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Two-Strip Narrow-Frame Monopole Antenna with a Capacitor Loaded for Hepta-Band Smartphone Applications

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Abstract—A two-strip narrow-frame monopole antenna for hepta-band WWAN/LTE smartphone applications is proposed. The brightest point of the proposed antenna is that its narrow edge has a width of only 5 mm, which is very practical for current smartphone applications with larger touch-screens. In addition, the proposed narrow-frame antenna has a small volume of $60 \times 5 \times 5\,\mathrm{mm}^3$ and a simple structure, which comprises of a two-strip monopole loaded with a chip capacitor and an L-shape high-pass filter. Meanwhile, the propose antenna can cover the GSM850/900/1800/1900/UMTS2100/LTE2300/2500 bands. Finally, the operating principle of the proposed antenna is investigated and both simulated and measured results are presented and discussed.

1. INTRODUCTION

For smartphone applications, larger touch-screens with narrower frames are desired for the appearance design as well as user experiences. Thus, besides the fundamental demands of the multi-band operation, the smartphone antenna should also be small-size and narrow-frame, leaving more space for other modules such as the touch-screen.

Until now, various types of technologies [1–20] have been proposed for multi-band smartphone applications, such as loaded lumped chip elements [4, 5], distributed inductive strips [6, 7], coupled-fed feeding [8–13], LC matching circuits [14–16], parallel resonant structures [17, 18] and reconfigurable antennas [4, 19, 20]. All these technologies can reduce the sizes of the antennas and enhance the operating bandwidth. However, most of these antennas occupy too large sizes of the PCB with an edge of more than 10 mm, which can hardly meet the requirements of the narrow-frame antennas of 5 mm for WWAN/LTE smartphone applications. Note that the troubles in the multi-band narrow-frame antenna for smartphone applications in a limited space occur not only for the lower-band but also for the upper-band.

In this paper, a two-strip narrow-frame antenna for hepta-band WWAN/LTE smartphone applications is proposed and studied. The proposed antenna has typical advantages of a narrow frame of only 5 mm and a simple two-strip structure, which are quite practical for the narrow-frame smartphone applications. Besides, by employing a loaded chip capacitor and an L-shape high-pass filter, the obtained bandwidth are much broadened for both the upper-band and the lower-band, covering the operating bands of 824–960 and 1710–2690 MHz. The operating principles of the proposed antenna will be investigated and illustrated, while both simulated and measured results will be given in the next several sections.

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2. PROPOSED ANTENNA CONFIGURATION

Figure 1 shows detailed geometry of the proposed two-strip narrow-frame monopole antenna, which is located on the bottom edge of the FR4 printed circuit board and occupies a small volume of $60 \times 5 \times 5\,\text{mm}^3$ of no-ground area. On the back side of the FR4 printed circuit board is a ground plane with a size of $105 \times 60\,\text{mm}^2$. A 50-Ω mini coaxial feed line is employed to excite the antenna, which is connected to the feeding point (point A) and the shorting point (point C). In the study, a 1-mm thick plastic slab of relative permittivity 3.0 and conductivity 0.02 S/m is also employed to build a plastic housing, which encloses the antenna and the system circuit board to simulate the handset housing in practical applications.

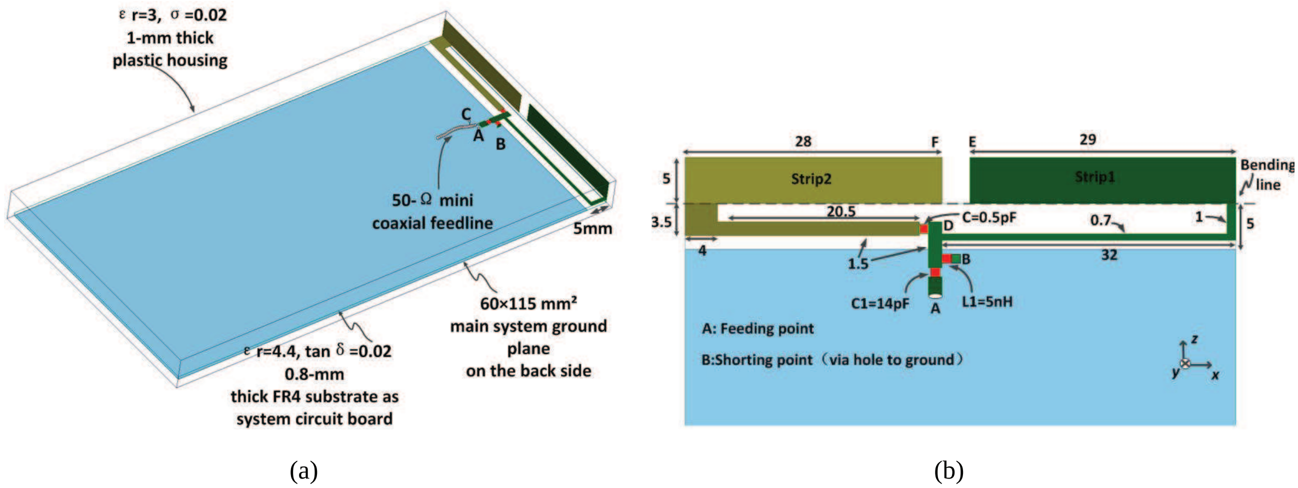

Figure 1. Proposed antenna configuration. (a) Geometry of the proposed antenna for WWAN/LTE smartphone applications. (b) Detailed dimensions of the proposed antenna (unit: mm).

The proposed antenna mainly comprises of two strips of close length, namely strip 1 and strip 2 with a loaded chip capacitor. The strip 1 is designed to generate a 0.44-wavelength resonant mode at about 2200 MHz with a length of about 65 mm, which just covers the operating bands of UMTS/LTE2300/2500. However, the strip 1 and the strip 2 are of close length, leading to quite near resonant mode, which fails to widen the bandwidth for the upper-band. To solve this trouble, a chip capacitor of 0.5 pF is loaded in the strip 2, which generates the other upper-frequency resonant mode different from the upper-frequency resonant mode contributed by the strip 1. Thus, with the help of the loaded chip capacitor, the operating bands of GSM1800/1900/UMTS/LTE2300/2500 is covered.

In addition, the strip 1 also generates a resonant mode at about 1050 MHz, which is not quite ideal to cover the operating bands of GSM850/900. Besides, due to the extremely narrow frame and the small size, the bandwidth can hardly be wide enough to meet the operating demands for the lower-band. Therefore, an L-shape high-pass filter with a series capacitor of 14 pF and a shunt inductor of 5 nH is incorporated, which generates one lower-frequency resonant mode at about 880 MHz to successfully cover the operating bands of GSM850/900, and simultaneously contributes another upper-frequency resonant mode at about 2500 MHz for the upper-band. Consequently, the proposed narrow-frame antenna has finally covered the GSM850/900/1800/1900/UMTS/LTE2300/2500 operation.

3. RESULTS AND DISCUSSION

The proposed small-size narrow-frame hepta-band antenna was successfully fabricated and tested, as shown in Figure 2. The simulated results are obtained by Ansoft HFSS version 13, while the measured results are tested by using an Agilent N5247A vector network analyzer. The measured and simulated return losses for the prototype are presented in Figure 3 with good agreement for the lower-band. The differences for the upper-band are mainly due to the accuracy in fabrication. The measured impedance

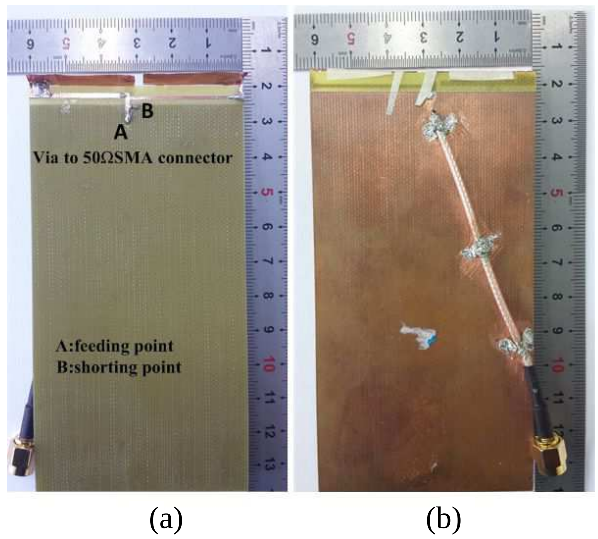

Figure 2. Photos of the manufactured antenna for hepta-band LTE/WWAN operation in the internal mobile phone. (a) Front view. (b) Back view.

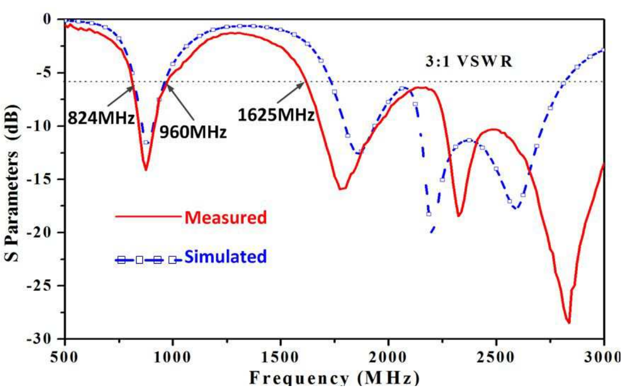

Figure 3. Simulated and measured reflection coefficient against frequency for the proposed antenna.

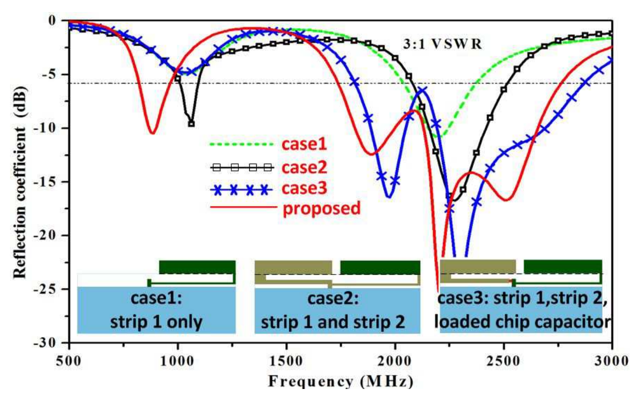

Figure 4. Simulated reflection coefficient for the referred and proposed antennas.

matching bandwidth based on 3 : 1 VSWR, which is generally accepted as the design specification of the internal WWAN handset antennas, is seen to cover the desired 824–960 and 1710–2690 MHz bands for the hepta-band WWAN/LTE operations.

To make a thorough analysis of the operating principle of the proposed antenna, three references are employed to compare with the proposed antenna. Figure 4 shows the simulated return loss of the proposed antenna and the selected three references, namely the reference with strip 1 only (case 1), the reference with strip 1 and strip 2 (case 2), the reference with strip 1, strip 2 and the loaded chip capacitor (case 3). The geometries of the last three cases are also given in the figure, and all the corresponding dimensions are the same as the proposed antenna. For the referred case1 (with strip 1 only), the strip 1 generates one lower-frequency resonant mode and one upper-frequency resonant mode. However, the impedance matching is quite poor. Compared to the case1, the referred case 2 (with strip 1 and strip 2) has a better impedance matching for the upper-band. In spite of this, the bandwidth fails to cover the desired operating bands for the upper-band. Thus, a chip capacitor is employed to improve the impedance matching for the case 3 (with strip 1, strip 2 and the loaded chip capacitor), which generates the other upper-frequency resonant mode, covering the GSM1800/1900/UMTS/LTE2300/2500 operation. Nevertheless, the impedance matching for the lower-

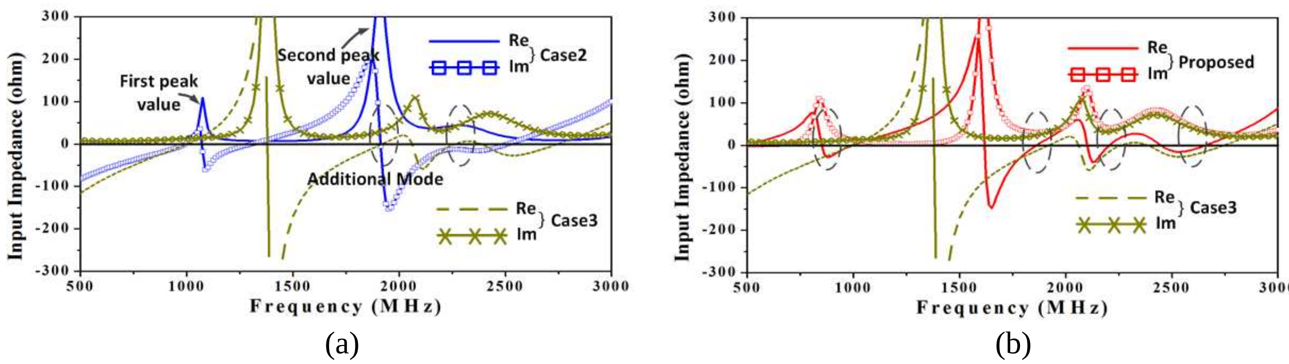

Figure 5. Simulated input impedance of the referred antennas and the proposed antenna. (a) Case 2 and case 3. (b) Case 3 and the proposed antenna.

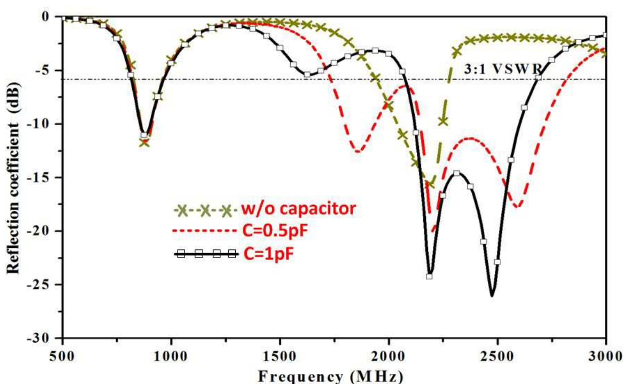

Figure 6. Simulated reflection coefficient with different values C of the loaded chip capacitor.

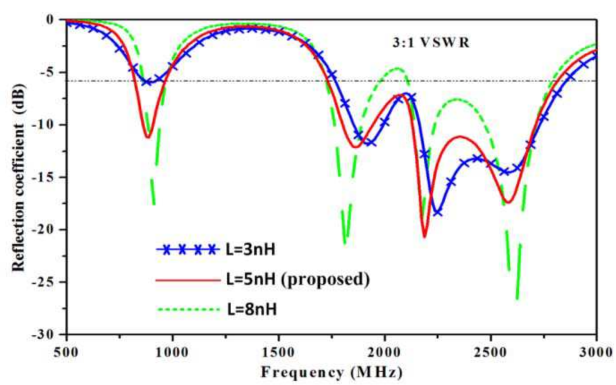

Figure 7. Simulated reflection coefficient with different values of the shunt inductor when the value of the series capacitor is fixed as 14 pF.

band is still poor. Accordingly, an L-shape high-pass filter is incorporated to generate one lower-frequency resonant mode to cover the GSM850/900 bands, while contributes another upper-frequency resonant mode at about 2500 MHz. Finally, the bandwidth of the proposed narrow-frame antenna is wide enough to cover GSM850/900/1800/1900/UMTS/LTE2300/2500 bands.

As the forementioned discussions, the loaded chip capacitor and the L-shape high-pass filter play vital roles on the impedance matching for the upper-band and the lower-band, respectively. Furthermore, to investigate the principle of the loaded chip capacitor and the L-shape high-pass filter, the simulated input impedances of the referred antennas and the proposed antenna are shown in Figure 5, respectively. As shown in Figure 5(a), compared to the case 2, the points of peak values of the case 3 are shifted to higher frequencies, which are shifted from about 1070 MHz to 1380 MHz for the first peak value and from about 1900 MHz to 2075 MHz for the second peak valuerespectively. In addition, the second shifted peak value also reduces the real part nearly to $50\,\Omega$ in desired bands and generates one higher-frequency resonant mode at about 1970 MHz. As shown in Figure 5(b), for the lower-band, by incorporating the L-shape high-pass filter, both the real part and the imaginary part are pulled up to generate one lower-frequency resonant mode at about 880 MHz, which can cover the operating bands of GSM850/900. Therefore, the fine design of the loaded chip capacitor and the L-shape high-pass filter can greatly improve the impedance matching of the upper-band and the lower-band, finally covering the GSM850/900/1800/1900/UMTS/LTE2300/2500 bands.

Furthermore, the loaded capacitor is further parametrically investigated. The simulated return losses with different values C of the loaded chip capacitor are shown in Figure 6. Large effects on the impedance matching over the upper-band can be seen when the value C varied from 0 to 1 pF, while the effects over the lower-band can be ignored. So the performance of the antenna can be optimized by adjusting the value of the loaded chip capacitor. In this study, the value of the loaded chip capacitor is chosen as 0.5 pF.

In addition, the main role of the L-shape high-pass filter comprised of a shunt inductor and a series capacitor is to contribute a lower-frequency resonant mode at about 880 MHz. Compared with the series capacitor, the shunt inductor determines greater influence on the impedance matching. Simulated return losses with different values of the shunt inductor with a fixed value of the series capacitor as 14 pF are shown in Figure 7. When the value of the shunt inductor is 3 nH, the bandwidth for the upper-band is better, however, the impedance matching for the lower-band is unacceptable. When the value of the shunt inductor is 8 nH, the impedance matching for the lower-band is better yet not desirable for the upper-band. Thus, based on the impedance matching for both the upper-band and the lower-band, the values of the shunt inductor and the series capacitor can be optimized as 5 nH and 14 pF, respectively.

The radiation characteristics of the proposed antenna are also measured in SATIMO anechoic chamber. The measured radiation patterns at 900, 1920, and 2560 MHz are depicted in Figure 8, respectively. As seen in Figure 8, smooth variations in the xy-plane at 900 MHz as well as yz-plane at 1920 and 2560 MHz are obtained, which can provide good coverage in the corresponding planes. Several nulls specially at high frequency are mainly owing to the higher-order resonant modes, which

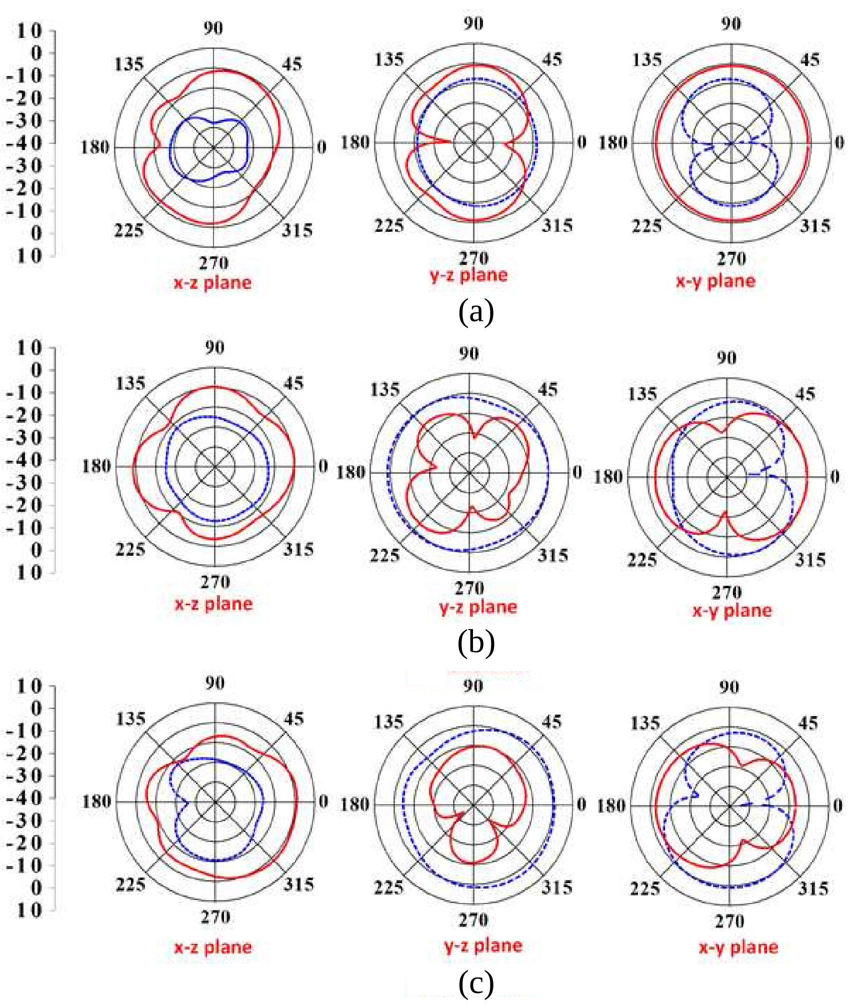

Figure 8. Measured 2-D radiation patterns (dotted line is E_φ, solid line is E_θ, unit: dBi). (a) 900 MHz. (b) 1920 MHz. (c) 2560 MHz for the proposed antenna.

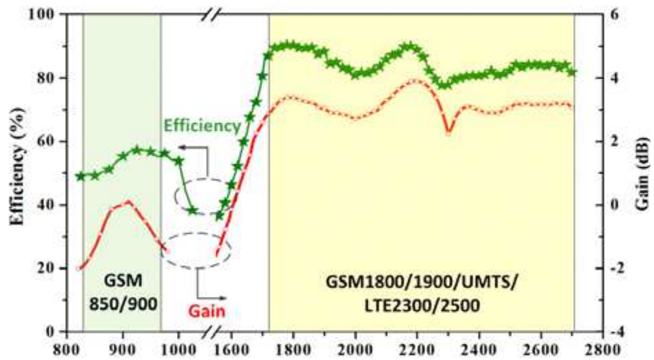

Figure 9. Measured radiation efficiencies and gains over the operating bands for the proposed antenna.

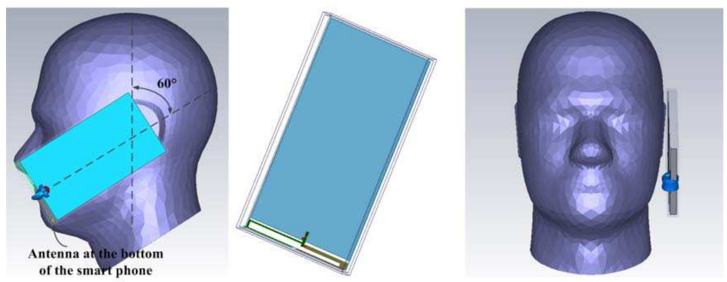

Figure 10. SAR simulation model of the proposed narrow-frame antenna.

are contributed by the ground relative longer than half wave-length. However, the antenna can be useful for real LTE communication environments. General speaking, the real LTE communication environments have many obstacles. Then the reflection, scattering, and diffraction for the transmitting wave will occur and its polarization will often change. For the terminal received wave transmitted by the base station, the two components of E_θ and E_φ have the relative same levels. Although the patterns of the proposed antenna shown in Figure 8 have many nulls, there are some obvious rules that the two components of E_θ and E_φ will not appear to be nulls at the same orientation angle. For example, in the case of the xy-plane pattern at 2650 MHz in Figure 8(c), at $\varphi = 0°$ and 160°, the E_φ components are both nulls and the E_θ components are not nulls; at $\varphi = 70°$ and 300°, the E_θ components are both nulls and the E_φ components are not nulls. This complementary patterns of the terminal antenna guarantee the robustness for the real LTE communication environments.

The measured radiation efficiencies and gains of the proposed small-size narrow-frame hepta-band antenna are shown in Figure 9. For the lower-band of GSM850/900 (824–960 MHz), the measured gains vary from about −2.1 dBi to 0.01 dBi and the efficiencies are over 50%, which are acceptable for practical applications. For the upper-band of GSM1800/1900/UMTS/LTE2300/2500 (1710–2690 MHz), the measured gains are 2.24∼3.91 dBi, while the corresponding efficiencies are larger than 77%. Hence, the measured efficiencies and gains of the proposed antenna meet the requirement for smartphone applications over desired operating bands.

Figure 10 shows the model for SAR simulation and Table 1 shows the corresponding simulated SAR values for 1-g head tissues, which is provided by CST version 2012. In the process of simulation, the system circuit board is enclosed by a 1-mm thick plastic housing, which is placed close to the head phantom ear and inclined to the vertical line by a degree of 60°. The obtained 1-g SAR values as well as the corresponding return losses at 859, 925, 1795, 1920, 2045, 2350 and 2595 MHz are shown in Table 1. The input power for the SAR simulation is 24 dBm (0.25 W) for 859 and 925 MHz, and 21 dBm (0.125 W) for 1795, 1920, 2045, 2350 and 2595 MHz. The achieved SAR values for the proposed antenna are all below the SAR limit of 1.6 W/Kg for 1-g tissue, which indicates that the proposed antenna is quite suitable for practical smart phone applications.

Table 1. Simulated SAR values for 1-g head tissues.

Frequency (MHz)	859	925	1795	1920	2045	2350	2595
1-g SAR (W/Kg)	0.601	1.17	0.833	0.882	0.828	0.333	0.311
Input power (Watt in dBm)	24	24	21	21	21	21	21
Return loss (dB)	14.0	8.1	9.7	9.4	8.0	9.6	14.0

4. CONCLUSION

A two-strip narrow-frame antenna for hepta-band WWAN/LTE smartphone applications is proposed and studied. By employing a loaded chip capacitor and an L-shape high-pass filter, the proposed antenna successfully covers the desired GSM850/900/1800/1900/UMTS/LTE2300/2500 operation. The achieved measured results including return loss, radiation efficiency and gains are presented, which satisfy the requirements for mobile systems. The biggest highlight of the proposed antenna is that the edge of the no-ground area to support the antenna is quite narrow, which is only 5 mm and exactly promising for the narrow-frame smartphone applications. In addition, the structure of the proposed antenna is really simple, which will bring great conveniences and reduce the production costs for practical applications.

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