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SMALL PLANAR INTERNAL WIRELESS WIDE AREA NETWORK TABLET COMPUTER ANTENNA

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Received 21 April 2011

ABSTRACT: *A planar penta-band wireless wide area network (WWAN) antenna with a small size of 12 × 35 mm² for application in the tablet computer as an internal antenna is presented. The antenna is printed on a 0.8-mm thick FR4 substrate on which a radiating portion and an antenna ground for accommodating a matching circuit are formed. The antenna is mounted at the top edge of the display ground which supports a 9.7-inch display for the tablet computer. The antenna's radiating portion comprises a feeding strip, a parasitic strip short-circuited to the antenna ground, and a printed distributed parallel resonant circuit. The latter two contribute a 0.25-wavelength dual-resonance mode at about 850 MHz for the GSM850/900 operation. The feeding strip generates a 0.25-wavelength resonant mode at about 1800 MHz to combine with a higher-order resonant mode at about 2200 MHz contributed by the shorted strip for the GSM1800/1900/UMTS operation. Additionally, the matching circuit on the antenna ground replacing the function of the matching circuit that is usually disposed on the system circuit board and provides a convenient means to adjust the impedance matching of the antenna to cover the desired operating bands. Owing to the new configuration of the antenna, the size of the proposed antenna is about the smallest among the internal WWAN antennas that have been reported for the tablet or laptop computer applications.* © 2011 Wiley Periodicals, Inc. Microwave Opt Technol Lett 54:426–431, 2012; View this article online at wileyonlinelibrary.com. DOI 10.1002/mop.26559

Key words: *mobile antennas; tablet computer antennas; wireless wide area network antennas; printed antennas; multiband antennas*

1. INTRODUCTION

The reported internal wireless wide area network (WWAN) antennas for the tablet computers or laptop computers are generally required to have a length of about 50 mm or larger to be mounted along the top edge of the display ground to achieve a wide lower band at about 900 MHz to cover the GSM850/900 operation [1–14]. The antenna length of about 50 mm or larger is generally required to achieve a large bandwidth for the WWAN antenna's lower band for tablet computer applications. For the present, the large lower-band bandwidth requirement for the GSM850/900 operation is a major design challenge for achieving a small internal WWAN antenna with a length of about or less than 40 mm for tablet computer applications.

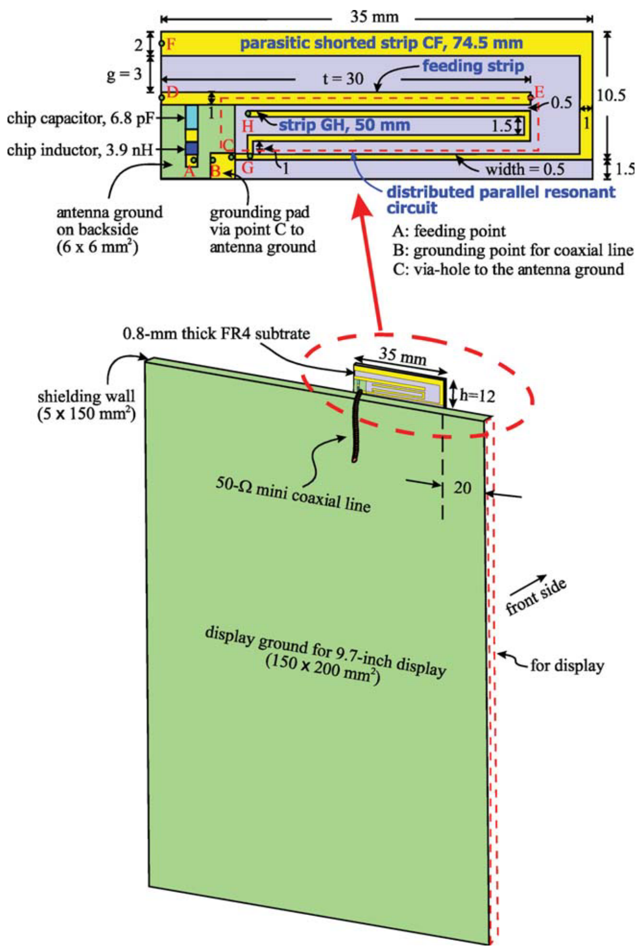

Figure 1 Geometry of the proposed planar WWAN tablet computer antenna. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

When a planar structure for the internal WWAN antenna is demanded for application in slim tablet computers with very thin thickness, the design challenge on achieving decreased size of the antenna is even bigger.

In this article, we present a new antenna structure especially suitable for the internal WWAN antenna to achieve decreased size for slim tablet computer applications. The antenna structure is to be disposed on a thin FR4 substrate and comprises an antenna ground and a radiating portion. For achieving penta-band WWAN operation in the GSM850/900/1800/1900/UMTS bands (824–894/880–960/1710–1880/1850–1990/1920–2170 MHz), the proposed antenna requires a small printed area of 12 × 35 mm² on a 0.8-mm thick FR4 substrate. The antenna size is about the smallest among the internal WWAN antennas that have been reported for the tablet or laptop computer applications [1–14].

In the proposed design, the antenna ground accommodates a matching circuit, which provides a convenient means to adjust the impedance matching of the antenna to cover the desired operating bands [15–17]. The radiating portion of the antenna comprises a feeding strip, a parasitic strip short-circuited to the antenna ground, and a printed distributed parallel resonant (DPR) circuit. The printed DPR circuit is an effective bandwidth enhancement technique, which generates an antiresonant mode or a parallel resonant mode at the high-frequency tail of the 0.25-wavelength resonant mode contributed by the shorted strip. Owing to the antiresonant mode, an additional resonance

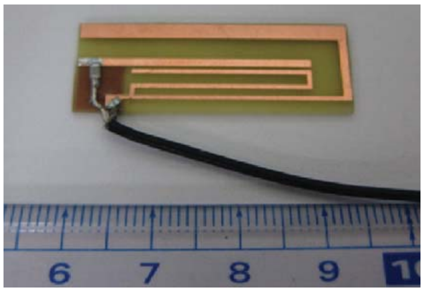

Figure 2 Photo of the fabricated antenna. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

(zero reactance) can occur at a frequency higher than the resonant frequency of the 0.25-wavelength mode contributed by the shorted strip. Details of the bandwidth enhancement using the printed DRP circuit technique are analyzed in the article. This greatly enhances the bandwidth of the lower band of the antenna at about 900 MHz, allowing it easy to cover the GSM850/900 operation. For the antenna's upper band, it is formed by a 0.25-wavelength mode contributed by the feeding strip and a higher-order resonant mode of the shorted strip. The upper band also has a large bandwidth to cover the GSM1800/1900/UMTS operation. The proposed antenna was also fabricated and tested. Details of the operating principle and obtained results of the antenna are presented and discussed.

2. PROPOSED ANTENNA

Figure 1 shows the geometry of the proposed planar internal WWAN tablet computer antenna. As shown in the figure, the antenna is printed on a 0.8-mm thick FR4 substrate of relative permittivity 4.4, loss tangent 0.02, and size 12 $\times$ 35 mm^2. The antenna is mounted along the edge of the shielding metal wall (size 5 $\times$ 150 mm^2) at the top edge of the display ground of size 150 $\times$ 200 mm^2. The display ground is for accommodating a 9.7-inch display for the tablet computer, which is commercially available on the market. Note that the antenna is not placed at the center of the shielding wall, but with a distance of 20 mm to one corner of the shielding wall. In this case, other internal antennas (not studied here) can also be possible to be mounted along the shielding wall, leading to more efficient integration of the internal antennas along the edges of the tablet computer.

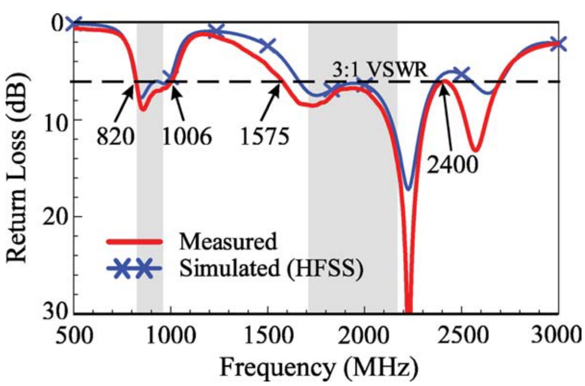

Figure 3 Measured and simulated return loss of the proposed antenna. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

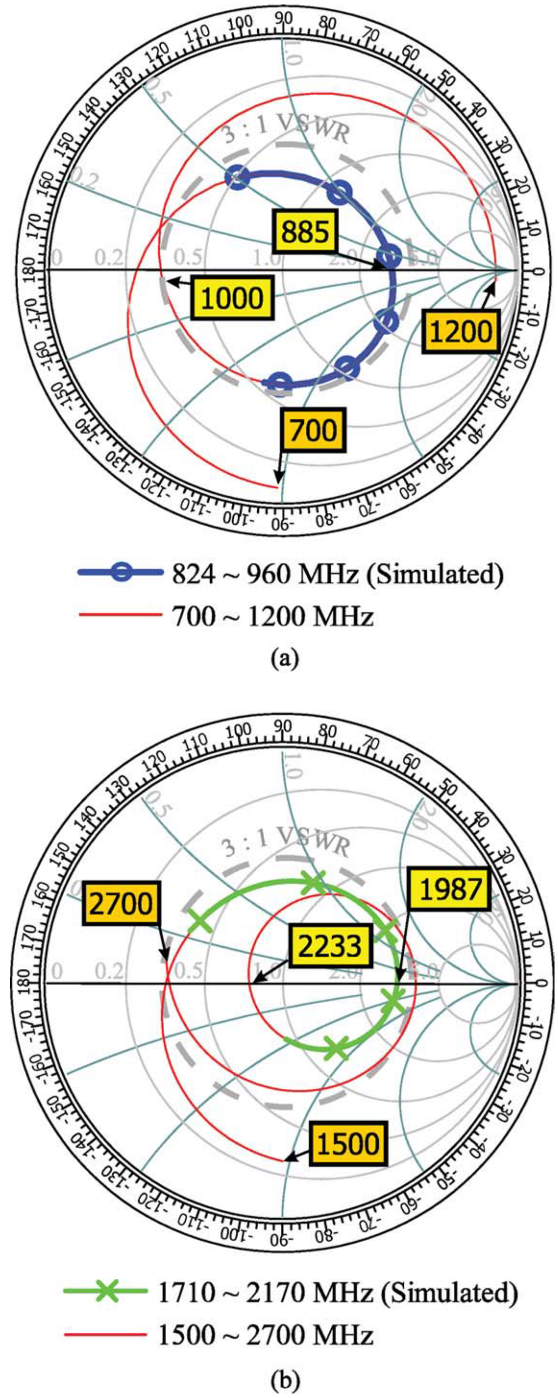

Figure 4 Simulated input impedance in Smith chart for the proposed antenna. (a) Frequency range of 700–1200 MHz. (b) Frequency range of 1500–2700 MHz. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

As shown in the figure and the photo of the fabricated antenna shown in Figure 2, in addition to the radiating portion of the antenna, there is an antenna ground of size 6 $\times$ 6 mm^2 disposed at one corner of the back side of the FR4 substrate. On the antenna ground region of the FR4 substrate, a series LC matching circuit of a chip capacitor 6.8 pF and a chip inductor 3.9 nH is disposed. This matching circuit makes it convenient to adjust the impedance matching of the antenna, especially the impedance matching for frequencies in the upper band of the

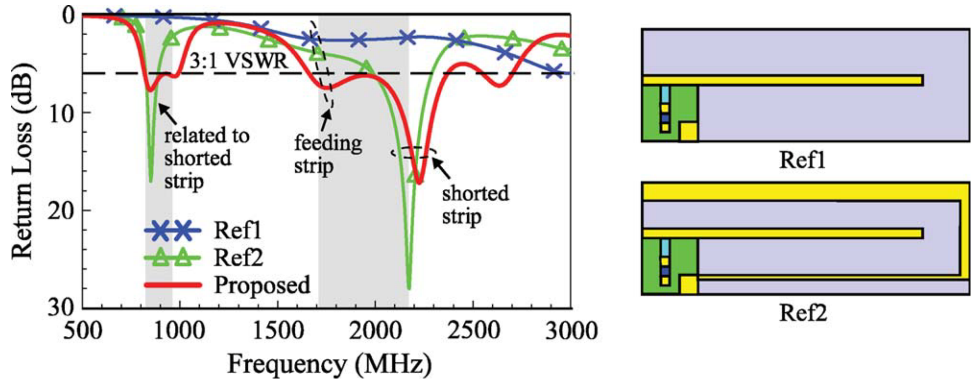

Figure 5 Comparison of the simulated return loss for the proposed antenna, the case with the feeding strip only (Ref1), and the case with the feeding strip and parasitic shorted strip only (Ref2). [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

antenna. Effects of the matching circuit are analyzed in Figure 7 in Section 3.

The radiating portion of the antenna comprises a feeding strip, a parasitic shorted strip, and a DPR circuit. The feeding strip (section DE in the figure) has a length of 30 mm (t), which is connected to the series LC matching circuit and then to be fed by a 50-Ω mini coaxial line. The central conductor and outer grounding sheath of the coaxial line are respectively connected to point A and B on the antenna ground region of the FR4 substrate. Note that point B is at a grounding pad which is electrically connected to the antenna ground through a via-hole at point C. For practical tablet computer applications, the coaxial line is further connected to a transceiver module disposed on the back side of the display ground (not shown here). The feeding strip is used to generate a 0.25-wavelength resonant mode at about 1800 MHz.

The parasitic shorted strip (section CF) has a length of 74.5 mm and is short-circuited to the antenna ground through the grounding pad. The shorted strip is parasitically excited by the feeding strip and encircles the feeding strip to achieve a compact size for the antenna. The shorted strip can generate a 0.25-wavelength resonant mode at about 850 MHz and a higher-order resonant mode at about 2200 MHz. The latter can be combined with the resonant mode at about 1800 MHz contributed by the feeding strip to form the desired antenna's upper band to cover the GSM1800/1900/UMTS operation. As for the 0.25-wavelength resonant mode contributed by the shorted strip, it is generally of narrow bandwidth and cannot cover the desired antenna's lower band for the GSM850/900 operation, when the DPR circuit is not present.

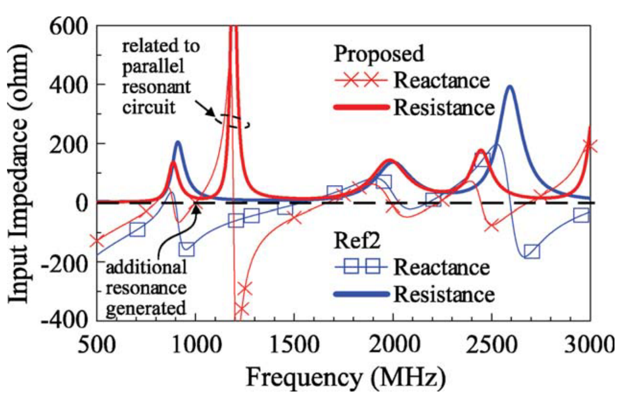

Figure 6 Comparison of the simulated input impedance for the proposed antenna and the case with the feeding strip and parasitic shorted strip only (Ref2 in Fig. 5). [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

To effectively enhance the antenna's lower-band bandwidth, the DPR circuit is printed in-between the feeding strip and the shorted strip. The parallel resonant circuit is formed by adding the strip GH of 50 mm, with its one end connected to the shorted strip at point G close to the grounding pad and its end section capacitively coupled through a 0.5-mm gap to the feeding strip. The capacitive coupling at the end section of the strip GH contributes a capacitance, while the strip GH itself contributes an inductance [18–20]. The contributed capacitance and inductance can be adjusted to result in a parallel resonance at a frequency slightly higher than the resonant frequency of the 0.25-wavelength mode of the shorted strip. In this study, the parallel resonance occurs at about 1200 MHz, and an additional resonance (zero reactance) is occurred at about 1000 MHz. This results in a dual-resonance excitation of the 0.25-wavelength mode of the shorted strip and greatly enhances the antenna's lower-band bandwidth for the GSM850/900 operation. Detailed effects of the DPR circuit are discussed in Figures 5 and 6 in Section 3.

3. RESULTS OF FABRICATED ANTENNA

Figure 3 shows the measured and simulated return loss of the fabricated antenna (see the photo shown in Fig. 2). Note that in the experimental study, the grounding pad of the antenna is connected to the shielding metal wall, and the antenna is tested along with the display ground shown in Figure 1. Good agreement between the measured data and the simulated results obtained using commercial simulation software high frequency structure simulator version 12 [21] is observed. Based on 3:1 VSWR (6-dB return loss), which is widely used as the design specification of the internal WWAN antenna [22–26], two wide operating bands are obtained. The lower and upper bands respectively cover the desired 824–960 and 1710–2170 MHz bands for the penta-band WWAN operation.

The simulated input impedance in Smith chart for the proposed antenna is also shown in Figure 4. In Figure 4(a), the input impedance for frequencies in the range of 700–1200 MHz is shown, and results show that there are two resonances (zero reactance) at 885 and 1000 MHz. The two resonances lead to the dual-resonance excitation seen in Figure 3 for the antenna's desired lower band, and the resonance at 1000 MHz is owing to the presence of the DPR circuit. Figure 4(b) shows the input

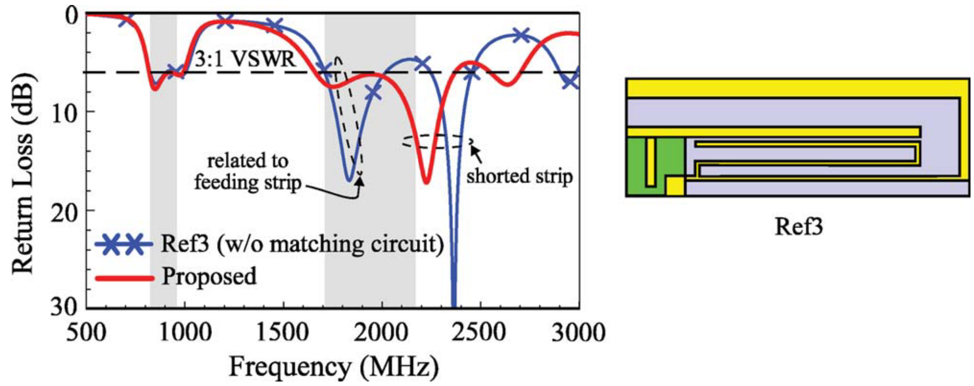

Figure 7 Comparison of simulated return loss for the proposed antenna and the case without the matching circuit (Ref3). [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

impedance for frequencies in the range of 1500–2700 MHz. Two resonances at 1987 and 2233 MHz are seen, which are related to the excited resonant modes in the antenna's desired upper band.

To analyze the operating principle of the antenna, Figure 5 shows a comparison of the simulated return loss for the proposed antenna, the case with the feeding strip only (Ref1), and the case with the feeding strip and parasitic shorted strip only (Ref2). From the results, it can be concluded that the resonant mode at about 1800 MHz is mainly contributed by the feeding strip, while the resonant modes at about 850 and 2200 MHz are mainly contributed by the parasitic shorted strip. Further, by adding the strip GH to Ref2 to form the proposed antenna, an additional resonance at about 1000 MHz is seen, which greatly enhances the lower-band bandwidth of the antenna.

To see more clearly, the effects of adding the strip GH to form a DPR circuit, Figure 6 shows a comparison of the simulated input impedance for the proposed antenna and the case with the feeding strip and parasitic shorted strip only (Ref2 in Fig. 5). Results clearly show that a parallel resonance is excited at about 1200 MHz, which greatly modifies the impedance matching of the frequencies of the high-frequency tail of the 0.25-wavelength resonant mode contributed

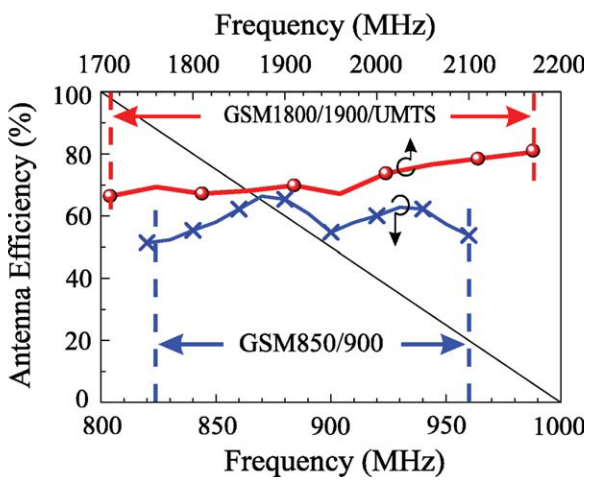

Figure 8 Measured antenna efficiency (mismatching loss included) of the proposed antenna. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

by the shorted strip. An additional resonance is then generated at about 1000 MHz, which leads to a dual-resonance excitation for the 0.25-wavelength resonant mode contributed by the shorted strip to achieve a wide lower band for the antenna.

To analyze the effects of the matching circuit disposed on the antenna ground region of the FR4 substrate, Figure 7 shows a comparison of simulated return loss for the proposed antenna and the case without the matching circuit (Ref3). Small effects on the lower band are seen. On the other hand, the matching circuit can effectively tune the impedance matching for frequencies in the upper band and result in good impedance of at least 6-dB return loss for frequencies in the desired upper band.

Figure 8 shows the measured antenna efficiency of the proposed antenna. The antenna efficiency includes the mismatching loss of the antenna. Over the GSM850/900 and GSM1800/1900/UMTS bands, the measured efficiency is respectively about 52–66% and 67–80%. The measured three-dimensional (3D) total-power radiation patterns are plotted in Figure 9. Three radiation patterns seen in different directions are shown at the center frequencies (859, 925, 1795, 1920, and 2045 MHz) of the five WWAN operating bands. Because of the relatively much larger size of the display ground (150×200 mm^2) compared to the system ground plane (generally about 110×60 mm^2 or smaller) of the mobile handset or smartphone [27–30], the radiation patterns at 859 and 925 MHz are no longer close to that of a traditional dipole antenna. At 859 and 925 MHz, the radiation patterns show dips or nulls in the azimuthal plane (*x*–*y* plane). At higher frequencies (1795, 1920, and 2045 MHz), the radiation patterns are different from those at lower frequencies, and more variations in the radiation patterns are seen. This characteristic is reasonable, since more excited surface current nulls are generally occurred in the display ground at higher frequencies than at lower frequencies.

4. PARAMETRIC STUDY

A parametric study for some design parameters is also conducted. Figure 10 shows the simulated return loss as a function of the length *t* of the feeding strip. Other parameters are the same as in Figure 1. Results for the length *t* varied from 24 to 30 mm are presented, and it shows that the first resonant mode in the antenna's upper band is shifted to higher frequencies with a decrease in the length *t*. This confirms that the resonant mode at about 1800 MHz is mainly contributed and can be controlled by the feeding strip. At the same time, since the variation in the

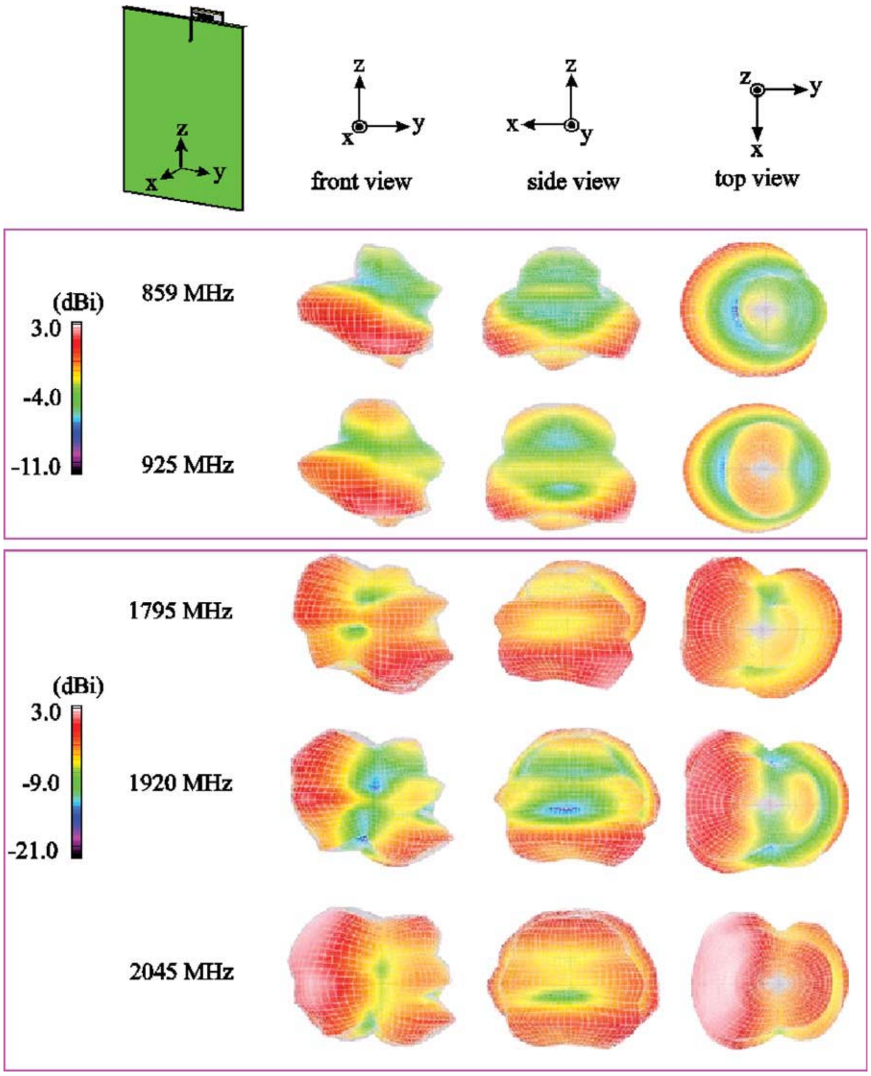

Figure 9 Measured 3D total-power radiation patterns of the proposed antenna. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

length t affects the capacitance between the strip GH and the feeding strip, the additional resonant mode at about 1000 MHz contributed by the DPR circuit is greatly affected. For the two resonant modes at about 850 and 2200 MHz, which are mainly contributed by the shorted strip, the effects are mainly on the impedance matching, and the central frequencies of the two

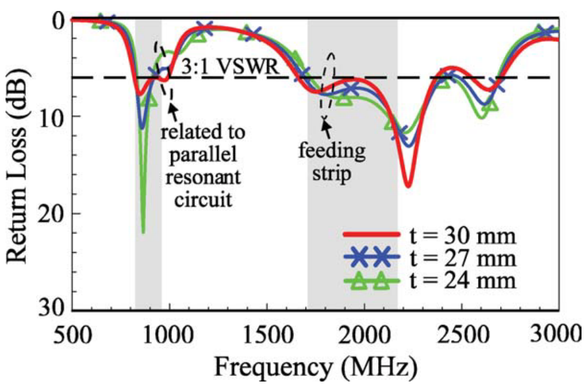

Figure 10 Simulated return loss as a function of the length t of the feeding strip. Other parameters are the same as in Figure 1. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

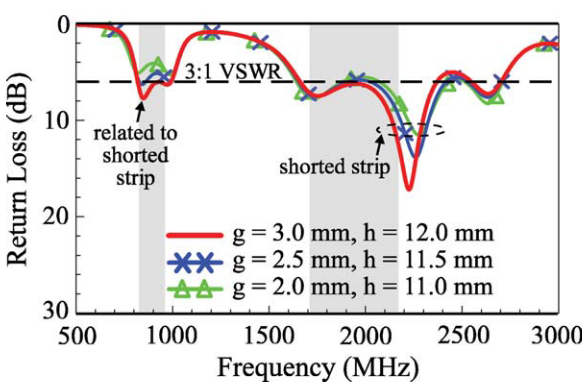

Figure 11 Simulated return loss as a function of the gap g between the feeding strip and parasitic shorted strip; antenna height $h = g + 9$ mm. Other parameters are the same as in Figure 1. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

resonant modes are almost not affected. This observation is also reasonable.

Figure 11 shows the simulated return loss as a function of the gap g between the feeding strip and parasitic shorted strip. In this study, the antenna height h is determined by $g + 9$ mm, with other dimensions the same as given in Figure 1. That is, the antenna height is decreased with a decrease in the gap g. Results show that the two resonant modes at about 850 and 2200 MHz contributed by the shorted strip are greatly affected, while the effects on the other modes are relatively much smaller. As the shorted strip is parasitically excited by the feeding strip through the gap g, the observed results are reasonable.

5. CONCLUSION

A small planar internal WWAN antenna with a size of 12×35 mm^2 for tablet computer applications is presented. The antenna has a planar structure and can be printed on a thin FR4 substrate at low cost. The proposed antenna successfully applies the bandwidth-enhancement technique of using a printed DPR circuit, which leads to the excitation of a dual-resonance mode for the antenna's lower band. A wide lower band is hence obtained for the GSM850/900 operation. A matching circuit disposed on the antenna ground of the proposed antenna has also been shown to be very helpful for tuning the impedance matching of the resonant modes in the antenna's upper band. With the DPR circuit and the matching circuit disposed on the dielectric substrate on which the antenna is printed, small size of the proposed WWAN antenna is obtained. It is expected that the bandwidth-enhancement techniques introduced in this study can be applied to the related internal tablet computer antennas to achieve small size yet wideband operation.

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