Printed Monopole Slot Antenna for WWAN Metal-Rimmed Smartphone Applications

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***Abstract*—A printed L-shaped slot antenna for WWAN metal-rimmed smartphone applications is presented in the paper. Embellished by the metal rim, the modern smartphones have achieved enhanced mechanic strengthen as well as better cosmetic appearance. However, the only problem should be addressed on the resonance disorder introduced by the metal rim. Although it has been partially solved by etching slits and adding grounded patches, yet the metal rim resonances are not fully utilized which results in large size consumption. In the proposed scheme, the resonances generated by the metal rim are better exploited to further reduce the antenna size. Four resonant modes are generated by the disjoint metal rim and double L-shaped slots to cover the WWAN band operation. With small size occupation and wide band coverage, the proposed antenna is a promising candidate for the metal-rimmed smartphone applications.**

Keywords—metal-rimmed smartphone; monopole antenna; slot antenna; WWAN antenna.

I. INTRODUCTION

Recent years, the metal-rimmed smartphones have been very popular owing to their aesthetic appearance and mechanical strength. However, since the metal rim is placed with close proximity to the radiating elements, it is inevitable that the metal rim will have adverse effects on the antenna performance, such as deteriorated impedance matching and low radiation efficiencies. Thus, it is a challenging task to design wideband and high-efficiency antenna for metal-rimmed smartphone applications both in academia and industrial field.

To mitigate the negative effect, one solution [1] is to divide the metal rim into several parts and then push the redundant resonances generated by the metal rim out of the working frequency band. But in this case the metal rim resonances are not utilized which results in large size consumption. To obtain better usage of the metal rim resonance, a slot antenna design in [2] is proposed for metal-rimmed smartphone application. With three grounded patches between the metal rim and system ground plane, the slot antenna achieved penta-band operation with a planar size of 15.5×56.5 mm^2. However, since narrow frame has become the trend for smartphones, the width of the antenna is better to be no longer than 10 mm. So it is desirable to have more creative antenna designs to achieve further compactness and better integration [3].

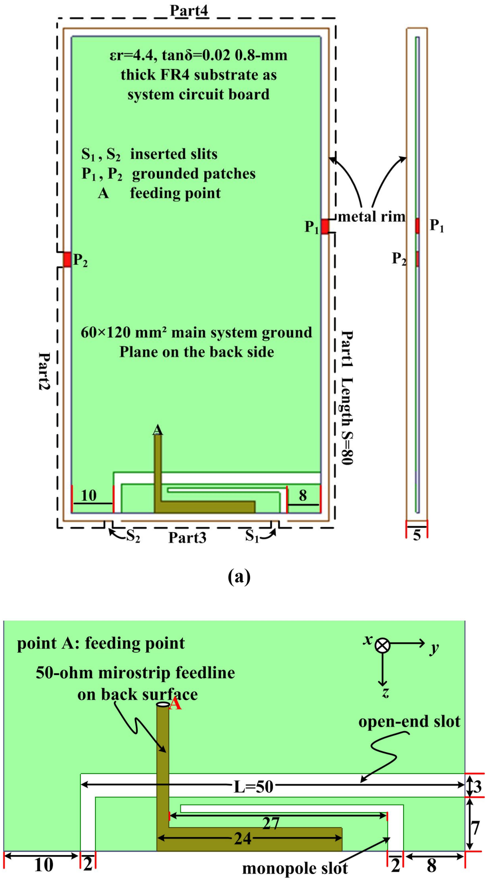
In the paper, a novel compact slot antenna is designed for metal-rimmed smartphone applications. As the main radiator, the slot antenna is composed of one monopole slot and an open-end slot which occupy a small area of 10×50 mm^2 on the system circuit board corner. The two slots generate a dual-resonance mode to cover the upper band of 1710-2170 MHz which includes GSM1800/1900/UMTS2100. However, only the slot antenna is insufficient to cover the whole WWAN band operation. Inspired by ideas from the reported literatures, the metal rim is divided into four parts by adding two slits and two grounded patches. The metal rim creates two nearby resonances to cover the GSM850/900 band from 824 MHz to 960 MHz. Since the lower frequency resonances of the antenna depend greatly upon the length of the disjointed metal rim parts, the locations of the slits and the grounded patches are fairly critical and well tuned in the proposed antenna design.

By exploiting resonances generated by the slots and the metal rim effectively, the proposed antenna successfully covers the WWAN band operation with small size occupation and simple configuration. One prototype of the proposed antenna is fabricated and tested. Detailed study of the proposed antenna is provided in the following sections.

II. PROPOSED ANTENNA CONFIGURATION

Fig.1 shows the geometry of the proposed antenna for metal-rimmed smartphone applications. As shown in Fig.1 (a), the slot antenna is printed on the bottom side of the main system circuit board and surrounded by a 5-mm height metal rim. A 0.8-mm thick FR4 substrate of relative permittivity 4.4, loss tangent 0.024 and size of 120×60 mm^2 is utilized as the system circuit board in this study. It is seen that with a distance of 2 mm to the substrate, the brass sheet, whose thickness can be negligible, encloses the main circuit board as the metal rim frame. By adding two slits (S_1 and S_2) and two grounded patches (P_1 and P_2), the metal rim is divided into four parts, which are Part1, Part2, Part3 and Part4 as depicted in Fig.1 (a). To achieve good impedance matching and high efficiency, the locations of the slits and grounded patches are well adjusted.

Detailed dimensions of the proposed antenna are shown in Fig.1 (b). It can be observed that the antenna is composed of two L-shaped slots (one open-end slot and one monopole slot) which occupies an area of 10×50 mm² totally. The open-end slot has a length of 60 mm and it separates the ground plane into two main portions including a small portion and the main ground portion. A monopole slot is etched on the small portion and a protruded portion with size of 10×10 mm² is left on the main ground portion to accommodate other electronic components. The monopole slot has a length of 35 mm and its open end is aligned to the slit S_1 for better radiation performance.



(a)

(b)

Fig. 1 Proposed antenna configuration: (a) the geometry of L-shaped slot antenna for WWAN metal-rimmed smartphone applications. (b) Detailed dimensions of the proposed antenna (Unit: mm).

Generally, the open-end slot primarily works as a half-wavelength resonant structure [4-6] and the monopole slot often generates quarter-wavelength resonant mode [7-12]. Composed of a monopole slot and an open-end slot, the proposed antenna generates two resonant modes at 1750 MHz and 2150 MHz for the upper band radiation. While the lower band operation is mainly contributed by the metal-rim resonances produced by Part1 and Part2. To illustrate the working mechanism of each part of the proposed antenna, detailed design consideration is presented and parameter study is done in Section III.

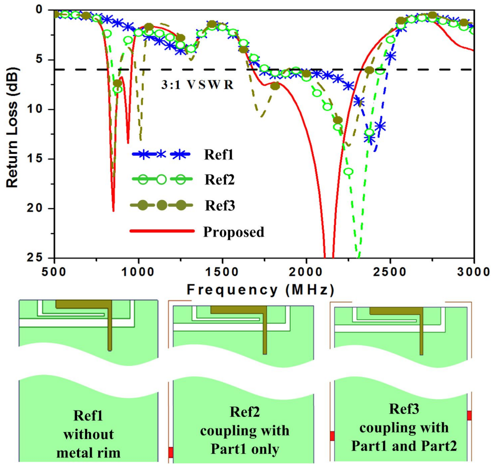


Fig. 2 Simulated return loss for the case without metal rim (Ref1), the case coupling with Part1 only (Ref2), the case coupling with Part1 and Part2 (Ref3). Other parameters are the same as given in Fig. 1.

III. OPERATING PRINCIPLE AND PARAMETER STUDY

To analyze the working mechanism for each part of the proposed antenna, several reference antennas are provided. Fig.2 shows the simulated return loss for the case without the metal rim (Ref1), the case with Part1 only (Ref2) and the case with Part1 and Part2 (Ref3). In theory, with a length of 60 mm the open-end slot generates a λ/2 resonant mode at 2150 MHz while the monopole slot creates a λ/4 resonant mode at 1750 MHz with a total length of 35 mm. Due to the coupling between the two slots, the resonant modes are slightly shifted. So it can be observed that for Ref1 there are only two resonant modes in the upper band at 1700 MHz and 2450 MHz which is generated by the monopole slot and open-end slot respectively. In the case, the two resonances work jointly to cover the upper band operation from 1710 MHz to 2170 MHz but the lower band do not meet the requirements.

By dividing the metal rim into four parts, the adverse effects of the metal rim resonances are turned into favorable contributions to the lower band radiation. When Part1 with a length of 80 mm, is added in Ref2, a λ/4 monopole resonance is generated at 850 MHz. However, the 850 MHz resonant mode is not wide enough to cover the GSM850/900 band. Thus to further widen the lower band operation, in Ref4 a nearby 1000 MHz resonant mode is introduced by Part2. With a length of 73 mm, Part2 originally generates another λ/4 monopole resonance at 900 MHz. But the resonance is slightly shifted to 1000 MHz due to the coupling between Part2 and ground. When Part3 and Part4 of the metal rim are added to compose the completed metal rim along the frame of the smartphone, compared with Ref4 the resonant modes are slightly shifted and finally cover the WWAN band successfully.

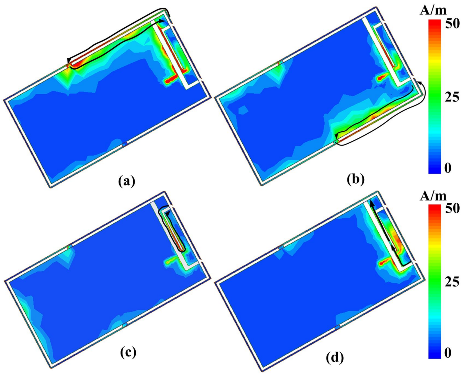


Fig. 3 Simulated surface current distributions of the proposed antenna at the resonant frequencies. (a) 850 MHz, (b) 900 MHz (c) 1750 MHz, (d) 2150MHz.

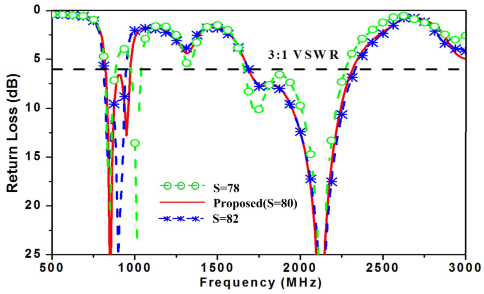


Fig. 4 Simulated return loss as a function of the length *S* for the antenna. Other parameters are the same as given in Fig. 1.

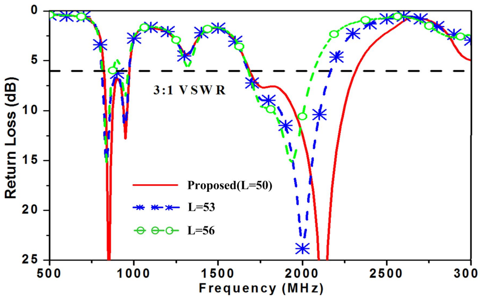


Fig. 5 Simulated return loss as a function of the length *L* for the antenna. Other parameters are the same as given in Fig. 1.

Fig.3 shows the simulated surface current distributions for proposed antenna at 850 MHz, 900 MHz, 1750 MHz and 2150 MHz. At 850 MHz and 900 MHz, there are strong surface current distributed on the Part1 and Part2 accordingly, which indicates that the proposed antenna's lower resonant modes are mainly contributed by Part1 and Part2 separately. Fig.3 (c) shows that at 1750 MHz the strong surface current distributions flow along with the monopole slot, which confirms that the monopole slot can provide a resonant path for the resonant mode at around 1750 MHz. Clearly shown in Fig.3 (d) strong surface current is distributed on the open-end slot, which demonstrates that the open-end slot makes the main contribution to the 2150 MHz resonance.

Effects of some key design parameters are also studied. The simulated return loss as a function of the length *S* defined as the length of Part1 and varied from 71 to 75 mm is shown in Fig.4. Controlling the resonance at 900 MHz, the length *S* is quite important. With the increase of the length *S*, the resonant modes are shifting towards lower frequencies. Hence, the value of *S* should be tuned accordingly and it has been finally optimized as 73 mm. Part1 and Part2 have similar structures and working mechanism, thus here only Part1 is discussed.

According to the discussions in Section II, the upper-band resonances are mainly controlled by the length of the two L-shaped slots. As the monopole slot [6, 9,12] has been widely discussed, here only the open-end slot is investigated. Fig.5 shows the simulated return loss as a function of the length *L* of the open-end slot. Large effects on the upper band are seen when the length *L* varies from 50 to 56 mm. The resonant modes are moved to lower frequencies with an increase of the length *L*. For *L*=53 or 56 mm, the bandwidth is too narrow to cover the working frequencies. In this study, the optimum length of *L* is chosen as 50 mm to have full coverage of the upper band operation.

Fig.6 Photos of the manufactured slot antenna for for WWAN Metal-Rimmed smartphone applications: (a) Front side, (b) Back side

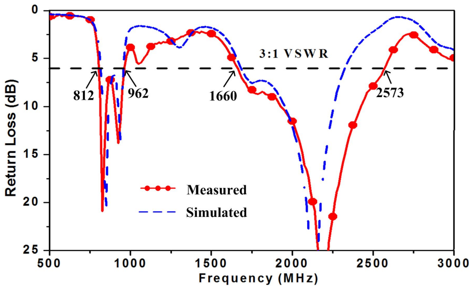


Fig.7 Simulated and measured return loss against frequency for the proposed antenna.

IV. RESULTS

The proposed slot antenna for metal-rimmed smartphone applications is manufactured and shown in Fig.6. Results of the measured and simulated return loss are presented in Fig.7. The simulation is done by using full-wave electromagnetic field simulation software HFSS version 13.0 and the experimental results are obtained on an Agilent N5247A vector network analyzer. As seen in Fig.8, the proposed slot antenna generates four resonances which are located at frequencies of 850 MHz, 900 MHz, 1750 MHz and 2150 MHz separately. With impedance matching better than 6 dB (3:1 VSWR) [11-14], the proposed antenna covers GSM850/900 /1800/1900/UMTS2100 bands well.

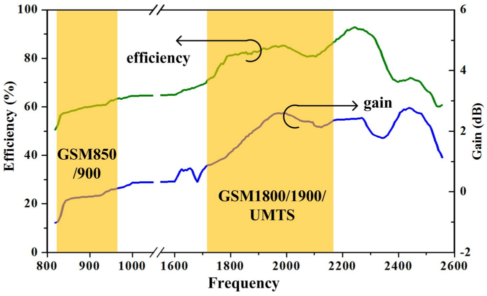


Fig. 10. Measured antenna gains and efficiencies across the operating bands for the proposed antenna.

The measured efficiencies and antenna gains of the fabricated antenna are presented in Fig. 9. For the lower band of GSM850/900 (824-960 MHz), the antenna gain varies from -1.02 to 0.89 dBi and the efficiency are about 50~62%, which are acceptable for practical metal-rimmed smartphone applications. For the desired upper bands of GSM1800/1900/ UMTS2100 (1710-2170 MHz), the obtained antenna gain ranges from 0.75 to 2.43 dBi and the corresponding total radiation efficiencies are better than 65%. As a result, the measured radiation characteristics of the proposed antenna within the operating bands satisfy the requirements for the smartphone systems.

V. CONCLUSION

A compact slot antenna for metal-rimmed smartphone applications is presented. By etching two slits and adding two grounded patches to divide the metal rim into four parts and optimizing the locations of the grounded patches and the slits reasonably, the metal-rim resonances are effectively utilized. In this case, the proposed antenna covers the penta-band operation (GSM850/900/GSM1800/1900/UMTS2100) with a small planar size of 10×50 mm². In addition, good radiation characteristics over the desired operating bands are obtained. The measured results including return loss, antenna gain, and efficiency are presented. With compact size occupation, wide band operation and metal-rimmed configuration, the proposed antenna is very promising for practical metal-rimmed smartphone applications.

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REFERENCES

[1] Q. Guo, R. Mittra, F. Lei , Z. Li , J. Ju and J. Byun, “Interaction between internal antenna and external antenna of mobile phone and hand effect,” *IEEE Trans. Antennas Propag.*, vol. 61, no. 2, pp. 862-870, 2013.

[2] B. Yuan, Y. Z. Cao, G. F. Wang, and B. Cui, “Slot antenna for metal-rimmed mobile handsets,” *IEEE Antennas Wireless Propag. Lett.*, vol. 11, no. 1, pp. 1334-1337, 2012.

[3] Y. L. Ban, Y. F. Qiang, Z. Chen, K. Kang and L. W. Li, "Low-profile narrow-frame antenna for seven-Band WWAN/LTE smartphone applications." *IEEE Antennas Wireless Propag. Lett.*, vol. 13, pp. 463-466,2014.

[4] C. K. Hsu and S. J. Chung, “Compact antenna with U-shaped open-end slot structure for multi-band handset applications,” *IEEE Trans. Antennas Propag.,* vol.62, no.2, pp. 929-932, 2014.

[5] P. Vainikainen, J. Ollikainen, O. Kivekäs, and I. Kelander, “Resonator-based analysis of the combination of mobile handset antenna and chassis,” *IEEE Trans. Antennas Propag.*, vol.50, no.10, pp. 1433-1444, 2002.

[6] M. Zheng, H. Y. Wang, and Y. Hao, “Internal hexa-band folded monopole/dipole/loop antenna with four resonances for mobile device,” *IEEE Trans. Antennas Propag.*, vol.60, no. 6, pp. 2880-2885, 2012.

[7] H. Wang, M. Zheng, and S. Q. Zhang, “Monopole slot antenna”, US patent 6 618 020 B2, Sep. 9, 2003.

[8] K. L. Wong, S. C. Sun, P. P. Li, “Simple printed penta-band WWAN monopole slot antenna for mobile phone application,” *Microw. Opt. Technol. Lett.*, vol. 53, no.6, pp. 1160-1162, 2011.

[9] Y. L. Ban , J. H. Chen, S. Yang, L. W. Li, and Y. J. Wu, “Low profile printed/WWAN octa-band LTE mobile phone can antenna using be used embedded parallel resonant structure,” *IEEE Trans. Antennas Propag.* Vol. 61, no. 7, pp. 3889-3894, 2013.

[10] C. H. Chang and K. L. Wong, “Bandwidth enhancement of internal WWAN antenna using an inductively coupled plate in the small-size mobile phone,” *Microw. Opt. Technol. Lett.*, vol. 52, no. 6, pp. 1247-1253, 2010.

[11] D. G. Kang and Y. Sung, “Compact hexa-band PIFA antenna for mobile handset applications,” *IEEE Antennas and Wireless Propag. Lett.,* vol. 9, pp.1127-1130,2010.

[12] K. L. Wong, P. W. Lin and C. H. Chang, “Simple printed monopole slot antenna for penta-band wireless wide area network operation in hte mobile handset,” *IEEE Trans. Antennas Propag.,* vol. 58, no. 10, pp. 3426-3431, 2010.

[13] Y. L. Ban, C. L. Liu, L. W. Li, J. Guo, and Y. Kang, “Small-size coupled-fed antenna with two printed distributed inductors for seven-band WWAN/LTE mobile handset,” *IEEE Trans. Antennas Propag.,* vol.61. no.11, pp5780-5784, 2013

[14] Y. K. Park and Y. Sung , “ A reconfigurable antenna for quad-band mobile handset applications,” *IEEE Trans. Antennas Propag.,* vol. 60, no. 6, pp. 3003-3006, 2012.