Small-size Loop MIMO Antenna with Metal-frame for the LTE Smartphone

Shaoting Liu\textsuperscript{a}, Long Jin\textsuperscript{b} and Xiangyi Wei\textsuperscript{c}

University of Electronic Science and Technology of China, Chengdu 611731, China
\textsuperscript{a}839076577@qq.com, \textsuperscript{b}jinlong@uestc.edu.com, \textsuperscript{c}819627983@qq.com

Abstract. A pair of loop antennas with metal frame for the LTE smartphone are proposed. The proposed antennas are placed on the top and bottom of the system board, respectively. The substrate used for the circuit board is FR4 with relative permittivity 4.4 and loss tangent of 0.02. The volume of the circuit board is 85×160×0.8mm\textsuperscript{3}, with each antenna occupying an area of 10×38mm\textsuperscript{2}. The antennas are mainly composed of a capacitive feed loop combined with a metal frame. On both sides of the ground plate, rectangular ground are added to reduce the coupling and improve the isolation of the two antennas. The proposed antenna is fabricated and measured, the measured operating bands with $S_{11}/S_{22}$ lower -6 dB cover the LTE low band (698-960 MHz) and LTE middle band (1710-2690 MHz), meanwhile, the isolation is better than 10 dB at LTE low frequency bands and 17 dB at LTE middle frequency. The details of the proposed antenna will be discussed.

1. Introduction

Recently, disposing metal frame around the casing is an attractive method to enhance its mechanical robustness, on the other hand, as the antenna’s radiating element, metal frame has been widely used [1, 2]. In many smartphone antenna designs, loop antennas are used to achieve the LTE (long term evolution) operation [3]. The loop antenna with a capacitive feed have been shown to be capable of operating in their quart-wavelength resonant mode as the lowest mode for mobile phone application [4]. The loop antenna can realize miniaturized size, meanwhile, due to the explosive growth of mobile subscribers, the requirement of channel capacity has also increased substantially, and therefore multiple Input Multiple Output (MIMO) antennas were proposed. Because of the advantages of high data rate and incremented channel capacity, MIMO antenna are widely used in communication systems [5, 6]. But the coupling between multiple antennas is unavoidable. How to effectively reduce the coupling between antennas is the challenge of MIMO antenna design.

In this paper, a pair of loop antennas with metal frame have been presented to achieve multiband operation for the smartphone. Each antenna consists of a loop antenna with metal frame antenna to cover LTE low band of 698-960 MHz and LTE middle band of 1710-2690 MHz. In order to reduce the coupling between two antennas, rectangular ground are added in the middle of the ground plane. The simulated results are obtained by using simulating software HFSS version 15.0 [7]. The proposed antenna is fabricated and tested, experiment and simulation results of the fabricated antenna are presented and analysed.
2. Antenna Design

The geometry of the proposed antenna and details on component configuration are illustrated in Figure 1. Fig. 1(a) shows the overall size, Fig. 1(b) shows antenna without high-pass matching and decoupling circuit and Fig. 1(c) shows details of the Part I. The overall size of the FR4 substrate is 85×160×0.8 mm$^3$, with each antenna comprised of a small size of 10×38×2 mm$^3$, the detailed dimensions of each radiator element are shown in the Fig. 1(c). Metal frame surround the circuit board and a ground plane is printed on the back surface. There are four symmetrical gaps (0.5 mm in width) on left and right sides of the metal frame, meanwhile, two USB slots are reserved on upper and lower sides. The FR4 substrate in the middle of the metal frame.

![Figure 1. Geometry of loop MIMO antenna with metal frame: (a) Overall view; (b) without high-pass matching and decoupling circuit antenna (Ant1); and (c) detailed dimensions of MIMO antenna element.](image)

The loop antenna shown in Fig. 1(c) is capacitive excited through a narrow gap (0.4 mm width and 11.5 mm in length) by an L-type feeding strip. The antenna consists of two parts, the first part is the microstrip from A to D, and the second part contains the metal frame and a thin metal plate of 38×5×0.03 mm$^3$. As shown in Fig. 1(c), the total length of the first part of loop antenna is about a quarter-wavelength (87.7 mm) at 900 MHz. Combined with the L-Type capacitive feed, the LTE low frequency band can be generated, and with the aid of an extra high-pass matching circuit, the LTE low-band bandwidth can be broadened to enable the proposed antenna to cover the LTE low band (698-960 MHz). Considering the coupling of the antenna element and the adjacent metal frame, we adjust the gap width between the adjacent frame, finally we choose $g = 0.5$ mm. Combined with the loop antenna high-order resonance mode, the antenna with metal frame can cover the LTE middle band (1710-2690 MHz). The high-pass matching circuit consists of a cascaded capacitor of 2 pf (C1) and an inductor of 4.7 nH (L1) and a paralleled inductor of 12 nH (L2) to ground. Thus, the antenna unit can cover the LTE low and middle band with the size of 10×38×2 mm$^3$. 
Fig. 2(a) shows the simulated return loss and isolation of Ant1 (antenna in Fig. 1(b)) and Ant1 added with high-pass matching circuit. It is seen that antenna with high-pass matching circuit can cover two LTE bands, the 698-960 MHz for LTE low band, and the 1710-2690 MHz for LTE middle band, respectively. Specific frequency bands as shown in the shadow color. It shows that the matching circuit adds an additional resonant mode which can broaden the bandwidth in the low frequency band.

However, The isolation of antenna becomes worse when we add the high-pass matching circuit based on Ant1, therefore, rectangular ground are added to reduce the coupling and improve the isolation of the two antennas. By simulating the current distribution of the antenna units before and after decoupling, the results are depicted in Figure 3, it can be seen that the current paths are increased and the ground current distribution is changed by Protruding ground and digging corners of ground plane, so that the current of excitation port to the non-excited port is reduced, thus improving the isolation of the antenna. Fig. 4 shows the simulated isolation as a function of d (the length of rectangular ground for proposed antenna). Through the study of the parameters, ultimately we choose d=6 mm. In this case, we obtain the isolation of antenna better than 10 dB and S11 changes very little. Fig. 2(b) shows simulated S-parameter of the proposed antenna. We can see that S11< -6 dB and S21<-10 dB at LTE low band and S21<-17 dB at LTE middle band.

![Figure 2](image-url)
3. Results and Discussion

Based on the design model in Fig. 1(a), the proposed antenna is fabricated whose prototype is shown in Figure 5. The Fig. 6 shows good agreement of return loss and isolation between simulation and measurement, i.e, the proposed antenna can work well in the LTE low band and LTE middle band.

Figure 3. Simulated surface current distributions of proposed antenna ((d)(e)(f)) and without decoupling antenna ((a)(b)(c)) at different frequency: (a)(d) at 880 MHz; (b)(e) at 935 MHz; (c)(f) at 1850 MHz.

Figure 4. Simulated S-parameters as a function of d: (a) S21; and (b) S11.

Figure 5. Photograph of the fabricated antenna
Figure 6. Measured and simulated S-parameter of proposed antenna.

Figure 7 shows the measured and simulated normalized radiation pattern of the proposed antenna at different frequency. When port 1 of the proposed antenna is excited, while port 2 is terminated with 50 Ω load. The simulated and measured radiation patterns with some difference that is mainly due to the fabrication limitations and the measurement procedure, which involves the use of RF connection cables and connectors.

Figure 7. Measured and simulated normalized radiation pattern of the proposed antenna at (a) 712.5 MHz, (b) 912.5 MHz, (c) 1.95 GHz and (d) 2.525 GHz.
The Peak gains, efficiencies and ECC (the envelope correlation coefficient) of the proposed MIMO antennas at different frequencies are shown in table I. The simulated gains and efficiencies have been extracted from HFSS15.0. The values of ECC have been calculated by using the s-parameters method [8]. It can be seen that the values are well below the value of 0.01 which promises a good diversity performance.

Table I. Peak gain, efficiency and ECC of the proposed MIMO antennas

| Frequency (GHz) | Peak Gain (dBi) | H (%) | ECC   |
|----------------|----------------|-------|-------|
| 0.7125         | 1.22           | 72.8  | 0.006 |
| 0.915          | 1.63           | 58.3  | 0.007 |
| 0.960          | 1.28           | 71.3  | 0.001 |
| 1.710          | 1.62           | 76.5  | 0.008 |
| 1.950          | 1.48           | 90.1  | 0.003 |
| 2.525          | 2.54           | 89.3  | 0.0002|

4. Conclusion
A loop combined with metal frame MIMO antenna for the LTE low band (698-960MHz) and the LTE middle band (1710-2690MHz) applications have been proposed. Through the use of high-pass matching circuit to expand the bandwidth, and by adding rectangular ground, we improve the isolation of the antenna. Measured results match well with the simulation and show steady radiation across working band. Therefore, the proposed loop with metal frame MIMO antenna is suitable for LTE communication applications.

References
[1] Chang, H.-J, Wong, K.-L, “Compact LTE Frame Antenna with a Narrow Metal Clearance and a Radiating Feed Network for the Metal-Casing Smartphone,” EUCAP2017, 3069-3073, Mar. 19 - 24, 2017.
[2] Chen, H., Zhao, A., “LTE Antenna Design for Mobile Phone With Metal Frame,” IEEE Antenna & Wireless Propagation Letters, VOL. 15, 1462-1465, 2016.
[3] Wong, K.-L., Chen, Y.-C., “Small-Size Hybrid Loop/Open-Slot Antenna for the LTE Smartphone,” IEEE Transactions on Antenna and Propagation, VOL. 63, NO. 12, 5837 - 5841, 2015.
[4] Wong, K.-L., Chi, Y.-W., “Quarter-Wavelength Printed Loop Antenna for GSM/DCS/PCS/UMTS Operation,” APMC2008, 1-4, Dec. 16-20, 2008.
[5] Sultan, S., Imran, S., Noshrwan, S., and Chen, X.D., “MIMO Antennas for Mobile Handsets,” IEEE Antenna & Wireless Propagation Letters, VOL. 14, 799-802, 2015.
[6] Sun, J.-S., Fang, H.- S, and Lin, P.-Y, “Triple-Band MIMO Antenna for Mobile Wireless Applications,” IEEE Antenna & Wireless Propagation Letters, VOL. 15, 500-503, 2016.
[7] http://www.ansoft.com/products/hf/hfss, Ansoft Corporation HFSS.
[8] Votis, C., Tatsis, G., and Kostarakis, P., “Envelope correlation parameter measurements in a MIMO antenna array configuration,” Int. J. Communications, Network and System SCiences, 350-354, Apr. 11, 2010.