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SMALL-SIZE LTE/WWAN COUPLED-FED LOOP ANTENNA WITH BAND-STOP MATCHING CIRCUIT FOR TABLET COMPUTER

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ABSTRACT: *By combining the use of a coupling feed and a band-stop matching circuit, the proposed small-size loop antenna for the tablet computer application can operate at its quarter-wavelength mode as the lowest resonant mode and provide two wide operating bands (704–960 and 1710–2690 MHz) to cover the eight-band LTE/WWAN operation (LTE700/GSM850/900 and GSM1800/1900/UMTS/LTE2300/2500 bands). The loop antenna comprises a T-shape radiating feed, a coupled shorted strip, an antenna ground, and a band-stop matching circuit on the antenna ground. The antenna's metal pattern includes a printed pattern on a thin FR4 substrate of planar size 10 × 55 mm*^{2} *and a metal strip of size 4 × 55 mm*^{2} *formed a part of the coupled shorted strip and connected orthogonally to the printed pattern. The antenna's occupied volume and the required length of 55 mm along the top edge of the display ground are both the smallest among the internal LTE/WWAN antenna for the tablet or laptop computers that have been reported for the present. Detailed operating principle of the proposed antenna including the effects of the coupling feed using the T-shape radiating feed and the band-stop matching circuit for bandwidth enhancement is discussed.* © 2012 Wiley Periodicals, Inc. Microwave Opt Technol Lett 54:1189–1193, 2012; View this article online at wileyonlinelibrary.com. DOI 10.1002/mop.26765

Key words: *mobile antennas; tablet computer antennas; WWAN antennas; LTE antennas; band-stop matching circuit*

1. INTRODUCTION

To cover the existing mobile communication systems for the laptop or tablet computer applications, which mainly include the eight-band LTE/WWAN operation in the 704–960 and 1710–2690 MHz bands, several internal antennas have been reported [1–4]. To provide two wide operating bands for the LTE/WWAN operation, these reported internal antennas are required to occupy a volume of $4 \times 10 \times 80$ mm^3 [1], $4 \times 12 \times 70$ mm^3 [2], $4 \times 10 \times 70$ mm^3 [3], and $4 \times 10 \times 85$ mm^3 [4]. That is, the reported internal LTE/WWAN antennas require a length of at least 70 mm along the top edge of the display ground. To achieve a smaller size of the internal LTE/WWAN antenna for mobile devices remains a challenging task, owing to the very limited available space therein. This design issue is even more challenging in the tablet or laptop computers mainly because the system ground plane or the display ground is much larger compared to that of the mobile handset and generally, its chassis (ground plane) resonant mode cannot be generated to aid in enhancing the bandwidths of the antenna [5–12].

In this article, we present a promising design of the internal tablet computer antenna using the combined techniques of using a coupling feed and a band-stop matching circuit to cover the LTE/WWAN operation with a decreased antenna size. The antenna is a coupled-fed loop antenna [13] that operates at its quarter-wavelength mode as the lowest resonant mode [14, 15] and can provide two wide operating bands (704–960 and 1710–2690 MHz) to cover the eight-band LTE/WWAN operation (LTE700/GSM850/900 and GSM1800/1900/UMTS/LTE2300/2500 bands).

The use of a band-stop matching circuit which generally does not increase the occupied volume of the antenna and generates a parallel resonance [16] at about 1200 MHz, which results in a new resonance (zero reactance) occurred nearby and leads to a new resonant mode excited at about 950 MHz. This new resonant mode greatly enhances the bandwidth of the antenna's lower band and combines the quarter-wavelength mode of the coupled-fed loop antenna to cover the desired LTE700/GSM850/900 operation. The antenna's upper band is formed by the higher order resonant modes of the coupled-fed loop antenna and an additional resonant mode contributed by the coupling feed, which is a T-shape strip in the proposed design. The upper band shows a wide bandwidth of larger than 1 GHz to cover the desired GSM1800/1900/UMTS/LTE2300/2500 operation.

Owing to the proposed techniques of using a coupling feed and a band-stop matching circuit, the antenna requires a length of 55 mm along the top edge of the display ground of the tablet computer only. The antenna's metal pattern includes a printed pattern which can be disposed on a thin FR4 substrate of planar size 10×55 mm^2, and a metal strip of size 4×55 mm^2 which is connected orthogonally to the printed pattern on the substrate to form a part of the antenna's loop pattern. With comparison to the reported internal LTE/WWAN antenna for the tablet or laptop computers [1–4], the proposed antenna shows a smallest occupied volume for covering the LTE/WWAN operation. In this article, details of the proposed antenna are described. Effects of the coupling feed and the band-stop matching circuit for bandwidth enhancement of the proposed antenna are discussed.

2. PROPOSED ANTENNA

Figure 1 shows the geometry of the proposed LTE/WWAN coupled-fed loop antenna with a band-stop matching circuit. The loop antenna comprises a T-shape radiating feed, a coupled shorted strip, an antenna ground, and a band-stop matching circuit on the antenna ground. The antenna is mainly disposed on a

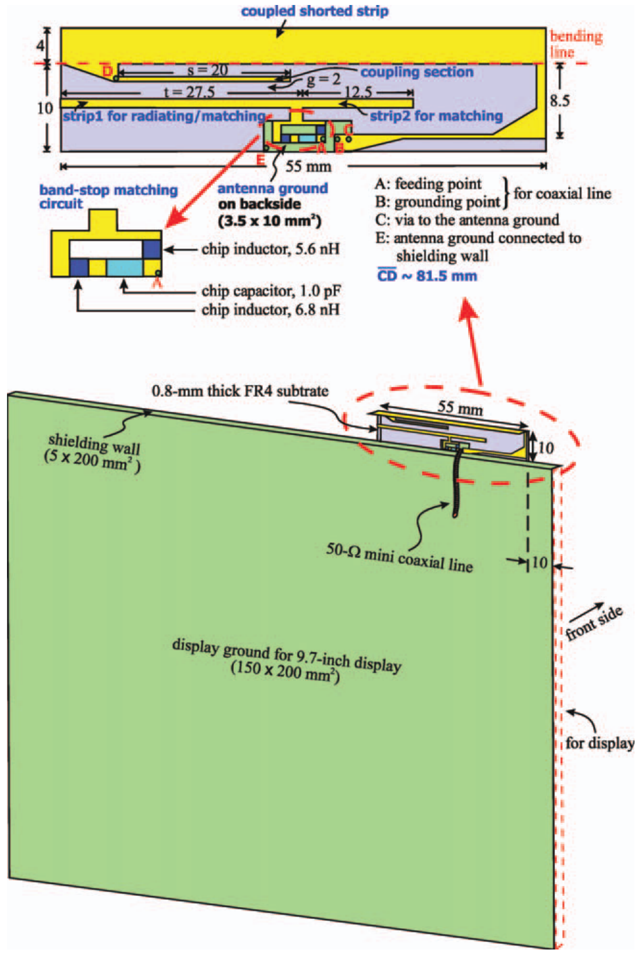

Figure 1 Geometry of the proposed LTE/WWAN coupled-fed loop antenna with a band-stop matching circuit for the tablet computer application. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

0.8-mm thick FR4 substrate of size 10 × 55 mm^2, relative permittivity 4.4, and loss tangent 0.024. On the back surface of the FR4 substrate, the antenna ground of size 3.5 × 10 mm^2 is printed. The antenna ground is connected at point E to the shielding wall of size 5 × 200 mm^2 at the top edge of the display ground, which is selected to have a size of 150 × 200 mm^2 to support a 9.7-in. display. The tablet computer with a 9.7-in. display is very common for the present market. The shielding wall at the top edge of the display ground can be used to accommodate the embedded antennas and may also decrease the possible isolation between the antennas and the display. However, note that the presence of the shielding wall will generally cause some degradation in the impedance matching of the antenna, owing to the possible coupling between the antenna and the nearby metal plate. In the experiment, the shielding wall and the display are cut from a 0.2-mm thick copper plate.

On the front surface of the FR4 substrate, the printed metal pattern mainly includes the T-shape radiating feed and the coupling section and shorted section of the coupled shorted strip. The middle section of the coupled shorted strip has a size of 4 × 55 mm^2 and is also cut from a 0.2-mm thick copper plate, which is connected orthogonally to the printed pattern on the FR4 substrate. The middle section and shorted section form the major part of the coupled shorted strip, which has a length of about 81.5 mm ($\overline{CD}$) and is coupled-fed through the coupling section (length s = 20 mm) and the coupling gap (g = 2 mm) by the T-shape radiating feed. With the coupling feed, the antenna can operate at its quarter-wavelength mode as the lowest resonant mode, which occurs at about 750 MHz in the proposed design.

Further, by disposing a band-stop matching circuit [16] which is formed by a 5.6-nH chip inductor in parallel connection with a 1.0-pF chip capacitor and a 6.8-nH chip inductor, a parallel resonance can be generated at about 1200 MHz, which is at the high-frequency tail of the quarter-wavelength loop mode. This parallel resonance can lead to a new resonance (zero reactance) generated at about 1000 MHz, which in turn generates a new resonant mode to combine the quarter-wavelength loop mode to provide a wide lower band for the antenna. This wide lower band can cover the desired 704–960 MHz for the LTE700/GSM850/900 operation. As no additional resonant elements are required to provide resonant modes to widen the lower-band bandwidth of the antenna, reduced size of the antenna is hence achieved.

Also, the T-shape radiating feed comprises a long strip (strip1) for radiating and matching and a shorter strip (strip2) for matching. The strip1 has a length t of 27.5 mm and is an efficient radiator [1, 17–19] to generate a resonant mode at about 2100 MHz, in addition to function as a coupling feed for the coupled shorted strip. Although the strip2 has a length of 12.5 mm and can improve the impedance matching of the excited higher order resonant modes of the coupled-fed loop antenna at about 1800 and 2550 MHz. The two higher order loop resonant modes and the one contributed by the strip1 form the wide upper band for the antenna. This wide upper band can cover the desired 1710–2690 MHz for the GSM1800/1900/UMTS/LTE2300/2500 operation.

Note that the coupled shorted strip is short circuited to the antenna ground at point C, and a 50-Ω coaxial line whose central conductor and grounding sheath are connected, respectively, to point A and point B as shown in the figure is used to feed the antenna. The proposed antenna was fabricated (see the photos shown in Fig. 2), and the results are presented and discussed in Section 3. Detailed operating principle of the antenna and a parametric study for some design dimensions of the antenna are presented in Section 4.

3. RESULTS OF FABRICATED ANTENNA

Figure 3 shows the measured and simulated return loss of the proposed antenna. The simulated results are obtained using the

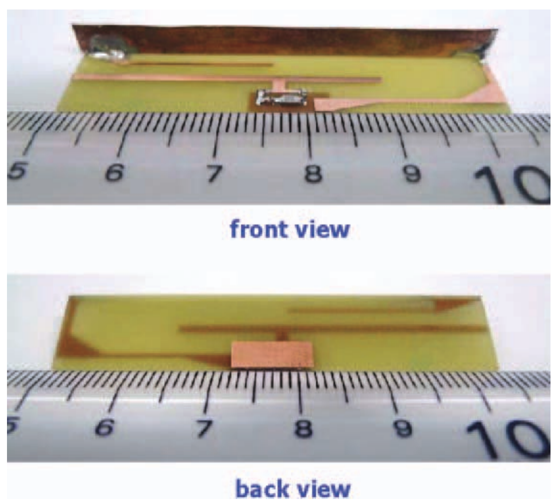

Figure 2 Photos of the fabricated antenna. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

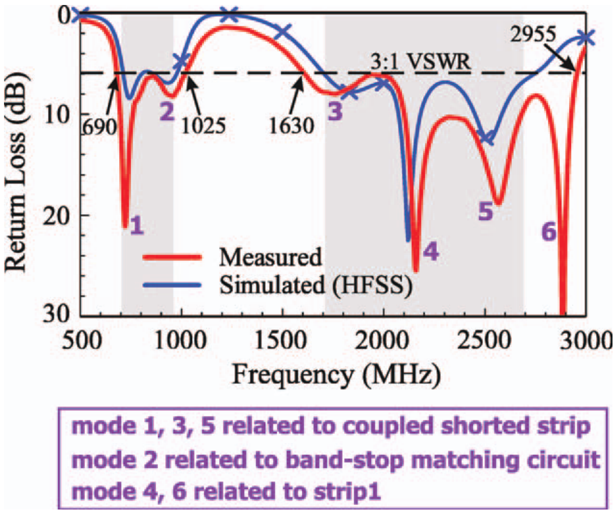

Figure 3 Measured and simulated return loss of the proposed antenna. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

three-dimensional (3D) full-wave electromagnetic field simulator high frequency structure simulator [20]. Agreement between the measured data and simulated results is observed. In the desired operating bands (the two shaded regions in the figure for 704–960 and 1710–2690 MHz), impedance matching for both the measured and simulated return loss is seems to be better than 3:1 VSWR or 6-dB return loss, a widely used design specification for the internal mobile device antenna for the WWAN and LTE operation [21–23]. For the lower band, there are two resonant modes excited, which are respectively contributed by the coupled shorted strip and the band-stop matching circuit, whereas for the upper band, it is generally formed by three resonant modes. The resonant modes at about 1800 and 2550 MHz are the higher order resonant modes of the coupled shorted strip as stated in Section 2. The resonant mode at about 2100 MHz, between the two higher order loop resonant modes, is contributed by the strip1 of the T-shape radiating feed. Also note that the resonant mode at about 2900 MHz seen in the measured data is also contributed by the strip1, although in the simulation this resonant mode is less prominent as seen in the measurement.

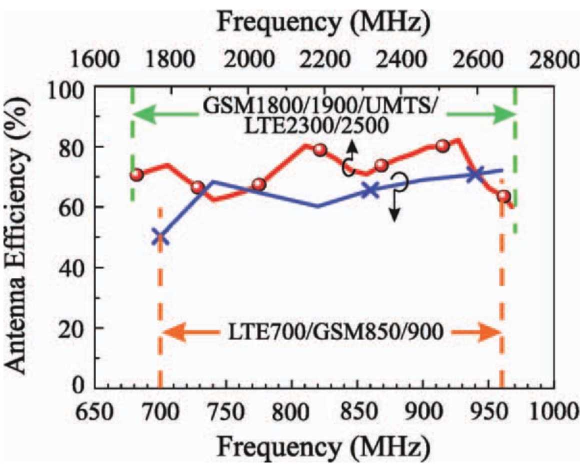

Figure 4 Measured antenna efficiency (mismatching loss included) of the proposed antenna. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

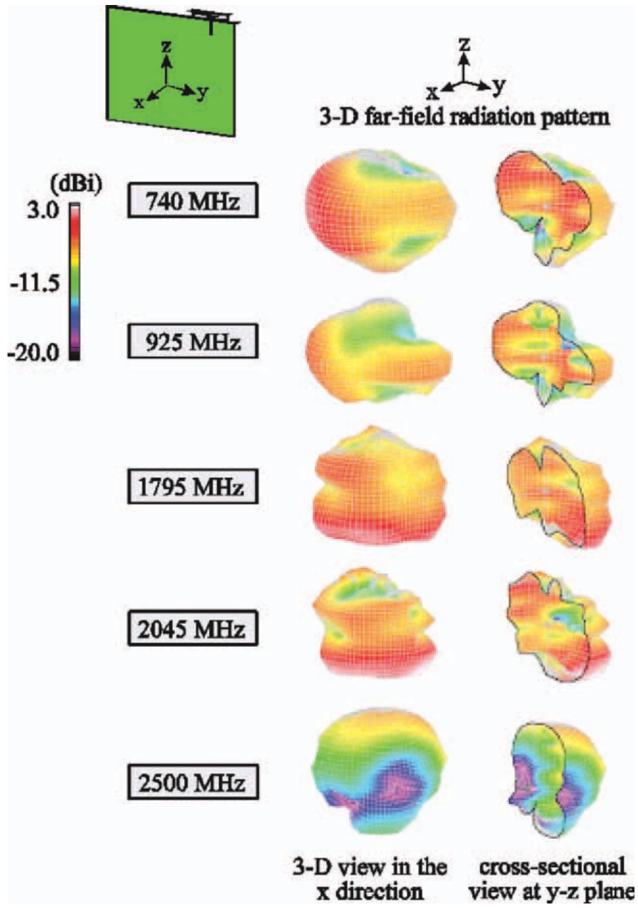

Figure 5 Measured 3D radiation patterns of the proposed antenna. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

Figure 4 shows the measured antenna efficiency of the proposed antenna. The measurement is conducted in a far-field anechoic chamber, and the measured antenna efficiency includes the mismatching loss. The antenna efficiency is about 50–70% and 60–80% in the antenna's lower and upper bands, respectively, which are acceptable for practical applications [24]. Figure 5 shows the measured 3D radiation patterns at five representative frequencies. At each frequency, the full 3D patterns seeing in the *x* direction and the half 3D patterns with the cross-sectional cut at the *y-z* plane are shown. More variations in the radiation patterns are seen at higher frequencies than at lower frequencies. This behavior is similar to the observations for the internal WWAN/LTE handset antennas [25–30], and is largely because there are more surface current nulls excited in the display ground at higher frequencies than at lower frequencies. This also suggests that although the display ground in the tablet computer does not dominate the radiation patterns of the embedded antenna as the system ground plane in the mobile handset does, the display ground still has large effects on the radiation patterns of the embedded antenna for the WWAN/LTE operation.

4. OPERATING PRINCIPLE AND PARAMETRIC STUDY

To analyze in detail the operating principle of the proposed antenna, Figure 6 shows the simulated return loss for the proposed antenna, the case with the strip1 only (Ref1), and the case with the strip1 and coupled shorted strip only (Ref2), and the case with the strip1, strip2, and coupled shorted strip only

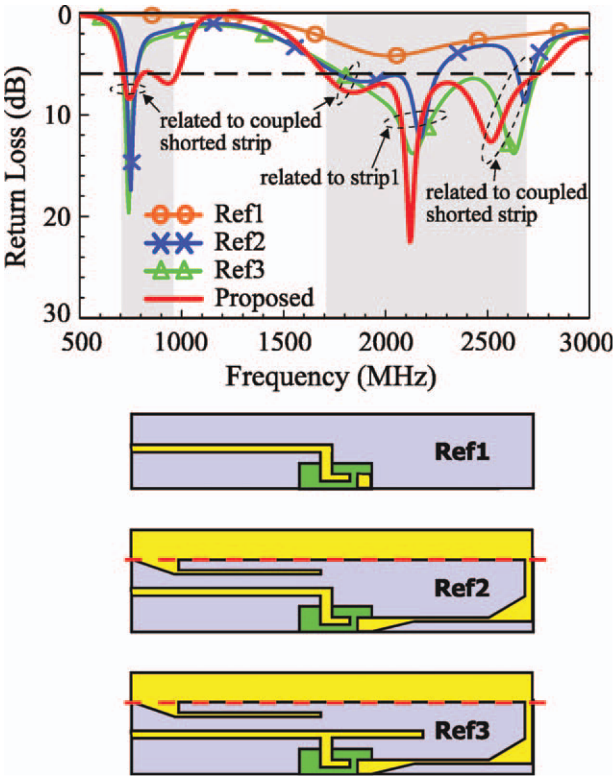

Figure 6 Simulated return loss for the proposed antenna, the case with the strip1 only (Ref1), and the case with the strip1 and coupled shorted strip only (Ref2), and the case with the strip1, strip2, and coupled shorted strip only (Ref3). [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

(Ref3). When there is the strip1 only, a resonant mode at about 2100 MHz is seen, which becomes more prominent as seen in Ref2, Ref3, and the proposed antenna. When the shorted strip is added to Ref2, the resonant mode at about 750 MHz for the antenna's lower band, and those at about 1800 and 2550 MHz for the antenna's upper band are generated. By further adding the strip2 to the strip1 to form the T-shape radiating feed, good impedance matching of the two resonant modes at 1800 and 2550 MHz is achieved. Then, by adding the band-stop matching circuit

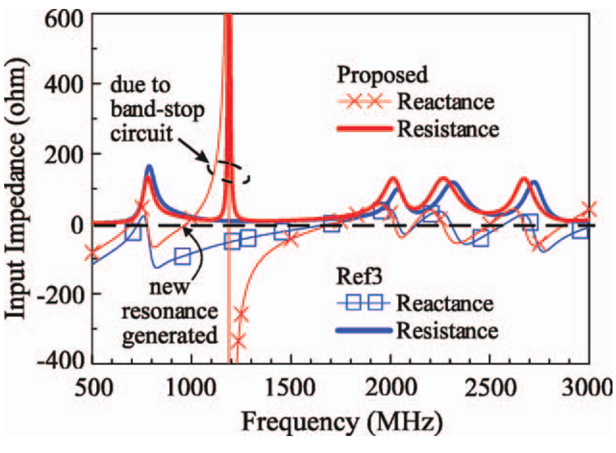

Figure 7 Comparison of the simulated input impedance for the proposed antenna and the case without the band-stop matching circuit (Ref3 in Fig. 6). [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

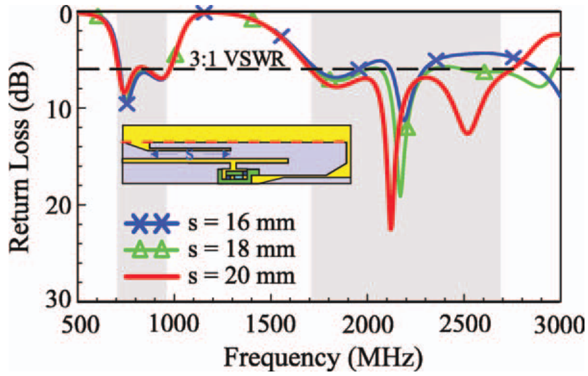

Figure 8 Simulated return loss as a function of the length *s* of the coupling section of the coupled shorted strip. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

to Ref3 to form the proposed antenna, it is clearly seen that a wideband resonant mode at about 950 MHz is generated, which makes the antenna capable of covering the desired 704–960 MHz band. This behavior can be explained more clearly from the comparison of the simulated input impedance for the proposed antenna and the case without the band-stop matching circuit (Ref3) in Figure 7. In the figure, it is clearly seen that a parallel resonance is generated at about 1200 MHz and a new resonance is occurred at about 1000 MHz which leads to the wideband resonant mode excited at about 950 MHz as shown in Figure 6.

Effects of the coupling feed are analyzed in Figures 8 and 9. The simulated return loss for the length *s* of the coupling section of the coupled shorted strip varied from 16 to 20 mm is presented in Figure 8. The major effect is seen in the resonant mode at about 2550 MHz. With a length of 20 mm, this resonant mode, a higher order mode contributed by the coupled shorted strip, is excited with good impedance matching and occurred in the desired upper band for the antenna. This behavior can be explained that the coupling section also accounts for a part of the resonant length of the coupled-fed loop antenna, especially at higher frequencies, and hence it will cause relatively large effects on the resonant modes at higher frequencies.

Results of the simulated return loss for the width *g* of the coupling gap varied from 1.0 to 2.0 mm are presented in Figure 9. In this case, large effects on the impedance matching of the resonant modes in both the lower and upper bands are seen. This indicates that the selection of a proper coupling-gap width is important in the proposed antenna to achieve good excitation

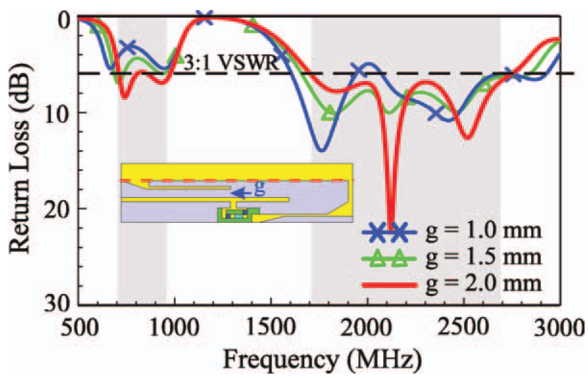

Figure 9 Simulated return loss as a function of the width *g* of the coupling gap. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

of the quarter-wavelength and higher order resonant modes of the proposed coupled-fed loop antenna. A proper width of 2.0 mm for the coupling gap is preferred in the proposed antenna.

5. CONCLUSIONS

A small-size coupled-fed loop antenna with a volume of $4 \times 10 \times 55$ mm^3 for the eight-band LTE/WWAN operation in the tablet computer has been proposed. The design techniques in achieving small size, yet wideband operation for the proposed antenna have been discussed in detail. The proposed antenna has also been fabricated and tested. Good radiation characteristics for practical applications have been observed. With the obtained results, the proposed antenna should be promising for practical tablet computer applications.

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NOVEL DUAL-BAND DESIGN OF PLANAR SLOT ARRAY ANTENNA FOR 4G LTE/WiMAX ACCESS POINTS

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ABSTRACT: *This article proposes a novel planar dual-band slot array antenna with high-gain operation for Long Term Evolution (LTE)/Worldwide Interoperability for Microwave Access (WiMAX) point. The impedance bandwidth, determined from VSWR $\leq$ 2.0, can reach about 18.3/14.6% (475/510 MHz) for the 2.6/3.5 GHz operating bands, respectively, which is covering the bandwidth specification for LTE*