Planar Printed Multi-Resonant Antenna for Octa-Band WWAN/LTE Mobile Handset

Changjiang Deng, *Student Member, IEEE*, Yue Li, *Member, IEEE*, Zhijun Zhang, *Fellow, IEEE*, and Zhenghe Feng, *Fellow, IEEE*

***Abstract*—In this letter, a planar printed multiple-band antenna is proposed for mobile handset applications. The antenna consists of a driven monopole with multiple branches, and a parasitic ground strip with an open slot. By properly tuning the dimensions and positions of each part of the proposed antenna, octa-band operation is achieved with good radiation efficiency. For lower frequency, the LTE700, GSM850, and GSM900 bands are provided by the $\lambda/4$ modes of the driven monopole and the parasitic ground strip. For upper frequency, the DCS, PCS, UMTS, LTE2300 and LTE2500 bands are covered by the higher order modes of the driven monopole and the parasitic ground strip. The open slot and the shorter driven branch are utilized to widen the bandwidth in the upper frequency. All the mentioned operating bands are achieved in a small area of 15×60 mm^2. The measured -6-dB reflection coefficient bandwidth is 405 MHz ($660 \sim 1065$ MHz) in the lower band and ranges from 1665 MHz to more than 3000 MHz in the upper band.**

***Index Terms*—Handset antennas, mobile antennas, multiple frequency antennas.**

I. Introduction

THE RAPID development of mobile communication systems has inspired continuous research on antennas for mobile handsets. The mobile phone antenna for traditional wireless wide area network (WWAN) operation is usually required to cover GSM850 (824–894 MHz), GSM900 (880–960 MHz), DCS (1710–1880 MHz), PCS (1850–1990 MHz), and UMTS (1920–2170 MHz) bands. In addition, the recently introduced long term evolution (LTE) has assigned three new bands, including LTE700 (698–787 MHz), LTE2300 (2300–2400 MHz), and LTE2500 (2500–2690 MHz). Therefore, a handset antenna for WWAN/LTE operations needs to cover LTE700, GSM850, and GSM900 bands (698-960 MHz) for the lower band and DCS, PCS, UMTS, LTE2300, and LTE2500 bands (1710–2690 MHz) for the upper band.

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The authors are with the State Key Laboratory on Microwave and Digital Communications, Tsinghua National Laboratory for Information Science and Technology, Department of Electronic Engineering, Tsinghua University, Beijing 100084, China (e-mail: lyee@tsinghua.edu.cn).

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Numbers of promising mobile phone antennas have been studied for WWAN/LTE operations in the last decade [1]–[13]. Among these designs, the on-board printed antennas [7]–[13] are very attractive owing to the planar structure, ease of fabrication and low cost. Considering that the antenna profile is typically chosen as 15 mm, the 698-960 MHz band is difficult to cover by a single resonance. The typical method to cover the whole lower band is merging multiple resonances. For planar monopole antennas, there are two ways to generate the multiple resonances in the lower band. The first way is using one parasitic strip for multiple resonances [7]–[10]. To achieve a dual-resonant behavior in the lower band, several special structures are adopted, e. g., a parasitic ground strip with two unequal branches in [7] and [8], a printed distributed inductor in [9], and a planar inverted-F antenna (PIFA) with $\lambda/8$ mode in [10] are introduced. In these designs, coupling feeding and inductive strips are used to provide capacitance and inductance for impedance matching in the lower band. The second way is combining a driven strip and a parasitic strip [11]–[13]. Dual resonances are provided by the driven strip and parasitic strip, respectively. Compared with the first way, the second way has a clearer mode performance, thus is more flexible in antenna optimization. In addition, the tuning of higher order modes in the upper band without affecting the fundamental modes in the lower band is difficult. Therefore, the modes control in both the lower and upper bands needs to be well considered.

In this letter, a planar printed mobile phone antenna is proposed to cover the WWAN/LTE bands. Dual resonances in the lower band are generated by the $\lambda/4$ modes of a driven monopole strip and a parasitic ground strip. To cover the upper band and have more freedom for tuning, a shorter driven branch is added to the driven monopole strip and an open slot is etched on the parasitic ground strip. Thus, two new $\lambda/4$ modes are introduced in the upper band, apart from the two existing $3\lambda/4$ modes of the driven monopole and the parasitic ground strip. By combining all the related modes in the upper band, a wide bandwidth of more than 1335 MHz (1665–3000 MHz) is achieved. Parametric study is carried out to demonstrate that the tuning of the upper band is with little effect on the lower band tuning.

II. Antenna Design

Fig. 1 shows the geometry and dimensions of the proposed antenna. A 0.8-mm-thick FR4 substrate ($\varepsilon_r = 4.4$, $\tan\delta = 0.02$) is used as the system circuit board of the mobile phone. The size of the substrate is 1×60 mm^2 A main ground with a size of 105×60 mm^2 is printed on the back layer of the substrate. The

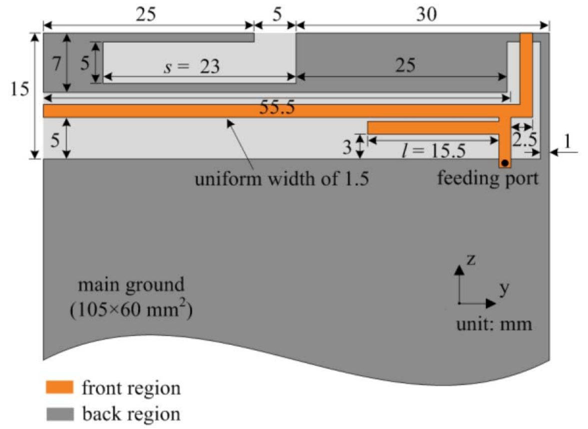

Fig. 1. Geometry and dimensions of the proposed antenna.

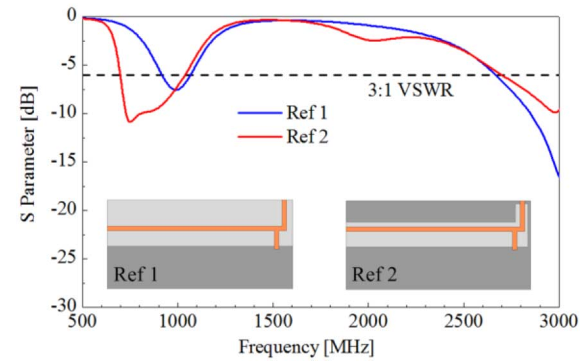

Fig. 2. Comparison of the simulated S_{11} for different antennas, Ref 1: only the longer driven strip, Ref 2: Ref. 1+ parasitic short ground strip.

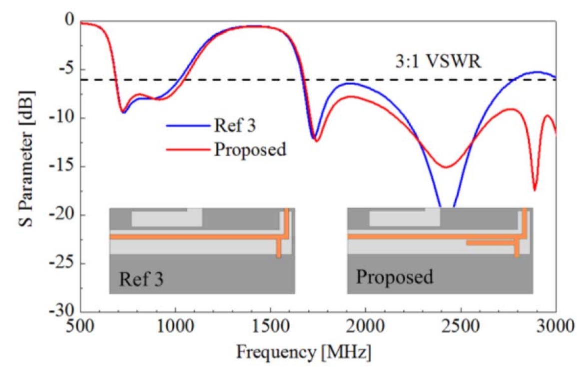

Fig. 3. Comparison of the simulated S_{11} for different antennas, Ref 3: Ref. 2+ open slot, proposed: Ref. 3+ shorter driven branch.

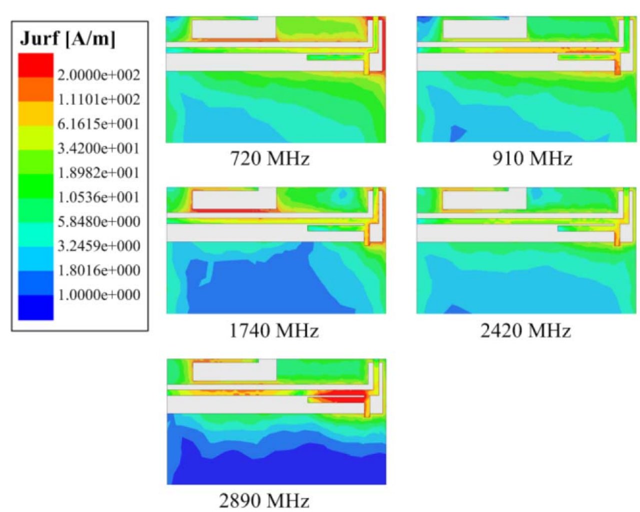

Fig. 4. Simulated current distributions of the proposed antenna at different resonant frequencies.

proposed antenna occupies a small size of 15×60 mm^2 and consists of a driven monopole strip and a parasitic ground strip. The monopole strip and the parasitic ground strip are printed on the front and back sides of the substrate, respectively. The driven monopole strip has two branches. Each of the branches has a uniform line width and is fed by a microstrip line directly. The parasitic strip is connected with the main ground and forming an L-shaped gap. A wide L-shaped open slot is etched on the end of the parasitic ground strip. The commercial software Ansoft HFSS is used to optimize the dimensions of the proposed antenna.

The design process of the proposed antenna is shown in Figs. 2 and 3. Fig. 2 shows the tuning of the lower band. The longer driven monopole strip in Ref 1 generates a resonance at 1000 MHz, which corresponds to the $\lambda/4$ mode. To increase the bandwidth of the lower band, another resonance is generated by the parasitic ground strip. The resonant frequency is at approximately 720 MHz, corresponding to the $\lambda/4$ mode of the parasitic ground strip. By merging the two resonant modes, wide coverage of the lower band for LTE700, GSM850, GSM900 bands is achieved. Fig. 3 shows the tuning of the upper band. $3\lambda/4$ modes are provided by both the driven and parasitic strips in the upper band. However, additional resonances are needed to broaden the bandwidth in the upper band. Based on Ref 2, an open slot is etched in Ref 3. It is shown that the $3\lambda/4$ mode of the parasitic ground strip is shifted to approximately 1700 MHz, and another resonance is provided by the etching slot itself in the upper band. To further improve the performance in the upper band, another shorter driven monopole branch is added to the driven monopole strip. It is shown that the shorter driven branch provides additional resonance at approximately 2800 MHz. By merging all the resonances, wide coverage of the upper band for DCS, PCS, UMTS, LTE2300, and LTE2500 bands is achieved.

The simulated current distributions at different resonant frequencies are plotted in Fig. 4. Two resonances in the lower band and three resonances in the upper band are plotted. At 720 MHz, strong current can be seen on the parasitic ground strip. At 910 MHz, strong current can be seen on the longer driven branch. Therefore, the two resonances are generated by the parasitic ground strip and the longer driven monopole strip, respectively. At 1740 MHz, the current distribution is strong on the parasitic ground strip, and there is also a deep current null on the parasitic ground strip. This distribution indicates that the resonance at 1740 MHz is mainly provided by the $3\lambda/4$ mode of the parasitic ground strip. At 2420 MHz and 2890 MHz, strong currents can be observed around the open slot and the shorter driven branch. Therefore, the two resonances are generated by the $\lambda/4$ modes of the open slot and the shorter driven branch, respectively. From the analysis of current distributions, the operating mode of the proposed antenna at different frequencies is straightforward.

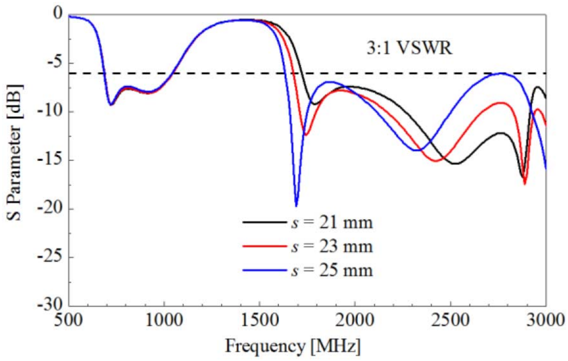

Fig. 5. Simulated S_{11} with different lengths of the open slot.

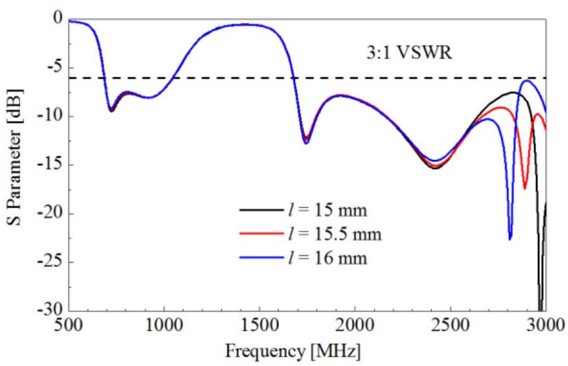

Fig. 6. Simulated S_{11} with different lengths of the shorter driven strip.

The effects of key parameters on tuning the bandwidth are analyzed and discussed. It is obvious that the dual resonances in the lower band are determined by the lengths of the longer driven branch and the parasitic ground strip. The tuning of the two modes is simple. Therefore, the focus is mainly on the two resonances generated by the open slot and the shorter driven branch. Fig. 5 shows the effect of the open slot on S_{11}. The resonant frequencies at approximately 1700 MHz and 2500 MHz decrease as the length of the open slot increases, while the resonances at other frequencies keep unchanged. It indicates that the change of s affects the $\lambda/4$ mode of the open slot and the $3\lambda/4$ mode of the parasitic ground strip. Fig. 6 shows the effect of the shorter driven branch on S_{11}. It is shown that the increase of l, the length of the shorter driven branch, only changes the frequency at approximately 2850 MHz. It depicts that the $\lambda/4$ mode of the shorter driven branch can be tuned independently. Compared with the antennas in [7]–[13], the proposed antenna is more flexible in tuning the upper band.

III. Measurement Results

Based on the parameters in Fig. 1, the proposed antenna is fabricated and tested. The feeding port is connected directly with a 50 Ohm coaxial cable, whose outer conductor is soldered with the ground plane, and inner conductor is soldered with the feeding port via a hole. Fig. 7 shows the measured reflection coefficient of the proposed antenna, which agrees well with the simulated result. The difference between the simulated and measured results is mainly caused by fabrication error and measurement error. A broad -6-dB bandwidth of 405 MHz (660 $\sim$ 1065 MHz) is measured, which covers the LTE700, GSM850, GSM900 operations. The measured -6-dB bandwidth is ranged from 1665 MHz to more than 3000 MHz, which is wide enough to cover the DCS, PCS, UMTS, LTE2300 and LTE2500 bands. It is worth mentioning that further size reduction of the antenna is possible when pursuing a low-profile design, owing that the bandwidth is much wider than the desired bands.

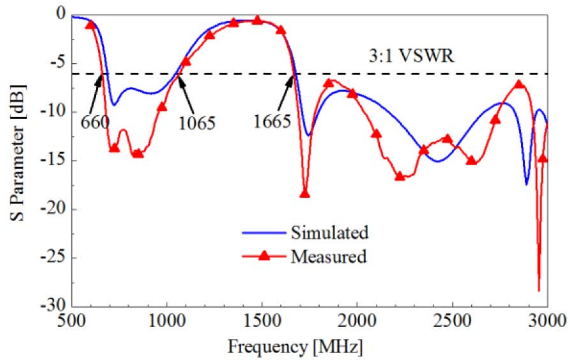

Fig. 7. Simulated and measured S_{11} of the proposed antenna.

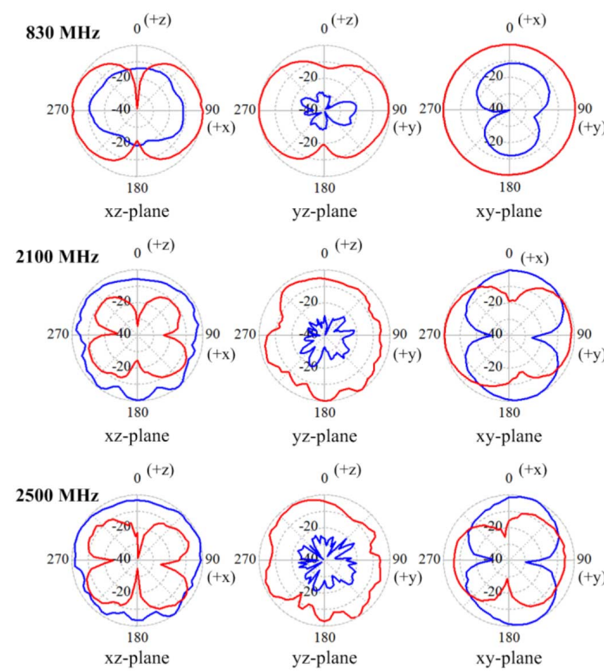

Fig. 8. Measured normalized radiation patterns of the proposed antenna at different frequencies. (the red line is E_θ, the blue line is $E\varphi$).

Fig. 8 shows the measured normalized radiation patterns of the proposed antenna in the three principal planes. Three typical frequencies, one in the lower band and two in the upper band, are selected and shown. For 830 MHz in the lower band, a dipole-like radiation pattern can be observed. For 2100 MHz and 2500 MHz in the upper band, the radiation patterns are similar with the $3\lambda/2$ radiation pattern mode of a dipole. In addition, large variations and nulls can be observed in the radiation patterns. As is explained in [11], the reason is that the length of the system ground plane is comparable to the wavelength in the upper band.

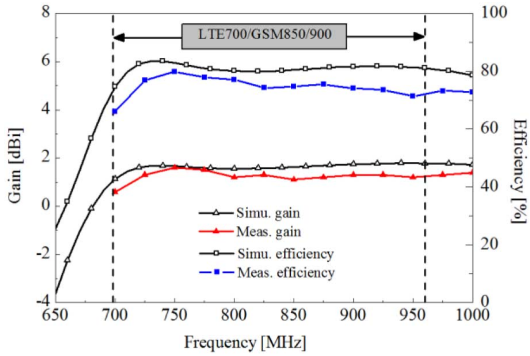

Fig. 9. Simulated and measured gain and efficiency in the lower band.

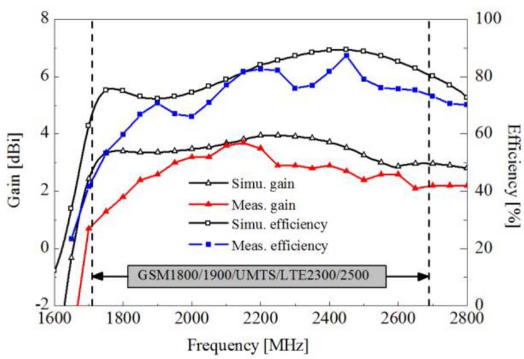

Fig. 10. Simulated and measured gain and efficiency in the upper band.

The simulated and measured gains and total radiation efficiencies of the proposed antenna are also analyzed. Fig. 9 and Fig. 10 show the results in the lower and upper bands, respectively. In the lower band (698–960 MHz), the measured antenna gain is about 0.5–2 dBi and the measured total radiation efficiency varies from 60% to 84%. In the upper band (1710–2690 MHz), the measured antenna gain is about 0.5–3 dBi and the measured total radiation efficiency ranges from 42% to 88%. Except the measured value around 1710 MHz, all the efficiencies in the WWLAN/LTE operations are above 50%. The total radiation efficiency performance is acceptable in practical applications.

IV. Conclusion

In this letter, a planar printed antenna for mobile handset has been proposed. Two broad bandwidths for octa-band WWAN/LTE operations are achieved by merging the multi-resonances of a driven monopole strip and a parasitic ground strip with an open slot. Dual resonances are generated in the lower band to provide bandwidth for LTE700, GSM850 and GSM900 operations. Four resonances are excited in the upper band to provide sufficient bandwidth for DCS, PCS, UMTS, LTE2300 and LTE2500 operations. The measured results, including reflection coefficient and radiation efficiency, indicate that the proposed antenna is promising for planar mobile phone applications.

References

[1] K. L. Wong, W. Y. Chen, C. Y. Wu, and W. Y. Li, “Internal coupled-fed dual-loop antenna integrated with a USB connector for WWAN/LTE mobile handset,” *Microw. Opt. Technol. Lett.*, vol. 52, no. 10, pp. 2244–2250, 2010.
[2] F. H. Chu and K. L. Wong, “Internal coupled-fed dual-loop antenna integrated with a USB connector for WWAN/LTE mobile handset,” *IEEE Trans. Antennas Propag.*, vol. 59, no. 11, pp. 4215–4221, Nov. 2011.
[3] Y. Li, Z. Zhang, J. Zheng, and Z. Feng, “Compact heptaband reconfigurable loop antenna for mobile handset,” *IEEE Antennas Wireless Propag. Lett.*, vol. 10, pp. 1162–1165, 2011.
[4] Y. Li, Z. Zhang, J. Zheng, Z. Feng, and M. Iskander, “A compact heptaband loop-inverted F reconfigurable antenna for mobile phone,” *IEEE Trans. Antennas Propag.*, vol. 60, no. 1, pp. 389–392, Jan. 2012.
[5] Y. L. Ban, C. L. Liu, Z. Zhen, J. Li, and K. Kang, “Small-size multiresonant octaband antenna for LTE/WWAN smartphone applications,” *IEEE Antennas Wireless Propag. Lett.*, vol. 13, pp. 619–622, 2014.
[6] J. Lee, Y. Liu, and H. Kim, “Mobile antenna using multi-resonance feed structure for wideband operation,” *IEEE Trans. Antennas Propag.*, vol. 62, no. 11, pp. 5851–5854, Nov. 2014.
[7] D. G. Kang and Y. Sung, “Coupled-fed planar printed shorted monopole antenna for LTE/WWAN mobile handset applications,” *Microw., Antennas Propag.*, vol. 6, no. 9, pp. 1007–1016, Jun. 2012.
[8] Z. Xie, W. Lin, and G. Yang, “Coupled-fed printed antenna for LTE mobile handset applications,” *Microw. Opt. Technol. Lett.*, vol. 56, no. 8, pp. 1752–1756, 2013.
[9] C. T. Lee and K. L. Wong, “Planar monopole with a coupling feed and an inductive shorting strip for LTE/GSM/UMTS operation in the mobile phone,” *IEEE Trans. Antennas Propag.*, vol. 58, no. 7, pp. 2479–2483, Jul. 2010.
[10] K. L. Wong, M. F. Tu, C. Y. Wu, and W. Y. Li, “Small-size coupled-fed printed PIFA for internal eight-band LTE/GSM/UMTS mobile phone antenna,” *Microw. Opt. Technol. Lett.*, vol. 52, no. 9, pp. 2123–2128, 2010.
[11] F. H. Chu and K. L. Wong, “Planar printed strip monopole with a closely-coupled parasitic shorted strip for eight-band LTE/GSM/UMTS,” *IEEE Trans. Antennas Propag.*, vol. 58, no. 10, pp. 3426–3431, Oct. 2010.
[12] T. Zhang, R. L. Li, G. P. Jin, G. Wei, and M. M. Tentzeris, “A novel multi-band planar antenna for GSM/UMTS/LTE/Zigbee/RFID mobile devices,” *IEEE Trans. Antennas Propag.*, vol. 59, no. 11, pp. 4209–4214, Nov. 2011.
[13] H. J. Liu *et al.*, “A multi- broadband planar antenna for GSM/UMTS/LTE and WLAN/WiMAX handsets,” *IEEE Trans. Antennas Propag.*, vol. 62, no. 5, pp. 2856–2860, May 2014.