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A Tunable Multiband LTE Antenna for Metal-Rimmed Smartphone Applications

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Abstract—In this paper, a tunable multiband LTE antenna is designed for metal-rimmed smartphone applications. The antenna only uses a broken metal ring, which comprises an IFA (Inverted-F antenna) section and a parasitic section, and generates three resonant modes through this layout for the feeding point and shorting point. In addition, loading a matching circuit at the feeding point and a RF switch at shorting point of the IFA is used to switch low frequency to lower frequency. The bandwidth can completely cover 824–960 and 1710–2690 MHz. So the proposed antenna can work at GSM850, 900; DCS1800; PCS1900; WCDMA band 1, 2, 4, 5, 8; TD-SCDMA band 34, 39; CDMA BC0, BC1 and LTE band 1, 3, 7, 38, 39, 40, 41. Also, the total size of the cellphone is 150 mm × 75 mm × 3.5 mm, which is very suitable for 4G slim smart mobile phone applications.

1. INTRODUCTION

With the popularity of 4G network, mobile antenna design is facing more and more challenges such as multiband, wide bandwidth, small size, low cost and easy manufacture. Furthermore, a smartphone with a metal rim has become an obvious trend. The metal rim can not only provide sufficient mechanical strength to extend the service life of the smartphone, but also possess a wonderful appearance, which is very desirable for consumers. However, this increases difficulties for antenna designers.

Conventional antenna design methods including patch antenna, PIFA antenna [1] and loop antenna [2], even slot antenna [3] were studied to apply in these metal environments. Recently, several promising solutions [4, 5] have been demonstrated which can resolve the effects of metal rim. In [4], the author inserted three gaps and two grounded patches and chose the locations of the gaps and the grounded patches, which can alleviate the effects of the metal rim. A compact slot antenna of 15.5 × 56.5 mm by adding several grounded patches between the bottom system ground and the unbroken metal rim is proposed in [5]. The antenna can cover GSM850/900/DCS/PCS/UMTS2100 operation. However, its biggest drawbacks of the antennas are narrowband and too much space of the PCB (clearance area) occupied. Furthermore, because the space left for antenna is getting smaller and smaller, several scholars proposed using impedance matching circuit at feeding port to obtain broadband coverage [6–9]. RF switch is also used to design a reconfigurable antenna to achieve a wideband by combing several different statuses. In [10–12], a RF switch was used to change the antenna's resonant length, so the antenna can work at different frequencies by changing the switch's status. All these methods can provide a thought for our design. But if the RF switch is in series or u over two switches are used in the antenna like the references, this may cause too much loss, so a different connection method is proposed in this paper.

In this paper, a tunable multiband LTE antenna for metal-rimmed smartphone applications is presented. The antenna uses only a metal rim without any other structures. Due to the usage of

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matching circuit at the feeding point and RF switch at the shorting point, the proposed antenna can completely cover 824–960 and 1710–2690 MHz. Details of the antenna design are presented, and return loss, bandwidth, efficiency of the antenna are studied in this paper.

2. ANTENNA CONFIGURATION AND DESIGN

The basic geometry of the proposed antenna is shown in Fig. 1, and (a) shows the front view while (b) shows the side view. In this paper, a 0.8 mm thick FR4 substrate of relative permittivity 4.4 and loss tangent 0.024 is used as the system circuit board. On both sides of the FR4 substrate, a ground plane of length 126 mm and width 60 mm is printed to serve as system ground plane of the mobile phone. The whole clearance area with no ground is 10 mm $\times$ 75 mm. The outer metal rim is connected to the system ground with metal domes except for a length of 47 mm broken metal ring, and the open slots are with a width of 1 mm. In order to better simulate the real environment, a speaker and USB connector are laid out at the left and middle of the metal rim, respectively. A 0.5 mm thickness LCD screen and touch panel is also put under the main board. All these devices are connected to the system ground in order to avoid EMI (Electro-Magnetic Interference) problem.

Figure 2 shows a schematic diagram of the proposed antenna. Due to the matching circuit at the feeding point, the proposed antenna can achieve a very wide bandwidth, larger than 1 GHz, to cover the desired operating band of 1710–2690 MHz. Here a 0.7 pF capacitor is shunted, and a 2.2 nH inductor is in series, which is a low pass circuit for high-band impedance match and has little influence on the low band.

As can be seen, a SP4T is placed at the shorting point in Fig. 2, which is an active RF switch used to tuning the low band to cover GSM 850 MHz. This kind of RF switches, such as RFMD 1119A,

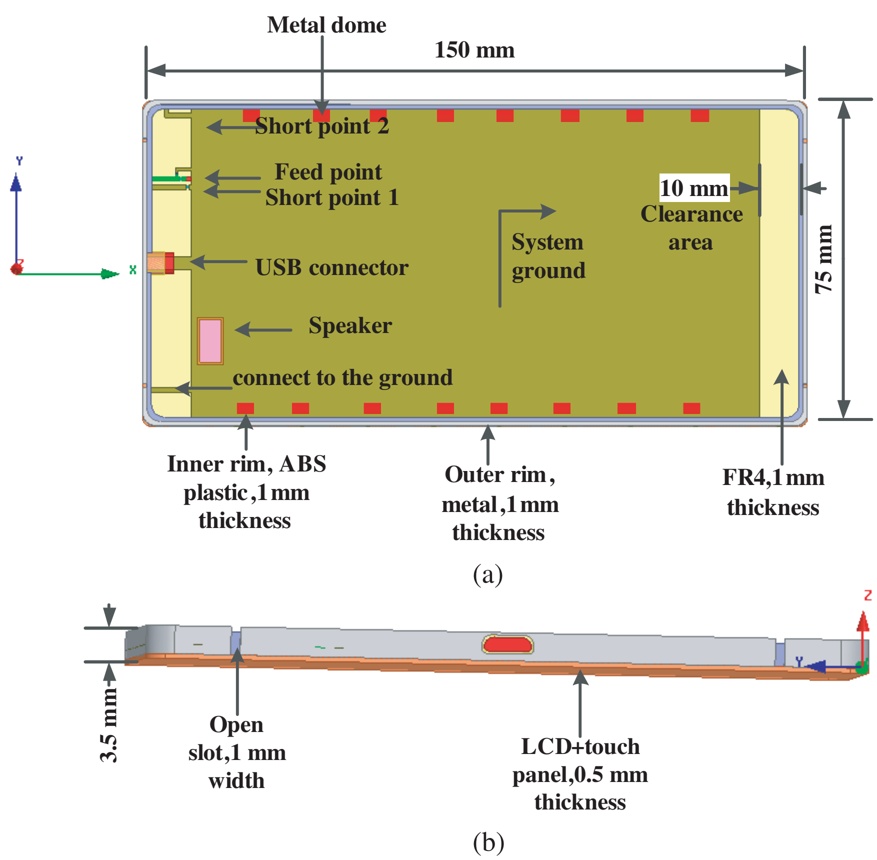


Figure 1. Geometry of proposed tunable multiband LTE antenna for metal-rimmed smartphone applications. (a) Front view, and (b) side view.

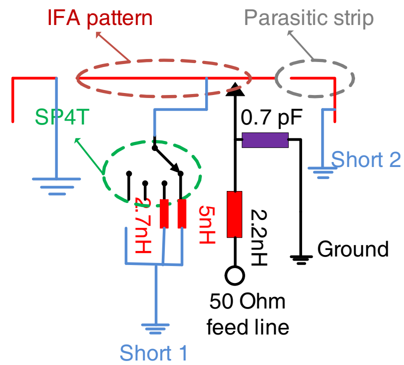


Figure 2. The schematic diagram of the proposed antenna.

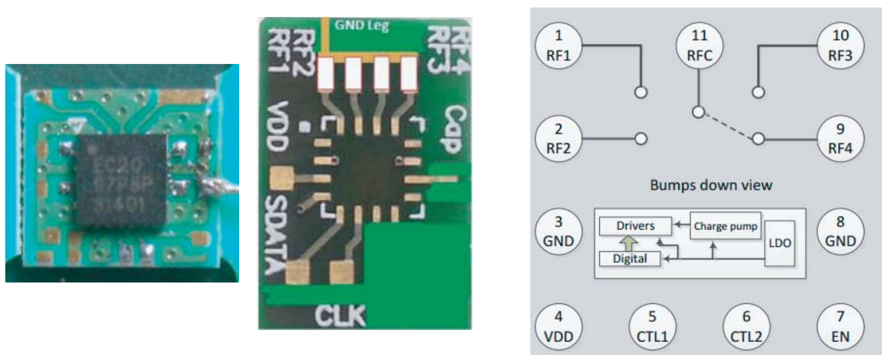


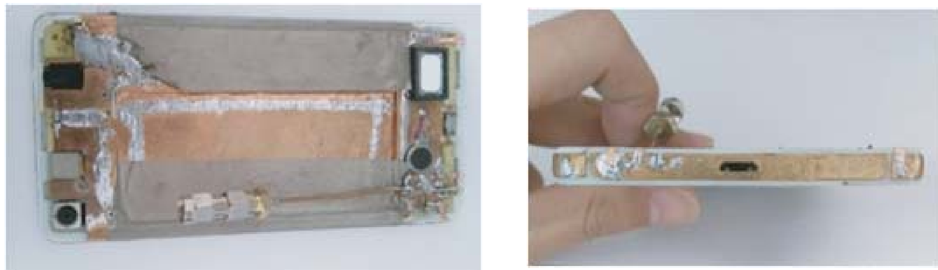
Figure 3. Pictures and functional schematic of RF switches.

Ethertronics EC 723 and EC 949, shown in Fig. 3, have been widely used in antenna design. The function of switch is simulated, and passive results are achieved in this paper. 5 nH and 2.7 nH inductors are in series at the shorting point respectively, which can be selected by the SP4T automatically. The antenna can work at 824–894 MHz when the 5 nH inductor (state1) is selected by the switch, and when the 2.7 nH inductor (state2) is connected, the low frequency can cover 880–960 MHz. According to the resonance theory, the equivalent inductance L increases when an inductor is in series, so the resonant frequency f will be lower, which is equivalent to stretching the length of the antenna. All these demonstrate that the proposed antenna can be reconfigurable at low frequency.

3. RESULTS AND DISCUSSION

Photos of the fabricated antenna are shown in Fig. 4. To test the antenna, a short 50 Ohm cable with a SMA connector is connected to the feeding point, and 0402 lumped elements are used for impedance matching and analog function of the RF switch. Results of the measured and simulated S_{11} for the fabricated antenna are presented in Fig. 5. The simulated results are obtained using Ansoft simulation software high frequency structure simulator (HFSS), and the measured results are obtained using Agilent 5071C. Reasonable agreement between the simulation and measurement is observed, and two separate wideband widths are obtained. The bandwidth of the lower band, determined by 3 : 1 VSWR or -6 dB S_{11}, covers 824–960 MHz due to the two states while the upper band covers 1710–2690 MHz due to a low-pass impedance matching circuit. The proposed antenna generates three resonant modes, and the low frequency and intermediates frequency are generated by IFA section, which are basic mode and the second harmonic respectively, while the high frequency is generated by parasitic section.

In order to achieve a wide band at low frequency, a RF switch (SP4T) is used. For state1, a 5 nH inductor is connected to the shorting point. The obtained input impedance is better than 3 : 1 VSWR or S_{11} less than -6 dB, which can cover 824–894 and 1710–2690 MHz. On the other hand, the RF



(a) (b)

Figure 4. Fabricated prototype of the proposed antenna. (a) Front view, and (b) side view.

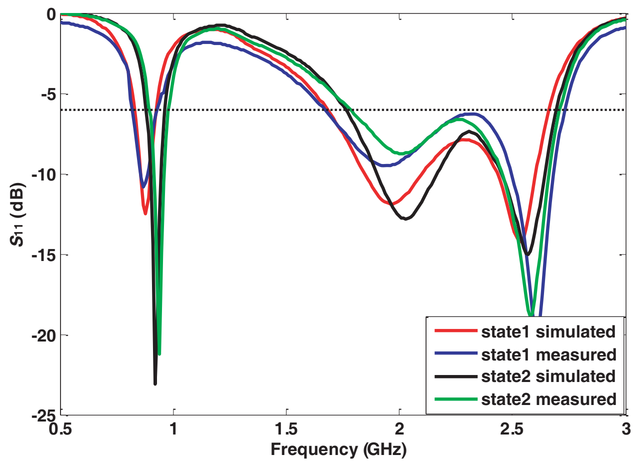
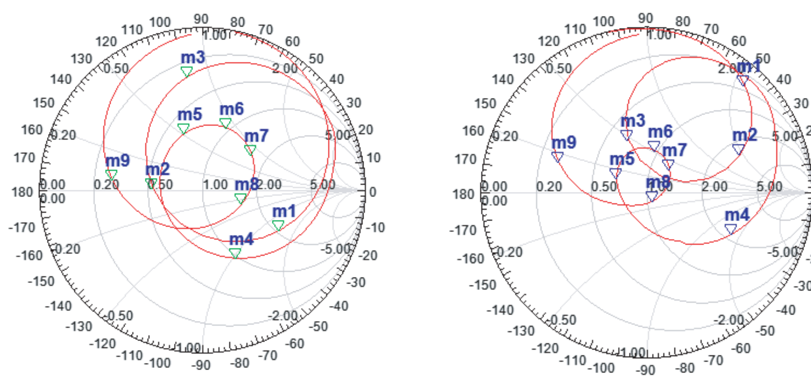


Figure 5. Simulated and measured S_{11} of the proposed antenna.

Name	Freq (GHz)
m1	0.824
m2	0.894
m3	0.96
m4	1.71
m5	2.17
m6	2.3
m7	2.4
m8	2.496
m9	2.69



state 1 **state 2**

Figure 6. Simulated state1 and state2 Smith chart of the proposed antenna.

switch changes to another state (state2), when a 2.7 nH inductor is connected to the shorting point. In this state, a higher frequency (880–960 MHz) can be achieved. Due to the two states, the proposed antenna can cover GSM850, 900; DCS1800; PCS1900; WCDMA band 1, 2, 4, 5, 8; TD-SCDMA band 34, 39; CDMABC0, BC1 and LTE band 1, 3, 7, 38, 39, 40, 41, which is very suitable for LTE smart phone applications.

Figure 6 shows the simulated Smith chart of state1 and state2. It is clear that the entire bands have good impedance in state1. However, the points of low frequency and intermediate frequency rotate along the impedance circle diagram counterclockwise to the capacitance area. This is because when the value of the inductor decreases, the inductance weakens, or the capacitance increases. This change also demonstrates that the low frequency and intermediate frequency are generated by IFA section, while the high frequency has almost no change when the RF switch changes states.

To study whether the USB connector, touch panel and LCD have impacts on the proposed antenna, we simulate the model without USB connector, touch panel and LCD, respectively, and then compare with the proposed antenna. Fig. 7 shows the results that the USB connector has almost no influence on the antenna. This is because the USB is connected to the system ground to avoid EMI problems. However, when removing the touch panel and LCD, the whole frequency moves to higher frequency. This is due to the change of equivalent dielectric constant. How the RF switch works is also shown in Fig. 8. The results demonstrate that when an inductor is in series, the frequency moves to lower frequency while series an capacitor, the frequency moves to higher frequency. According to the resonance theory, series an inductor or a capacitor is equivalent to changing the length of the antenna. Another phenomenon can be seen that when changing different LC elements, only the low and intermediate resonant frequency change and almost no influence on high resonant frequency. This demonstrates that the IFA section generates two resonant modes, one at the low frequency, and the other at the intermediate frequency, which is an octave of the low frequency.

The efficiency of the fabricated antenna is measured in Satimostargate 24 chamber, and the measured results for the combined two states are presented in Fig. 9. The measured radiation efficiency is about 32–44% and 40–75% for frequencies over the lower band and upper band, respectively.

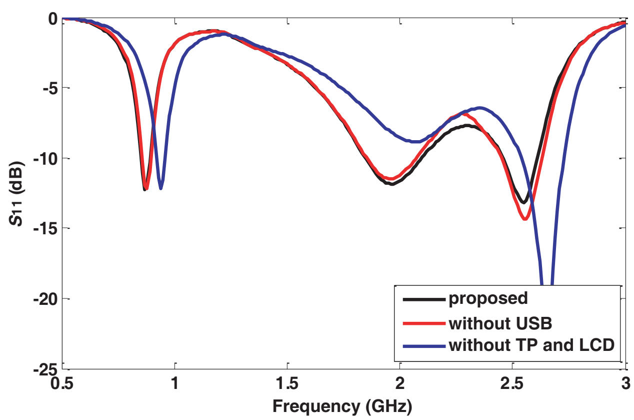


Figure 7. The influence of USB, TP and LCD on the proposed antenna.

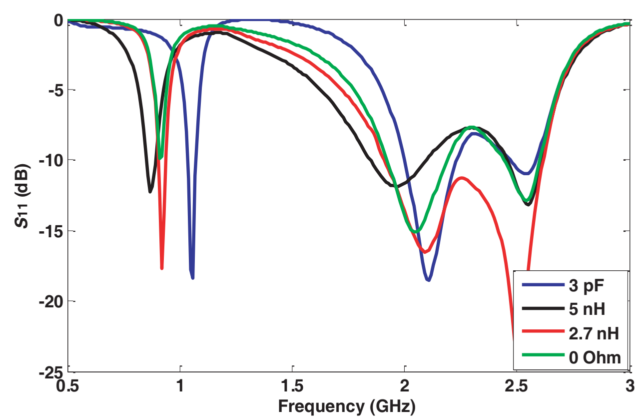


Figure 8. The influence of RF switch on the proposed antenna.

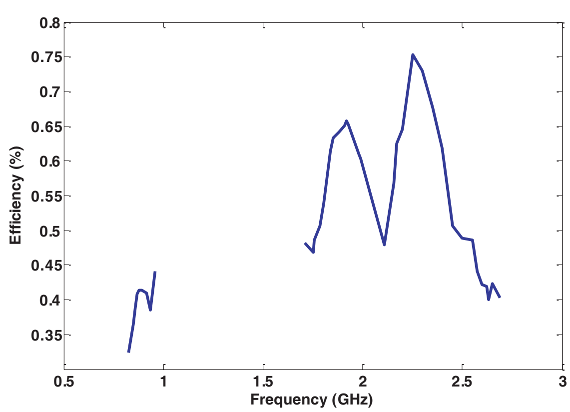


Figure 9. Measured radiation efficiency for the fabricated antenna.

4. CONCLUSION

In this paper, a tunable multiband LTE antenna for metal-rimmed smartphone applications is presented. The antenna uses only a metal rim without any other structures. Due to the usage of matching circuit at feeding point and RF switch at shorting point, the proposed antenna can completely cover 824–960 and 1710–2690 MHz. The proposed antenna can work at GSM850, 900; PCS1800; DCS1900; WCDMA band 1, 2, 4, 5, 8; TD-SCDMA band 34, 39; CDMA BC0, BC1 and LTE band 1, 3, 7, 38, 39, 40, 41. Also, the total size of the cellphone is 150 mm × 75 mm × 3.5 mm, which is very suitable for 4G slim smart mobile phone applications.

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