Design of small-size nine-band LTE/WWAN smartphone antenna using defected ground structure

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Abstract. A novel small-size LTE/WWAN smartphone antenna for multi-band operation is proposed and investigated. Defected ground structure (DGS) is used in this antenna. The antenna structure is simple, compact and only occupied a small space of 15 × 28 mm². It operates over the frequency ranges, 0.8-0.97 GHz, 1.55-2.84 GHz and 3.22-3.65 GHz, and suitable for GNSS/2G/3G/4G/5G (VSWR < 3) mobile phone applications. The antenna consists of dual L-shaped strips, an inverted S-shaped strip and a bent coupled-fed strip. In the meantime the ground is grooved, which changes the distribution current of the antenna, greatly improves the complete coverage of the whole-band, and obviously improves the low-band (824-960 MHz) impedance matching. It is particularly worth mentioning that the coupled-fed strip can provide a 0.2λ resonant mode at 880 MHz which was the usual mobile phone antenna does not have. In addition, detailed simulation, experimental measurement and parametric analysis are presented.

1. Introduction
In recent years, with the rapid development of the mobile communication technology, especially since the GHz era, the users put forward higher requirements to 4G mobile business. To meet the needs of users, the multiband antennas to cover the current 4G and future 5G standards is needed [1-3]. The current communication bands mainly include GSM850/900/DCS1800/PCS1900/UMTS2100 and LTE2300/2500/3500 bands [4]. LTE technology include LTE2300/2500 have great advantage in high-speed data transmission, which has been selected as the communication band of China's fourth generation mobile communication system. And LTE 3500 is an important selectable communication band for China's future fifth generation mobile communication system [1-2]. Additionally, mobile-phone antennas are also required to be compact and low profile [5-6]. However, reduce the size of the antenna will cause the Q value larger, the bandwidth of the antenna narrower and cannot meet the requirements of the multi-band. Therefore, taking into account the future 5G communication band requirements, designing a small-size mobile phone antenna with multi-band and broadband has important application value and great challenge.
Figure 1. (a) Geometry of the proposed antenna for nine-band WWAN/LTE operation in the internal mobile phone. (b) Dimensions of the metal pattern of the antenna. (c) shows the system ground plane’s configuration (unit: mm).

In order to achieve miniaturization and multi-band coverage of the antenna, the antenna engineers put forward a lot of key technologies. The antennas in [7-10] designed by loading the lumped element achieve the coverage of eight bands including LTE700, but the antenna size is larger than 15 × 35 mm². In [11-12] Chen et al. and Ban et al. using reconfigurable technology can reduce the size of the antenna, but the antenna is designed with 3D structure, which is not conducive to ultra-thin
smartphone applications. To this end Chang et al. and Ban et al. [13-15] have designed several planar antennas by loading the printed distributed inductor technology. Among them, Chang et al. [13] earlier proposes the printed distributed inductor antenna that works in the WWAN band, but the antenna can’t meet the current multi-band and miniaturization requirements. While Ban et al. [14-15] improve the antenna’s structure and achieve miniaturization, but these two antenas can only cover seven-band WWAN/LTE (five WWAN bands of GSM850/900/1800/1900/UMTS2100 and two LTE bands of LTE2300/2500) operation. After that, Xu et al. [16] successful designs a high-performance small-size (11×30×5 mm$^3$) mobile phone antenna through coupled-fed technology, which covers eight bands including the GNSS band, but the antenna’s height is up to 5mm. Moreover, all the above antennas do not cover the future 5G communication band. For this reason Wu et al. [1] designed a LTE/WWAN mobile phone antenna, which includes a possible band for future 5G communication, but the antenna size is relatively large, and it's space is up to 5 × 8 × 60mm$^3$.

In this paper, a small-size nine-band LTE/WWAN smartphone antenna is proposed, in which the feeding part is composed of a double L-shaped feeding strips and an inverted S-shaped feeding strip. The coupled-fed strip is composed of a bending short strip and two upright parasitic strip. In addition, unlike the conventional coupled-fed antenna prototype using a relatively intact ground plane, in this design the ground was cut out by shaped slots and thus forms a DGS. The purpose is to changing the current distribution of the system ground plane and improve the impedance matching of the desired band, then WWAN (GSM850/900/1800/1900/UMTS2100), GNSS (COMPASS, GALILEO, GPS, GLONASS) and LTE (LTE 2300/2500/3500) bands are successfully covered.

![Figure 2. Photos of the manufactured antenna: (a) Front side, (b) Back side.](image)

2. Antenna configuration

Figure 1 (a) is the three-dimensional image of the proposed antenna’s geometry, figure 1 (b) is the detailed configuration of the antenna’s metal pattern (units are mm) and figure 1 (c) shows the system ground plane’s configuration. As can be seen from figure 1, the proposed antenna with a small-size of 15×28mm$^2$ is directly printed on the bottom corner of the FR4 substrate. This arrangement can lead to the decrease of the specific absorption rate (SAR) values and is attractive for practical applications. In this study, a 0.8-mm thick FR4 substrate with relative permittivity 4.4, loss tangent 0.02, and size 115×60 mm$^2$ is used as the system circuit board of the practical smartphone applications on the present market. The system ground plane is printed on the back of the FR4 substrate, which includes a clearance area of 15×30mm$^2$ and three rectangular slots as can be seen from figure 1(c). In addition, one end-portion (point A) of the feeding strip is the feeding point of the proposed antenna, which is excited by 50-Ω coaxial feed line. The end-portion (point B) of the coupling strip is directly connected to the main ground plane through a via-hole in the system circuit board. And the proposed antenna was successfully fabricated as shown in figure 2.
The antenna is composed of two parts: one part is the feeding strip connected with the 50 ohm feed port which includes the feeding strip 1, the feeding strip 2 and the feeding strip 3; the other part is the shorted strip directly connected to the ground plane which includes shorted strip CL, parasitic shorted strip 1 and parasitic shorted strip 2. Firstly, the feeding strip can produce two high-frequency resonant modes at about 2300 MHz and 3500 MHz, respectively. Secondly, a resonant mode at 880 MHz can be excited by the shorted strip whose length is about 70mm (about 0.2 times wavelength at 880 MHz). Finally, the proposed antenna altogether has nine resonant modes which can support the GSM850, GSM900, GNSS, DCS1800, PCS1900, UMTS2100, LTE2300, LTE2500, and LTE3500 systems.

3. Experiment results and discussion
In this part, simulated and measured results of the proposed antenna are presented. The simulated results are obtained by Ansoft HFSS ver. 17, and the measured results are tested by an Agilent N5230C vector network analyzer. The results of S-parameter showed in figure 3 indicate a good agreement between simulation and measurement. In the design, 3:1 VSWR is used as the specification of the impedance matching bandwidth. As shown in figure 3, there are four resonant frequencies for...
the measured results. The measured lower band is 0.8–0.97 GHz and upper band is 1.55–2.84 GHz and 3.22–3.65 GHz, which can support GSM850, GSM900, DCS1800 and PCS1900 in the 2G communication standards, UMTS2100 in the 3G communication standards, and LTE2300, LTE2500 in the 4G communication standards and LTE3500 in the 5G communication standards. While in the high-band, the simulated result slightly differs from the measured result. This is mainly due to the tolerances of fabrication (processing precision and handmade reprocessing of PCB plate), measurement and the feeding cable effects.

**Figure 5.** Simulated surface current distributions on the printed metal strip for the proposed antenna at (a) 880 MHz (b) 1750 MHz (c) 2300 MHz (d) 3500 MHz.

**Figure 6.** Simulated input impedance in the Smith chart (a) Frequency range: 824-960 MHz. (b) Frequency range: 1710-3500 MHz. (red line for the proposed antenna, blue line for the Ref 2 antenna).

To analyze the operating principle of the antenna, three referenced antennas are selected to compare with the proposed antenna. As shown in figure 3 (b), the antenna used the close-coupled feeding, the feeding strip is not connected with the shorted strip, to realize power coupling through electromagnetic effect. The key feature of close-coupled feed is that it is essentially capacitive coupling mechanism, and direct contact method is mainly inductive. These capacitance and inductance characteristics make the close-coupled feed method can obtain a wider impedance bandwidth. As shown in figure 4 (a), three reference antennas, the case with Ref 1, Ref 2 and Ref 3, are selected to compare with the proposed antenna. For Ref 1 and Ref 2, only one and two wide resonant mode, centered at about 2250 MHz and 2350 MHz, 3250 MHz are generated respectively. It can be confirmed that the new added resonant mode at about 3250 MHz is contributed by Ref 2. And by adding a simple shorted strip to the feeding strip (see Ref 3 shown in the figure 4 (a), a resonant mode at about 880 MHz is excited. However, the Ref 3 can’t completely cover the low band (824 MHz-960 MHz) and the high-band LTE 3500 (3400 MHz-3600 MHz). In order to perfectly cover the whole
band, a complete antenna is provided using the defected ground structure based on the structure of Ref 3. Four resonances occur at 880, 1760, 2250, and 3400 MHz which leads to good excitation of the desired bands. Such situation can be easily explained from the simulated input impedance shown in figure 4 (b). As shown in figure 4 (b), no resonant modes be excited at about 880 MHz for lower band for Ref 1 and Ref 2. There are three resonances (zero reactance) occur at about 880, 2000 and 3250 MHz for Ref 3 by adding the simple shorting strip to Ref 2, and the input resistance at the two resonances is also increased to be close to 50. Meanwhile for the proposed antenna, owing to the use of the DGS, four resonances (zero reactance) occur at 880, 1760, 2250 and 3400 MHz. It hence leads to good excitation of the desired bands. From the above analysis, it can be well illustrated that the operating principle of the antenna.

![Diagram](image)

**Figure 7.** Measured 2-D radiation patterns at (a) 860 MHz (b) 1750 MHz (c) 2300 MHz for the fabricated antenna.

Current distribution is used to further study the principle of the antenna. Figure 6 shows the simulated current distributions for the antenna radiator at 880 MHz, 1750 MHz, 2300 MHz and 2500
MHz. As figure 5 (a) shows at 880 MHz, there are strong surface current distributed on the shorted strip accordingly, which indicates that the proposed antenna’s lower resonant modes are mainly contributed coupled-fed strip. From comparisons of current distributions of 1750 MHz, 2300 MHz and 3500 MHz, shown in figure 5 (b)-(d), respectively, it is obviously observed that strong currents are on the feeding strip. So the resonant mode at 1750 MHz, 2300 MHz and 3500 MHz is mainly contributed by the feeding strip. Notice that, since the proposed antenna is an entire structure formed by the feeding strip, the coupling strip, and the system ground plane of the mobile phone, the whole antenna configuration fabricates an effective radiating system to cover the desired operating bands of the 824-960 MHz, 1710-2690 MHz and 3400-3600 MHz.

The ground mode resonance controlling is demonstrated by the simulated input impedance in a Smith chart, as shown in figure 6, through whether there are slots on the ground. In the low-band (824-960 MHz), it can be seen from figure 6 (a) that the input impedance curve (in the circle) of the Ref 2 is less than that of the proposed antenna. Then, the input impedance curve is shifted toward the circle (VSWR=3:1) after the ground is slotted. Thus, the antenna achieves good impedance matching in the low frequency band. Similarly, in the high-band (1710-3500 MHz), figure 6 (b) shows that the input impedance curve is shifted toward the circle (VSWR=3:1), too. Therefore, the high-band (1710-3500 MHz) is covered.

![Image](image_url)

**Figure 8.** Measured antenna gain and radiation efficiency for the fabricated antenna.

The radiation characteristics of the proposed antenna are also measured in SATIMO anechoic chamber and studied in this section. Figure 7 plots the measured 2D radiation patterns at 880, 1750 and 2300 MHz, respectively. As shown in the figure, omnidirectional radiation in the xoy-, yoz- and xoz-planes is seen which is advantageous for practical smartphone applications, due to the complex wave propagation environment. While at 2300 MHz, the radiation patterns have some changes, mainly due to the high-order resonance. In fact, the ground of mobile phone system is an effective radiator in the low-band and a reflector in high-band, which has a greater influence on radiation characteristic of smartphone antenna.

Figure 8 shows the measured antenna gain and radiation efficiency. For the whole desired low-band (824-960 MHz), high-band (1710-2690 MHz) and LTE3500 (3400-3600 MHz), the measured antenna gain is about 0.5-3.5dBi, 2.0-5.1dBi and 0.4-2.3dBi, respectively. The measured radiation efficiency is about 46%-62%, 64%-84% and 37%-54%, respectively. The measured radiation characteristics of the proposed antenna are acceptable for practical internal mobile phone application.
4. Conclusions
A small-size nine-band LTE/WWAN smartphone antenna with defect ground structure is proposed in this paper. In the design, 3:1 VSWR is used as the specification of the impedance matching bandwidth. With the skills of defecting the ground plane, the proposed antenna can generate multiple resonant modes at lower and higher bands for support GSM850, GSM900, DCS1800 and PCS1900 in the 2G-standards, UMTS 2100 in the 3G-standards, and LTE 2300, LTE 2500, and LTE 3500 in the 4G and 5G standards. And the antenna only occupies a small size of 15×28mm$^2$, which realizes the demand of miniaturization and multi-band. In addition, the measure results including the return loss, radiation pattern, efficiency and gain also meet the actual needs. Therefore, the measured radiation characteristics suggest that the proposed antenna is suitable in practical mobile communication.

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