Dual-Wideband Open-Slot Antennas with Two Open Ends for the LTE Metal-Framed Tablet Device

Kin-Lu Wong, Chih-Yu Tsai, and Pei-Rong Wu
Department of Electrical Engineering
National Sun Yat-sen University
Kaohsiung, Taiwan

***Abstract*—The open-slot antennas are very suitable for the metal-framed tablet device applications. In this article, the open-slot antenna with two open ends and simple slot structure is demonstrated to be promising candidate for achieving dual-wideband LTE operation in the tablet device, such as the smartphone and tablet computer. Two design examples are shown. The first one is a linear open-slot antenna with two open ends for the smartphone application. The second one is a U-shape open-slot antenna for the tablet computer application. Both antennas can cover the 698~960 and 1710~2690 MHz bands for the LTE operation. The operating principles and antenna performances for such open-slot antennas are presented and discussed.**

***Keywords*—mobile antennas; open-slot antennas; LTE antennas; dual-wideband antennas; metal-framed tablet computers**

I. Introduction

The modern tablet devices such as the smartphone and tablet computer are becoming very slim in their appearance. For such slim tablet devices, a metal frame is usually added around the edges thereof to increase the robustness of the device [1]. However, the metal frame will cause significant effects on the traditional antennas such as the inverted-F antennas or monopoles embedded therein [2], [3]. On the other hand, the open-slot antenna [4] is especially suitable for such metal-framed tablet device application, mainly because the metal frame can serve as a part of the open-slot antenna and improve the impedance matching of the antenna as well.

In this article, the open-slot antennas with two open ends are demonstrated to be suitable for such metal-framed tablet device applications. Two such open-slot antennas are presented, including a linear open-slot antenna [5] and a U-shape open-slot antenna, both having two open ends. With two open ends, more slot resonant modes can be supported, which is an advantage over the traditional open-slot antenna with one open slot [6], [7]. With more slot resonant modes supported, wideband operation of the antenna will become easier to achieve. Both the linear and U-shape open-slot antenna in this study can achieve dual-wideband operation to cover the LTE operation in the 698~960 and 1710~2690 MHz bands. In addition, the U-shape open-slot antenna can have a low profile of 7 mm only, which is an advantage over the traditional antennas [2], [3]. Details of such open-slot antennas with two open ends are described. The operating principles and antenna performances are presented and discussed.

II. Linear Open Slot with Two Open Ends

Fig. 1 shows the geometry of the linear open-slot antenna with two open ends for the smartphone application. The antenna is denoted as Ant1 here. Ant1 is disposed on an FR4 substrate of relative permittivity 4.4, loss tangent 0.02, and dimensions 75 × 130 mm^2, which can be treated as the system circuit board of a 5.5-inch smartphone. Ant1 has a slot length of 75 mm and a narrow slot width of 2 mm, with its two open ends located at the two opposite side edges of the system ground plane printed on the system circuit board. A vertical metal plate of width 6 mm is present at the top edge of the system ground plane and near Ant1.

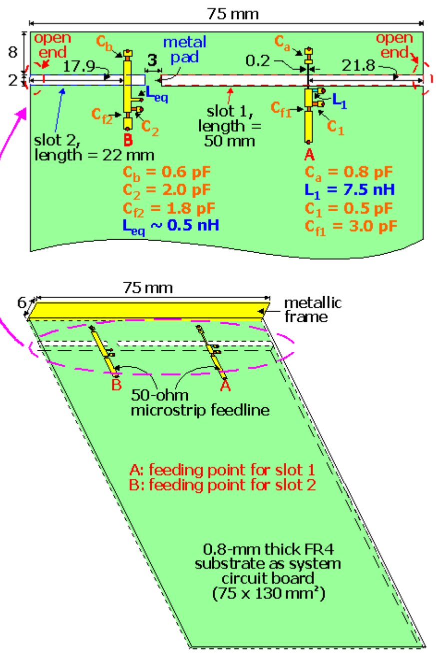

Fig. 1. Geometry of the linear open-slot antenna with two open ends for the LTE smartphone application (Ant1).

Ant1 can create two open-slot radiators (slot 1 and slot 2) by using a metal pad shorting at a proper position of the linear slot. Slot 1 can contribute a wide lower band to cover the 698~960 MHz band with the aid of a high-pass matching circuit. In addition, slot 1 can also generate a wideband higher-order resonant mode at about 2.5 GHz to combine with a wideband resonant mode excited by slot 2 to about 2 GHz to form a wide higher band to cover the 1710~2690 MHz band. The measured *S* parameters are shown in Fig. 2, in which it is seen that Ant1 can provide a dual-wideband operation to cover the desired LTE bands of 698~960 and 1710~2690 MHz bands (see the shaded frequency regions in the figure). The simulated results are obtained using the ANSYS HFSS version 15 [8].

The measured and simulated antenna efficiencies of Ant1 are also presented in Fig. 3. The radiation characteristics are measured in a far-field anechoic chamber. Agreement between the measurement and simulation is also seen. The antenna efficiency includes the mismatching losses. The measured antenna efficiency is about 55~63% and 60~95% in the lower and higher bands, respectively, which is acceptable for practical mobile communication application [9], [10]. More results will be shown in the presentation.

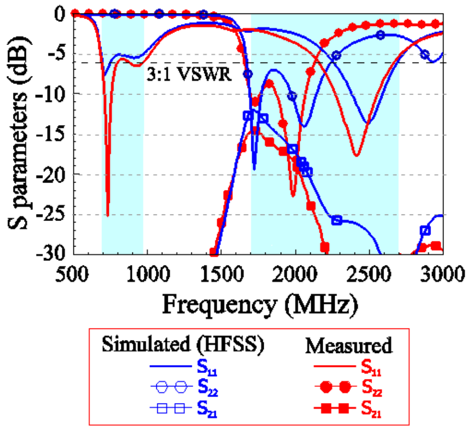

Fig. 2. Measured and Simulated *S* parameters for Ant1.

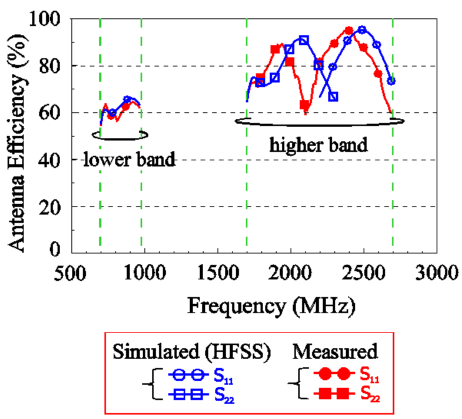

Fig. 3. Measured and simulated antenna efficiencies for Ant1.

III. U-SHAPE OPEN SLOT WITH TWO OPEN ENDS

A. Antenna Configuration and Operating Principle

The second promising open-slot antenna with two open ends is a U-shape open slot as shown in Fig. 4, which is denoted as Ant2 here. An enlarged view of the feeding network and the inverted-U strip (denoted as U-strip here) connecting across the U-slot are shown in Fig. 5(a). The U-slot antenna is disposed in the narrow spacing of 7 mm between the display panel and top edge of the metal-framed tablet computer. Note that in the study, the device ground plane is selected to have a size of 157 × 200 mm^2, which is a typical size for the popular tablet computer with a 9.7-inch display panel. In the experiment, the device ground plane is cut from a 0.2-mm thick copper plate. The display panel is not included in the simulation and experimental studies. Also note that the U-strip can be replaced by a chip inductor of 4.7 nH in this study, which is shown in Fig. 5(b). This indicates that the U-strip generally functions like a distributed inductor in the U-shape open-slot antenna.

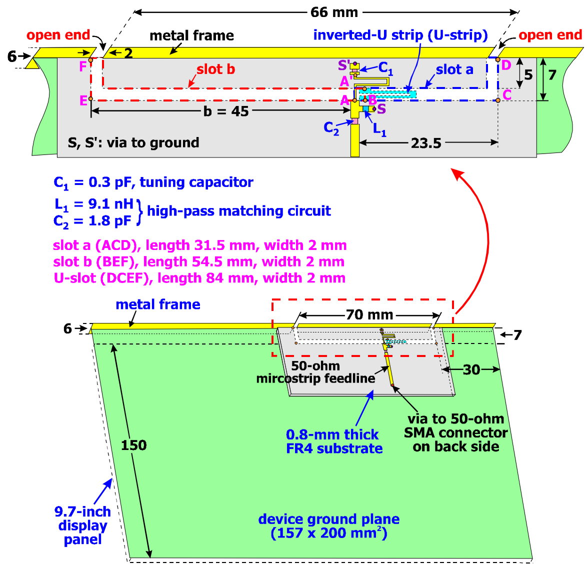

Fig.4. Geometry of the U-shape open-slot antenna with two open ends for the LTE tablet computer application (Ant2).

Ant2 has two slot openings of width 2 mm in the metal frame at the top edge of the device ground plane. Ant2 is fabricated on a 0.8-mm thick FR4 substrate of relative permittivity 4.4 and loss tangent 0.02. The ground plane of the U-slot antenna is connected to the device ground plane, which is also connected to the 6-mm wide metal frame as shown in the figure. Note that for practical cases, the metal frame is usually disposed at all the four edges of the metal-framed tablet computer. In the antenna structure shown in Fig. 4, only the metal frame at the top edge is added so as to simplify the study. The obtained results, however, are expected to be in general the same as the case with the metal frame added at all the four edges. Also note that one slot opening of the U-slot is disposed at about the center of the top edge, where the magnetic field distribution is generally maximum for the dipole-like chassis (device ground plane) mode, which can lead to good excitation of the desired slot resonant modes. Note that the optimum position of the slot opening is different from the selection of the feed position for the tradition planar inverted-F antenna (PIFA) [11].

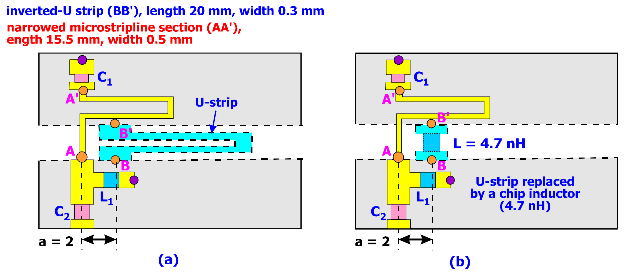

Fig. 5. (a) Enlarged view of the feeding network and the U-strip in Ant2 and (b) the case using a chip inductor replacing the U-strip.

The U-slot has a slot width of 2 mm and a slot length of 84 mm (section DCEF), while the length of the U-slot along the top edge is 70 mm. Through the excitation of the end-shorted 50-Ω microstrip feedline, the U-slot itself can generate a 0.5-wavelength slot resonant mode in the antenna's desired higher band. This excited 0.5-wavelength slot resonant mode in this study has strong electric fields at the two slot openings and a null electric field at about the slot center, which is different from the traditional 0.5-wavelength closed-slot resonant mode.

A 0.25-wavelength slot resonant mode can also be generated by slot a of length 31.5 mm (section ACD) in Ant2, which is the slot region between the slot opening at point D and the microstrip feedline as a virtual shorting [12]. The 0.5-wavelength U-slot mode and the 0.25-wavelength slot-a mode are formed into a very wide higher band for the antenna to cover the desired 1710~2690 MHz band.

By adding the U-strip across the U-slot, an additional open-slot radiator (slot b) of length 54.5 mm (section BEF) is formed. The U-strip (section BB′) has a length of 20 mm and a width of 0.3 mm. This U-strip functions like a distributed inductor (see Fig. 5), which leads to a lengthened resonant length of slot b. A similar result can be obtained by replacing the U-strip using a chip inductor of 4.7 nH, which will be discussed with the aid of Fig. 8 later. With the presence of the U-strip, a 0.25-wavelength slot resonant mode contributed by slot b can be generated at about 800 MHz, with small effects on the generation of the slot modes contributed by the U-slot and slot a. By further aided with the high-pass matching circuit of L_1 (9.1 nH) and C_2 (1.8 pF) in the microstrip feedline, the antenna's lower band can be widened to cover the desired 698~960 MHz band. Also note that the capacitor C_1 (0.3 pF) added near point S′ is used to compensate for the equivalent inductance owing to the end-shorting of the microstrip feedline. The narrowed strip section AA′ following the capacitor C_1 and passing across the U-slot has a length of 20 mm and a width of 0.5 mm, which can effectively fine-tune the impedance matching of the antenna.

B. Experimetal Results

Ant2 was fabricated and tested. Fig. 6 shows the measured and simulated return losses for the fabricated antenna. The measured data agree well with the simulated results. The impedance matching of the frequencies in the desired LTE bands is seen to be better than 6 dB (3:1 VSWR). The measured and simulated antenna efficiencies for the fabricated antenna are presented in Fig. 7. Agreement between the measurement and simulation is also generally seen. The measured antenna efficiencies are about 40~63% and 60~86% for the desired lower and higher bands, respectively, which are also acceptable for practical mobile communication applications [9], [10].

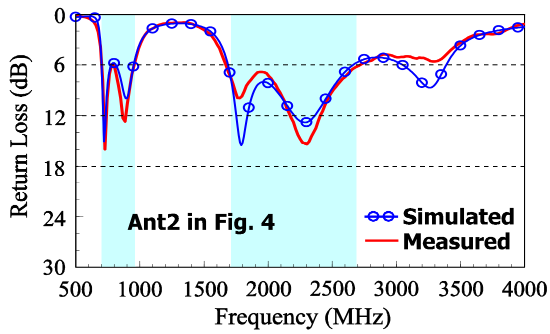

Fig. 6. Measured and Simulated S parameters for Ant2.

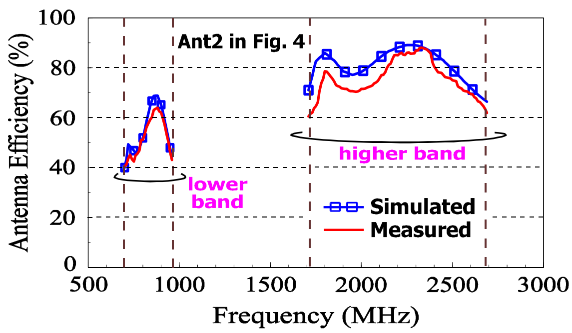

Fig. 7. Measured and simulated antenna efficiencies for Ant2.

C. U-strip Effects as a Distributed Inductor

Fig. 8 shows the simulated return loss for Ant2 and the case with a chip inductor replacing the U-strip connecting across the slot. It is seen that two cases show similar return loss results. This behavior suggests that the U-strip mainly functions like a distributed inductor, which creates a new open-slot radiator (slot b) and also causes small effects on the existing slot radiators of the U-slot and slot a. Hence, additional resonant modes can be obtained to achieve widened bandwidth for the antenna to cover the LTE operation in both the 698~960 and 1710~2690 MHz bands.

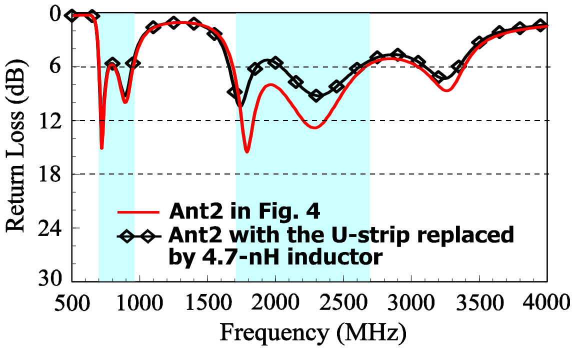

Fig. 8. Simulated return loss for Ant2 and the case with a 4.7-nH chip inductor replacing the U-strip across the slot.

IV. Conclusions

The open-slot antennas with two open ends have been shown to be promising for practical LTE applications in the modern slim smartphone and tablet computer. For covering the LTE operation in the 698~960 and 1710~2690 MHz bands, the linear open-slot antenna with two open ends shows a low profile of 10 mm to the top edge of the system ground plane of the smartphone. For the U-shape open-slot antenna with two open ends, it shows a very low antenna profile of 7 mm for covering the desired LTE dual-wideband operation. Both antennas have simple open-slot structures yet exhibits a dual-wideband LTE operation. From the obtained results, the presented open-slot antennas with two open ends are promising for applications in modern slim metal-framed smartphones and tablet computers, especially for those having a narrow spacing between the metal frame and the display panel thereof.

References

[1] Y. L. Ban, Y. F. Qiang, Z. Chen, K. Kang, and J. H. Guo, "A dual-loop antenna design for hepta-band WWAN/LTE metal-rimmed smartphone applications," *IEEE Trans. Antennas Propag.*, vol. 63, pp. 48-58, 2015.

[2] K. L. Wong and Z. G. Liao, "Small-size dual-wideband monopole antenna with inductive and capacitive feeding branches for long term evolution tablet computer application," *Microwave Opt. Technol. Lett.*, vol. 57, pp. 853-860, 2015.

[3] K. L. Wong and Z. G. Liao, "Passive reconfigurable triple-wideband antenna for LTE tablet computer," *IEEE Trans. Antennas Propag.*, vol. 63, 2015.

[4] H. Wang, M. Zheng, and S.Q. Zhang, "Monopole slot antenna," US Patent No. 6618020 B2, 2003.

[5] K. L. Wong and P. R. Wu, "Dual-wideband linear open slot antenna with two open ends for the LTE/WWAN smartphone," *Microwave Opt. Technol. Lett.*, vol. 57, pp. 1269-1274, 2015.

[6] C. I. Lin and K. L. Wong, "Printed monopole slot antenna for internal multiband mobile phone antenna," *IEEE Trans. Antennas Propag.*, vol. 55, pp. 3690-3697, 2007.

[7] K. L. Wong and L. C. Lee, "Multiband printed monopole slot antenna for WWAN operation in the laptop computer," IEEE Trans. Antennas Propag., vol. 57, pp. 324-330, 2009.

[8] http://www.ansys.com/products/hf/hfss/, ANSYS HFSS.

[9] K. L. Wong and M. T. Chen, "Small-size LTE/WWAN printed loop antenna with an inductively coupled branch strip for bandwidth enhancement in the tablet computer," *IEEE Trans. Antennas Propag.*, vol. 61, pp. 6144-6151, 2013.

[10] Y. L. Ban, S. C. Sun, P. P. Li, J. L. W. Li, and K. Kang, "Compact Eight-Band Frequency Reconfigurable Antenna for LTE/WWAN Tablet Computer Applications," *IEEE Trans. Antennas Propag.*, vol. 62, pp. 471-475, Jan. 2014.

[11] T. Y. Wu and K. L. Wong, "On the impedance bandwidth of a planar inverted-F antenna for mobile handsets," *Microwave Opt. Technol. Lett.*, vol. 32, pp. 249-251, 2002.

[12] N. Behdad and K. Sarabandi, "A multiresonant single-element wideband slot antenna," *IEEE Antennas Wireless Propag. Lett.*, vol. 3, pp. 5-8, 2004.