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Very-Low-Profile, Small-Sized, Printed Monopole Antenna for WLAN Notebook Computer Applications

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Abstract—A simple, small-sized, printed monopole antenna loaded with a chip inductor for achieving dual-band operation in notebook computers is introduced. The design consisted of a simple 5 GHz monopole, a chip inductor, and a tuning end portion. With the inductor inserted at the end of the 5 GHz monopole and connected to the tuning portion, the lower band resonance in 2.4 GHz band can be attained, together with a reduced design footprint for 2.4 GHz operation. The frequency ratio of the upper and lower bands were also controllable by inductance values. The results showed that the antenna was capable of operating in 2.4 GHz (2400–2484 MHz) and 5 GHz (5150–5825 MHz) wireless local area network (WLAN) bands and yet occupied a small size of 5 mm $\times$ 12 mm (about $0.04\lambda \times 0.09\lambda$ at 2.4 GHz) only.

1. INTRODUCTION

To achieve a smaller lateral length than those conventional, wireless local area network (WLAN) notebook antennas, small-sized printed monopoles and planar inverted-F antennas (PIFAs) have been studied [1–3]. The reduced lateral lengths of these antennas are about 5.4 to 7 mm, but the antenna widths (heights) reach about 8.7 to 9 mm. Nowadays, the large screen-to-body-ratio feature is much in demand for notebook computer manufacturers. The bezel widths between the edge of the display and the outside border of the casing can be less than 5 mm. In this case, although the overall area is small, these small-sized antennas cannot be fitted into the narrow-bezel space of the present-day notebook computers.

Very recently, a few novel antenna designs are presented for the aforementioned, narrow-bezel notebook applications [4–7]. These designs include the uses of slot antennas [4], short-circuited monopole antennas [5], loop antennas [6, 7], and require antenna heights of no more than 5 mm. However, the drawback of these antennas is that the required, minimum lateral length is at least greater than 20 mm. For Gbps communications in the near future, multiple WLAN antennas are expected to be embedded in the notebook computers. Accordingly, new design considerations for notebook antennas to acquire a low profile of 5 mm and a small lateral length are becoming substantially important. To fulfill these new requests, a very-low-profile, small-sized printed monopole antenna is proposed in this paper.

The proposed monopole antenna was constructed on a single-layered substrate and comprised a simple 5 GHz monopole, a chip inductor, and a tuning end portion. The design footprint, including the monopole strip and its antenna ground, occupied a small size of only 5 mm $\times$ 12 mm. To achieve a 5-mm low profile, the 5 GHz monopole of height 4 mm was bent into a U shape and short-circuited to the antenna ground. By loading a chip inductor at the end of the 5 GHz monopole and further connecting it to the tuning portion, additional quarter-wavelength resonance for 2.4 GHz band was generated. In other words, a dual-band WLAN operation in the small form factor of the 5 GHz monopole can be

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achieved. The chip inductor in this study was used as a low-pass matching circuit to facilitate 2.4 GHz operation with possible smaller size and at the same time to control the frequency ratio of the upper and lower bands [8, 9]. Details of the design prototype are described, and the results thereof are discussed in the article.

2. PROPOSED SMALL-SIZED MONOPOLE ANTENNA

Figure 1(a) shows the proposed monopole antenna affixed to the top edge of the display metal plate in the notebook computer for the prototype studies. The antenna was built on a 0.4-mm-thick, flame retardant 4 (FR4) substrate ($\varepsilon_r = 4.4$) of size 5 mm × 12 mm. The metal plate of a 14-inch display measuring 182 mm × 315 mm was chosen as the large system ground. The small antenna ground of size 1 mm × 12 mm was reserved in the design footprint as it is required to be connected to the display ground via the conductive tape for practical applications. Notice that the size of display plate is chosen as a design example not for limiting the proposed design. Also notice that for antenna assembly in the real notebook products, the antenna will be installed in the bezel of the display inside the notebook housing using the adhesive, double-sided tap, which is commonly practiced in the notebook industry.

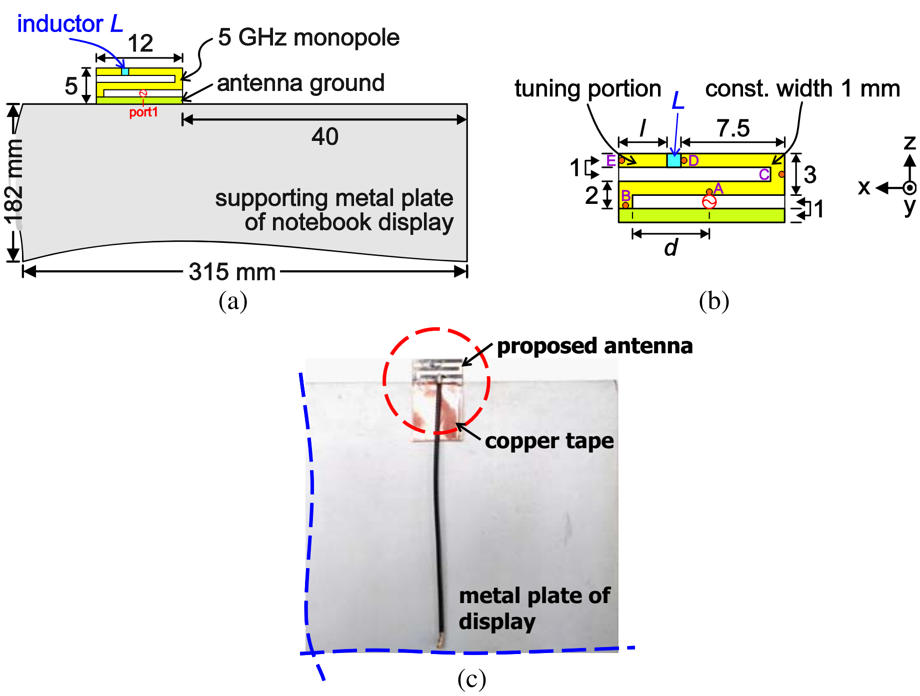

Figure 1. (a) Geometry of the very-low-profile, small-sized monopole antenna affixed to the supporting metal plate of a 14-inch notebook display. (b) Detailed dimensions of the proposed antenna. (c) Photo of a constructed prototype.

Parameters of the design prototype are detailed in Fig. 1(b). For achieving a 5-mm low profile, the monopole strip was bent into a U shape and short-circuited to the antenna ground. The design mainly consisted of a 5 GHz monopole of size 4 mm × 12 mm, a Murata 0603 chip inductor L, and a tuning end portion of length l. The widths of the monopole strip and the tuning portion were all kept the same at 1 mm. When no inductor and no tuning portion were employed, the monopole (see Ant2 in Fig. 4) can operate at its quarter-wavelength resonant mode in the 5 GHz band. With the inductor loaded at the end of the 5 GHz monopole and connected to the tuning portion, additional quarter-wavelength resonance for 2.4 GHz band was generated. In other words, a dual-band WLAN operation for the monopole antenna in smaller size can be achieved.

To maintain a small lateral length, the shorting point B was fixed at the left end of the antenna ground, and the location (distance d) of the feeding point A and the length of the end section C, D of the 5 GHz monopole were first adjusted for 5 GHz WLAN operation. Then, the inductor L was incorporated and treated as a low-pass matching circuit, in combination with the tuning portion to obtain the lower band resonance in 2.4 GHz band. The 5 GHz band was not largely affected, and the antenna frequencies for 2.4 GHz operation can be fine-tuned by adjusting the length of the tuning portion. For testing the prototype, a short, 50-Ω mini-coaxial cable of length 70 mm was used to feed the monopole across a feed gap of 1 mm. See the photo of the prototype in Fig. 6(c). In this study, the near-optimum parameters were simulated by the electromagnetic solver, ANSYS HFSS [10].

3. EXPERIMENTAL AND SIMULATION RESULTS

Figure 2 shows the measured and simulated return losses for the proposed antenna. The shaded frequency ranges mark 2.4 and 5 GHz WLAN bands. It is seen that the experimental data compare favorably with the simulation results. Two resonant modes respectively in the lower and upper bands are generated. The impedance matching in 2.4/5 GHz bands all exceeds the 9.6-dB return loss (about VSWR of 2), which meets the industrial specification for WLAN notebook antenna applications. The corresponding simulated surface-current distributions for the antenna excited at 2442 and 5490 MHz, the center frequencies of 2.4 and 5 GHz bands, are shown in Fig. 3. Two resonant paths (path1, path2) for 2.4 and 5 GHz operations are observed. No current nulls are seen on the antenna, which indicates that the quarter-wavelength monopole resonance is excited for both 2.4 and 5 GHz bands. For the lower band resonance, large currents are distributed along path1 [path B, A, C, D, E via the chip inductor in Fig. 1(b)]. On the other hand for the upper band resonance, much larger surface currents are seen populated along path2 [path A, C, Din Fig. 1(b)], which confirms that the 5 GHz operation is mainly attributed to the 5 GHz monopole strip.

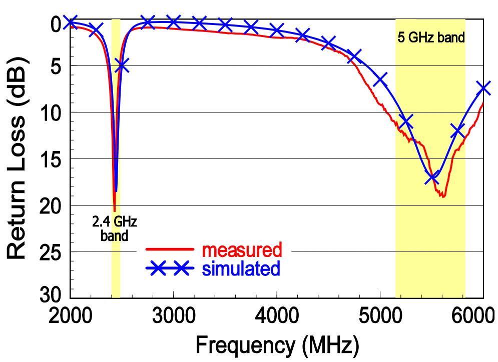

Figure 2. Measured and simulated return losses for the design prototype; $d = 5.3$ mm, $l = 3.5$ mm, $L = 16$ nH.

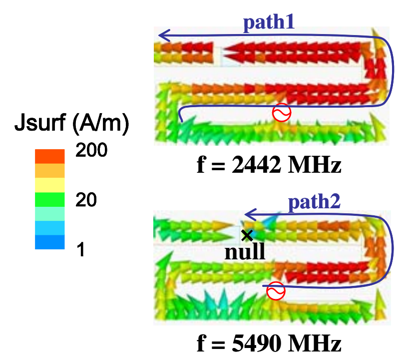

Figure 3. Simulated surface current distributions at 2442 and 5490 MHz for the prototype studied in Fig. 2.

Two reference antennas, Ant1 and Ant2, are further analyzed in Fig. 4. For the proposed design without the chip inductor L (see Ant1), the antenna operates at its quarter-wavelength resonant mode at about 3.77 GHz. For a simple 5 GHz monopole of Ant2 (proposed without L and end portion), the obtained operating frequencies and its impedance matching are similar to those of the proposed design. It is also noticed that by comparing with Ant1, the overall size reduction for the proposed design is about 35% in order to achieve the same, lower band resonance for 2.4 GHz operation, and at the same time a dual-WLAN-operation can be attained without increasing the size of the single-band 5 GHz monopole (Ant2). The simulated current distributions for Ant1 and Ant2 were also studied. As seen in Fig. 5, the surface currents on Ant1 and Ant2 are similar to those for the proposed antenna excited at 2442 and 5490 MHz, respectively. Both Ant1 and Ant2 show the quarter-wavelength resonant path at their operating frequencies. In this case, the proposed design can be considered combining two quarter-wavelength monopoles into a small design footprint of 5 GHz monopole antenna only, much different

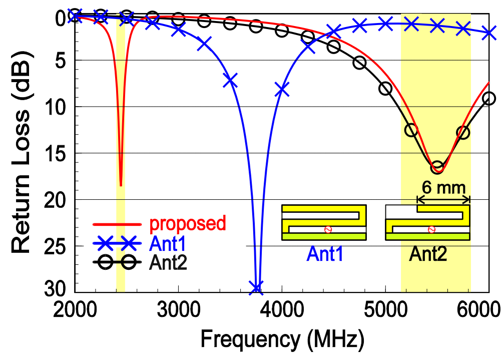

Figure 4. Simulated return losses for the proposed antenna, Ant1 (proposed without L), Ant2 (simple 5 GHz monopole; proposed without L and end portion).

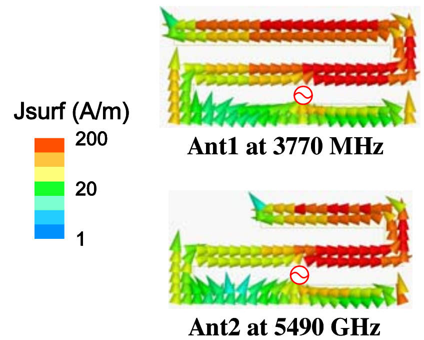

Figure 5. Simulated surface current distribution for Ant1 at 3770 MHz and Ant2 at 5490 MHz studied in Fig. 4.

from the two-branch monopole antennas in [2, 3, 5].

The over-the-air (OTA) performance of the antenna in free space was studied. The measurement was taken at our 4 m × 4 m × 4 m, SATIMO chamber of model SG 64, which uses the conical-cut method [11]. Figs. 6(a) and (b) show the measured radiation patterns in E_θ and E_φ fields for the proposed antenna at 2442 and 5490 MHz. The patterns were normalized with respect to the peak gain in each cut. In general, the omnidirectional radiation patterns are observed in the x-y planes over the upper and lower bands, together with larger antenna gain in the upper half space above the large display ground. The average antenna gains in the x-y plane are −2.3 and −1.2 dBi at 2442 and 5490 MHz, respectively. Notice that comparable E_θ and E_ϕ fields are also seen in the x-y and y-z planes, which is advantageous for WLAN operation in the complex propagation environment. Fig. 6(c) presents the corresponding, simulated, 3D radiation patterns at 2442 and 5490 MHz. The peak gains are about 4.3 and 5.2 dBi at 2442 and 5490 MHz. Overall, the 3D patterns are similar to the measured patterns in each plane as shown in Figs. 6(a) and (b). The measured, peak antenna gain and antenna efficiency against frequency are presented in Fig. 7. The peak gain in 2.4 GHz band is in the range of 2.8 to 4.3 dBi with antenna efficiency of 45–65%. Over 5 GHz band, the gain varies from 4.3 to 5.9 dBi with efficiency exceeding 75%. The OTA measurement here took account of antenna mismatch loss; the realized gain [12] and antenna efficiency [13] were measured.

4. PARAMETRIC STUDIES

Among a few parameters that affect antenna operating frequencies, three parameters are chosen in this section for further discussion. First, the simulated return losses for the design as a function of the feed port distance d to the shorting portion are plotted in Fig. 8. The resonance for 2.4 GHz operation and the impedance matching thereof are nearly unchanged; only the frequencies and the matching over the 5 GHz band are affected. When the distance d increases, the upper resonance shifts toward the higher operating frequencies. This behavior is expected because the resonant path for 5 GHz operation mainly starts from feeding point A to point D [see Fig. 1(b)], as previously discussed in Fig. 3, such that increasing distance d would reduce the resonant path for the upper band resonance, leading to increased antenna frequencies.

Figure 9 shows the results for the return losses as a function of tuning portion l for the proposed antenna. It is clearly seen that length l of the tuning portion has big effects on the lower band resonance. With an increase in the portion length l, the antenna frequencies in the lower band decrease while the upper-band frequencies and the impedance thereof are nearly the same. This suggests that inductor L acts as a low-pass matching circuit, allowing the proposed design to be fine tuned for 2.4 GHz operation using the tuning portion without affecting the 5 GHz band. The results also confirm that the occurrence of the upper band resonance is dominated by the 5 GHz monopole with its resonant path2 (depicted in Fig. 3) length kept the same in the studies of Fig. 9.

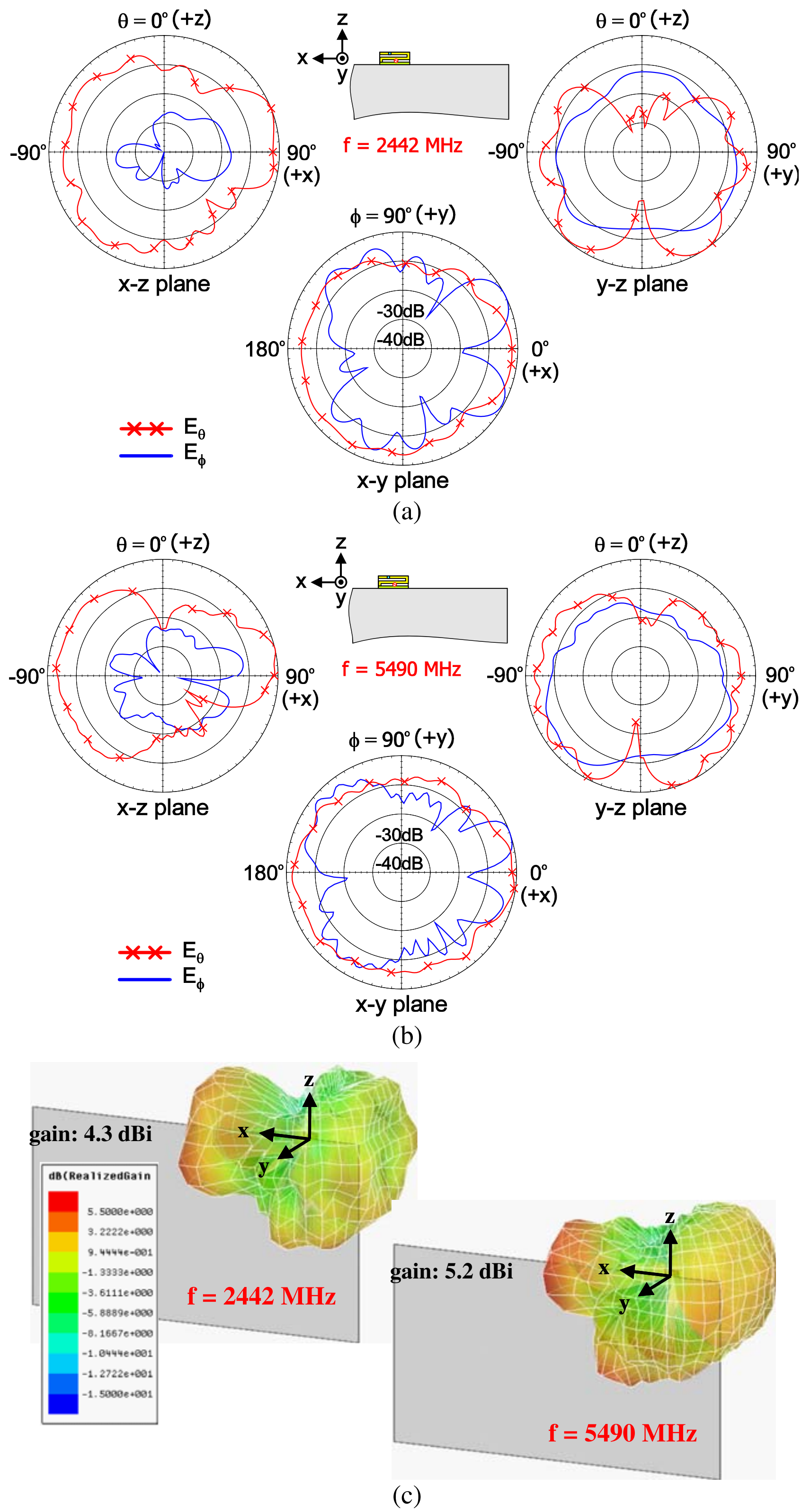

Figure 6. Measured 2D radiation patterns for the proposed antenna at (a) 2442 MHz, (b) 5490 MHz, and (c) simulated 3D radiation patterns.

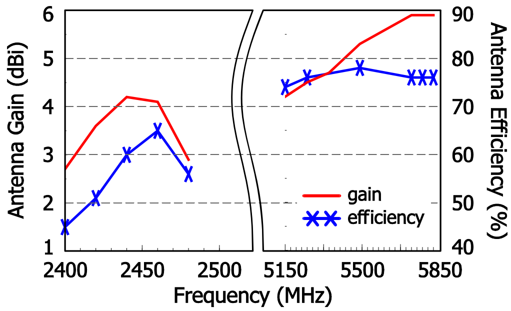

Figure 7. Measured peak antenna gain and antenna efficiency for the antenna studied in Fig. 6.

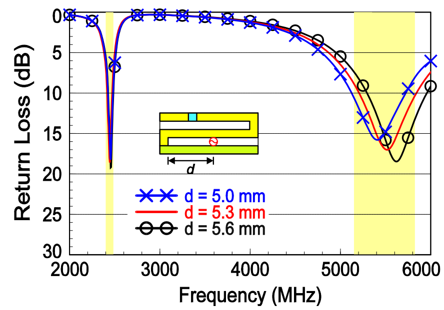

Figure 8. Simulated return losses for the proposed antenna as a function of the feed port distance d to the shorting portion. Other dimensions are the same as studied in Fig. 2.

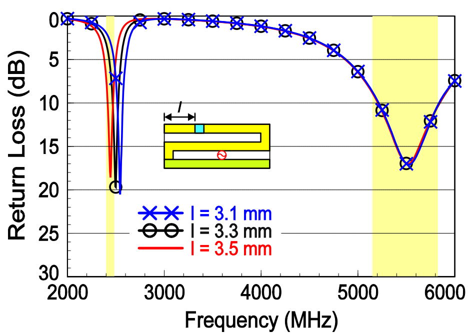

Figure 9. Simulated return losses for the proposed antenna as a function of the tuning portion length l. Other dimensions are the same as studied in Fig. 2.

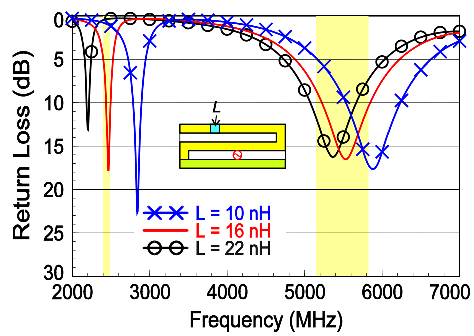

Figure 10. Simulated return losses for the proposed antenna as a function of the inductor L. Other dimensions are the same as studied in Fig. 2.

Finally, the effects of the inductor L on the antenna are also looked into, and the results of the simulated return losses are given in Fig. 10. The frequency ratio of the upper and lower resonance is found to decrease from 2.5 (5355/2180 MHz) to 2.1 (5875/2840 MHz) when inductance value L decreases from 22 to 10 nH with antenna frequencies of the two resonant modes becoming higher. Also, smaller values of inductance L lead to better impedance matching over the lower and upper bands. In this case, inductor L of 16 nH, which gives moderate operating frequencies with frequency ratio of 2.3, is the near-optimum value in this study.

5. CONCLUSION

A new, very-low-profile monopole antenna targeted on the narrow-bezel notebook computers for dual-band WLAN operation has been presented. The design footprint, including the monopole strip and its small antenna ground, occupied a small size of only 5 mm × 12 mm. The antenna design utilized a simple, quarter-wavelength 5 GHz monopole and comprised a matching inductor and a tuning portion. With the inductor loaded to the end of the 5 GHz monopole strip and connected to the tuning portion, additional quarter-wavelength monopole resonance can be attained in the lower band for 2.4 GHz operation. The operating frequencies in the upper and lower bands can be individually fine-tuned. In addition, the proposed design without the chip inductor can only generate a single resonant mode at about 3.77 GHz. In other words, about 35% size reduction for the proposed design is achieved for obtaining the lower 2.4 GHz band. Good radiation performance with antenna efficiency larger than 45% and 75% over 2.4 and 5 GHz bands were obtained. Owing to its very low profile and small lateral length, the design can be applied to future 4 × 4 multiple notebook antennas integrated for Gbps communications.

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