Small-size planar printed loop antenna for octa-band WWAN/LTE smartphone application

Yitao Song, Haomiao Zhou\(^1\) and Can Wang

College of Information Engineering, China Jiliang University, Hangzhou, 310018, P. R. China

\(^1\)E-mail: zhouhm@cjlu.edu.cn

Abstract. In this letter, a planar printed loop antenna which can cover eight bands of LTE (LTE2300/2500), WWAN (GSM850/900/DCS1800/PCS1900/UMTS2100) and LTE (LTE3500) in 5G communication is proposed for smartphone application. The antenna adopts the principle of coupled-fed, and its structure consists of a T-shaped feeding strip, a coupling bending shorted strip and a tuning line. To further attain good impedance matching for WWAN/LTE bands, a tuning line is used. In addition, the proposed antenna is very simple and compact, only occupying a size of 15×27 mm\(^2\), and the proposed antenna is very easy to be fabricated. Finally, from the measurement results, it shows over 40% of good antenna efficiencies in LTE/WWAN communication bands of 824MHz-960MHz, 1710MHz-2690MHz and 3300MHz-3600MHz.

1. Introduction

With the rapid development of wireless communication technologies, users also put forward higher requirements for the volume, quality and functional diversity of antennas. In order to meet the requirements of users, miniaturization, multiband, and wideband have become important standards for the design of current mobile antenna [1-3]. At the moment, in order to adapt and promote the application and development of the fifth generation communication system (5G system) in our country, 3300-3600MHz and 4800-5000MHz bands have been used as the operating bands of the 5G system. However, in the case of giving consideration to the 5G band, it is an enormous challenge for mobile phone antenna to be miniaturized while covering so many bands.

At present, many literatures have studied and discussed the miniaturization and multiband of antennas. Now the miniaturized and multiband technologies are used by mobile phone antennas which mainly include parasitic ground structures, matching circuit technology, loading gap technology, and coupled-fed technology. A parasitic ground structure is used in [4], and covers eight bands including the LTE700, but the size of the antenna is larger than 15×30mm\(^2\). With the use of matching circuit technology in [5] and [6], multiband and wideband are achieved, but due to the introduction of lumped elements, the loss of the antenna may be increased and the performance of the antenna may be reduced. The technique of loading gap used in [7] can reduce the overall size of the antenna while connecting the L-shaped metallic plate to the top edge of the system board to improve the impedance matching of the operating bands. However, in the frequency range of 1710-2690MHz, there is a frequency band (about 1837-2055MHz), which is slightly less than the return loss of -6dB. In addition, [8-10] has successfully designed several mobile phone antennas with planar structures through coupled-fed technology to achieve miniaturization of the antenna. The antenna area in [10] only occupies a size of 15×27 mm\(^2\).
15×28mm², but in these three antennas only seven bands can be covered. The above antennas do not cover the 5G communication band. For this reason, a 3D structure mobile phone antenna is designed in literature [11] that can take into account both the 5G bands and the WWAN/LTE bands. Unfortunately, the antenna is relatively large in size and occupies a space of 5×60×8mm³.

In this letter, a small-size planar printed loop antenna is proposed that can be used in an octa-band WWAN/LTE smartphone application. The structure consists of a T-shaped feeding strip, a coupling bending shorted strip and a tuning line. In order to successfully cover the eight bands of LTE (LTE2300/2500), WWAN (GSM850/900/DCS1800/PCS1900/UMTS2100) and LTE (LTE3500) in 5G communication, the principle of coupled-fed is used in the proposed antenna. At the same time, the proposed antenna does not perform any slot processing on the ground plate to achieve the purpose of broadening the bandwidth. Instead, the tuning line [12] is introduced to achieve good impedance matching of the antenna and does not occupy additional space of the mobile phone. Therefore, the proposed antenna only occupies a substrate area of 15×27 mm² when covers so many bands. And the structure is very compact, which achieves miniaturization of the antenna. Next, the design and parameter study of the proposed antenna will be introduced and discussed in the following sections detailedly.

2. Antenna configuration
The geometric dimensions of the proposed planar printed loop antenna are shown in figure 1(a). The detailed structure and optimized dimensions (in mm) is shown in figure 1(b). From figure 1, we can see that the mobile phone antenna with a geometric size of 15×27mm² is directly printed in the narrow space at the bottom edge of the dielectric substrate. The size of the substrate is 115×60×0.8mm³, and the material is FR4 (the relative dielectric constant is 4.4 and the loss tangent is 0.02). The ground plane of the antenna is printed on the back of the dielectric substrate, including a clearance area of 15×30mm², which can reduce the specific absorption ratio (SAR). The proposed antenna can be excited by a 50-Ω micro coaxial feed line at feeding point A, and the end portion (point B) of the coupling bending shorted strip is directly connected to the ground plate through a via-hole in the system circuit board.

![Figure 1](image_url)

**Figure 1.** (a) Geometry of the proposed antenna for octa-band WWAN/LTE operation in the internal mobile phone. (b) Dimensions of the metal pattern of the antenna. (unit: millimeters).
The proposed antenna is mainly composed of T-shaped feeding strip AE, coupling bending shorted strip BF and tuning line GH. The T-shaped feeding strip directly feeds and covers the high band. And the T-shaped feeding strip can generate two high-frequency resonances at about 2150MHz and 3400 MHz. The coupling bending shorted strip has a wind distributed inductor to cover low band by coupling feed. A low frequency resonance can be generated at about 880MHz by coupling bending shorted strip. In addition, the T-shape feeding strip and the coupling bending shorted strip all have vertical metal sheets, which can save the substrate space and improve the bandwidth. Finally, through the tuning line GH, the impedance matching of the two operating bands of low frequency and high frequency can be further improved, so that the antenna can well cover the 824MHz-960MHz/1710MHz-2690MHz bands and the LTE3500 (3300MHz-3600MHz) in 5G communication without the aid of the slotting technology and the matching circuit.

3. Antenna design evolution and analysis

The proposed antenna was designed through high frequency structural simulator (HFSS) simulation tools. The design evolution of the proposed planar printed loop antenna is described below. Figure 2 shows the simulated return losses of the proposed antenna and the two reference antennas (Ref1 and Ref2). In the case of only T-shaped feeding strip (Ref1), high frequency resonance mode is excited at approximately 2550MHz and 3750MHz, which can cover the LTE3500 band, but it can not completely cover the high band (1710MHz-2690MHz). In order to better cover the upper band and lower band, a coupling bending shorted strip is added by coupled-fed technology, ie, the reference antenna Ref2 is shown in figure 2. We can see that a low-frequency resonant mode is excited at about 860MHz, but it still can not fully meet the design requirements of the low band (824MHz-960MHz). In the end, we adopted the structure of tuning line. With the help of the tuning line, the impedance matching of the lower band and the upper band has been effectively improved, and the required bands can be completely covered.

![Figure 2](image_url)

*Figure 2. Simulated S-parameter for the proposed antenna, the case with T-shaped feeding strip only (Ref 1), the case with T-shaped feeding strip and coupling bending shorted strip (Ref 2) and the case with T-shaped feeding strip, coupling bending shorted strip and tuning line (Proposed).*

In order to better analyze the working mode of the antenna, the simulation of the surface current distribution of the proposed antenna in different resonant modes is shown in figure 3. It is observed from figure 3 (a) that a strong current distribution can be seen on the coupling bending shorted strip at 880 MHz (0.25\(\lambda\)), indicating that the current is mainly supplied by a coupling bending shorted strip, and the total length of the shorted strip is about 68mm. Figures 3 (b) and 3 (c) show the surface current distribution at 2150MHz and 3400MHz, respectively. From the diagram, the T-shaped feeding strip has a strong current distribution. It can be seen from figures 3 (b) and 3 (c) that two high-frequency
resonant modes can be directly generated by feeding strip. In addition, because the proposed print loop antenna is a whole structure formed by the feeding strip, the coupling strip and the system ground plane, the entire antenna is equivalent to an effective radiation system, so it can cover the required 2G/3G/4G/5G operating bands.

Figure 3. Simulated surface current distributions on the proposed antenna at (a) 880MHz (b) 2150MHz (c) 3400MHz.

The simulation return losses when changing the tuning line length L are shown in figure 4. From the result, it can be seen that the tuning line has little effect on the resonant frequency of the three resonant modes. However, when the tuning line is removed (without tuning line), the impedance matching of the three resonant modes will become worse. Through further experiments, we optimize the length of the tuning line. When the length of L is increased to 2mm, the antenna can get the best impedance matching under these three resonant modes, which can fully cover the low frequency band and high frequency band.

Figure 4. Simulated S-parameter when varying the length L of tuning line.

4. Experimental results
In order to verify the above analysis, the proposed octa-band planar printed loop antenna was fabricated and measured based on the dimensions in figure 1, and the manufactured antenna is shown in figure 5. Figure 6 shows the simulated and measured return loss of the proposed antenna. Experimental results are obtained from the Agilent N5230C vector network analyzer. From figure 6, we can see that the simulation and actual measurement of return loss are in good agreement. The -6dB return loss bandwidth of the lower band is 15.7% (820MHz-960MHz), which covers GSM850 and GSM900 operating bands. The -6dB return loss bandwidth of the upper band is 55.3% (1570MHz-
2770MHz) and 18.1% (3270MHz-3920MHz), which covers the DCS1800/PCS1900/UMTS2100/LTE2300/2500/3500 operating bands.

![Antenna Photographs](image)

**Figure 5.** Photographs of the fabricated planar printed loop antenna: (a) Front side, (b) Back side.

![S-parameter Graph](image)

**Figure 6.** Simulated and measured S-parameter of proposed antenna.

The radiation pattern of the proposed planar printed loop antenna was measured in a standard SATIMO anechoic chamber. Figure 7 shows the measured radiation pattern at three resonant frequencies of 880MHz, 2150MHz and 3400MHz. It is observed from the diagram that good omnidirectional is shown at 880 MHz, and the radiation pattern at 2150 MHz and 3400 MHz is slightly poor. Figure 8 shows the measured antenna efficiencies for the three required operating bands of WWAN/LTE (820MHz-960MHz), (1570MHz-2770MHz), and (3270MHz-3920MHz). It can be seen from figure 8 that the measured efficiencies of the antenna are 47.7%-58.1%, 76.1%-93.7% and 59.9%-68.9% at these three operating bands respectively. The measured antenna efficiencies show that at least three of the required frequency bands have more than 40%, which is acceptable in practical applications.
Figure 7. Radiation patterns of proposed antenna: (a) 880MHz, (b) 2150MHz, (c) 3400MHz.

Figure 8. Measured antenna efficiencies of proposed antenna.

5. Conclusions
Based on the principle of coupled-fed, a planar printed loop antenna has been successfully designed for LTE/WWAN smartphone applications. In order to broaden the operating bandwidth, the tuning lines was used. Lower and upper bands of impedance matching are achieved. While realizing miniaturization, it completely covers eight bands of GSM850/900/DCS1800/PCS1900/UMTS2100/LTE2300/2500/3500. The measured results include return loss, radiation pattern, antenna radiation efficiencies and gain, which all meet the actual requirements. The structure of proposed mobile phone antennas very simple and compact, and covers the LTE3500 band, which has a good application prospect.

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