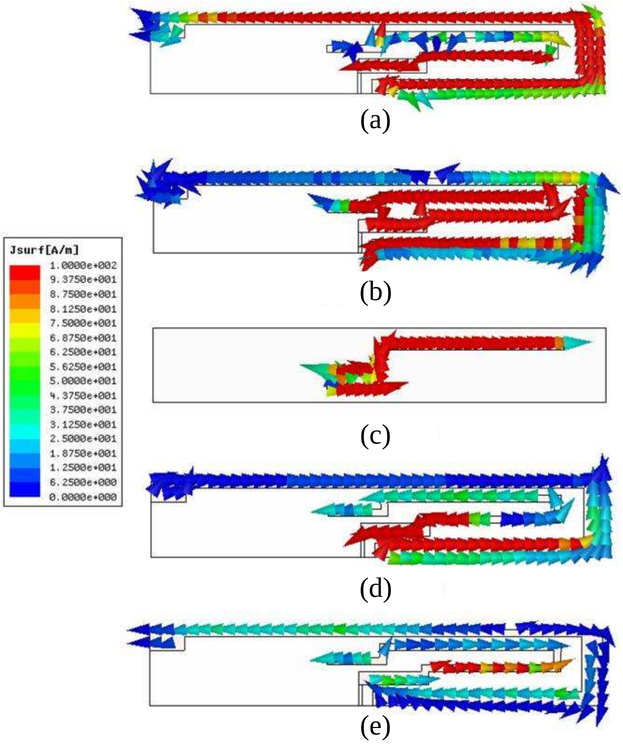

Figure 2. Simulated surface current distributions for the proposed antenna. (a) 720 MHz, (b) 940 MHz, (c) 1900 MHz, (d) 2120 MHz, (e) 2600 MHz.

Clearly, above five resonant modes of the antenna can be combined to create two wide operating bands for LTE/WWAN operation.

The geometric model and electrical characteristics of the proposed antenna are performed and analyzed by utilizing a full-wave simulator, SEMCAD [15]. The design parameters optimized for the antenna have been eventually determined with $L_1 = 65$ mm, $L_2 = 57$ mm, $L_3 = 5$ mm, $L_4 = 7.5$ mm, $L_5 = 24$ mm, $L_6 = 9$ mm, $L_7 = 19$ mm, $L_8 = 27$ mm, $L_9 = 7$ mm, $W_1 = 11$ mm, $W_2 = 2$ mm, $W_3 = 1$ mm, $W_4 = 2$ mm, $W_5 = 2$ mm, $W_6 = 4$ mm, $W_7 = 2.8$ mm and $W_8 = 5.8$ mm. Detailed size comparison for the proposed antenna with prior designs presented in [1–13] are also given in Table 1. It is clear that significant size reduction can be achieved with the antenna. As a result, the proposed compact monopole antenna having eight-band operation is well suitable to be embedded inside a laptop computer device as an internal antenna for LTE and WWAN applications.

Table 1. Size comparison for the proposed antenna with previous LTE/WWAN designs.

Reference	Antenna Size	Size Reduction Ratio (Proposed /Reference)
[1] Lee and Wong	40(L) × 12(W) × 0.8(H) mm^3 (0.384 cm^3)	74.5%
[2] Chen and Wong	60(L) × 10(W) × 1(H) mm^3 (0.6 cm^3)	47.7%
[3] Chu and Wong	60(L) × 15(W) × 0.8(H) mm^3 (0.72 cm^3)	39.7%
[4] Chen and Wong	40(L) × 15(W) × 3(H) mm^3 (1.8 cm^3)	15.9%
[5] Chiu et al.	60(L) × 10(W) × 6.5(H) mm^3 (3.9 cm^3)	7.3%
[6] Wong et al.	25(L) × 15(W) × 3(H) mm^3 (1.125 cm^3)	25.4%
[7] Kang et al.	80(L) × 10(W) × 4(H) mm^3 (3.2 cm^3)	8.9%
[8] Wong and Ma	75(L) × 10(W) × 4(H) mm^3 (3 cm^3)	9.5%
[9] Wong and Lee	50(L) × 4(W) × 3(H) mm^3 (0.6 cm^3)	47.7%
[10] Wong and Lin	75(L) × 12(W) × 0.8(H) mm^3 (0.72 cm^3)	39.7%
[11] Wong et al.	60(L) × 12(W) × 3.8(H) mm^3 (2.736 cm^3)	10.5%
[12] Kang and Wong	70(L) × 12(W) × 4(H) mm^3 (3.36 cm^3)	8.5%
[13] Hu et al.	96(L) × 11.2(W) × 0.5(H) mm^3 (0.537 cm^3)	53.3%
Proposed design	65(L) × 11(W) × 0.4(H) mm^3 (0.286 cm^3)	NA

3. SIMULATED AND EXPERIMENTAL RESULTS

A fabricated prototype of the proposed eight-band LTE/WWAN monopole antenna was constructed and examined, as shown in Figure 3. The prototype was fed by a 50-Ω coaxial cable and mounted

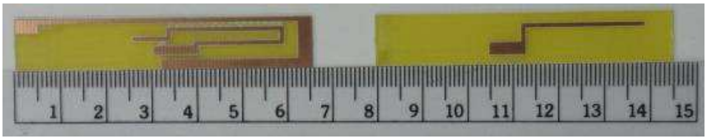

Figure 3. Fabricated prototype of the proposed antenna.

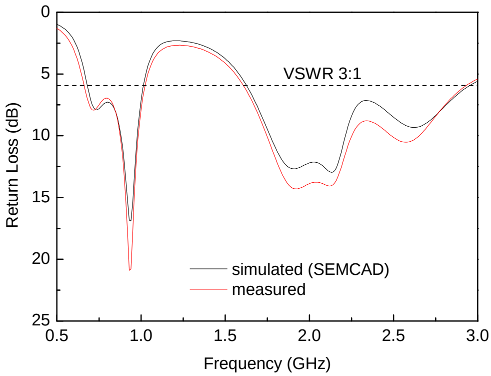

Figure 4. Simulated and measured return losses of the proposed antenna.

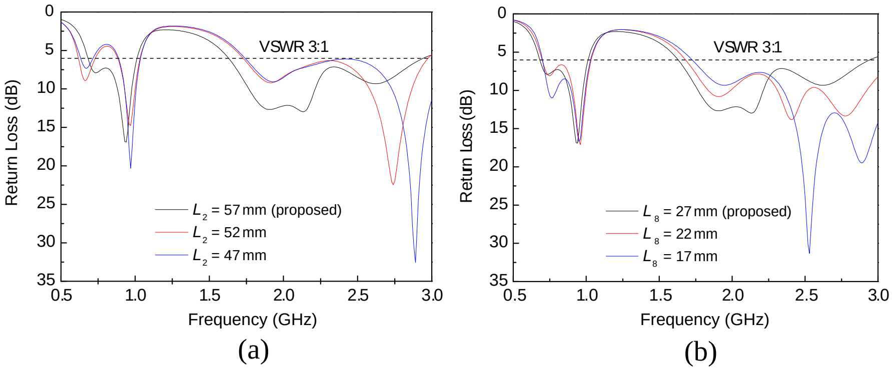

Figure 5. Parametric study for the proposed antenna. (a) strip L_2, (b) strip L_8.

on the top edge of the ground plane for performance test, where a vector network analyzer (Agilent ENA E5071B) was employed for antenna measurement. The simulated and measured return losses of the antenna were plotted and compared in Figure 4. We can observe that fairly good agreements between the simulations and measurements can be obtained for the antenna. With 6 dB return loss (VSWR 3:1), two measured impedance bandwidths of the antenna have been determined to be about 665–1023 MHz and 1612–2924 MHz. Hence

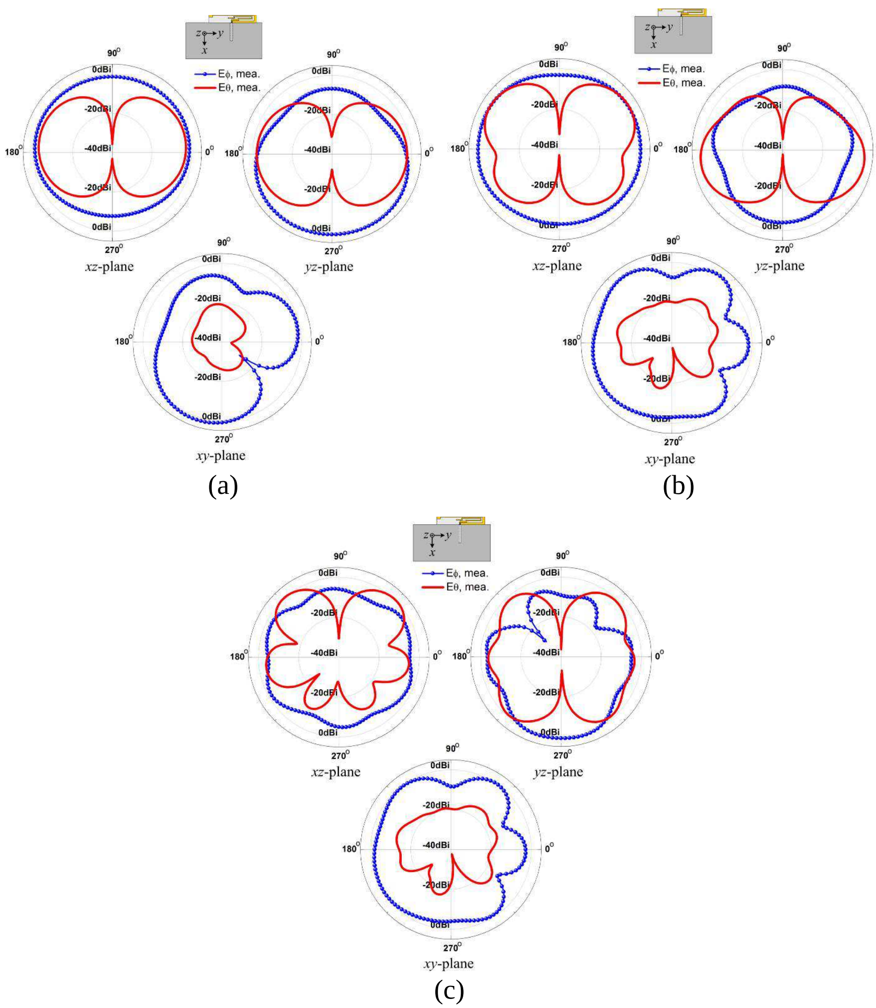

Figure 6. Measured radiation patterns of the proposed antenna. (a) 860 MHz, (b) 1800 MHz, (c) 2600 MHz.

the desired LTE700/2300/2500 and GSM850/900/1800/1900/UMTS bands can be well satisfied with the antenna.

In order to further study the antenna's operation, two strips L_2 and L_8 capable of adjusting the antenna performance are also analyzed with various lengths. The simulations for above two parameters are performed using the software package SEMCAD. As shown in Figure 5(a), while the strip L_2 located on the end of the path E-F-G-H is reduced, the antenna's upper band will be shifted toward higher frequency. It is also found that the two resonant modes of the lower band are separated apart because the coupling effect from the path E-F-G-H to the path A-B-C-B is changed. Moreover, the influence of the strip L_8 for the antenna is illustrated in Figure 5(b). As the strip L_8 is shortened for the antenna, the operating frequency does not change significantly in the lower band but increases obviously in the upper band. This can be attributed to the significant reduction in coupling between the paths A-B-C-D and I-J-K-L.

Figure 6 indicates the measured radiation patterns in *xz*-, *yz*- and *xy*-planes at the frequencies of 860 MHz, 1800 MHz and 2600 MHz for the antenna, respectively. Nearly good omnidirectional patterns at the *xz*-plane can be obtained across these three frequencies. The patterns in the *yz*-plane for these three frequencies are close to bidirectional. The measured peak gain and radiation efficiency of the antenna are plotted in Figure 7. For the lower band, the antenna gain varies from 1.1 to 1.6 dBi and the radiation efficiency is around 50–58%, as shown in Figure 7(a). Results in the upper band are given in Figure 7(b), where the antenna gain varies within a range of 2.15–2.44 dBi and the efficiency is around 63–68%. Stable variation for both the gain and

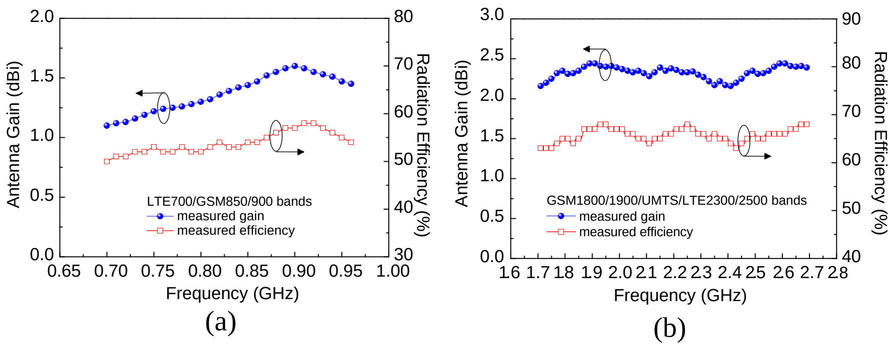

Figure 7. Measured peak gain and radiation efficiency of the proposed antenna. (a) LTE700/GSM850/900 bands, (b) GSM1800/1900/UMTS/LTE2300/2500 bands.

efficiency throughout the desired LTE/WWAN bands can be therefore received with the antenna. These experimental results also illustrate that the proposed design with good radiation performance may act as an internal LTE/WWAN antenna for laptop computer application.

4. CONCLUSION

A printed monopole antenna for the eight-band LTE/WWAN application has been presented and studied in this paper. The proposed design is compact and thus suitable to be embedded inside a laptop computer device as an internal antenna. By properly forming the driven and coupled strips, the eight-band operation can be achieved with the antenna. Several design parameters to optimize the antenna's performance are also analyzed and discussed. Owing to good coverage and stable gain variation, the proposed internal LTE/WWAN antenna will be a promising solution for laptop computer application.

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