Compact Folded Monopole Antenna Excited by a Conductor-Backed Coplanar Waveguide with Vias

Jin Hyuk Kim and Keum Cheol Hwang

A compact monopole antenna excited by a conductor-backed coplanar waveguide (CBCPW) is developed for wireless USB dongle applications. The proposed antenna has a compact dimension of 14 mm × 47.4 mm × 3.5 mm, which is suitable for a USB dongle housing. A slotted elliptical patch and a CBCPW with vertical vias are employed to achieve a further size reduction and an improved impedance bandwidth. The measurement result demonstrates that the fabricated antenna resonates from 2.25 GHz to 10.9 GHz, which covers all of the important wireless communication bands, including WiBro (2.3 GHz to 2.4 GHz), Bluetooth (2.4 GHz to 2.484 GHz), WiMAX (2.5 GHz to 2.7 GHz and 3.4 GHz to 3.6 GHz), satellite DMB (2.605 GHz to 2.655 GHz), 802.11b/g/a WLAN (2.4 GHz to 2.485 GHz and 5.15 GHz to 5.825 GHz), and ultra-wideband (3.1 GHz to 10.6 GHz) services. The radiation characteristics of the proposed antenna when attached to a laptop are tested to investigate the influence of the keypad and the LCD panel of the laptop.

Keywords: Monopole antenna, ultra-wideband (UWB), wireless USB dongle, conductor-backed coplanar waveguide.

I. Introduction

As a novel device for high-speed data communication, the wireless universal series bus (WUSB) dongle technology has attracted much interest because it not only operates based on a simple plug-and-play function, but it also supports a high data transmission rate of 480 Mbit/s [1]. These WUSB dongle devices require a miniaturized, multiresonant antenna that can be embedded within a compact dongle housing to accommodate multiband services. The designs of various antennas utilizing a planar inverted-F antenna [2] and a loop-coupled spiral patch [3] have been completed in an effort to implement multiband antennas suitable for WUSB dongle applications. A monopole patch antenna with an additional matching stub has also been demonstrated for ultra-wideband (UWB) WUSB applications [4]. Feeding of the antennas was conducted via a conventional coaxial probe between a radiating patch and a system ground plane.

In this letter, as an extension of the work in [5], we propose a compact UWB WUSB dongle antenna fed by a conductor-backed coplanar waveguide with vias. Conventional conductor-backed coplanar waveguides (CBCPWs) are applied in a slot antenna design to change the radiation from bidirectional to unidirectional [6]. However, these types of conventional CBCPWs usually generate undesired parallel-plate mode leakage, which deteriorates the antenna gain and efficiency. Therefore, the antenna proposed in this letter utilizes multiple vias to prevent the generation of parallel-plate modes [7]. Details of the proposed antenna design and measurement results are presented and discussed in the subsequent sections.

II. Antenna Design

The geometry of the proposed antenna is shown in Fig. 1. An elliptical, folded monopole patch with dual slots is mounted on the upper side of a compact WUSB circuit board 14 mm × 29 mm in size. The elliptical monopole patch has a width of r_a on the x-axis and a length of r_b on the y-axis. A pair of symmetric slots with a width of 0.4 mm is also located on a lower section of the elliptical patch to achieve an electrically miniaturized antenna design. Then, as shown in Fig. 1(b), the

Manuscript received Nov. 2, 2012; revised Jan. 24, 2013; accepted Jan. 30, 2013.
This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (2011-0009815).
Jin Hyuk Kim (phone: +82 2 2260 3330, thefiction@paran.com) and Keum Cheol Hwang (corresponding author, kchwang@dongguk.edu) are with the Division of Electronics and Electrical Engineering, Dongguk University-Seoul, Seoul, Rep. of Korea.
http://dx.doi.org/10.4218/etrij.13.0212.0485

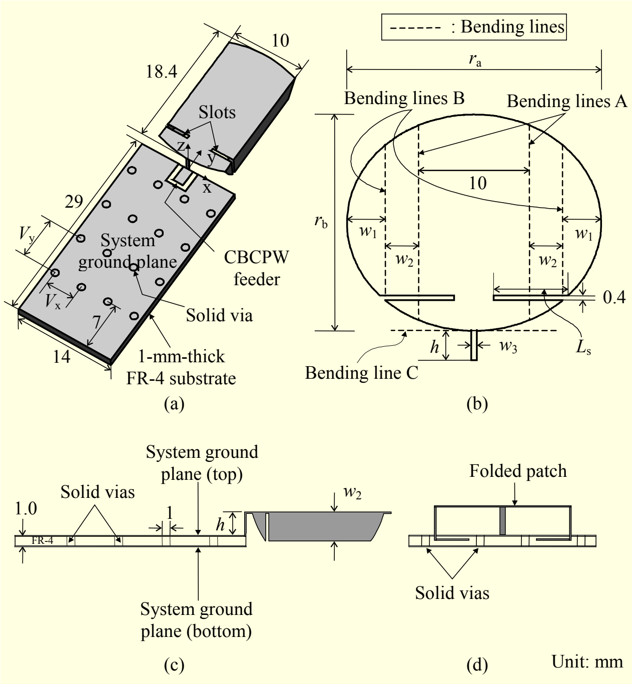

Fig. 1. (a) Geometry of proposed antenna with coordinate system, (b) detailed parameters of patch, (c) side view, and (d) upper view.

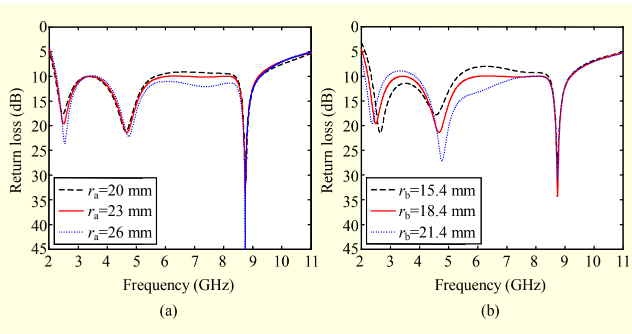

Fig. 2. Simulated return loss of unfolded, elliptical patch with different values of (a) r_a and (b) r_b.

main patch is vertically folded twice (along bending lines A and B), after which it is folded horizontally (along bending line C) to decrease the horizontal dimension and vertical dimension, respectively, of the radiating patch. This miniaturized elliptical patch is excited by a feeding strip with a dimension of $w_3 \times h$, which is vertically connected to a CBCPW feeder. The CBCPW feeder and system ground plane are etched on a 1-mm-thick FR-4 substrate (ε_r=4.6 and tanδ=0.025). Sixteen solid vias with radii of 0.5 mm, which connect to upper and lower ground planes, are embedded on the substrate. For a further understanding of the effect of the radiating patch on the return loss, only one parameter is investigated at a time while the others are kept invariant unless specifically indicated.

First, to determine the optimum dimension of the unfolded

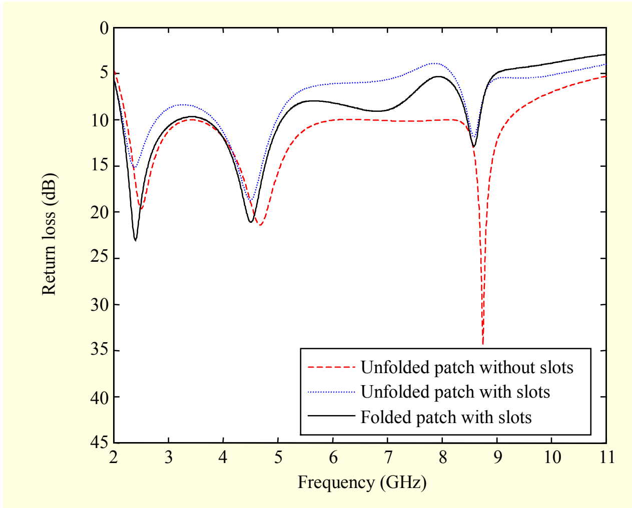

Fig. 3. Effect of slots on return loss of antenna.

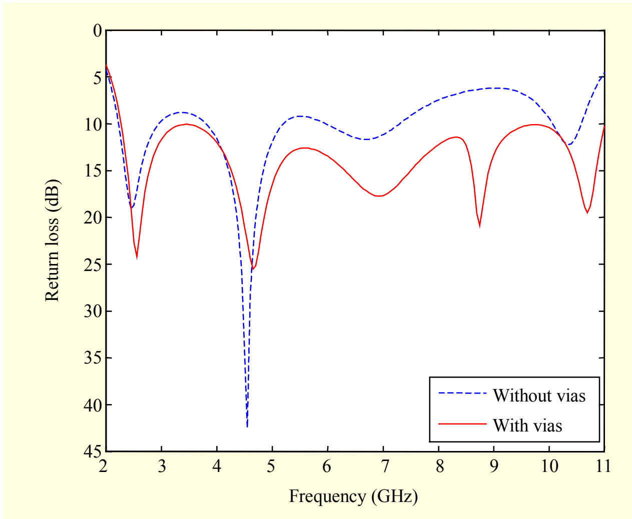

Fig. 4. Simulated return loss of antenna with and without vias.

elliptical patch, two simulations are performed with the various values of r_a and r_b. The simulated results for r_a and r_b are shown in Figs. 2(a) and 2(b), respectively. Figure 2(a) shows that the patch width r_a does not perturb the resonant frequency but enhances the level of impedance matching between 5.5 GHz and 8.5 GHz, as r_a varies from 20 mm to 26 mm. On the other hand, as shown in Fig. 2(b), the length of patch r_b affects both the resonant frequency and the level of impedance matching below 8 GHz. We observe that the resonant band shifts to the lower frequency region as r_b increases from 15.4 mm to 21.4 mm; however, increasing r_b makes the return loss worse in the frequency region between 2.5 GHz and 4 GHz. Moreover, in most cases, increasing the patch dimension is not practical due to the small interior space of the WUSB housing. To miniaturize the antenna electrically without increasing the physical dimensions, a pair of parallel slots is made in the lower section of the patch, in the manner shown in Fig. 1. These added slots increase the electric length of the patch structure, thereby allowing the antenna to resonate at a lower frequency compared to a non-slotted type of patch geometry with the same dimensions. Figure 3 shows the simulated return loss of the elliptical patch with and without slots. We find that the resonant frequency is decreased due to the presence of the slots; however, these slots deteriorate the level of impedance matching at all of the simulation frequencies. The figure also indicates that the folding of the elliptical patch enhances its impedance matching characteristic in the lower frequency band as compared to the unfolded case. Figure 4 illustrates the effect of the multiple vias embedded in the substrate on the return loss of the antenna. Although the vias are originally utilized to suppress the leakage caused by the generation of parallel-plate modes in the CBCPW, they also improve the impedance matching performance between 2.5 GHz and 11 GHz. This result demonstrates that the vias are among the design parameters. Therefore, we optimize the position of the vias as well as the other design parameters. Ultimately, the optimized antenna parameters using the Ansys HFSS are r_a=23 mm, r_b=18.4 mm, w_1=3.5 mm, w_2=3 mm, w_3=0.5 mm, h=2.5 mm, L_s=6.7 mm, V_x=4 mm, and V_y=6 mm.

III. Measured Results

A prototype of the proposed antenna fed by the CBCPW with vias is fabricated in a USB dongle case (19 mm × 52 mm × 7 mm, acrylic material with ε_r=3.0), as shown in Fig. 5. To investigate the effect of a laptop on the reflection and radiation performances, the antenna is attached to the right side of a laptop in two different cases, oriented vertically and horizontally, as shown in Figs. 5(b) and 5(c), respectively. Figure 6 shows the simulated and measured return losses of the fabricated antenna. We observe that the measured results exhibit a wide resonant band from 2.25 GHz to 10.9 GHz, covering WiBro (2.3 GHz to 2.4 GHz), Bluetooth (2.4 GHz to 2.484 GHz), WiMAX (2.5 GHz to 2.7 GHz and 3.4 GHz to 3.6 GHz), satellite DMB (2.605 GHz to 2.655 GHz), 802.11b/g/a WLAN (2.4 GHz to 2.485 GHz and 5.15 GHz to 5.825 GHz), and UWB (3.1 GHz to 10.6 GHz) services, regardless of the presence or absence of the case and laptop.

To check the validation of our antenna design, we compared the measured radiation patterns with the simulated patterns. As shown in Fig. 7, we observed good agreement between the two patterns. The measured radiation efficiency of the antenna with the case ranges from 45.8% to 90.65%, whereas the antenna

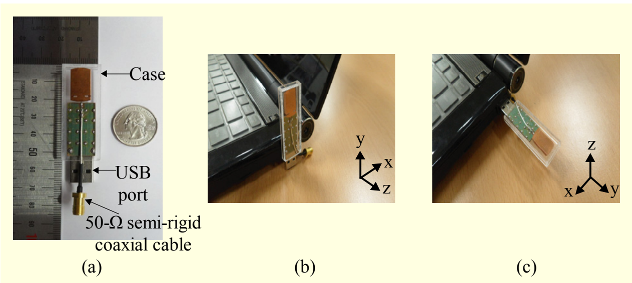

Fig. 5. (a) Photograph of fabricated antenna, (b) antenna vertically attached to laptop (case 1), and (c) antenna horizontally attached to laptop (case 2).

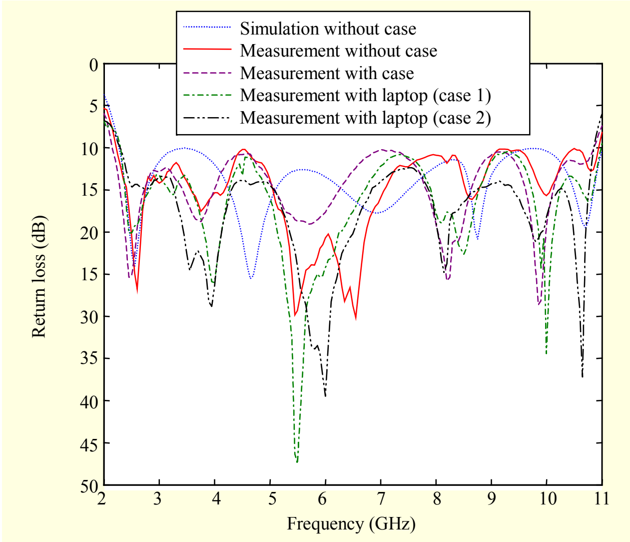

Fig. 6. Simulated and measured return losses of fabricated antenna.

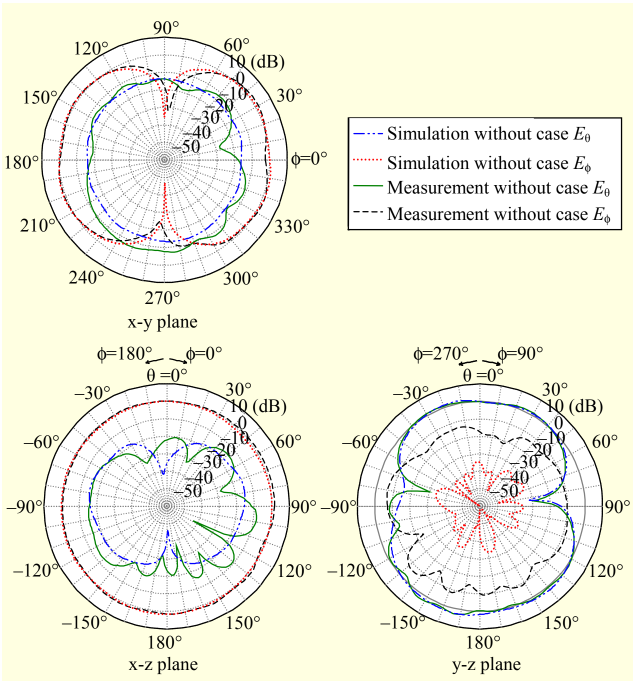

Fig. 7. Simulated and measured radiation patterns of antenna at 6.5 GHz.

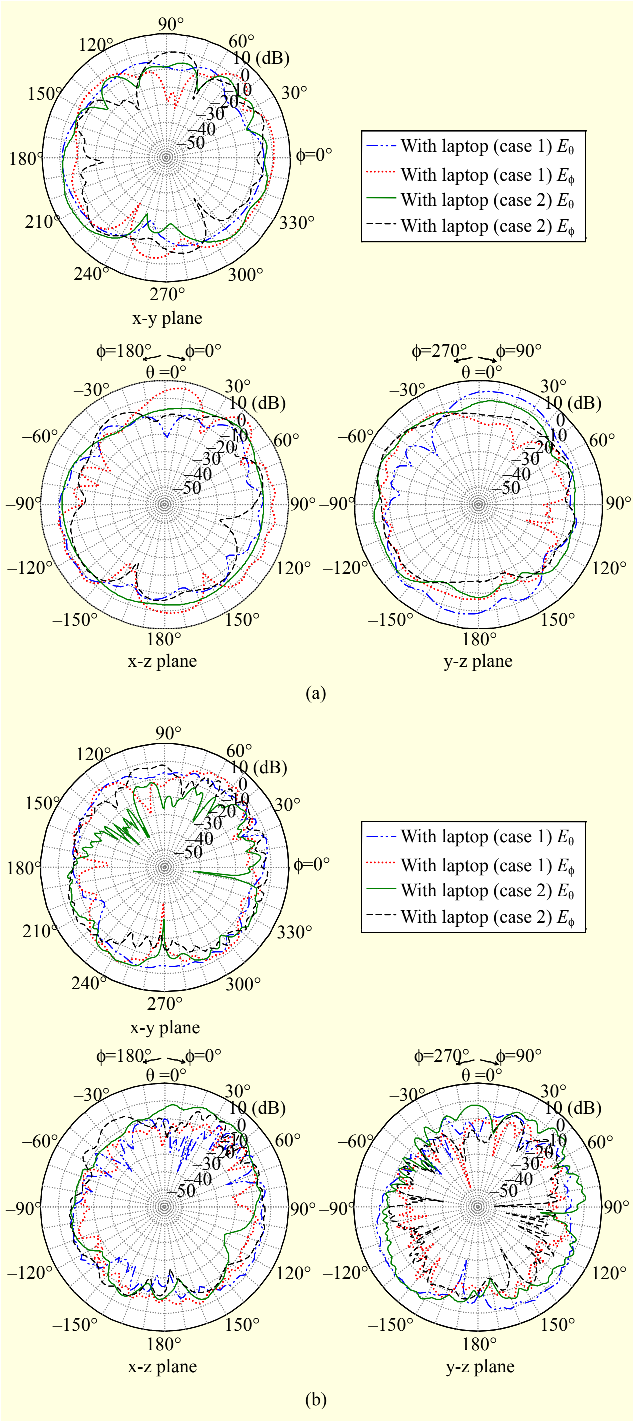

Fig. 8. Measured radiation patterns of antenna oriented vertically and horizontally to laptop at (a) 2.5 GHz and (b) 10.5 GHz.

efficiency without the case varies from 51.6% to 97.6% within the entire frequency band (2.3 GHz to 10.6 GHz). The measured far-field radiation patterns of the antenna on the laptop at 2.5 GHz, 6.5 GHz, and 10.5 GHz are also depicted in Fig. 8. When the antenna is vertically loaded on the laptop, significant nulls appear between θ = 30° to 120° on the x-z plane due to the blockage effect of the LCD panel. On the y-z plane, the keypad of the laptop mainly deteriorates the radiation pattern between θ = 30° to 120°. On the other hand, when the antenna is horizontally loaded, the radiation pattern is relatively uniform on the x-z plane. However, similar to the case in which the antenna is vertically loaded, multiple nulls caused by the effect of the LCD panel and the keypad are observed on the x-y and y-z planes. For both antenna orientations, measured gains higher than 3.51 dBi are obtained at all resonant frequencies.

IV. Conclusion

A compact UWB monopole antenna was proposed and tested for wireless USB dongle devices. The proposed antenna was excited by a CBCPW with vias to suppress the generation of parallel-plate modes. The effects of the keypad and the LCD panel of a laptop were also considered and assessed to validate the proposed antenna design. The measured 10-dB return loss substantiated a wide resonant bandwidth that supports the WiBro, WLAN, Bluetooth, WiMAX, satellite DMB, and UWB services. The measured average gain also exhibited a sufficient gain higher than 3.5 dBi. Therefore, the proposed antenna can be feasibly applied to a UWB antenna for wireless USB dongle devices.

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