

Compact Mobile Quad-Band Slot Antenna Design for GPS L1, WiMAX, and WLAN Applications

Haiyan Piao¹ · Yunnan Jin¹ · Jinpil Tak² · Jaehoon Choi^{1,*}

Abstract

In this paper, an asymmetric compact multiband slot antenna is proposed for global positioning system (GPS), worldwide interoperability for microwave access (WiMAX), and wireless area network (WLAN) applications. The top plane, a ground is composed of a rectangular slot with a trapezoidal-like stub, an inverted U-shaped slot at the right side of the rectangular slot, an inverted L-shaped slot at the left side of the rectangular slot, and three stubs. The proposed antenna is fed by an asymmetric cross-parasitic strip on the bottom plane. By properly designing the slots and stubs, four resonant frequency bands are achieved with -10 dB reflection coefficient bandwidths of 50 MHz, 400 MHz, 390 MHz, and 830 MHz in the 1.57 GHz GPS band, 2.4 GHz WLAN band, 3.5 GHz WiMAX band, and 5.5 GHz WLAN bands, respectively. The antenna has a total compact size of 13 mm × 32 mm × 0.8 mm. Simulated and measured results indicate that the proposed antenna has sufficient bandwidth and good radiation performance in each band.

Key Words: GPS, Quad-Band, Slot Antenna, WiMAX, WLAN.

I. INTRODUCTION

With the rapid development of modern wireless communication technology, the demand for multi-band antennas for wireless communication devices has been increasing. In modern wireless communication, it is desirable to integrate multi-band systems, such as global positioning system (GPS), worldwide interoperability for microwave access (WiMAX), and wireless area network (WLAN), into a single wireless device. Planar slot antennas possess a low profile characteristic, wide impedance bandwidth, compact size, easy integration, and low cost for mass production [1]. Therefore, slot antennas have been widely studied and applied in various practical situations, especially for multi-band operations [2–17].

Previous studies [2–5] achieved dual-band operations by

etching two separate slots with a U-shape, an annular shape, or a meander shape. In other research, parasitic patches [6], loaded strips [7], and feeding structures [8] were effectively used in a slot antenna for dual-band operation. Furthermore, triple-band slot antennas for WLAN/WiMAX applications were presented in [1] and [9–15]. In [1, 9, 10], multiple slots were inserted into the ground plane to generate separate resonance for each operating band, whereas other researchers used additional strips [11–13] and stubs [14] as well as a triangular slot [15] inserted into a large slot to obtain multiple bands. However, a four-band slot antenna is in high demand to simultaneously satisfy the requirements for GPS, WiMAX, and WLAN applications. Accordingly, a rectangular wide-slot antenna with a dimension of 36 mm × 42 mm × 1 mm was proposed by using L-shaped feeding line and three stubs [16]; however, the size of the an-

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antenna is very large and its gains are small. In addition, a slot antenna with a T-shaped feed patch, an inverted T-shaped stub, and two E-shaped stubs was also proposed with an area of $56 \text{ mm} \times 22.4 \text{ mm}$ ($0.44\lambda_g \times 0.18\lambda_g$) (where λ_g is the guide wavelength) in a ground plane of $56 \text{ mm} \times 44 \text{ mm}$ ($0.44\lambda_g \times 0.35\lambda_g$) for four-band operations [17]. However, its large size and symmetric structure make its implementation difficult. Therefore, a compact slot antenna design with multiband operation, easy implementation, and smaller size is required. A previous study determined that a wide-slot [16] or a large rectangular slot [17] determines the antenna size, and a smaller size can be achieved by miniaturizing the large slot. An effective technique is introduced by using narrow slots and protruded stubs, which can be interpreted as an equivalent LC resonant circuit in parallel to the large slot, to create new resonances [18] or to increase the effective length of the large slot [14], while maintaining smaller size.

In this paper, we propose a compact multiband slot antenna with a trapezoidal-like stub for GPS (1.57–1.59 GHz), WiMAX (3.3–3.6 GHz), and WLAN (2.4/5.2/5.8 GHz) band applications. To achieve a compact design, a narrow slot with an inverted U-shape and a narrow slot with an inverted L-shape are inserted as quarter-wavelength resonators to achieve additional resonance in the GPS band and to allow for frequency adjustment in the 2.4 GHz WLAN band, respectively (see Fig. 1). To optimize the bandwidths in the 1.57 GHz and 2.4 GHz bands, two stubs (Stub 1 and Stub 2 in Fig. 1) are added at the left and right sides. Furthermore, a protruded stub (Stub 3 in Fig. 1) is utilized to independently control the impedance matching in the 3.5 GHz WiMAX band. In addition, to improve the overall impedance matching, an asymmetric cross-type microstrip line (see Fig. 1) is placed on the bottom plane. The proposed antenna occupies an area of $13 \text{ mm} \times 32 \text{ mm}$ ($0.11\lambda_g \times 0.27\lambda_g$), which is 62% smaller than the one in [17], in a $50 \text{ mm} \times 32 \text{ mm}$ ($0.43\lambda_g \times 0.27\lambda_g$) ground plane, which is 37% smaller than the one in [17], where λ_g is the guide wavelength. This paper is organized as follows. In Section II, the proposed antenna design is introduced, and the design process is analyzed in detail. The proposed slot antenna was fabricated, and the simulated results were compared with measured ones in Section III. The proposed antenna was designed with Ansoft HFSS and measured using Agilent 8753ES Network Analyzers in a $6 \text{ m} \times 3 \text{ m} \times 3 \text{ m}$ 3D Cellular Telephone Industries Association Over-the-Air chamber.

II. ANTENNA CONFIGURATION AND DESIGN PROCESS

The configuration of the proposed slot antenna is shown in Fig. 1. The antenna size and the total dimensions, including the ground plane, are $13 \text{ mm} \times 32 \text{ mm} \times 0.8 \text{ mm}$ and $50 \text{ mm} \times 32 \text{ mm} \times 0.8 \text{ mm}$, respectively, which are only 38% and 63% of the dimensions given in [17], respectively. The ground plane is printed on a low-cost FR-4 ($\epsilon_r = 4.4$, $\tan\delta = 0.02$) substrate with a thickness of 0.8 mm. The antenna portion consists of a rectangular slot ($W \times L$) loaded with a trapezoidal-like stub at the upper edge. To achieve additional resonances for the 1.575 GHz GPS and 2.4 GHz WLAN bands within a compact size, an inverted U-shaped and inverted L-shaped narrow slots (depicted by the solid blue lines in Fig. 1(a)) are inserted into the right and left sides of the trapezoidal-like stub, respectively. The width of the slots is 0.5 mm. Stub 1 (L_6) and Stub 2 (L_7) increase the effective length of each slot. Furthermore, a protruded stub (Stub 3) is added to control the impedance matching in the 3.5 GHz WiMAX band. On the bottom of the substrate, an asymmetric cross-shaped strip with three branches is used for impedance matching, as shown in Fig. 1(b). The left-side and right-side branches (L_8 and L_9 , respectively) are responsible for

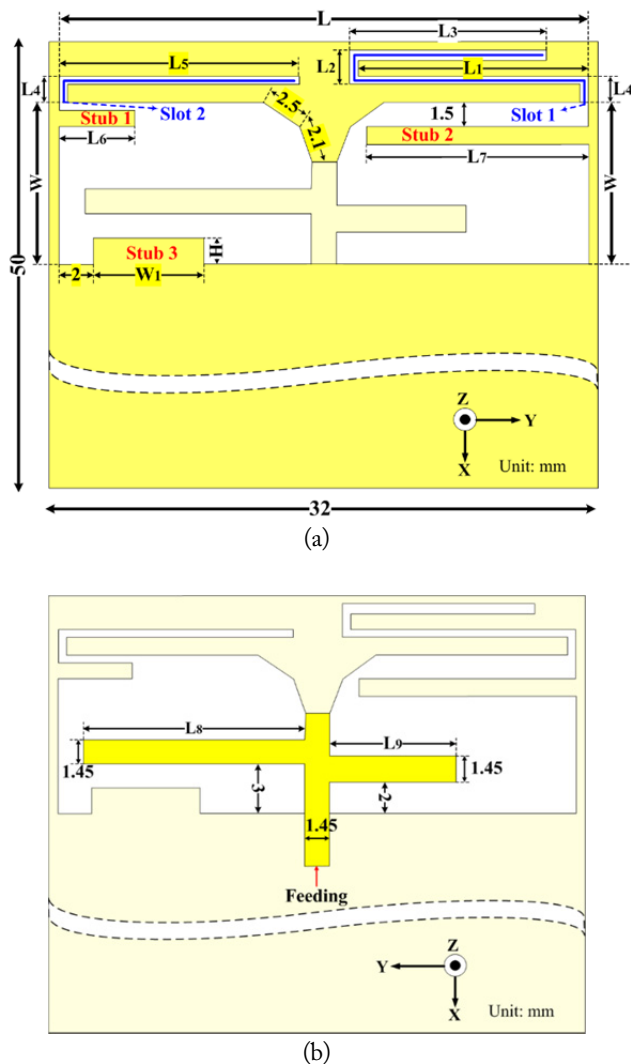


Fig. 1. Configuration of the proposed slot antenna. (a) Top view and (b) bottom view (dark yellow, metal in front; light yellow, metal in bottom).

the 3.5 GHz WiMAX and 5.5 GHz WLAN bands, respectively. The proposed antenna is fed by a microstrip line with a width of 1.45 mm to achieve an impedance of 50 Ω . The three branches have the same width as that of the microstrip line. The detailed design parameters of the proposed antenna are listed in Table 1.

To describe the operating principle of the proposed slot antenna, the reflection coefficients for various antenna structures are shown in Fig. 2. First, a rectangular slot ($W \times L$) with a feeding structure (Ant 1) is designed by determining its circumference such that it works as a one-wavelength resonator. The simulated reflection coefficient characteristic in Fig. 2 reveals three resonances: 2.7 GHz, 3.7 GHz, and 5.4 GHz. The first resonant frequency at $f = 2.7$ GHz can be obtained approximately using the total length of the circumference ($L_C = 2(L + W)$) according to the following formula:

$$L_C = \frac{c}{f \cdot \sqrt{\epsilon_{eff}}} \quad (1)$$

where c is the speed of light in free space and ϵ_{eff} is an effective dielectric constant, which can be expressed as $\epsilon_{eff} \approx (\epsilon_r + 1)/2 = 2.7$ (ϵ_r is the relative permittivity of the substrate). To improve the impedance bandwidth in the 2.4 GHz WLAN band, a

Table 1. Optimized antenna parameters

Parameter	Value (mm)	Parameter	Value (mm)
L	31	L_7	13
L_1	13.5	L_8	13.2
L_2	2	L_9	7.5
L_3	11.5	W	9.5
L_4	1.5	W_1	6
L_5	14	W_2	1.5
L_6	4.5	-	-

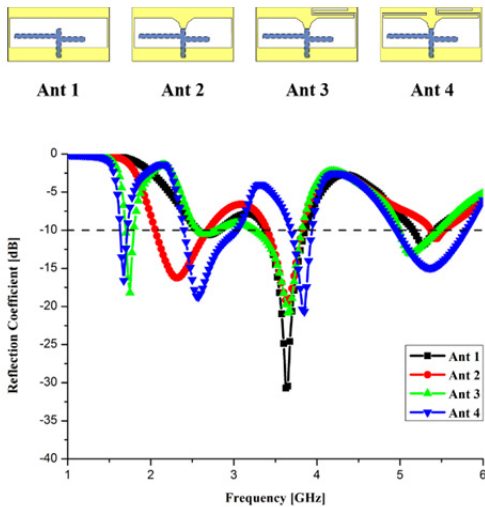


Fig. 2. Simulated reflection coefficients for various antenna structures.

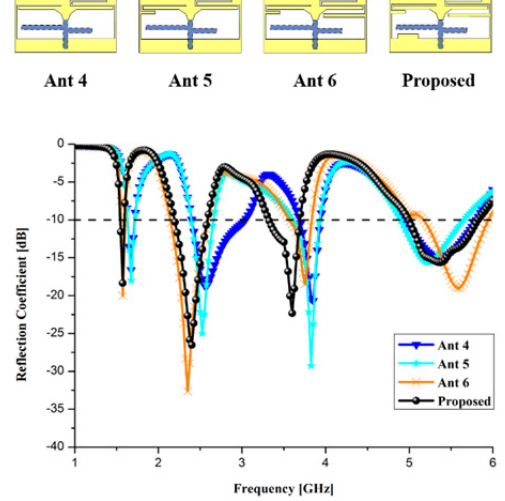


Fig. 3. Simulated reflection coefficients for different antennas during the optimization process.

trapezoidal-like stub is added to the upper side of the rectangular loop (Ant 2).

To obtain the GPS resonant frequency, Slot 1, with a length of $L_1 + L_2 + L_3 + L_4$, is a quarter-wavelength open-slot resonator located on the right side of the trapezoidal-like stub (Ant 3). Accordingly, an additional resonance at 1.7 GHz is generated (Fig. 2). In addition, this slot is designed in an inverted U-shape to save space on the ground plane. The total length of Slot 1 ($L_G = L_1 + L_2 + L_3 + L_4$) is determined by the following formula:

$$L_G = \frac{c}{4f_G \cdot \sqrt{\epsilon_{eff}}} \quad (2)$$

Finally, to independently control the resonant frequency in the 2.4 GHz WLAN band, an inverted L-shaped narrow slot (Slot 2) with a length of $L_4 + L_5$ is added at the left side, and it operates as a quarter-wavelength resonator in the 3 GHz band (Ant 4). Consequently, a four-band slot antenna has been achieved. Both Slot 1 and Slot 2 are inserted to the upper side of the large rectangular slot to achieve smaller size.

To further optimize the resonant frequency and bandwidth of each operating band, we added Stub 1 near the open portion of the inverted L-shaped slot (Ant 5), as shown in Fig. 3. As a result, Stub 1 increased the effective electrical length of the L-shaped slot; thus, the resonant frequency shifted from 3 GHz to 2.5 GHz without affecting other resonance characteristics (Fig. 3).

Fig. 4(a) shows the reflection coefficients for the proposed antenna with various lengths (L_6) of Stub 1. As L_6 increased, the resonant frequency of the 2.4 GHz WLAN band decreased. When $L_6 = 4.5$ mm, the resonant frequency was 2.4 GHz. In the same way, the resonant frequency of the GPS band can be optimized by adding Stub 2 near the inverted U-shaped narrow

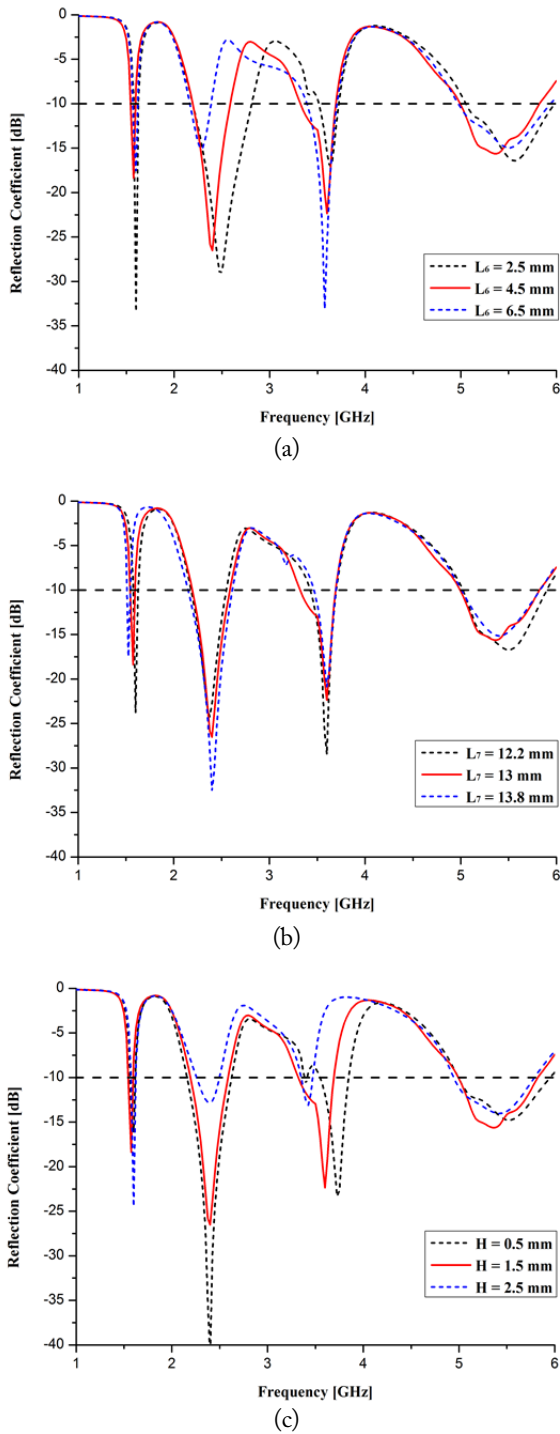


Fig. 4. Simulated reflection coefficients for the proposed antenna with different values. (a) L_6 , (b) L_7 , and (c) H .

slot (Ant 6 in Fig. 3). Fig. 4(b) shows the reflection coefficients for the proposed slot antenna with various lengths of Stub 2. The resonant frequency of the GPS band shifted from 1.6 GHz to 1.53 GHz as L_7 was varied from 12.2 mm to 13.8 mm. When $L_7 = 13$ mm, the resonant frequency was 1.57 GHz. A protruding stub (Stub 3) controlled the resonant frequency of the 3.5 GHz WiMAX band and optimized the impedance

bandwidth (Fig. 3). Fig. 4(c) shows the reflection coefficients for the proposed slot antenna with various lengths of Stub 3 (H). When length H was 1.5 mm, resonant frequency was achieved in the 3.5 GHz WiMAX band.

The simulated surface current distributions at 1.575 GHz, 2.4 GHz, 3.5 GHz, and 5.5 GHz are presented in Fig. 5. Fig. 5(a) shows that the current distributions were mainly concentrated in Slot 1 at 1.575 GHz, with the maximum current at the shoring end and the minimum current at the open end. This

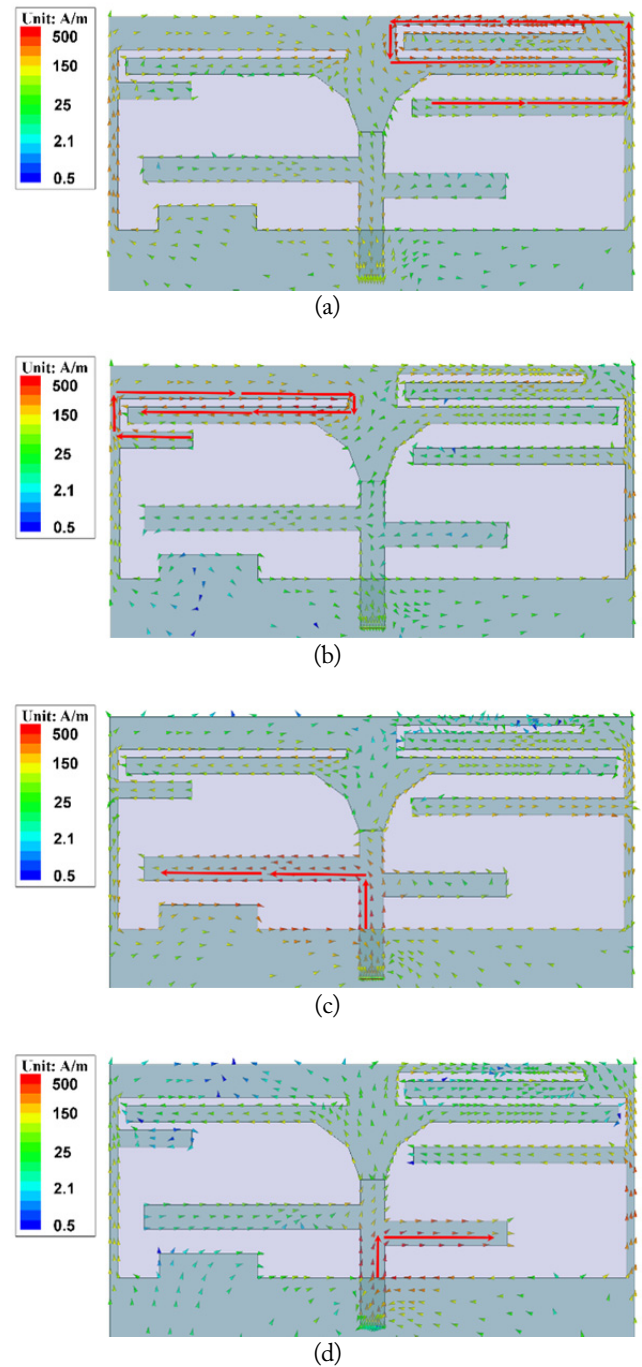


Fig. 5. Simulated surface current distributions at (a) 1.575 GHz, (b) 2.4 GHz, (c) 3.3 GHz, and (d) 5.5 GHz.

current mode agrees well with the quarter-wavelength resonance. Fig. 5(b) indicates that the currents at 2.4 GHz were mainly distributed around Slot 2, which is also consistent with the quarter-wavelength resonance. Therefore, the resonant frequencies at 1.57 GHz and 2.4 GHz can be controlled independently. At 3.5 GHz, the current was generated on the left-side branch (L_8) of the asymmetric cross-shaped strip and the protruded stub (Stub 3), as depicted in Fig. 5(c), so that the resonant frequency could be controlled by adjusting the height (H) of Stub 3. The current at 5.5 GHz was concentrated on the right-side branch (L_9) of the asymmetric cross-shaped strip, as shown in Fig. 5(d). The resonant frequency in the 5.5 GHz WLAN band could be adjusted by changing the value of L_9 . The surface current distributions confirmed that our design concept works properly and that the resonant frequency for each operating band can be controlled independently.

III. SIMULATED AND MEASURED RESULTS

The fabricated antenna is depicted in Fig. 6(a). Fig. 6(b) shows the simulated and measured reflection coefficient characteristics of the proposed slot antenna. In the simulated reflection coefficients, the proposed slot antenna satisfies a -10 dB impedance bandwidth from 1.54 GHz to 1.59 GHz (50 MHz) in the 1.575 GHz GPS band, from 2.19 GHz to 2.59 GHz (400 MHz) in the 2.4 GHz WLAN band, from 3.3 GHz to 3.69 GHz (390 MHz) in the 3.5 GHz WiMAX band, and from 4.99 GHz to 5.82 GHz (830 MHz) in the 5.5 GHz WLAN band. The fabricated antenna was measured using an Agilent 8753ES Network Analyzer. The measured -10 dB impedance bandwidths of the proposed antenna cover 1.53–1.59 GHz, 2.1–2.7 GHz, 3.18–3.8 GHz, and 5.0–5.82 GHz for the GPS/IEEE 802.11b, WLAN/WiMAX/IEEE 802.11a, and WLAN applications, respectively. Good agreement between the simulated and measured results is observed, and the slight difference can mainly be attributed to the cable effect (e.g., the altered current distributions caused by the feed cable in an electrically small ground plane [17]). Other potential reasons are the solder joints connecting the feed cables to the antenna and the differences between the actual and nominal loss tangents of the material.

As shown in Fig. 7, the measured efficiencies and peak gains of the proposed antenna are 70% and 3 dBi, 76% and 3.1 dBi, 80% and 5 dBi, and 78% and 4.2 dBi, respectively, at 1.57, 2.4, 3.5, and 5.5 GHz, respectively. In Fig. 8, the measured radiation patterns are normalized to the peak gain at each resonance frequency and plotted in the xz -plane (E-plane) and yz -plane (H-plane) at 1.57, 2.4, 3.5, and 5.5 GHz. The radiation patterns in the H-planes are quasi-omnidirectional at all operating frequency bands, while those in the E-planes are not. In addition,

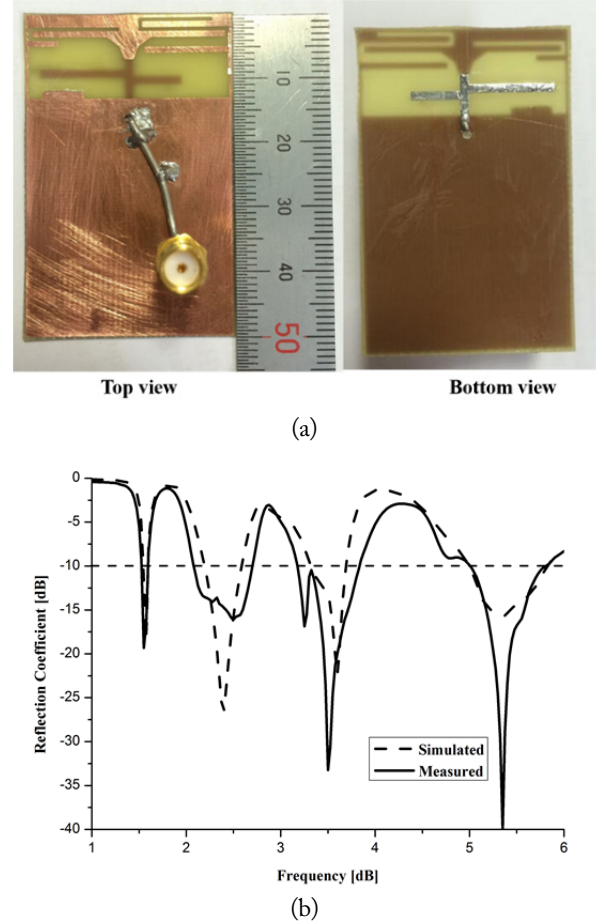


Fig. 6. (a) Geometry of the fabricated slot antenna and (b) simulated and measured reflection coefficients of the proposed slot antenna.

tion, the co-polarization components are higher than the cross-polarization components. The radiation patterns of the proposed antenna are near omnidirectional in the yz -plane at the required WiMAX and WLAN frequency bands. In addition, as a mobile receiving antenna, the GPS radiation pattern of the proposed antenna can still meet the requirements described in

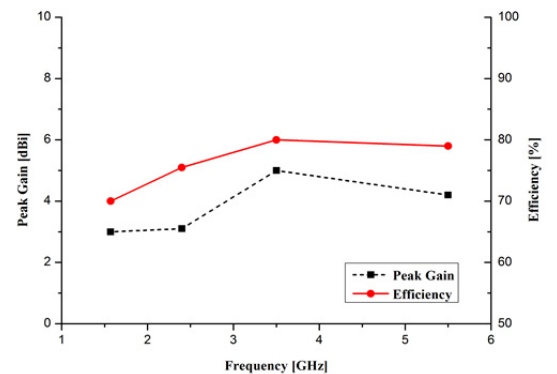


Fig. 7. Measured efficiency and peak gains of the proposed slot antenna.

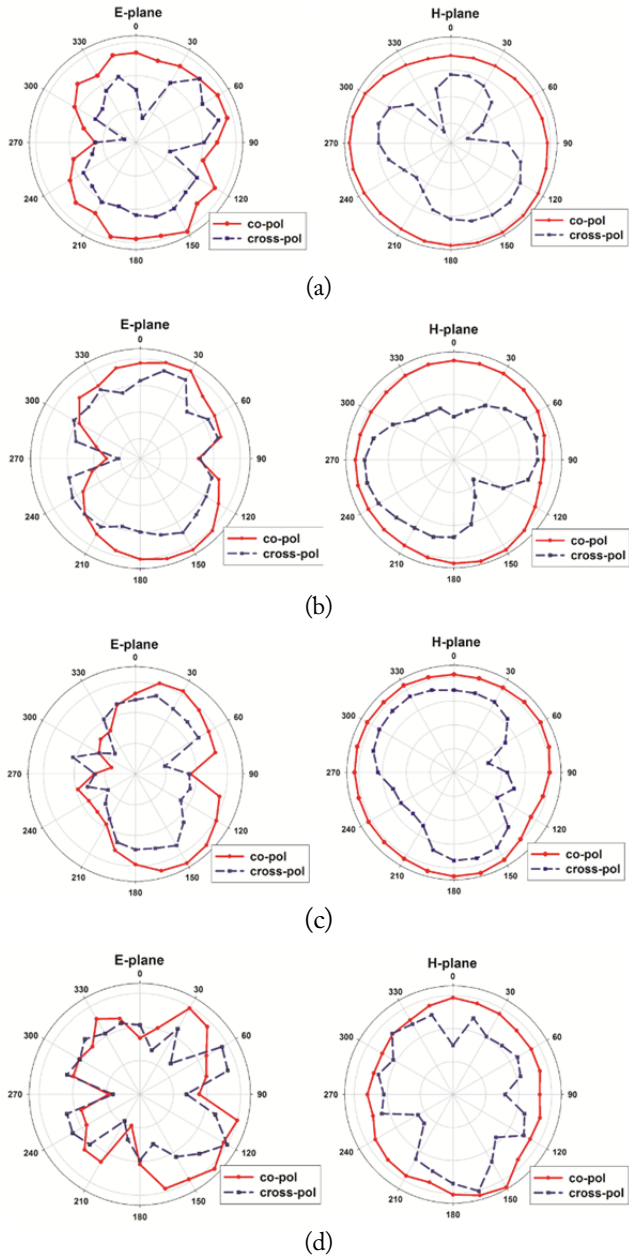


Fig. 8. Measured radiation patterns at (a) 1.575 GHz, (b) 2.4 GHz, (c) 3.5 GHz and (d) 5.5 GHz.

[16, 17]. The simulated 3D radiation patterns of the proposed antenna are also plotted in Fig. 9, indicating that the proposed antenna operates as a dipole-type mode along the x-axis. The measured results agree well with the simulated ones.

IV. CONCLUSION

In this paper, a compact four-band slot antenna for GPS (1.57 GHz), WLAN (2.4/5.2/5.8 GHz), and WiMAX (3.5 GHz) applications is proposed with a size of 13 mm × 32 mm (50 mm × 32 mm ground plane). An inverted U-shaped slot, an inverted L-shaped slot, the protruded stub, and the feed al-

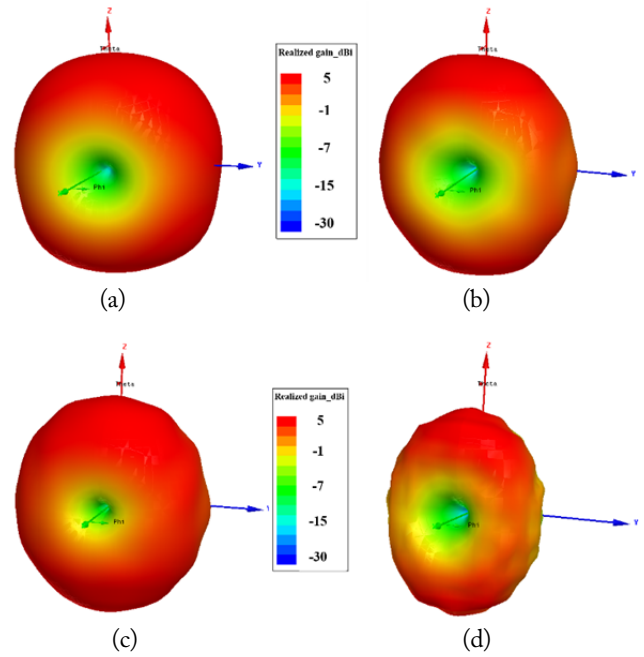


Fig. 9. Simulated 3D radiation patterns at (a) 1.575 GHz, (b) 2.4 GHz, (c) 3.5 GHz and (d) 5.5 GHz.

low for independent control of the 1.57 GHz GPS band, the 2.4 GHz WLAN band, the 3.5 GHz WiMAX band, and 5.5 GHz WLAN band, respectively. The proposed antenna attains a high average peak gain of 3 dBi and an efficiency greater than 70%. In addition, the antenna maintains a quasi-omnidirectional radiation pattern in the H-plane in all the operating frequency bands. Therefore, the proposed compact slot antenna is a good candidate for GPS, WiMAX, and WLAN (2.4/5.2/5.8 GHz) applications.

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