Planar Compact U-Shaped Patch Antenna with High-Gain Operation for Wi-Fi/WiMAX Application

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Abstract **─** A planar inverted U-shaped patch antenna with high-gain operation applied for WLAN/WiMAX access point or base station has been proposed and investigated. It provides relatively wider impedance bandwidth of 180 MHz covering the operating bandwidth for WLAN/WiMAX system. The proposed planar patch antenna also provides the directional radiation patterns with maximum antenna peak gain and efficiency of 8.0 dBi and 80% across the operating band, respectively. Only with the antenna size of 44 × 35 × 4.0 mm^3, the proposed patch antenna has the compact operation with more than 13% antenna size reduction.

Index Terms **─** Patch antenna, WiMAX, WLAN.

I. INTRODUCTION

In the last few years, due to tremendous development in wireless local area network (WLAN), especially for the IEEE 802.11a/b/g WLAN standards in the 2.4 GHz (2400–2484 MHz), 5.2 GHz (5150–5350 MHz), and 5.8 GHz (5725–5825 MHz) bands, dual-band operations are becoming demanding in practical applications. However, with the consideration of both market and technology ready to mass production, single-band 2.4/2.6 GHz for WLAN/WiMAX system with high-gain operation for access point (AP) or base station (BS) can specifically meet the low-cost requirements for the users. The related antenna designs have been presented by using a microstrip antenna [1], an array antenna [2], the suspended patch antenna [3], the roll monopole antenna [4], and the H-shaped slot antenna [5]. But, there is the disadvantage of having a larger antenna size for the above presented designs unable to meet the dimension consideration of the product. Therefore, in this article, by introducing the standard printed circuit board (PCB) substrate and production technology, we propose a novel printed inverted U-shaped patch antenna inset with a pair of T-shaped strips parallel coupled along the feed microstrip line to obtain 2.4/2.6 GHz operation for WLAN/WiMAX communication system. From the related results, it is found that, by properly adjusting the length and width of the T-shaped strips, the operating bandwidth is 180 MHz, which is enough for 2.4/2.6 GHz for WLAN/WiMAX communication system. Also, compared with the regular rectangular patch antenna, this proposed monopole antenna has more than 13% antenna size reduction to obtain a compact operation. The proposed inverted U-shaped patch antenna also provides antenna peak gain of 8.0 dBi with compact antenna size, which is more than that of the presented antenna designs [1-5] under the same peak gain consideration. Details of the proposed compact patch antenna designs are described, and experimental results for the obtained high-gain performance operated at the 2.4 GHz band are presented and discussed.

II. ANTENNA DESIGN

To meet the low-profile requirement for the WLAN or WiMAX access point, a novel planar compact inverted U-shaped antenna with high-gain operation has been proposed. Figure 1 illustrates the geometry of the proposed compact inverted U-shaped patch antenna. A 50Ω mini coaxial cable line is fed at the end of the microstrip line etched on the inexpensive FR-4 substrate with the volume of 44 × 35 × 0.4 mm^3, dielectric constant $\varepsilon_r = 4.7$, and loss tangent $\tan\delta = 0.0245$. A pair of T-shaped coupling strips are inset along the inside edge of the inverted U-shaped patch antenna, which is parallel to the microstrip line. The electromagnetic energy is transferred from the microstrip line to the proposed T-shaped coupling strips to excite the compact patch antenna. The iron plate is used as the ground plane with a volume of 58 × 37 × 0.1 mm^3, which has the air gap of 3.5 mm under the proposed patch antenna with the FR-4 substrate in this study. For achieving the resonant mode at 2.4 GHz band (IEEE 802.11 b/g or Bluetooth), a surface current route of the patch antenna starting from the point A to the end point B is chosen to be about 35 mm corresponding approximately to a quarter-wavelength for 2.4 GHz band, which is different from the regular rectangular patch antenna design with half-wavelength resonance. Therefore, in this article, the compact patch antenna design can be easily obtained. And, by properly adjusting the length and width of the T-shaped coupling strips, good impedance matching across the operating band can easily be achieved.

III. EXPERIMENTAL RESULTS AND DISCUSSIONS

To demonstrate the above deduction and guarantee the correctness of the simulated results, the electromagnetic simulator HFSS based on the finite element method [6] has been applied for the proposed compact patch antenna design. Figure 2 shows the related simulated and experimental results of the VSWR for the proposed compact patch antenna design of Fig. 1. The related results are listed in Table 1 as comparison. Probably due to the permittivity variation of the FR4 substrate, there are slight discrepancies between the simulated and the measured results. Results show the satisfactory agreement for the proposed compact patch antenna design operating at the 2.4 GHz band. From the experimental results, the measured impedance bandwidth (VSWR≦2) can reach 7.3 % (180 MHz) for 2.4 GHz band which provides much greater bandwidths than that (57 MHz, 2.3%) of the regular rectangular patch antenna (51 × 35 × 4.0 mm^3) to meet the 802.11 b/g specifications. To fully comprehend the excitation for WLAN band, the surface current distributions at 2.45 GHz are shown in Figure 3. It is clearly seen that the surface current path from point A to point B in this study is about 1/4 wavelength, not 1/2 wavelength distribution of the conventional rectangular patch antenna mode, which makes the proposed compact patch antenna need less material dimension to reduce the manufacture cost. Compared with the regular rectangular patch antenna of 51 × 35 × 4.0 mm^3, to operate at 2.45 GHz band, this proposed patch antenna has more than 13% antenna size reduction to obtain compact operation.

The measured VSWR with various gap widths between the T-shaped coupling strip and the inside edge of the proposed compact patch antenna are shown in Fig. 4. The related results are also listed in Table 2 as comparison. It is easily found that the operating frequency of the resonant mode significantly decreases with the gap width increased, which means the surface current route of the patch antenna starting from the point A to the end point B increased. Figure 5 shows the measured VSWR with various inside edge lengths of the inverted U-shaped patch antenna. The operating frequency of the resonant mode significantly decreases due to the surface current path of the compact patch antenna increasing with the inside edge length increased.

Table 1: Simulated and measured VSWR against frequency for the proposed patch antenna; L_{s1} = 16.7 mm, W_{s1} = 3 mm, L_{s2} = 21.7 mm, W_{s2} = 17 mm, W_{t1} = 1 mm, L_{t1} = 3 mm, W_{t2} = 1 mm, L_{t2} = 14 mm, W_{p1} = 35 mm, L_p = 44 mm, H = 4 mm

	f_1 (MHz)	BW (MHz, %)
The proposed patch antenna (Simulated)	2530	140, 5.5
The proposed patch antenna (Measured)	2469	180, 7.3
The regular rectangular patch antenna (Simulated)	2469	57, 2.3

The radiation measurement of the proposed compact inverted U-shaped patch antenna is carried out in anechoic chamber by introducing NSI 800F far-field system. Figure 6 shows the measured peak gain and efficiency across the operating band. The maximum measured peak antenna gain and efficiency is 8.0 dBi and 80% at 2.45 GHz, respectively. The gain variation across the operating band is less than 1.0 dB. The measured 2D and 3D radiation patterns of the proposed compact patch antenna at 2.45 GHz are plotted in Fig. 7. Note that the radiation patterns are directional in the whole *x*-*z* plane and *y*-*z* plane.

Table 2: Performance for the proposed compact patch antenna with various gap widths; other antenna parameters are given in Table 1

W_{t1} (mm)	*f* (MHz)	BW (MHz, %)
1.0	2469	180, 7.3
2.0	2403	214, 8.9
3.0	2334	182, 7.8

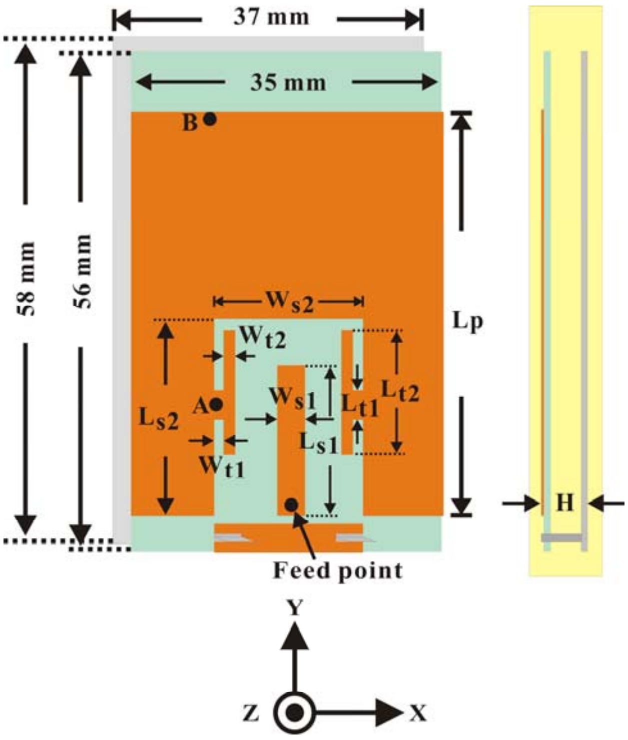


Fig. 1. Geometry of the proposed compact patch antenna with high-gain operation.

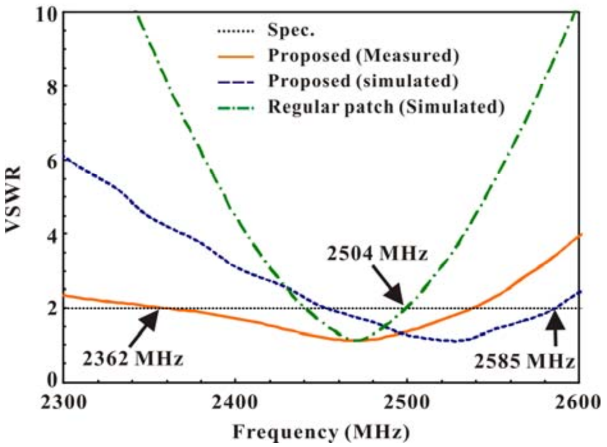


Fig. 2. Simulated and measured VSWR against frequency for the proposed compact patch antenna; antenna parameters are given in Table 1.

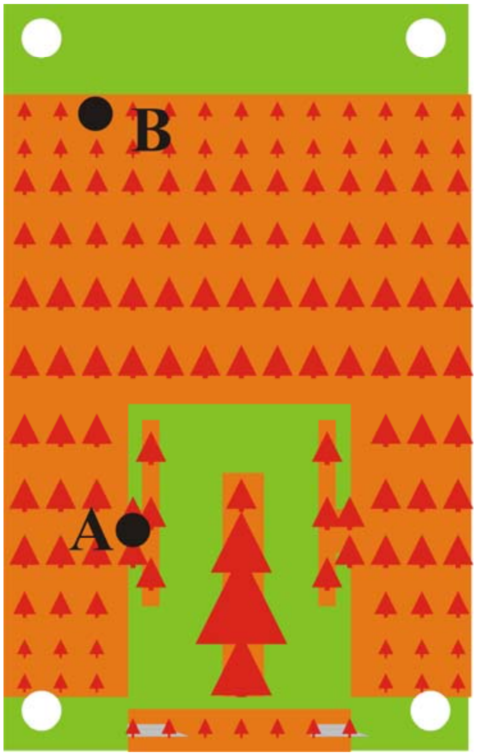


Fig. 3. Simulated surface current distribution for the proposed compact patch antenna at *f* = 2450 MHz.

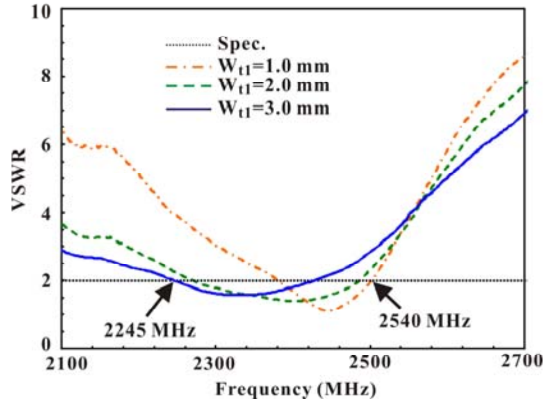


Fig. 4. Measured VSWR with various gap widths between the T-shaped coupling strip and the inside edge of the proposed patch antenna; other antenna parameters are given in Table 1.

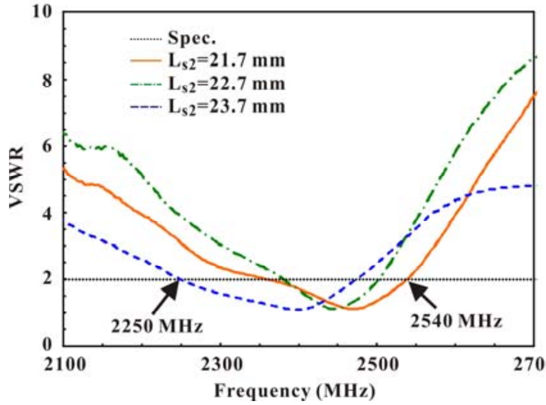


Fig. 5. Measured VSWR with various inside edge lengths of the inverted U-shaped patch antenna; other antenna parameters are given in Table 1.

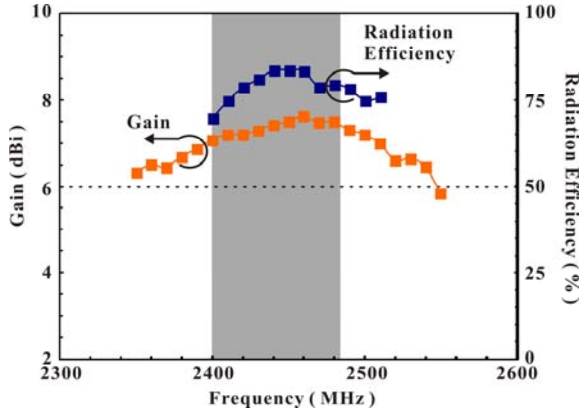
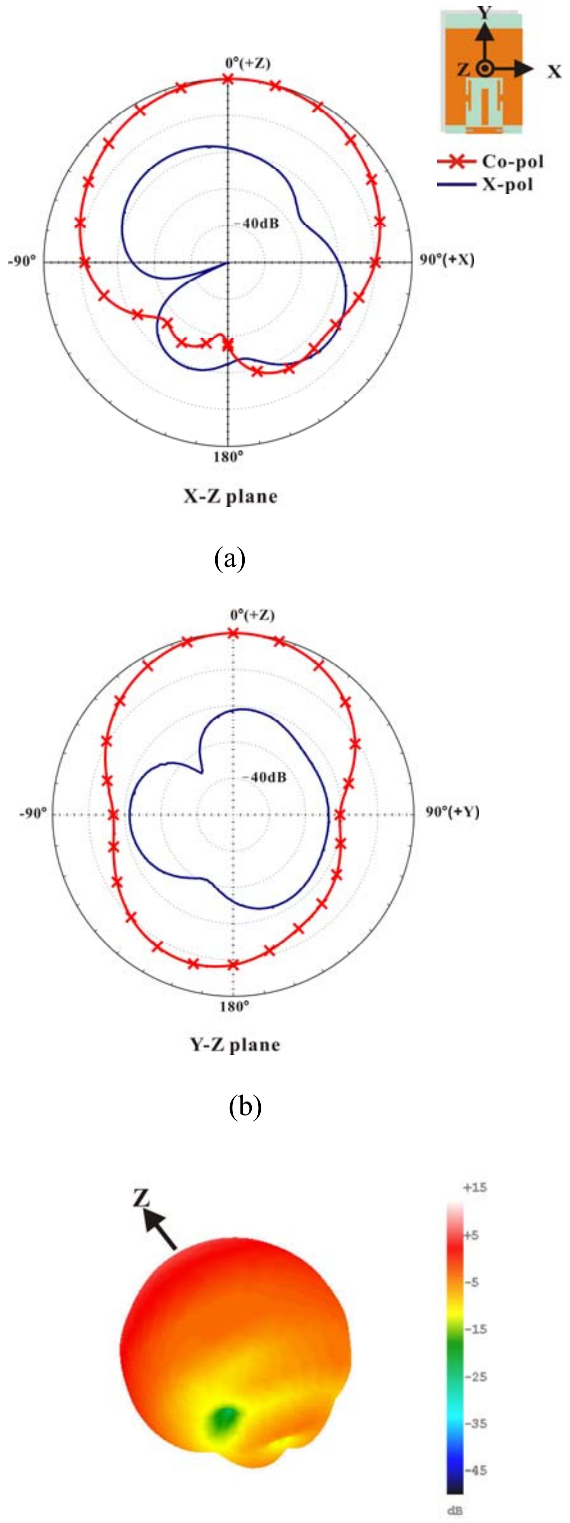


Fig. 6. Measured peak gain and efficiency across the operating frequency for the proposed compact patch antenna.



(a)

(b)

(c) 3D pattern

Fig. 7. 2D and 3D radiation patterns for the proposed compact patch antenna at f = 2450 MHz.

IV. CONCLUSIONS

A planar inverted U-shaped patch antenna with high-gain operation for Wi-Fi/WiMAX applications has been proposed and investigated. It provides relatively wider impedance bandwidth of 180 MHz covering the operating bandwidth for WLAN/WiMAX system. The proposed planar patch antenna also provides the directional radiation patterns with maximum antenna peak gain and efficiency of 8.0 dBi and 80% across the operating band, respectively. Only with the antenna size of 44 × 35 × 4.0 mm^3, the proposed patch antenna has the compact operation with more than 13% antenna size reduction.

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