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A NEW COUPLED-LOOP ANTENNA FOR EIGHT-BAND LTE/WWAN OPERATION IN ULTRA-THIN LAPTOP COMPUTER

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Abstract—A new structure of coupled-fed loop antenna connected with two branch radiators for eight-band LTE/WWAN (LTE700/GSM850/900/1800/1900/UMTS/LTE2300/2500) operation in the ultra-thin laptop computer is presented. The two branch strips of the antenna are efficient radiators and contributing multi-resonant modes to greatly enhance the bandwidth of the antenna. The proposed antenna on the top shielding metal wall of the laptop display, with a planar and compact size of $12.5 \times 70 \times 0.8\,\mathrm{mm}^3$, is suitable to be embedded inside the casing of the laptop computer. The proposed antenna is fabricated and tested, and good radiation performances are obtained. Compared with the existing published antennas, the volume of the planar antenna is quite small.

1. INTRODUCTION

Antenna serves as the key of the mobile terminal device, whose performance is directly related to the quality of signal transmission. For this application, promising penta-band WWAN internal laptop computer antennas have been devised and reported in published papers [1–6]. Very recently, owing to the introduction of the LTE (long term evolution) operation which can provide much higher data rate than the WWAN operation, it is now required in some laptop computers that their internal antennas should cover the LTE operation which includes the LTE700 (698–787 MHz), LTE2300 (2300–2400 MHz) and LTE2500 (2500–2690 MHz) bands. This imposes a challenge since there is a very limited space allowed in a mobile device for the embedded antenna.

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In [7, 8], the antennas designed in three-dimensional structures, are difficult to be applied to ultra-thin laptop computers and the cost is high. A PIFA antenna with multiple branches is proposed for laptop computers in [9], and the lump element is placed on the radiating structure in the end. However, it would increase the fabrication difficulty and cost. Another antenna is printed on both sides of Al_2O_3 ceramic substrate, according to [10, 11]. Compared with FR4 substrate, it is not ideal to be utilized in mass production.

Aiming at the defects of above-mentioned antennas, a new structure of coupled-fed loop antenna connected with two branch radiators for eight-band LTE/WWAN operation in the laptop computer is presented in this paper. The antenna has a uniplanar structure and is easy to be printed on an FR4 substrate at low cost. The size of antenna is $12.5 \times 70 \times 0.8\,\text{mm}^3$, which is smaller than that of the reported antenna in [7–11]. Operating principle of the proposed antenna is also discussed in this paper. The antenna is fabricated and tested, and the results of the fabricated antenna are discussed.

2. PROPOSED ANTENNA

Figure 1 shows the geometry of the proposed coupled-fed loop antenna connected with two branch radiators for eight-band LTE/WWAN operation in the laptop computer. In the study, the laptop computer is modeled as a display ground which measured $200 \times 260\,\text{mm}^2$. The antenna is mounted at the shielding metal wall of width 2 mm and length 260 mm, which is connected to the top edge of the display ground to provide some isolation between the internal antenna and the circuitry on the back side of the laptop display. However, the presence of the shielding metal wall usually results in some degrading effects on the impedance matching of the internal antenna, which decreases the bandwidths of the antenna. However the antenna can still generate two wide operating bands to respectively cover the desired eight-band operation. And also, since the central region is usually reserved for the lens of the embedded digital camera, the proposed antenna is placed with a small spacing to the center line of the laptop display.

The proposed antenna mainly comprises two branch radiators, a coupled-fed loop antenna (path ADEFC in Figure 1) with a longer branch strip (path FGH) and a shorter branch strip (path CJ), both of which are printed on a 0.8-mm thick FR4 substrate of relative permittivity 4.4. It can reduce the difficulty of the fabrication. The loop antenna ADEFC has a total length of about 94 mm and is excited capacitively using a coupling feed, which is formed by a feeding strip AM (width 2 mm and length 25 mm) and a coupling strip (width

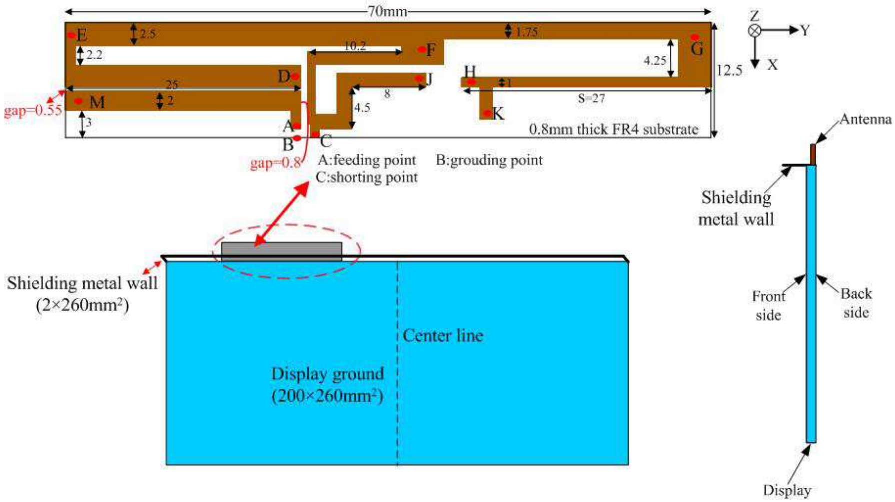

Figure 1. Geometry of the proposed coupled-fed loop antenna connected with two branch radiators for eight-band LTE/WWAN operation in the laptop computer.

2.25 mm and length 25 mm). A similar concept for handset antennas for multiband operation has been proposed in [12]. The directly excited path ADEFC can be called as driven strip, and it is not only serves as a capacitive feed to couple the energy for the proposed antenna, but also functions as an effective radiator to contribute a resonant mode (0.5-wavelength loop mode) at about 1.8 GHz. Note that for practical applications, the proposed antenna is fed by a 50 Ω mini-cable (diameter 1.37 mm), where the center conductor and outer grounding sheath are respectively connected to point A in the loop feed and point B at the shorted ground. At last, point C at the end point of the loop antenna is short-circuited to the shielding metal wall to form the closed loop path.

The longer branch strip FGH connected to driven strip (path ADEFC) at point F results in a new resonant. Also it can be called as parasitic strip. The new resonant path thus has a total length of about 94 mm is comprised by CFGK, which leads to the generation of a quarter wavelength resonant mode at about 0.8 GHz and a higher order resonant mode at about 2.5 GHz. In the same way, the shorter branch strip CJ connected to the loop antenna at point C provides a second new resonant path. The total length of the second new resonant path is hence about 18 mm, which contributes to a quarter-wavelength resonant mode at about 2.8 GHz. The three resonant modes at about 1.8, 2.5 and 2.8 GHz, contributed respectively by the loop antenna, the parasitic strip and the shorter branch strip, are combined into a wide operating band for the antenna's upper band to cover the desired GSM1800/1900/UMTS/LTE2300/2500 operation (1710–2690 MHz). On the other hand, the dual-resonant mode at low frequency which is contributed by the longer branch strip combined with the loop antenna provides a wide operating band to cover the desired LTE700/GSM850/900 operation (698–960 MHz). The two branch strips connected to the loop antenna hence greatly enhance the bandwidths of the antenna's lower and upper bands, allowing the antenna to cover the eight-band LTE/WWAN operation with a small occupied volume.

3. RESULTS AND DISCUSSIONS

The photo of the fabricated antenna is shown in Figure 2. In the experiment, a 50-Ω mini coaxial line aligned along the shielding metal wall is used to feed the antenna. Results of the measured and simulated return loss for the fabricated antenna are shown in Figure 3. The simulated results are obtained using simulation software HFSS version 13 [13]. From the results, the measured data are similar to the simulated results. The discrepancies between the measured and simulated results are related to the coupling between the mini-cable and the antenna in the experiment. From the measurement, the 3 : 1 VSWR (−6 dB return loss) bandwidth, which is widely used as the practical design specification of the internal antennas for mobile communications, is about 300 MHz (660–960 MHz) in the lower band and about 1100 MHz (1620–2790 MHz) in the upper band. That is, two wide operating bands are obtained, and the desired eight-band LTE/WWAN operation can be covered by the proposed antenna.

The operating principle of the proposed antenna is also analyzed. Results of the simulated return loss for the case with a coupled-fed loop antenna only (Rf1), Rf1 connected with a shorted branch strip (Rf2),

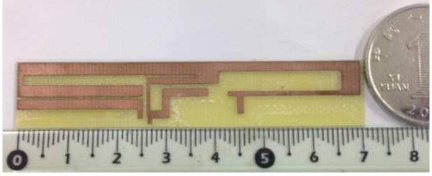

Figure 2. Photo of the fabricated antenna.

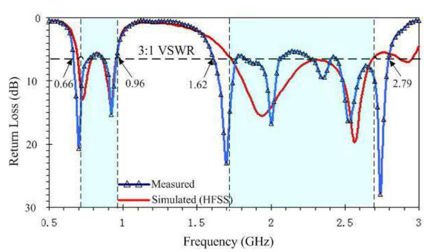

Figure 3. Measured and simulated return loss for the proposed antenna.

Rf1 connected with a longer branch strip (Rf3), and proposed antenna are shown in Figure 4. From the results, it can be concluded that the resonant mode excited at about 1.8 GHz in the proposed antenna is contributed by the loop antenna (Rf1). The 1.8 GHz resonant mode is the 0.5-wavelength loop mode, which is usually excited as the fundamental mode of the loop antenna for internal mobile device applications. From the comparison of Rf1 and Rf2, it can be easily deduced that the 2.8 GHz resonant mode is generated owing to the presence of the shorter branch strip.

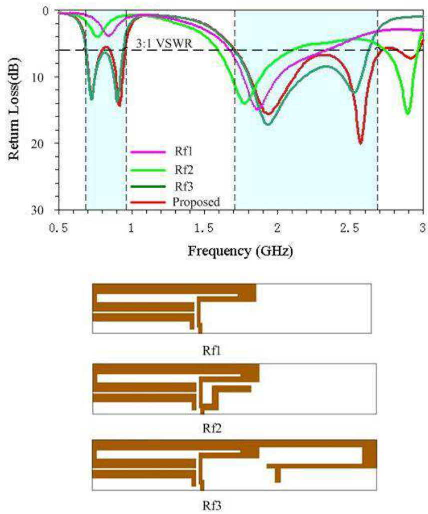

Figure 4. Simulated return loss for the case with Rf1, Rf2, Rf3 and proposed antenna.

By comparing Rf1 and Rf3 in Figure 4, it can be concluded that the 0.8 GHz resonant mode in low frequency and 2.5 GHz resonant mode are contributed by the longer branch strip. Furthermore, the resonant mode at about 0.8 GHz shows a dual-resonant property owing to the small values of its input impedance. Thus, a good impedance matching can be formed in low frequency. It is obviously that 2.5 GHz is the higher-order of 0.8 GHz. Without the longer branch strip, the bandwidth of the antenna's band is far from requirement.

The critical parameters S of the proposed antenna in Figure 1 is 27 mm. If the value of S parameters has changed, there would be small effects on the resonant mode at about 1.8 GHz contributed by the loop antenna. However, large effect on the resonant modes at about 0.8 and 2.5 GHz mainly contributed by the longer branch strip is easily seen. Some variations in the resonant modes at about 2.8 GHz contributed by

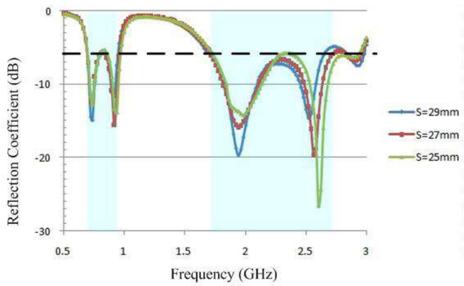

Figure 5. Reflection coefficient for different values of S.

the shorter branch strip can also be observed. This is largely because of the two ends of the longer and shorter branch strips facing each other with a small distance. Hence, there exists some coupling between the two branch strips. The results in Figure 5 are matched. It can be easily concluded when S is 27 mm, the performance of antenna is best.

By varying the length of AM and gap between the feeding strip and coupling strip, the capacitive excitation of the loop antenna can be adjusted. With the values of AM is changed from 27 mm to 25 mm in Figure 6, different return loss of antenna are obtained. The effect of the capacitive excitation is the best when the length of AM equals to 27 mm.

The surface current distributions for the proposed antenna at 0.8 GHz, 1.8 GHz, 2.5 GHz and 2.8 GHz are shown in Figure 7. It can be clearly seen that the driven strip (path ADEFC) connected to parasitic strip (path FGK) is excited at both 0.8 and 2.5 GHz. On the other hand, the 1.8 GHz resonant is excited by driven strip itself. At last, strong current distribution is observed in shorter branch strip CJ at 2.8 GHz, which confirms that 2.8 GHz resonance is generated by the patch CJ. And also, the surface current on driven strip is strong at all bands. This behavior suggests that driven strip is the major body of all resonances.

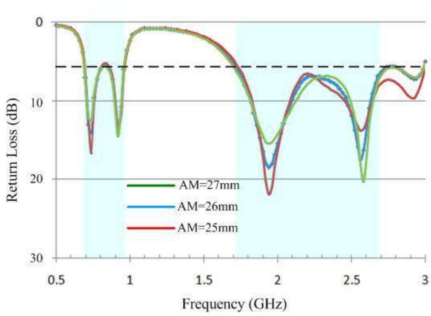

Figure 6. Return loss for different values of AM.

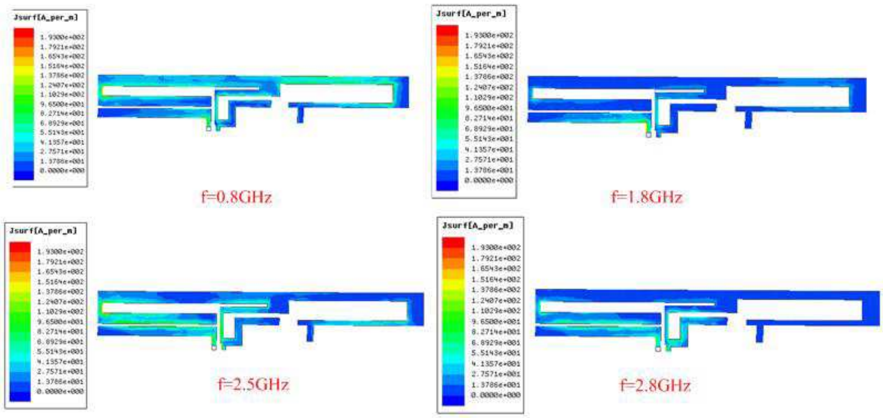

Figure 7. Surface currents distributions of the proposed antenna at 0.8 GHz, 1.8 GHz, 2.5 GHz and 2.8 GHz.

The measured radiation patterns at 830, 1940 and 2500 MHz for the fabricated antenna is shown in Figure 8. In the figure, the E_φ and E_θ components are shown. From the results, it can be obtained that the total power patterns will show no nulls in the vertical plane (y-z plane). No large variation in the radiation patterns versus frequency in each operating band of the eight-band LTE/WWAN operation has also been observed. Stable radiation patterns are therefore obtained for the proposed antenna for LTE/WWAN operation. This is an advantage for laptop computer applications.

The measured radiation efficiency and gain of the fabricated antenna placed in microwave anechoic chamber presented in Figure 9. First, an incident power is added into the proposed antenna. Then we use the horn antenna in microwave anechoic chamber to measure the radiation power. At last, radiation power divided by the incident power is the radiation efficiency of proposed antenna. Results for the lower and upper bands are respectively shown in Figures 9(a) and 9(b). The measured results show that the radiation efficiency is all larger than 50% over the eight operating bands. The measured antenna gain varies from about 0.6 $\sim$ 2.5 dBi over the lower band and about 0.73 $\sim$ 5.02 dBi over the upper band. The measured radiation characteristics are acceptable for practical laptop computer applications.

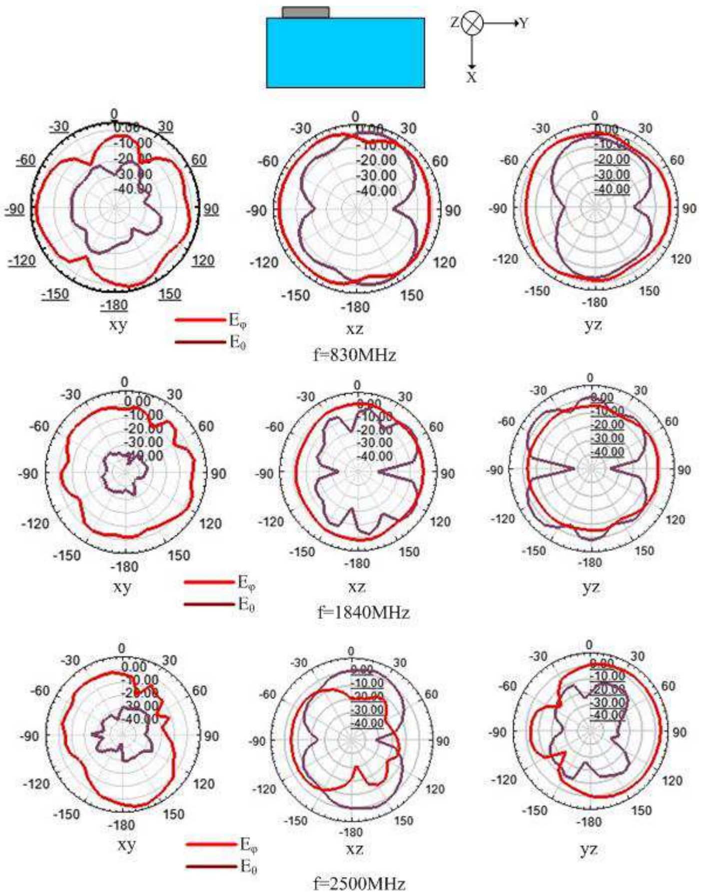

Figure 8. Measured radiation patterns for the proposed antenna.

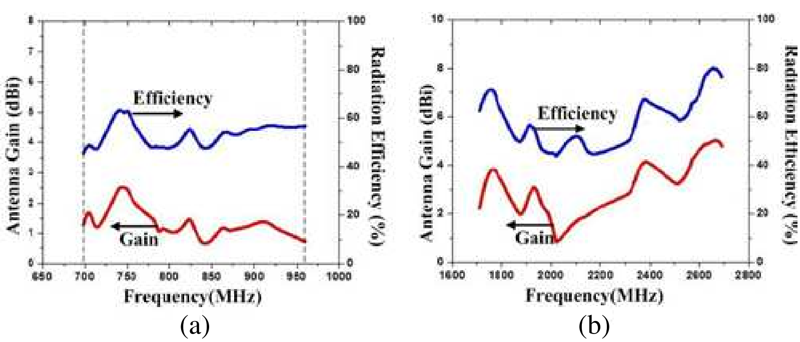

Figure 9. Measured radiation efficiency and antenna gain of the fabricated antenna.

4. CONCLUSIONS

A new structure of coupled-fed loop antenna connected with two branch radiators for eight-band LTE/WWAN operation in the ultra-thin laptop computer is presented. This antenna is flexible in tuning bandwidths and capable of good omni-directional coverage and high radiation efficiencies throughout those bands. A detailed description of the operating principle of the proposed antenna in exciting the resonant modes for the desired eight-band operation has also been provided. In addition, compared with previous designs, the proposed antenna is both compact and wideband, which is suitable to be installed within the ultra-thin laptop computer as an internal antenna.

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