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UNIPLANAR COUPLED-FED PRINTED PIFA FOR WWAN OPERATION IN THE LAPTOP COMPUTER

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ABSTRACT: *In this article, a uniplanar printed PIFA (planar inverted-F antenna) with a coupling feed for application as an internal laptop computer antenna for penta-band WWAN (wireless wide area network) operation is presented. The proposed PIFA has a compact structure and can be easily printed on one side of a small 0.8-mm thick FR4 substrate of size 11 × 59 mm², making it very promising to be embedded inside the casing of the laptop computer, especially for the thin-profile laptop computer. With the coplanar coupling feed, the large inductive input reactance of the PIFA at around 900 MHz is compensated, and dual-resonance excitation for the antenna's lower band at about 900 MHz is obtained, which allows it to easily cover GSM850/900 operation. A wide operating band is also achieved for the antenna's upper band at about 1900 MHz, and a bandwidth of larger than 500 MHz is obtained to cover GSM1800/1900/UMTS operation. That is, the proposed PIFA covers all the five operating bands of GSM850/900/1800/1900/UMTS for WWAN operation. Details of the proposed PIFA are presented.* © 2008 Wiley Periodicals, Inc. Microwave Opt Technol Lett 51: 549–554, 2009; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.24084

Key words: *internal laptop computer antenna; PIFA; WWAN antenna; multiband operation; coupling feed*

1. INTRODUCTION

The internal WWAN antennas for covering GSM850/900/1800/1900/UMTS (824–894/890–960/1710–1880/1850–1990/1920–2170 MHz) operation are becoming a necessity for many modern laptop computers. By incorporating the internal WWAN antenna and the traditional 2.4/5 GHz internal WLAN (wireless local area network) antenna embedded in the laptop computers [1–6], ubiquitous wireless internet access can be achieved. Some internal WWAN antennas for laptop computer applications have also been reported in the published papers. The recently reported internal WWAN antennas include a dual-band open-loop antenna for GSM900/1800 operation [7] and a quad-band antenna with parasitic elements for GSM850/900/1800/1900 operation [8]. The former design can be printed on a planar structure; however, only two of the five desired operating bands are obtained. The latter design, although four operating bands are obtained, shows a three-dimensional structure and is not promising for the thin-profile laptop computer applications.

A design on combining the GSM900/1800 WWAN and 2.4/5 GHz WLAN internal antennas into a combo antenna with optimized isolation has also been studied [9]. Embedding the WWAN antenna in the USB (universal series bus) dongle for the laptop computer to provide wireless internet access is also a promising alternative [10, 11] for the internal WWAN antenna for the laptop computers. However, these available antenna designs cannot cover all the five desired operating bands of GSM850/900/1800/1900/UMTS for WWAN operation.

In this article, we propose a uniplanar coupled-fed printed PIFA for penta-band WWAN operation in the laptop computer. The proposed PIFA is easily printed on one side of a thin FR4 substrate at low cost and occupies a small area of 11 × 59 mm², making it very promising for the thin-profile laptop computer applications. The proposed PIFA comprises two separate radiating strips of different lengths supporting two quarter-wavelength resonant modes at about 900 and 1900 MHz. Owing to the use of the coupling feed [12] in the proposed PIFA, the large input inductance seen for the conventional PIFA of using a direct contact feed at around 900 MHz is greatly compensated, resulting in a much smaller input reactance level for the proposed PIFA. This behavior makes it possible for the excitation of a dual-resonance quarter-wavelength mode at about 900 MHz, which forms the antenna's lower band to cover GSM850/900 operation. In addition, a wideband quarter-wavelength mode at about 1900 MHz can also be obtained, which easily covers GSM1800/1900/UMTS operation. That is, all five operating bands for WWAN operation [13, 14] can be obtained for the proposed PIFA. Detailed design of the proposed uniplanar coupled-fed printed PIFA is described in this study, and results for the fabricated prototype are presented. Radiation performances of the proposed PIFA including the three-dimensional average antenna gain over all of space, which needs to meet the required specification (Yageo corporation, private communication, http://www.yageo.com.tw) for practical applications of the internal WWAN antenna in the laptop computers, are also discussed.

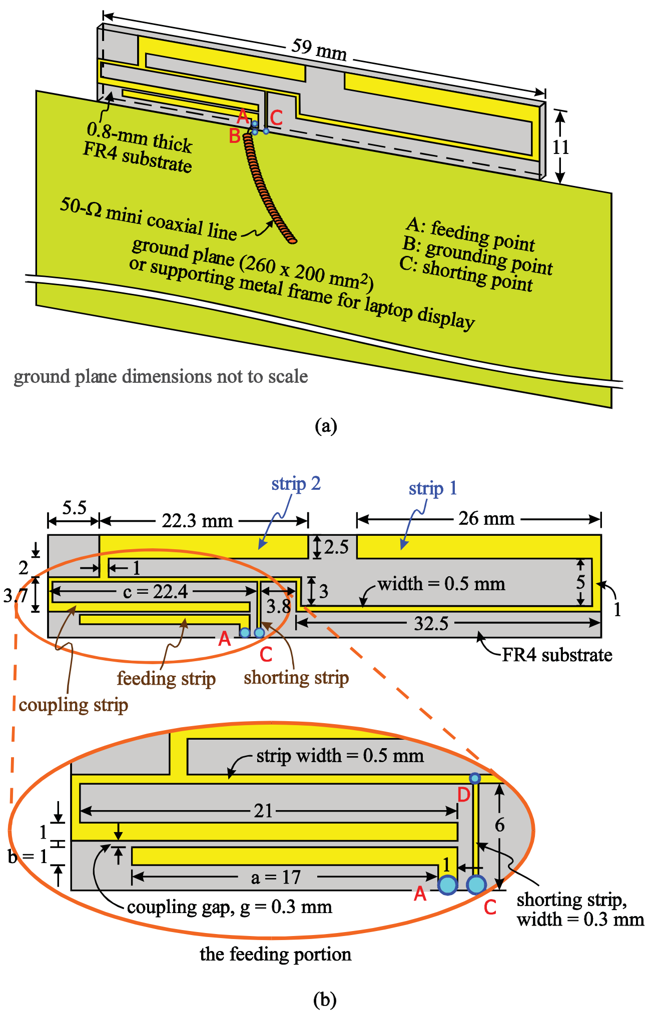

Figure 1 (a) Geometry of the uniplanar coupled-fed printed PIFA for GSM850/900/1800/1900/UMTS operation in the laptop computer. (b) Detailed dimensions of the metal pattern of the printed PIFA. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

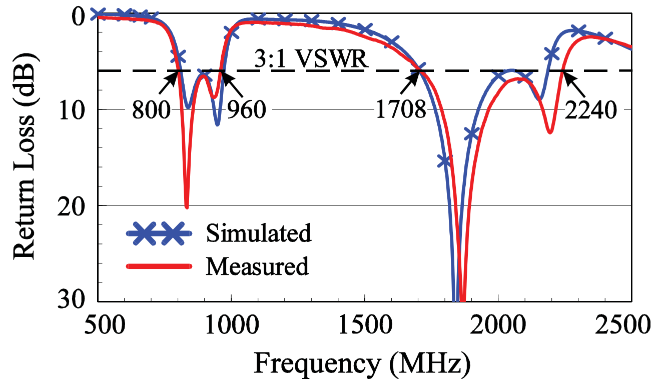

Figure 2 Measured and simulated return loss of the proposed PIFA. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

2. PROPOSED UNIPLANAR COUPLED-FED PIFA

Figure 1(a) shows the geometry of the proposed uniplanar coupled-fed printed PIFA for the laptop computer application. The proposed PIFA is printed on one side of a 0.8-mm thick FR4 substrate of area 11 $\times$ 59 mm^2 and is mounted at the center of the top edge of a large ground plane of length 260 mm and width 200 mm. The large ground plane is considered as the supporting metal

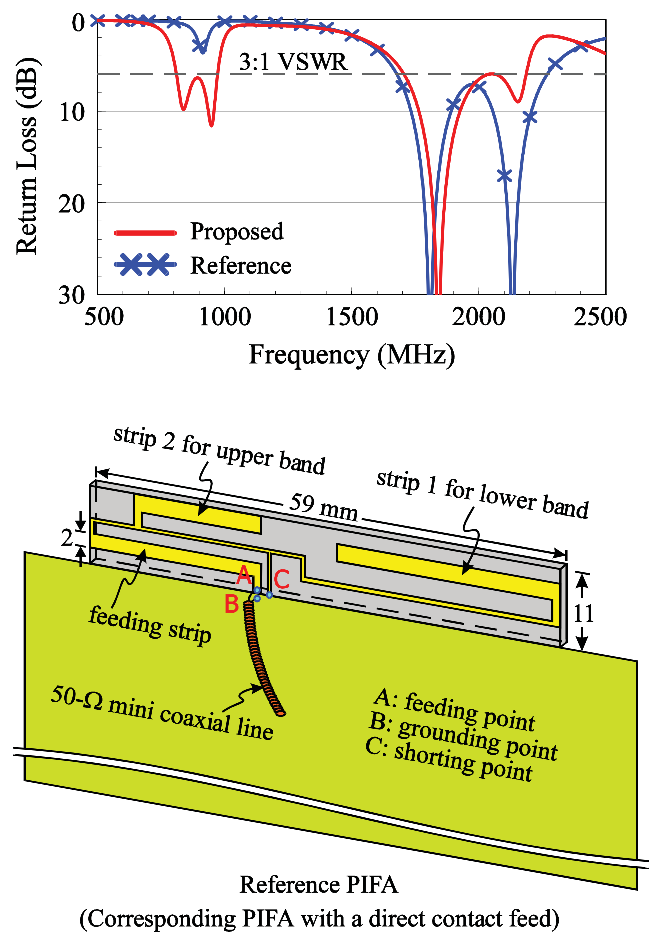

Figure 3 Comparison of the simulated return loss of the proposed PIFA and the reference PIFA (the corresponding PIFA with a direct contact feed). [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

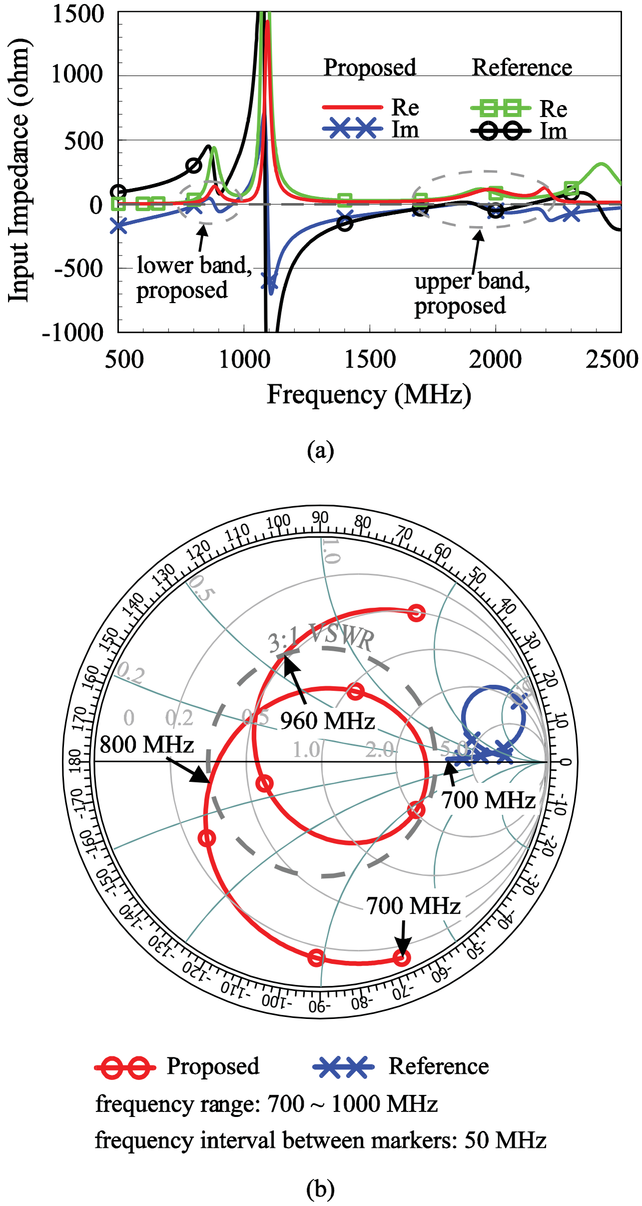

Figure 4 (a) Simulated input impedance versus frequency and (b) simulated input impedance on the Smith chart (frequency range 700 to 1000 MHz) for the proposed PIFA and the reference PIFA studied in Figure 3. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

frame for the display of the laptop computer, whose size selected here is reasonable for practical laptop computers. Detailed dimensions of the metal pattern of the proposed PIFA are shown in Figure 1(b). The PIFA mainly comprises a longer radiating strip (Strip 1), a shorter radiating strip (Strip 2), and the feeding portion. Strip 1 and Strip 2 support a resonant path of length close to about a quarter-wavelength at 900 and 1900 MHz, respectively. Also note that the open-end sections of the two radiating strips are widened to have a width of 2.5 mm, which is useful for achieving a more uniform excited surface current distribution at the open-end section of the radiating strip and is helpful for improving the impedance matching of the antenna to result in a wider bandwidth obtained [15, 16]. However, even with the widened end section, the excited quarter-wavelength mode at about 900 MHz for the conventional PIFA using a direct contact feed for the laptop computer application is difficult to achieve a wide bandwidth for covering GSM850/900 operation. This is mainly because the large ground plane connected to the conventional PIFA in the laptop computer cannot function as an efficient radiator, different from that for the mobile phone applications [17, 18].

The feeding portion mainly consists of a narrow shorting strip (length 6 mm and width 0.3 mm), a coupling strip (length 21 mm and width 1 mm), and a feeding strip (length a = 17 mm and width b = 1 mm). The shorting strip (section CD) is located at a distance of 22.4 mm (c) from the left edge of the printed PIFA. The shorting-strip location c is one of the major parameters for adjusting the impedance matching over the lower and upper bands of the proposed PIFA. One end (point A) of the feeding strip is the antenna's feeding point, and in between the feeding strip and the coupling strip, there is a coupling gap of width (g) 0.3 mm. By varying the dimensions (length a and width b) of the feeding strip and the width g of the coupling gap, the contributed capacitance of the feeding portion to the antenna's input impedance can be adjusted. The contributed capacitance can effectively compensate for the large input inductance seen for the conventional PIFA using a direct contact feed (see the detailed results shown in Figures 3 and 4 in the next section). In addition, owing to the presence of the coupling gap in the feeding portion, the excited surface currents in the feeding portion can be more uniformly distributed, which is also helpful in achieving improved impedance matching for the

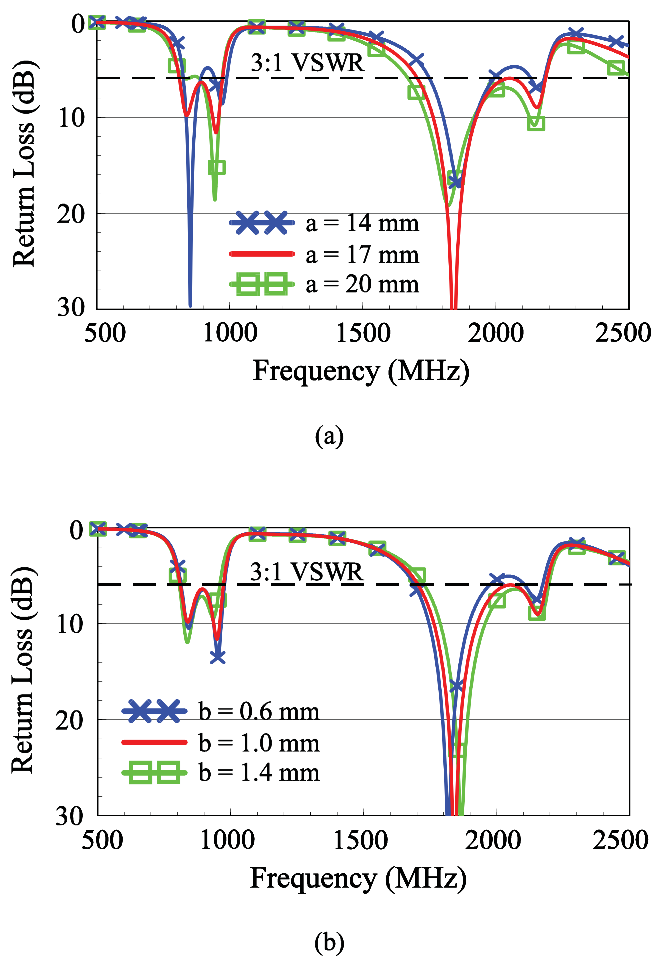

Figure 5 Simulated return loss as a function of (a) the length a and (b) the width b of the feeding strip in the antenna's feeding portion. Other parameters are the same as given in Figure 1. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

antenna [19]. The proposed coupling arrangement hence results in a dual-resonance excitation for the quarter-wavelength mode at about 900 MHz. This allows the proposed PIFA to have a wide lower band to cover GSM850/900 operation. A wideband quarter-wavelength mode at about 1900 MHz for the antenna's upper band can also be excited to cover GSM1800/1900/UMTS operation. Detailed effects of the parameters *a*, *b*, *c*, and *g* on the antenna performances will be analyzed in Figures 5 and 6 in the next section. Also note that for testing the proposed PIFA in the study, a 50-Ω mini coaxial line is used, whose central conductor and outer grounding sheath are connected to point A of the proposed PIFA and point C (the grounding point) near the top edge of the ground plane, respectively.

3. RESULTS AND DISCUSSION

Figure 2 shows the measured and simulated return loss of the proposed PIFA. Good agreement between the measured data and the simulated results obtained using Ansoft HFSS [20] is obtained. Two wide operating bands at about 900 and 1900 MHz are successfully excited. When compared to the corresponding PIFA using the direct contact feed, as shown in Figure 3, the results clearly indicate that the quarter-wavelength mode at about 900 MHz shows a dual-resonance excitation and a much wider operating band is obtained. The measured bandwidth defined by 3:1

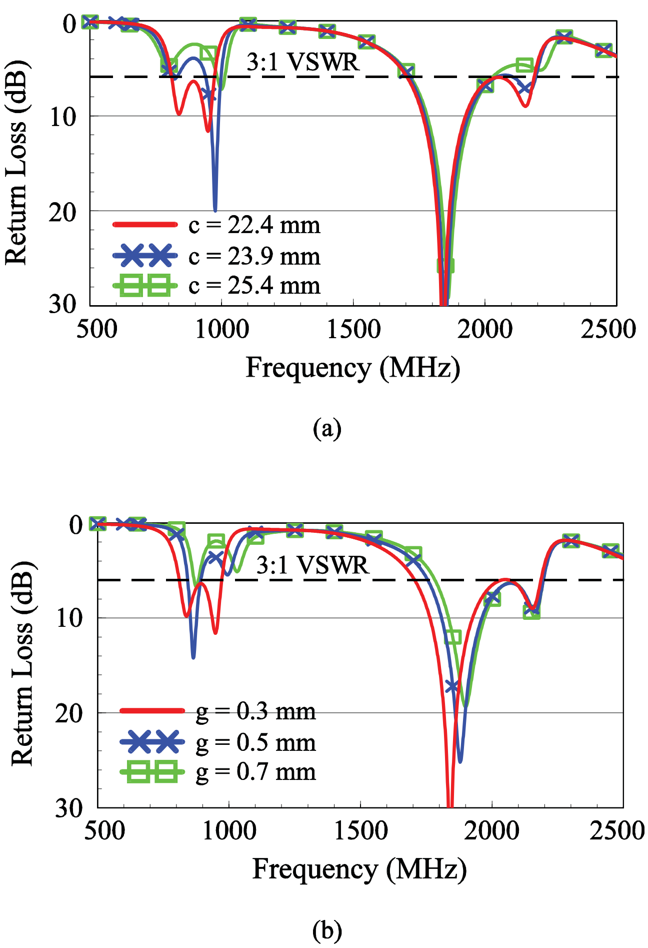

Figure 6 Simulated return loss as a function of (a) the location *c* of the shorting strip and (b) the width *g* of the coupling gap in the antenna's feeding portion. Other parameters are the same as given in Figure 1. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

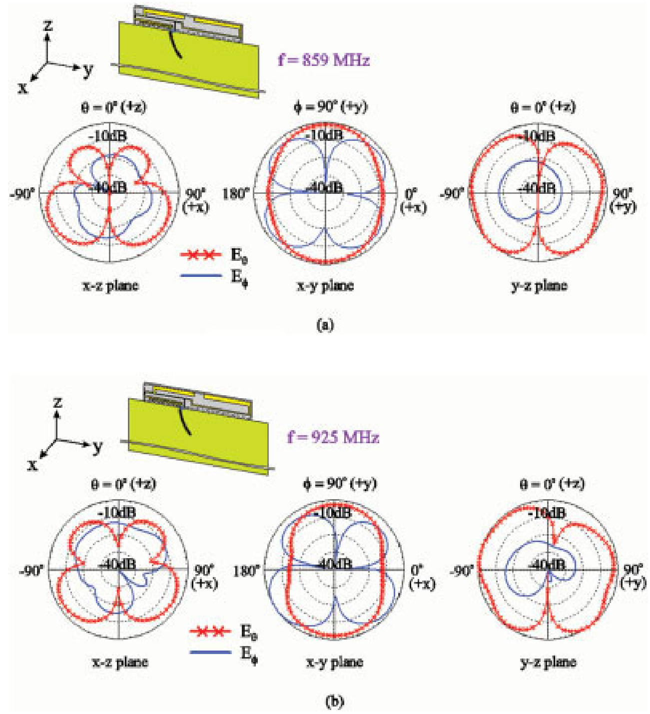

Figure 7 Measured radiation patterns at (a) 859 MHz and (b) 925 MHz for the proposed PIFA. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

VSWR (generally used for internal WWAN antennas in the mobile device for practical applications) reaches 160 MHz (800–960 MHz) for the antenna's lower band, which covers GSM850/900 operation. For the antenna's upper band at about 1900 MHz, the measured bandwidth is as large as 532 MHz (1708–2240 MHz), allowing it to cover GSM1800/1900/UMTS operation. The proposed PIFA hence covers all the five operating bands for WWAN operation.

Figure 4(a) shows the simulated input impedance versus frequency for the proposed PIFA and the reference PIFA studied in Figure 3. It is seen that at around 900 MHz, both the real part (Re) and imaginary part (Im) of the input impedance are decreased for the proposed PIFA, and good excitation of the quarter-wavelength mode for the antenna's lower band can be obtained. This can be seen more clearly in Figure 4(b), in which the simulated input impedance on the Smith chart for the frequency range of 700–1000 MHz is shown; along the impedance curve the frequency interval between markers is 50 MHz). With the use of the coupling feed in the proposed PIFA, dual-resonance excitation is obtained for the antenna's lower band, and a large bandwidth can be obtained. With the improvement in the impedance matching for frequencies over the antenna's lower band, good excitation of a wide operating band for the antenna's upper band can still be achieved for the proposed PIFA.

Figure 5 shows the effects of varying the length *a* and width *b* of the feeding strip in controlling the good excitation of the antenna's lower band. Results of the simulated return loss for the length *a* varied from 14 to 20 mm are given in Figure 5(a), while those for the width *b* varied from 0.6 to 1.4 mm are presented in Figure 5(b). From the comparison of the results in Figures 5(a) and 5(b), it can be seen that varying the length *a* is more effective in adjusting the two resonances excited at about 900 MHz to form a wide lower band for the antenna. At the same time, some variations in the antenna's upper band are also seen.

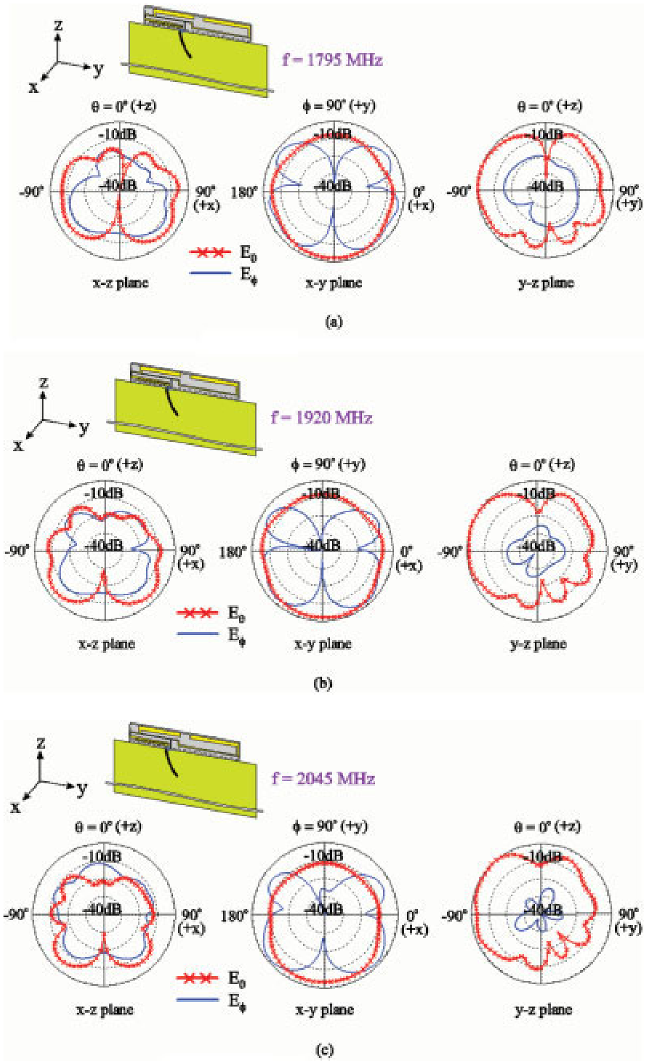

Figure 8 Measured radiation patterns at (a) 1795 MHz, (b) 1920 MHz, and (c) 2045 MHz for the proposed PIFA. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

More effective control in the impedance matching for frequencies over the antenna's lower and upper bands can be achieved by varying the location c of the shorting strip and the width g of the coupling gap. Results of the simulated return loss for the location c varied from 22.4 to 25.4 mm are shown in Figure 6(a), and those for the width g of the coupling gap varied from 0.3 to 0.7 mm are given in Figure 6(b). For both cases, large effects on the two excited resonances forming the antenna's lower band are seen. The location c of the shorting strip also shows strong effects on the second resonance in the antenna's upper band. In general, by adjusting the parameters a, b, c, and g in the antenna's feeding portion as shown in Figures 5 and 6, acceptable impedance matching for frequencies over the antenna's lower and upper bands can be obtained for the proposed PIFA to cover penta-band WWAN operation.

Figure 7 shows the measured radiation patterns at 859 and 925 MHz (central frequencies of the GSM850 and GSM900 bands) for the proposed PIFA. In the azimuthal plane (x-y plane), smooth variations in the vertical polarization E_θ over all of the ϕ angles are seen; this can provide good coverage for WWAN operation. Figure 8 plots the measured radiation patterns at 1795, 1920, and 2045 MHz (central frequencies of the GSM1800, GSM1900, and UMTS bands) for the proposed PIFA. Again, there are no dips or nulls for the E_θ radiation in the azimuthal plane (x-y plane), hence good coverage for WWAN operation can also be obtained.

Figure 9 shows the measured maximum antenna gain and simulated radiation efficiency for the proposed PIFA. Over the lower band shown in Figure 9(a), the maximum antenna gain is varied in a small range of about 0–0.9 dBi, and the radiation efficiency is about 55 to 65%. Figure 9(b) shows the results for the upper band. The antenna gain is varied from about 0.5 to 2.7 dBi, and the radiation efficiency ranges from about 68 to 95%.

Table 1 lists the three-dimensional (3D) average antenna gain over all of sphere, which is also an important factor required for practical applications of the internal WWAN antenna in the laptop computers (Yageo corporation), and its minimum value generally required for practical applications is also given in the table. From the results, the 3D average antenna gain of the proposed PIFA is much better than that required for practical applications. By further considering the power loss of the long mini coaxial line (generally about 70 mm) connected to the embedded antenna inside the laptop computer, which is estimated to be about 1.0 dB at 900 MHz and 2.0 dB at 1900 MHz, the proposed PIFA still shows better 3D average antenna gain than that required for practical laptop computer applications.

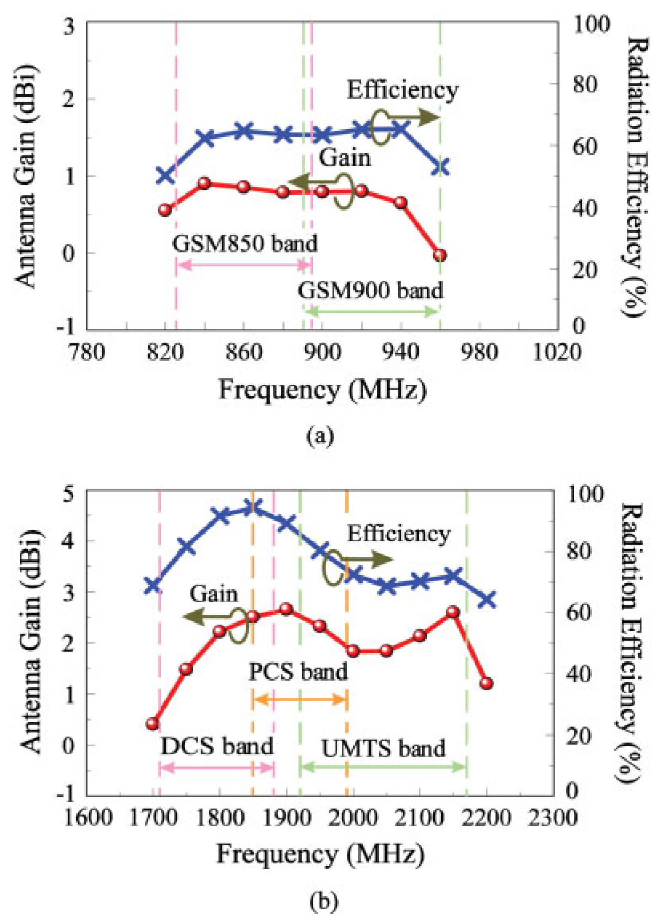

Figure 9 Measured maximum antenna gain and simulated radiation efficiency for the proposed PIFA. (a) The lower band for GSM850/900 operation. (b) The upper band for GSM1800/1900/UMTS operation. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

TABLE 1 Simulated Three-Dimensional (3D) Average Antenna Gain, Defined as the Average of the Antenna Gain Over All of Space, for the Proposed Antenna at the Central Frequencies of the Transmitting (Tx) Band and Receiving (Rx) Band in Each Operating System

3D average antenna gain (dBi)			Proposed PIFA (dBi)	Specification[a] (dBi)
GSM850	TxBand	837MHz	−2.1	−3.3
	RxBand	882MHz	−2.0	−4.0
GSM900	TxBand	903MHz	−1.9	−4.0
	RxBand	948MHz	−2.0	−6.0
GSM1800	TxBand	1747MHz	−0.9	−4.0
	RxBand	1842MHz	−0.2	−6.0
GSM1900	TxBand	1879MHz	−0.4	−3.3
	RxBand	1959MHz	−1.0	−4.5
UMTS	TxBand	1950MHz	−1.0	−4.5
	RxBand	2140MHz	−1.4	−6.0

The specification is the minimum 3D average antenna gain generally required for practical applications of the internal WWAN antenna in the laptop computers.

[a] Yageo Corporation, http:// www.yageo.com.tw.

4. CONCLUSION

A uniplanar coupled-fed printed PIFA, which is easy to fabricate and capable of penta-band WWAN operation in the laptop computer, has been proposed. The PIFA can be printed on a small-size thin FR4 substrate of 11×59 mm^2 and is especially suitable to be embedded inside the casing of the thin-profile laptop computer as an internal WWAN antenna. By using the coupling feed proposed in this design, two wide operating bands at about 900 and 1900 MHz have been successfully excited such that the antenna's lower and upper bands cover GSM850/900 and GSM1800/1900/UMTS operations, respectively. Thus, all the five operating bands for WWAN operation have been obtained for the proposed PIFA. Good radiation characteristics including the three-dimensional average antenna gain over all of space for frequencies over the five operating bands have also been observed. The proposed PIFA is promising as an internal WWAN antenna for the thin-profile laptop computer applications.

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A NOVEL P-SHAPED PRINTED MONOPOLE ANTENNA FOR RFID APPLICATIONS

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ABSTRACT: *In this article, a novel p-shaped printed monopole antenna is first proposed to operate simultaneously at the 2.45 and 5.8 GHz bands for radio frequency identification tag. Printed on a standard 1.6 mm FR4 substrate material, the printed monopole antenna has been demonstrated to provide an ultra wide 10 dB return loss bandwidth with satisfactory gains and radiation properties. The parameters which affect the performance of the antenna in terms of its frequency domain characteristics are investigated. A good agreement is achieved between the simulation and the experiment.* © 2008 Wiley Periodicals, Inc. Microwave Opt Technol Lett 51: 554–556, 2009; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.24083

Key words: *RFID; dualband; p-shaped; monopole antenna*

1. INTRODUCTION

In recent years, radio frequency identification (RFID) systems have become very popular in many service industries, purchasing