SMALL-SIZE MICROSTRIP-COUPLED PRINTED PIFA FOR 2.4/5.2/5.8 GHz WLAN OPERATION IN THE LAPTOP COMPUTER

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ABSTRACT: *With a microstrip-coupled feed, a small-size (9 × 10 mm²) printed PIFA capable of generating two wide bands to cover WLAN operation in the 2.4 GHz and 5.2/5.8 GHz bands for laptop computer application is presented. The PIFA is easily printed on a thin, inexpensive FR4 substrate at low cost. Although, the printed PIFA provides a resonant path of about 20 mm only (about 0.16 wavelength at 2.4 GHz), far less than the required resonant length for the conventional quarter-wavelength mode excitation and hence showing large inductive reactance at around 2.4 GHz, the applied microstrip-coupled feed in this study effectively compensates for it to result in a resonance (zero reactance) at about 2.4 GHz. A desired resonant mode for covering 2.4 GHz WLAN operation is thus excited for the proposed small-size printed PIFA. In addition, a higher-order resonant mode at about 5.5 GHz is also generated to cover the 5.2/5.8 GHz WLAN operation. Details of the proposed PIFA are described, and results of the fabricated prototype are presented and discussed.* Microwave Opt Technol Lett 51: 2072–2076, 2009; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/mop.24582

Key words: *internal laptop computer antenna; WLAN antenna; PIFA (planar inverted-F antenna); printed antenna; microstrip-coupled feed*

1. INTRODUCTION

Owing to the increasing numbers of the internal antennas to be embedded inside the laptop computer such as the notebook or netbook [1] for practical applications, the occupied size of the internal antennas is demanded to be as small as possible. For the internal WLAN (wireless local area network) antenna, which has become a standard embedded element in the general laptop computers, many promising dual-band or triple-band designs to cover the 2.4/5.2/5.8 GHz bands (2400–2484/5150–5350/5725–5875 MHz) have been reported in the published papers [2–14]. These antennas include using the slot element [2], the direct-fed metal-plate or printed PIFA (planar inverted-F antenna) [3–6], the monopole element [7–12], and the coupled-fed PIFA [13, 14]. However, it is noted that when mounted along the top edge of the system ground plane or supporting metal frame of the laptop display, most of these antennas [2–12] will occupy a length of about 20 mm or larger. Recently, it is demonstrated that by using the coupling feed [13, 14] for the printed PIFA, different from the cases of using the traditional direct feed [3–6], the occupied length of the internal WLAN antenna along the top edge of the system ground plane can be greatly decreased to be about 13 mm or less. This is mainly because the coupling feed can introduce additional capacitive reactance to compensate for the large inductive reactance caused by the reduced size or length of the PIFA for achieving the desired quarter-wavelength mode excitation.

In this article, we report another promising small-size (length 10 mm only) printed PIFA using a microstrip-coupled feed, different from the coupling-feed design used in Refs. 13, 14. The proposed microstrip-coupled printed PIFA requires a size of 9 × 10 mm² only and is suitable to be printed on a thin (0.8 mm here), inexpensive FR4 substrate at low cost. When the proposed PIFA is mounted at the top edge of the system ground plane of the laptop computer, it shows a height of 9 mm which is less than that (about 10 mm) of the internal WWAN antennas [15–19] and is promising for practical applications. Owing to the small size for the proposed PIFA, it can provide a resonant path of about 20 mm only (about 0.16 wavelength at 2.4 GHz), far less than the required resonant length for the conventional quarter-wavelength mode excitation. However, by applying the microstrip-coupled feed in the proposed PIFA, additional capacitive reactance can be introduced to compensate for the large inductive reactance caused by the small resonant length of the PIFA. In addition, a new resonance (zero reactance) can occur at about 2.4 GHz, which results in the successful excitation of a desired resonant mode covering the 2.4 GHz WLAN operation. A wideband higher-order resonant mode at about 5.5 GHz is also excited to allow the antenna to cover the 5.2/5.8 GHz WLAN operation. Detailed design considerations of the proposed printed PIFA are given in the article. Results of the fabricated prototype of the proposed PIFA are also presented and discussed.

2. PROPOSED MICROSTRIP-COUPLED PRINTED PIFA

Figure 1(a) shows the geometry of the microstrip-coupled printed PIFA for 2.4/5.2/5.8 GHz WLAN operation in the laptop computer, and detailed dimensions of the metal pattern of the printed PIFA are given in Figure 1(b). The PIFA is printed on a thin (0.8 mm) FR4 substrate of size 9 × 10 mm² and is mounted along the long edge of the top horizontal shielding metal plate (5 × 260

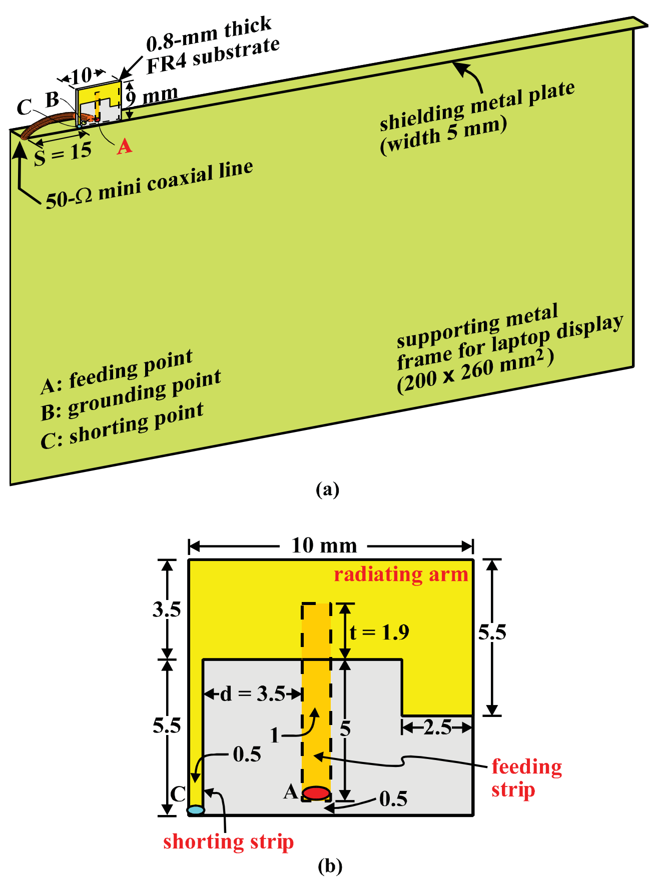

Figure 1 (a) Geometry of the microstrip-coupled printed PIFA for 2.4/5.2/5.8 GHz WLAN operation in the laptop computer. (b) Detailed dimensions of the metal pattern of the printed PIFA. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

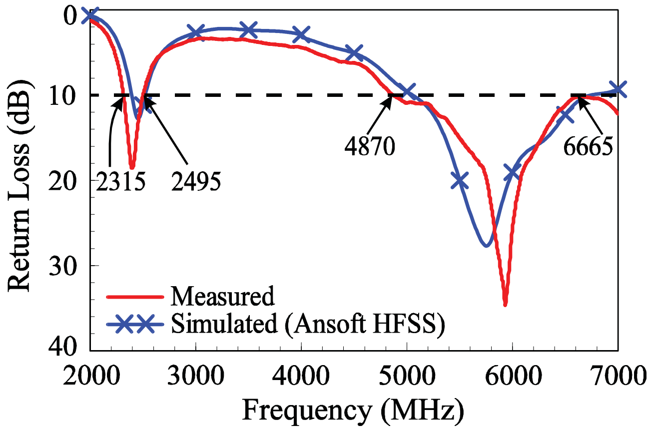

Figure 2 Measured and simulated return loss of the proposed PIFA. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

mm^2) connected to a large ground plane of length 260 mm and width 200 mm. The ground plane and the shielding metal plate form the system ground plane in the study and are fabricated from a 0.2-mm thick copper plate for the experiment. Below the shielding metal plate accommodates the display panel of the laptop computer. The system ground plane can be considered as the supporting metal frame for the laptop display in practical applications. Also note that with the geometry studied in Figure 1 the 50-Ω mini coaxial line used for feeding the PIFA is convenient to be placed on the top surface of the shielding metal plate and then follows along either side edge of the ground plane to the transceiver at the base of the laptop computer. In the experiment, the central conductor and outer grounding sheath are connected to point A (the feeding point) at the front end of the feeding strip and point B (the grounding point) at the shielding metal plate, respectively.

Along the long edge of the shielding metal plate, the PIFA is located at a distance *S* (15 mm in the study) to the side edge of the ground plane. The distance selected here is one of the promising positions for the internal WLAN antenna to be mounted along the long edge of the shielding metal plate in practical applications. The PIFA can also be mounted at various positions along the long edge of the shielding metal plate, and small effects on the antenna's impedance matching are seen. However, there are large effects on the antenna's radiation patterns, which will be discussed in the next section with the aid of Figures 6 and 7.

The proposed PIFA has a simple geometry and comprises a radiating arm, a shorting strip, and a feeding strip. Note that at point C, the shorting strip of length 5.5 mm and width 0.5 mm is connected to the shielding metal plate. Hence, through the shorting strip, the radiating arm is short-circuited. Limited to the small size of the proposed PIFA, the radiating arm and the shorting strip together can provide a resonant path of about 20 mm only, which is about 0.16 wavelength at 2.4 GHz and far less than the required resonant length for the desired quarter-wavelength mode excitation. In this case, when the conventional direct feed [20] is applied, the PIFA will show a very large inductive input reactance level at around 2.4 GHz, making it difficult to generate the desired resonant mode for the 2.4 GHz WLAN operation. By using the microstrip-coupled feed in the proposed PIFA, additional capacitive reactance can be introduced to compensate for the large inductive reactance seen at the feeding point (point A). In addition, the peak input resistance at around 2.4 GHz can also be greatly decreased to be close to 50 Ω. This behavior makes it possible for the proposed PIFA to generate a desired resonant mode for the 2.4 GHz WLAN operation. In addition, a higher-order resonant mode at about 5.5 GHz can also be successfully excited for the proposed PIFA to cover the 5.2/5.8 GHz WLAN operation. Fine-tuning of the impedance matching for the two desired resonant modes at 2.4 and 5.5 GHz can be obtained by adjusting the position *d* (3.5 mm here) and tuning length *t* (1.9 mm here) of the feeding strip in the proposed design. Detailed effects of tuning the impedance matching of the proposed PIFA are discussed in Figure 4 in the next section.

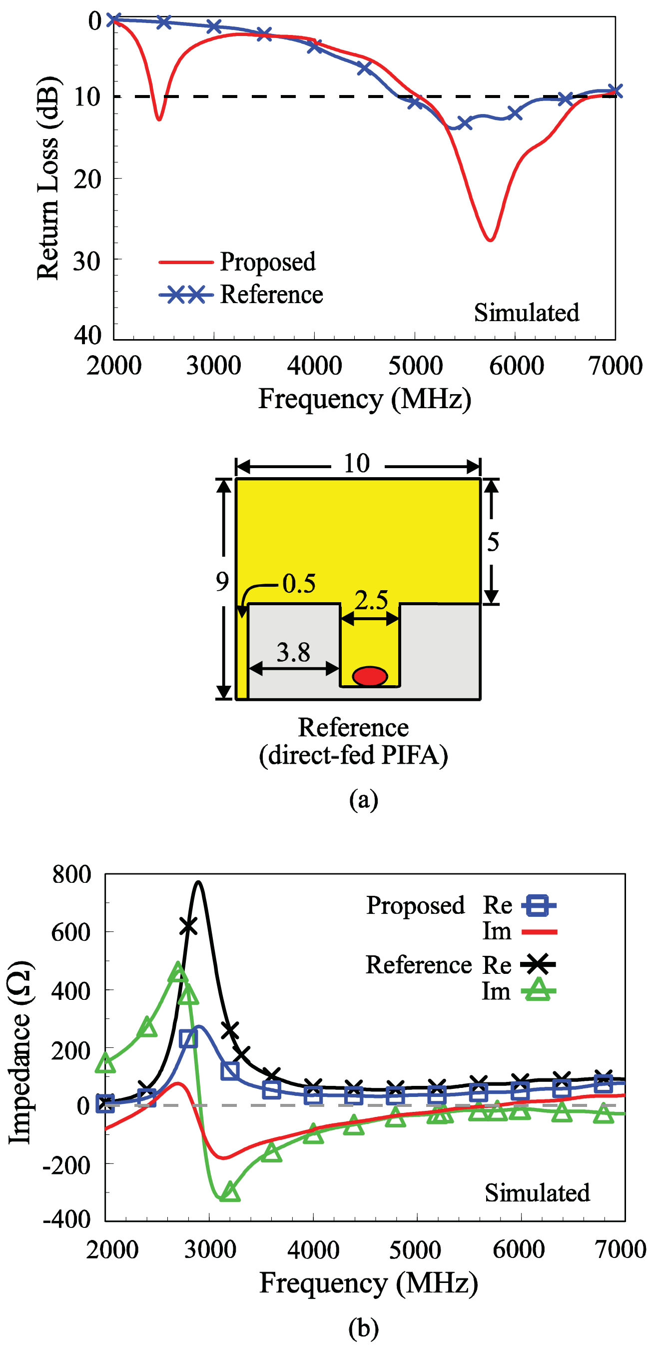

Figure 3 Comparison of (a) the simulated return loss and (b) the simulated input impedance of the proposed PIFA and the reference PIFA (the corresponding traditional PIFA with a direct feed). [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

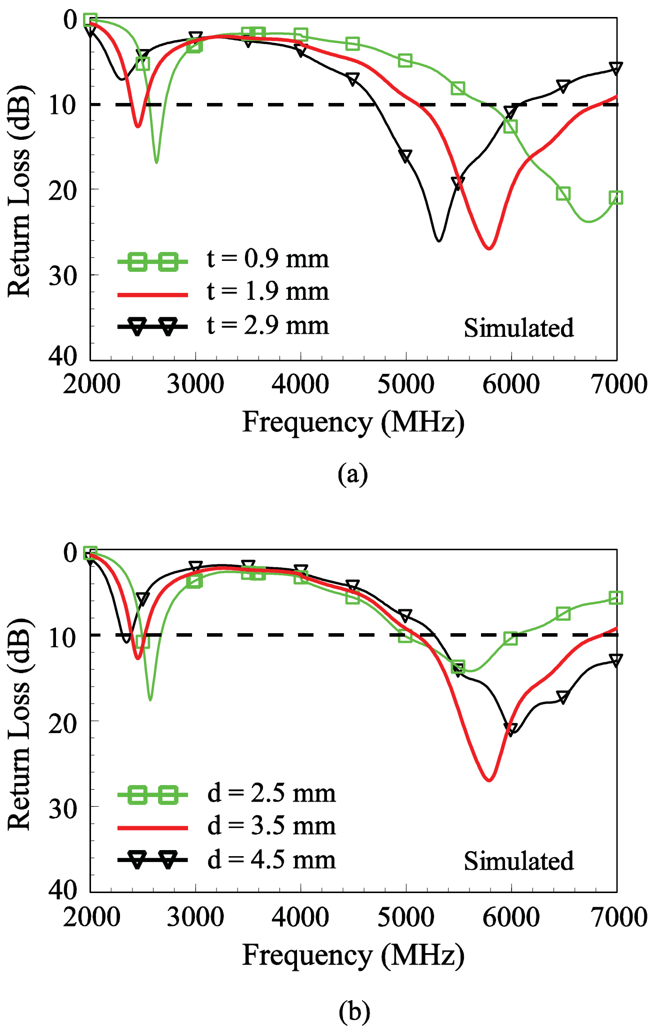

Figure 4 Simulated return loss as a function of (a) the tuning length *t* and (b) the feeding position *d* of the feeding strip. Other parameters are the same as given in Figure 1. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

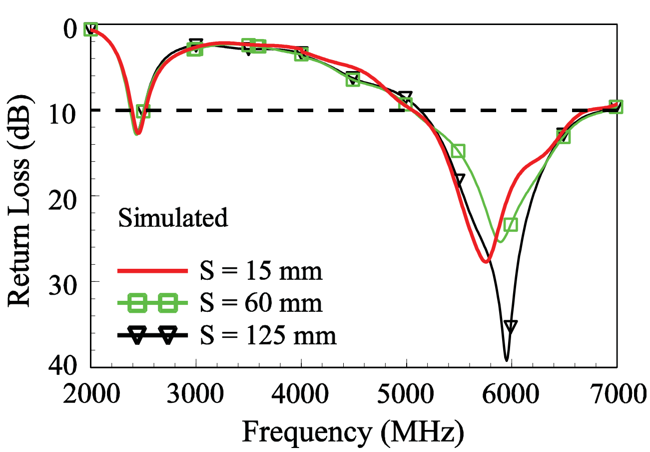

Figure 5 Simulated return loss as a function of the distance *S* to the side edge of the ground plane or the shielding metal plate. Other parameters are the same as given in Figure 1. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

3. RESULTS AND DISCUSSION

The proposed PIFA was fabricated and tested. Figure 2 shows the measured and simulated return loss. The simulated results obtained using Ansoft HFSS (High Frequency Structure Simulator) [21] are seen to agree with the measured data. Two desired operating bands at about 2.4 and 5.5 GHz are generated with good impedance matching, which cover the WLAN operation in the 2.4/5.2/5.8 GHz bands with return loss better than 10 dB.

To analyze the effect of the microstrip-coupled feed, Figure 3 shows the comparison of the simulated return loss and input impedance of the proposed PIFA and the reference PIFA (the corresponding traditional PIFA with a direct feed). The reference PIFA is also printed on a 0.8-mm thick FR4 substrate of size 9 × 10 mm^2, and the dimensions of the metal pattern are adjusted such that good impedance matching for its first (lowest) resonant mode can be achieved. From the results shown in Figure 3(a), it is seen that the reference antenna shows a lowest resonant mode at about 5.5 GHz, and no resonant mode at about 2.4 GHz is excited. This behavior can be explained from the simulated input impedance shown in Figure 3(b). At around 2.4 GHz, there are very large input resistance and inductive reactance for the reference antenna. While for the proposed PIFA, owing to the use of the microstrip-coupled feed, a resonance (zero reactance) occurs at about 2.4 GHz, and the input resistance at the resonance is also decreased to be close to 50 Ω. It hence leads to good excitation of the desired 2.4 GHz band for WLAN operation. Also, the resonance (zero

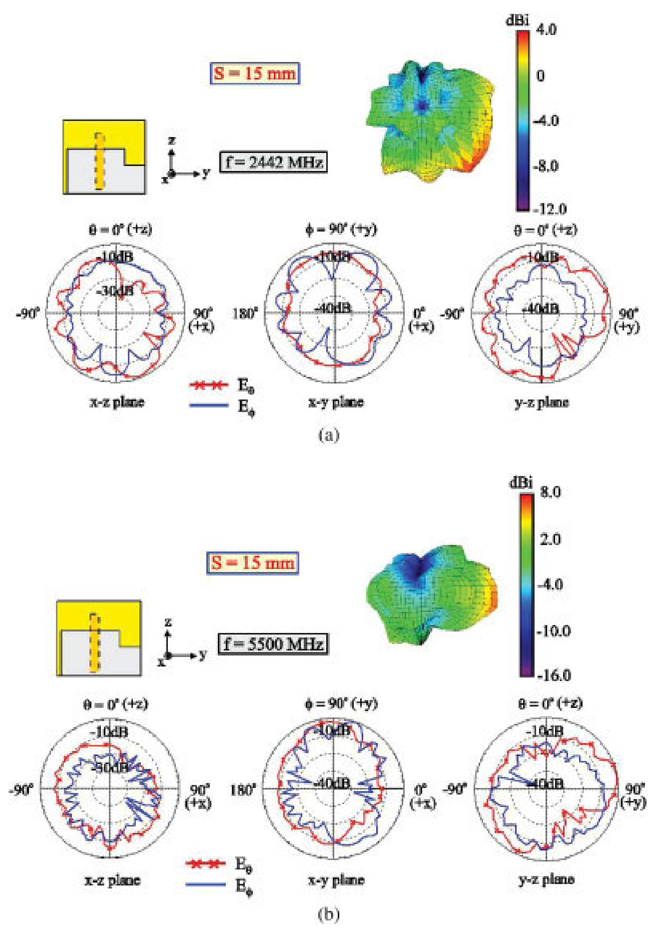

Figure 6 Measured 3D and 2D radiation patterns at (a) 2442 MHz and (b) 5500 MHz for the proposed PIFA with S = 15 mm. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

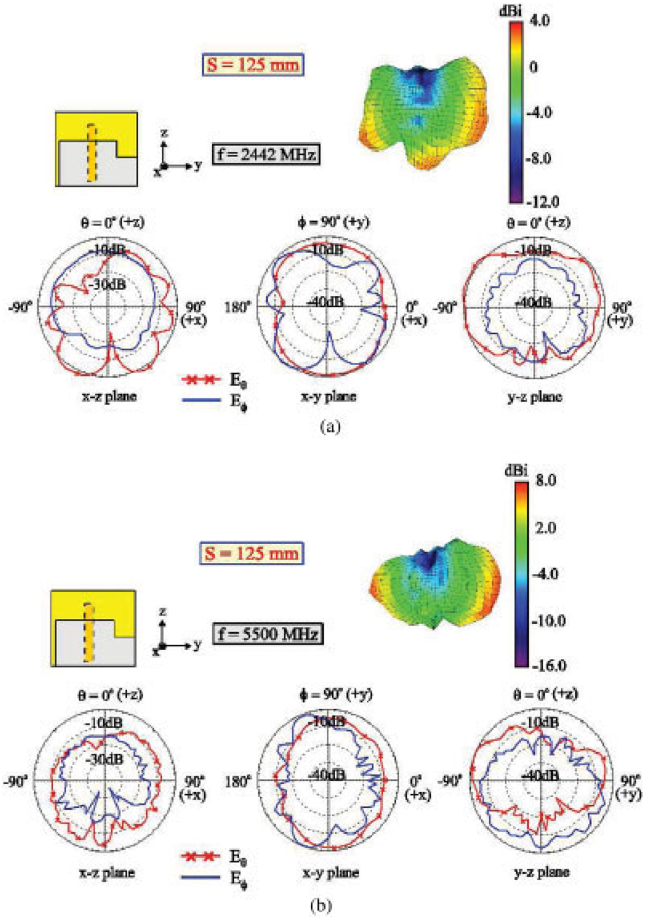

Figure 7 Measured 3D and 2D radiation patterns at (a) 2442 MHz and (b) 5500 MHz for the proposed PIFA with S = 125 mm. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

reactance) occurred at about 5.5 GHz is seen to be very slightly affected. Furthermore, the input resistance at around 5.5 GHz is decreased to be close to 50 Ω for the proposed PIFA. This behavior explains the improved impedance matching for frequencies over the desired 5.2/5.8 GHz bands seen in Figure 3(a).

Figure 4 shows the simulated return loss as a function of the tuning length t and the feeding position d of the feeding strip. Results for the tuning length t varied from 0.9 to 1.9 mm are presented in Figure 4(a), whereas those for the feeding position d varied from 2.5 to 4.5 mm are shown in Figure 4(b). Large effects of the feeding strip on both the 2.4 and 5.2/5.8 GHz bands are seen. This indicates that by adjusting the parameters of the feeding strip, the two desired resonant modes for WLAN operation in the 2.4 and 5.5/5.8 GHz bands can be effectively controlled.

Figure 5 shows the simulated return loss as a function of the distance S to the side edge of the ground plane or the shielding metal plate. Results for the distance S = 15, 60, and 125 mm are presented. For S = 125 mm, the proposed PIFA is located at the center of the long edge of the shielding metal plate. Small effects on the two desired operating modes are seen. This behavior is attractive for the proposed PIFA in practical applications, since the internal WLAN antenna may be placed at other possible positions along the long edge of the shielding metal plate.

Radiation characteristics of the proposed PIFA are studied in Figures 6–8. The measured three-dimensional (3D) and two-dimensional (2D) radiation patterns for S = 15 and 125 mm are plotted in Figures 6 and 7, respectively. From the comparison of the results for the two different PIFA locations, it is seen that more symmetric radiation patterns for S = 125 mm are observed for the patterns at both the lower (2442 MHz) and higher (5500 MHz) frequencies. Figure 8 shows the measured antenna gain and radiation efficiency for the proposed PIFA with S = 15 and 125 mm. For frequencies over the lower and upper bands shown in the figure, there are small variations in the radiation efficiency for the proposed PIFA with different locations (S = 15 and 125 mm) along the long edge of the shielding metal plate, especially over the 2.4 GHz band. The radiation efficiency is varied from about 62 to 70% over the 2.4 GHz band, and it is all larger than 76% over the 5.2/5.8 GHz bands. On the other hand, largely owing to the more symmetric patterns for S = 125 mm than for S = 15 mm observed in Figures 6 and 7, the antenna gain is about 1–2 dBi smaller for S = 125 mm than for S = 15 mm. For the case of S = 125 mm, the antenna gain is about 3 dBi over the 2.4 GHz band and about 6–7 dBi over the 5.2/5.8 GHz bands.

Finally, the average antenna gain defined as the average of the antenna gain over all of the ϕ angles in the azimuthal plane, which should meet the minimum requirement as shown in Table 1 (the specification shown in the table) [22] is also studied. The measured results of the average antenna gain for the proposed PIFA with S = 15 mm are presented in Table 1. Results for the condition including the power loss of the long mini coaxial line (can be as long as about 70 cm) connected to the internal antenna in the laptop

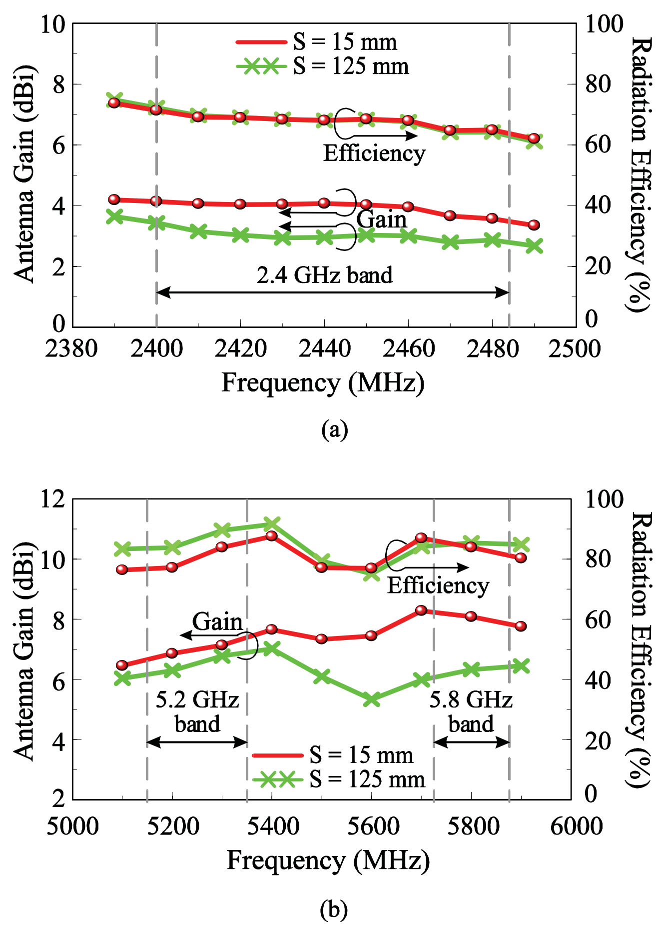

Figure 8 Measured antenna gain and radiation efficiency for the proposed PIFA. (a) The 2.4 GHz band. (b) The 5.2/5.8 GHz bands. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com]

TABLE 1 Measured Average Antenna Gain in the Azimuthal Plane for the Proposed PIFA Shown in Figure 1 with S = 15 mm

Average Antenna Gain (dBi)		Proposed PIFA (dBi)	Proposed PIFA with 70-mm Coaxial Line Loss (dBi)	Specification (dBi)
2.4 GHz band	2400MHz	−1.0	−3.0	−4.0
	2442MHz	−1.0	−3.0	−4.0
	2484MHz	−1.5	−3.5	−4.0
5.2/5.8 GHz bands	5150MHz	−0.3	−4.3	−5.0
	5350MHz	0.3	−3.7	−5.0
	5500MHz	0.5	−3.5	−5.0
	5725MHz	1.3	−2.7	−5.0
	5875MHz	1.1	−2.9	−5.0

The specification is the minimum average antenna gain required for practical applications of the internal WLAN antenna in the laptop computers [22].

computer are also given in the table. The power loss of the 70-cm long cable line is estimated to be −2 dB for frequencies over the 2.4 GHz band and −4 dB over the 5.2/5.8 GHz bands [22]. The obtained results indicate that the average antenna gain of the proposed PIFA easily meets the specification for practical applications. Also note that for other possible locations of S for the proposed PIFA mounted along the long edge of the shielding metal plate, since the obtained radiation patterns will become more symmetric than that at S = 15 mm, the obtained average antenna gain in the azimuthal plane will be better than that obtained in Table 1 and also easily meets the specification for practical applications.

4. CONCLUSIONS

A small-size microstrip-coupled printed PIFA suitable for WLAN operation in the 2.4 and 5.2/5.8 GHz bands has been proposed and studied. The proposed PIFA printed on a small-size, thin FR4 substrate of 9×10 mm^2 has been fabricated and mounted at the top edge of the system ground plane or supporting metal frame of the display panel of the laptop computer for testing. Results showed that owing to the use of the microstrip-coupled feed, the proposed small-size PIFA can generate two wide operating bands at about 2.4 and 5.5 GHz for the desired 2.4/5.2/5.8 GHz WLAN operation. Good radiation characteristics for frequencies over the desired operating bands have also been obtained. Results also indicate that the proposed PIFA can be mounted at various possible locations along the top edge of the system ground plane with small variations in the impedance matching of the antenna, which is attractive for its practical applications. The average antenna gain in the azimuthal plane for the proposed PIFA also easily meets the specification for practical applications.

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