Compact and Broadband Microstrip-Line-Fed Modified Rhombus Slot Antenna

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Abstract. *The printed microstrip-line-fed broadband rhombus slot antenna is investigated in this paper. With the use of the offset microstrip feed line and the corner-truncated protruded ground plane, the bandwidth enhancement and the slot size reduction for the proposed slot antenna can be obtained. The experimental results demonstrate that the impedance bandwidth for 10 dB return loss reaches 5210 MHz (108.2%, 2210-7420 MHz), which is about 2.67 times of a conventional microstrip-line-fed rhombus slot antenna. This bandwidth can provide with the wireless communication services operating in wireless local area network (WLAN) and worldwide interoperability for microwave access (WiMAX) bands. Under the use of the protruded ground plane, the slot size can be reduced by about 52%. Details of simulated and measured results are presented and discussed.*

Keywords

Rhombus slot antenna, protruded ground plane, WLAN/WiMAX.

1. Introduction

Various printed slot antennas are used for broadband applications because they have attractive characteristics such as wide impedance bandwidth, low cost and planar structure. In addition, they are easy to be integrated with active devices. In recent years, some microstrip-line-fed printed slot antennas [1-5] were reported because of their favorable broadband performances. In [5], a printed slot antenna with a fork-like tuning stub was proposed to achieve a bandwidth enhancement. However, the structure of microstrip feed line in [5] makes the antenna configuration more complicated. Another printed microstrip-line-fed slot antenna with a simple rotated slot for a wider bandwidth was suggested in [6]. As a result, a wide operating bandwidth of about 2200 MHz (48.9%) with respect to the center frequency at 4500 MHz was obtained. However, it is not enough for the impedance bandwidth to cover more operating bands for wireless communication services. In fact, most of wireless communication systems require miniaturized antennas for practical applications. It leads to much attention to reduce the slot size in antenna design.

In recent years, some techniques of compact slot antennas were reported by [7-13]. These antennas have many advantages individually but having their limitations. In [7-9], it is seen that both slot antenna and feed line structures are apparently complex. In [10-11], the small-size tapered slot antennas use a rectangular cut in the microstrip feed line in [10] and a transformer for the transmission-line impedance matching in [11]. Both antenna designs exhibit that the complicated microstrip feed line is used to achieve broadband operation. According to [12-13], antenna structures with meander and folded slots were investigated. But they also lead to the problem of great complexity in antenna design and fabrication. Recently, new slot antennas such as using an L-shaped strip line in the modified bow-tie slot antenna with a rectangular tuning stub [14] or a coplanar waveguide (CPW)-fed rhombus slot antenna with a rhombic ring feeding structure and rectangular bulge components [15] were proposed for dual-band operation.

In the previous study [16], we presented a microstrip-line-fed rhombus slot antenna with a pair of parasitic strips for the wideband operation. By embedding a pair of parasitic elements in this design, the slot antenna has an impedance bandwidth of 4290 MHz (108.7%). In order to achieve the operating bandwidth as large as [16], the compact broadband modified rhombus slot antenna is proposed and investigated in this paper. By using simple shifting the microstrip feed line and embedding the corner-truncated protruded ground plane, the modified rhombus slot antenna for broadband operation and slot size reduction can be realized.

2. Antenna Designs

Fig. 1 shows the evolution of the proposed microstrip-line-fed rhombus slot antenna. According to [6], a structure of rhombus-shaped slot is selected as shown in Fig. 1(a). For the operating frequency at around 4 GHz suitable for WLAN/WiMAX applications, the rhombus slot with the side length of 25 mm is printed on an FR4 substrate with thickness of 1.6 mm and relative permittivity ε_r

of 4.4. Note that the rhombus slot as indicated in Fig. 1(a) has a mean circumference of 50 mm, which is corresponding to approximately 1.1λ at the operating frequency of 4 GHz, where λ is the wavelength at the operating frequency given by $\lambda = \lambda_0/\sqrt{(1+\varepsilon_r)/2}$, with being λ_0 the free space wavelength. In order to achieve a wider operating bandwidth, a straight microstrip line with an offset distance is used as shown in Fig. 1(b). The distance is only 1 mm from the vertices of the rhombus slot to the ground plane so that this antenna has the size of 37.4 mm × 54 mm.

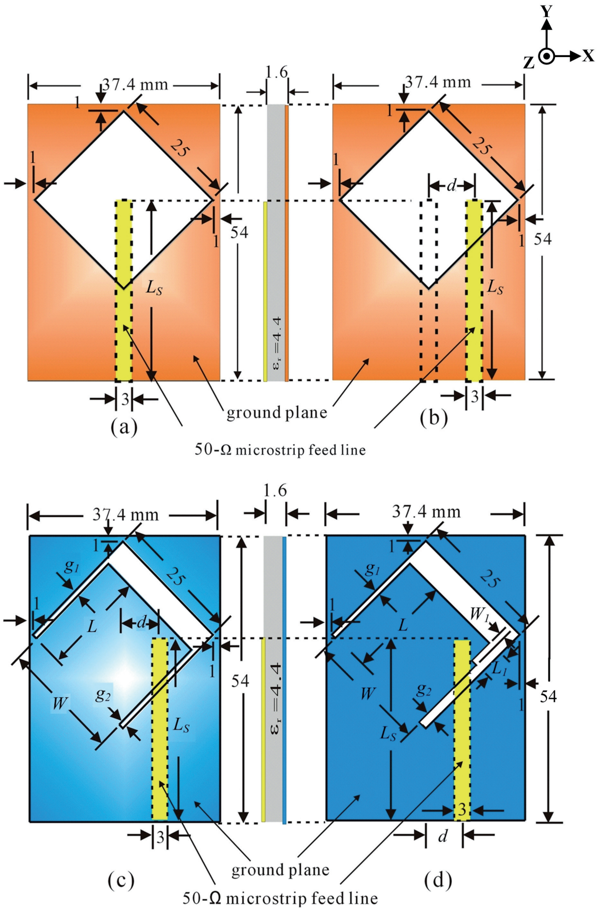

Fig. 1. Evolution of the proposed printed rhombus slot antenna.

Note that four antennas in Fig. 1(a) to (d) are all fed by the 50 Ω microstrip line with a length of L_S, which is printed on the opposite side of the FR4 substrate. For design simplicity, the width of the tuning stub is chosen to be the same to the 50 Ω microstrip feed line. In order to reduce the rhombus slot size, a protrusion of ground plane from one of rhombus sides is embedded as shown in Fig. 1(c) and 1(d). The protruded ground plane used for miniaturizing the slot size in Fig. 1(c) has a rectangular strip of $L \times W$ mm^2. In order to improve the impedance bandwidth of Fig. 1(c), the use of the corner-truncated protruded ground plane in Fig. 1(d) has a rectangular truncation ($L_1 \times W_1$ mm^2) near the corner of microstrip line. Simulated results from the aid of the 3D full-wave high frequency structure simulator (HFSS) indicate that the proper offset distance of microstrip feed line and dimensions of the proper corner-truncated protruded ground plane can enhance the antenna's operating bandwidth to operate at lower frequency. Then the proposed compact slot antenna with the improved impedance bandwidth can be achieved. In the following section, the parameter's study for the proposed antenna is presented in detail.

3. Studied Results and Discussions

In this study, experimental results of impedance bandwidth, radiation pattern, and gain are presented. The Agilent 8722ES network analyzer was used to measure the return loss. For the far-field performances, the NSI-800F-10 anechoic chamber was used for measurements of antenna's radiation pattern and gain.

d (mm)	L_S (mm)	Center Frequency f_C (MHz)	BW (MHz, %)
0 (conventional)	34	4000 (3190-4810)	1620, 40.5
3	34	4335 (3210-5460)	2250, 51.9
4	34	4470 (3230-5710)	2480, 55.5
5	35	4950 (3130-6770)	3640, 73.5
6	35	5310 (3360-7260)	3900, 73.4
7	35	5435 (3420-7450)	4030, 74.1

Tab. 1. The performance of impedance bandwidth in Fig. 1(b) with various offsets of d and L_S.

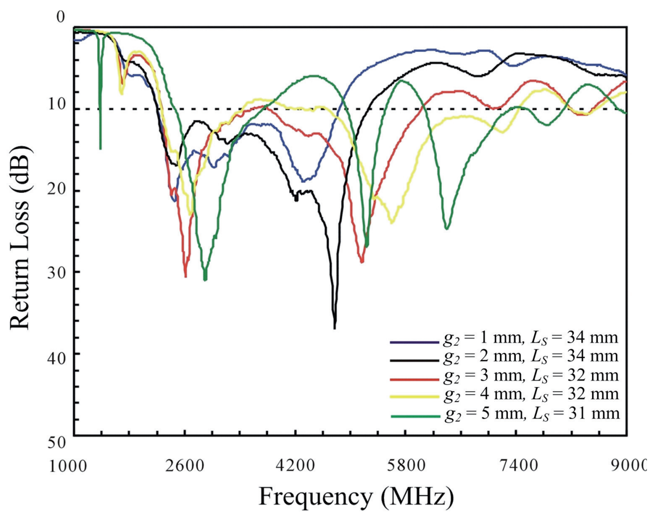

Fig. 2. Measured return loss against frequency of the proposed antenna in Fig. 1(c) with various values of g_2 and L_S as g_1 = 1 mm, d = 5 mm, L_S = 32 mm, W = 21 mm and L = 20 mm. (The same Tab. 2 shown).

Typically, a rhombus slot antenna such as Fig. 1(a) rotated from a square slot as suggested in [6] can provide a wideband operation with an impedance bandwidth about 40.5% as shown in Tab. 1 (as d = 0 mm). In order to excite a wider impedance bandwidth, an offset microstrip feed line is used in Fig. 1(b). By selecting the proper offset distance of microstrip feed line, the measured results about the impedance bandwidth are shown in Tab. 1. From Tab. 1, as $d = 5$ mm and $L_S = 35$ mm, the proposed antenna for the Fig. 1(b) can reach an impedance bandwidth of 73.5% (the center frequency of 4950 MHz), which can be about 1.8 times of a conventional rhombus slot antenna in Fig. 1(a).

g_2 (mm)	L_S (mm)	Center Frequency f_C (MHz)	BW (MHz, %)
1	34	3525 (2220-4830)	2610, 74.0
2	34	3735 (2220-5250)	3030, 81.1
3	32	4150 (2280-6020)	3740, 90.1
4	32	2850 (2270-3430)	1160, 40.7
5	31	3095 (2470-3720)	1250, 40.4

Tab. 2. The performance of impedance bandwidth in Fig. 1(c) with various offsets of g_2 and L_S.

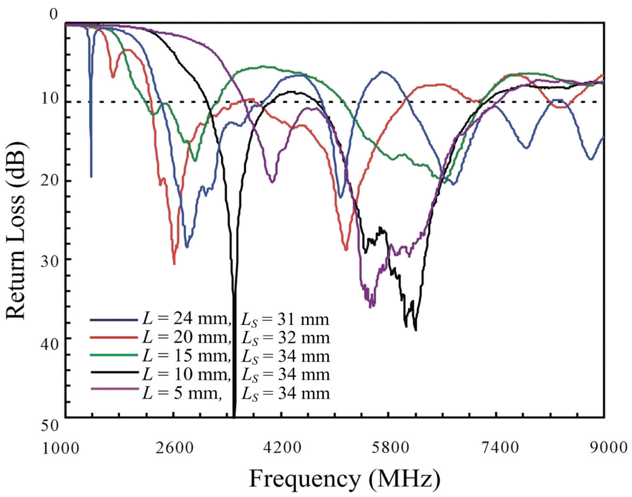

Fig. 3. Measured return loss against frequency of the proposed antenna in Fig. 1(c) with various values of L and L_S as $d = 5$ mm, $g_1 = 1$ mm, $g_2 = 3$ mm and $W = 21$ mm. (The same Tab. 3 shown)

L (mm)	L_S (mm)	Center Frequency f_C (MHz)	BW (MHz, %)
5	34	5535 (3670-7400)	3730, 67.4
10	34	3580 (3110-4050)	940, 26.3
15	34	2730 (2200-3260)	1060, 38.8
20	32	4150 (2280-6020)	3740, 90.1
24	31	3180 (2430-3930)	1500, 47.2

Tab. 3. The performance of impedance bandwidth in Fig. 1(c) with various offsets of L and L_S.

Moreover, in order to reduce the rhombus slot size, a rectangular protruded ground plane is used in Fig. 1(c) where the width (W) of the protruded ground plane is determined after the selections of g_1 and g_2. Note that, with the aid of simulation tool HFSS, the change of g_1 from 1 to 5 mm does not affect the performance of impedance bandwidth because the gap g_1 is far away from the offset microstrip feed line. Now, by varying the parameters of g_2 and L_S as $d = 5$ mm, $g_1 = 1$mm and $L = 20$ mm, the effect of g_2 for measured return loss is shown in Fig. 2 and Tab. 2. The measured results show that the proposed antenna has an optimum matching performance (in red line) in Fig. 2 when $g_2 = 3$ mm. Next, by varying the parameters of L and L_S as $d = 5$ mm, $g_1 = 1$ mm, $g_2 = 3$ mm and $W = 21$ mm, the effect of L for measured return loss is shown in Fig. 3 and Tab. 3.

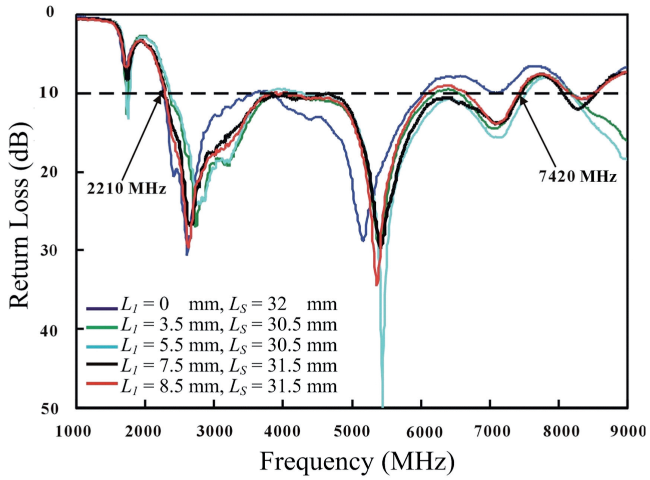

Fig. 4. Measured return loss against frequency of the proposed antenna in Fig. 1(d) with various values of L_1 and L_S as $d = 5$ mm, $g_1 = 1$ mm, $g_2 = 3$ mm, $L = 20$ mm, $W = 21$ mm and $W_1 = 1$ mm.

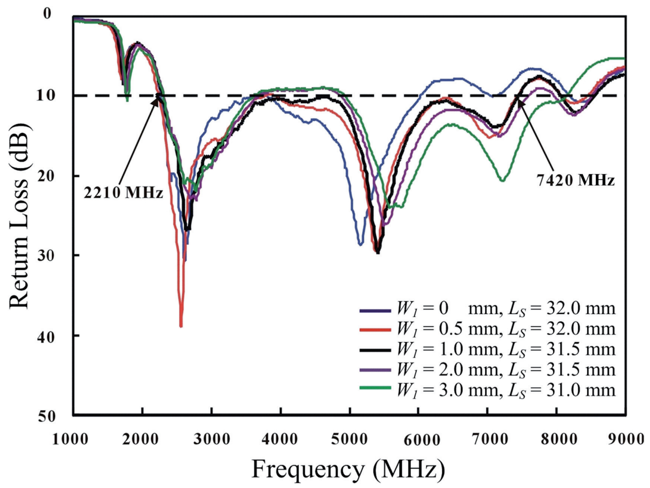

Fig. 5. Measured return loss against frequency of the proposed antenna in Fig. 1(d) with various values of W_1 and L_S as $d = 5$ mm, $g_1 = 1$ mm, $g_2 = 3$ mm, $L = 20$ mm, $W = 21$ mm and $L_1 = 7.5$ mm.

By selecting the proper length ($L = 20$ mm in red line) of the protruded ground plane in Fig. 3, it is found that this can make the dimensions of slot increase equivalently and lead the operating frequency to become lower. Thus the slot size in Fig. 1(c) can be miniaturized as compared to rhombus slot antennas in Fig. 1(a) and (b). In the case of $d = 5$ mm, $g_1 = 1$mm, $g_2 = 3$ mm, $L = 20$ mm, $W = 21$ mm and L_S = 32 mm illustrated in Fig. 1(c), the proposed antenna has an impedance bandwidth of 90.1% (the center frequency of 4150 MHz) but it is not as large as the antenna design in [16]. Finally, the corner-truncated protruded ground plane with a rectangular truncation ($L_1 \times W_1$ mm^2) is used in Fig. 1(d). By varying the parameters L_1 and W_1 as d = 5 mm, g_1 = 1 mm, g_2 = 3 mm, L = 20 mm and W = 21 mm, the effects of L_1 and W_1 for the measured results of return loss are shown in Fig. 4 and 5, respectively. These results show that the proposed antenna with the proper dimensions of the rectangular truncation near the microstrip feed line can achieve a good impedance matching. Thus, as L_1 = 7.5 mm, W_1 = 1 mm and L_S = 31.5 mm in Fig. 4 or 5, the impedance bandwidth of the proposed antenna for 10 dB return loss can reach 5210 MHz (108.2%), which can be as large as that of antenna shown in [16]. In other words, the impedance bandwidth will have a range of wideband operation from 2210 to 7420 MHz for the WLAN/WiMAX operations. In fact, the proposed antenna in Fig. 1(d) has good impedance tuning as the ranges of parameters L_1 from 0.5 to 7.5 mm and W_1 from 0.5 to 1 mm. It means that in these ranges the proposed wideband antenna has a good tolerance in fabrication for practical implementation. If the reduction ratio is defined as

$$\text{Reduction Ratio} = 1-\left(\frac{f_{(proposed)}}{f_{(conventional)}}\right)^2 \tag{1}$$

where $f_{(proposed)}$ and $f_{(conventional)}$ are the lower band-edge frequencies of proposed and conventional antennas, respectively. The slot size in Fig. 1(d) can be reduced by a reduction ratio of about 52% when $f_{(proposed)}$ = 2210 MHz and $f_{(conventional)}$ = 3190 MHz.

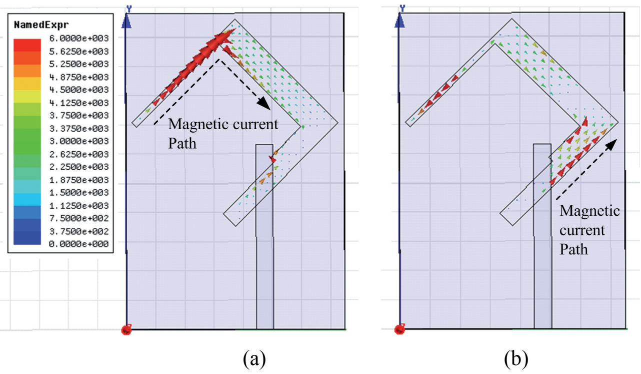

Fig. 6. Simulated equivalent magnetic current distributions at (a) 2.5 GHz, and (b) 5.5 GHz.

For the proposed antenna in Fig. 1(d), the modified rhombus slot can be regarded as a narrow radiated slot, which resonates at a half-wavelength for the operating frequency. To demonstrate this operation characteristic, Fig. 6(a) and (b) show the magnetic current distributions on the modified rhombus slot at 2.5 GHz and 5.5 GHz, respectively, as obtained from the HFSS simulation software. At the operating frequency of 2.5 GHz, Fig. 6(a) shows that a large equivalent magnetic current along the left-hand side of the slot. The path length is about 35 mm (≈ 0.48 λ) At 5.5 GHz, a stronger equivalent magnetic current along the right-hand side of the slot indicated in Fig. 6(b) has a path length of about 15 mm (≈ 0.45 λ). Simulated results demonstrate that the proposed antenna resonates approximately at a half-wavelength for operating at 2.5 and 5.5 GHz, respectively. Fig. 7(a) and (b) show the surface current distributions on the ground plane operating at 2.5 GHz and 5.5 GHz, respectively. The surface current appears on around the modified rhombus slot more significantly. This is because the slot serves as a radiating element so as to form the stronger excited current at operating frequency.

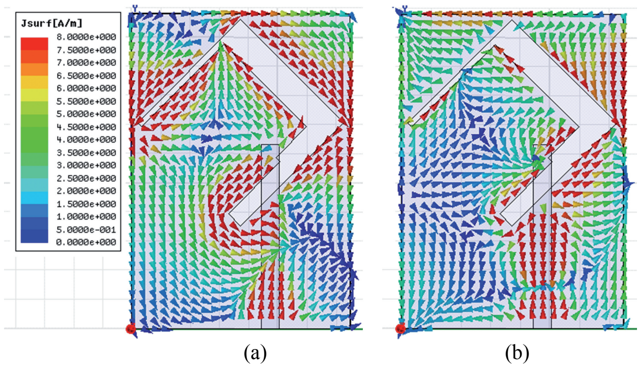

Fig. 7. Simulated surface current distributions at (a) 2.5 GHz, and (b) 5.5 GHz.

Fig. 8 presents the measured and simulated return loss results of the proposed antenna as d = 5 mm, g_1 = 1 mm, g_2 = 3 mm, L = 20 mm, W = 21 mm, L_1 = 7.5 mm, W_1 = 1 mm and L_S = 31.5 mm. It is seen that the measured results have similar operating resonant modes as compared to the simulated results.

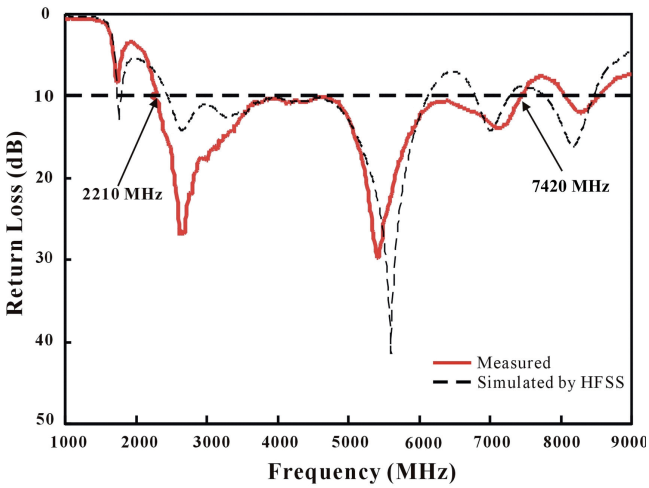

Fig. 8. Measured and simulated results of return loss against frequency of the proposed antenna with d = 5 mm, g_1 = 1 mm, g_2 = 3 mm, L = 20 mm, W = 21 mm, L_1 = 7.5 mm, W_1 = 1 mm and L_S = 31.5 mm in Fig. 1(d).

Fig. 9(a) to (c) show measured E-plane (x-y plane) and H-plane (x-z plane) radiation patterns of the proposed antenna at 2450 GHz, 3500 GHz and 5500 MHz in the WLAN/WiMAX bands, where the WiMAX band (2305-5825 MHz) includes 2.3 - 2.7, 3.3 - 3.8 and 5.2 - 5.8 GHz bands. It is noted that the radiation patterns show relatively high cross-polarization levels. According to [6], this behavior for a slot radiator is due to the large transverse electric field component, which leads to larger cross-polarization levels in the resulting radiation patterns. Because of the use of the protruded ground plane in this design, the shape of radiation slot becomes irregular, which can also make the cross-polarization level larger. From measured results, it is observed that the radiation patterns at the operating frequencies across the impedance bandwidth of this antenna from 2210 to 7420 MHz have the same polarization planes and similar broadside radiation patterns. And the radiation patterns measured in H-planes have the same omni-directions.

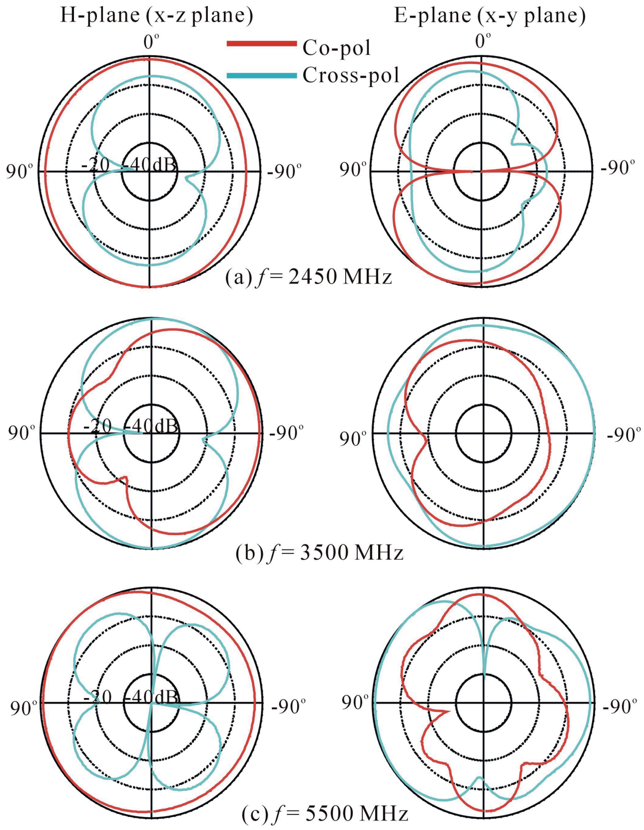

Fig. 9. Measured E-plane (x-y plane) and H-plane (x-z plane) radiation patterns for the Fig. 1(d) in the (a) WLAN/WiMAX (2450 MHz) band, (b) WiMAX (3500 MHz) band and (c) WiMAX (5500 MHz) band.

Fig. 10 shows the measured peak antenna gains within the wide operating bandwidth. A wideband antenna can usually provide larger operating impedance bandwidth. In the broadside direction, it is possible that the gain drops within the whole impedance bandwidth. From Fig. 8 for the WLAN/WiMAX bands, the antenna gain can be about 1.7 dBi on average in the range of 2.3-3.8 GHz and gain variations are observed to be less than 0.8 dB. The antenna gain can be about 2.5 dBi on average in the range of 5.2-5.8 GHz and gain variations are observed to be less than 0.5 dB. The prototype of the proposed modified rhombus slot antenna for Fig. 1(d) was fabricated as shown in Fig. 11.

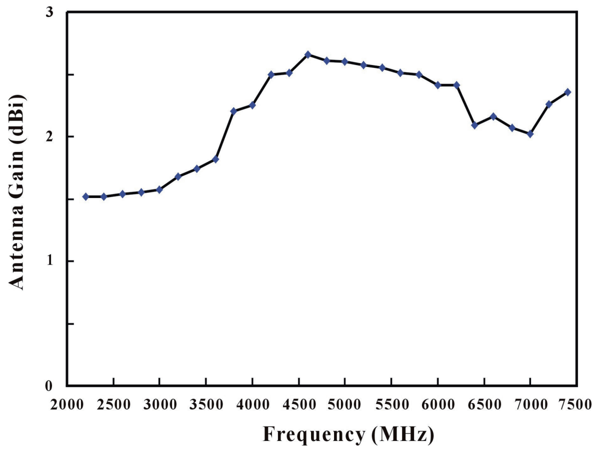

Fig. 10. Measured peak antenna gain against frequency for Fig. 1(d).

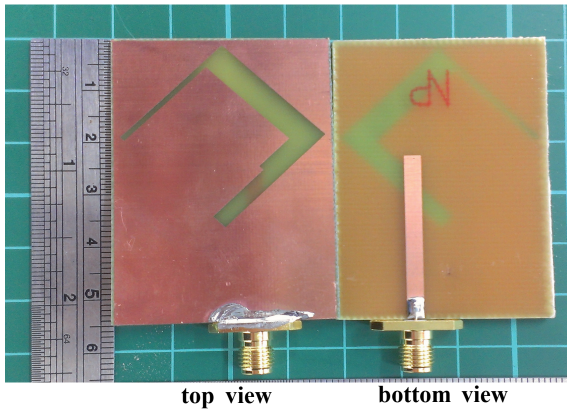

Fig. 11. Photograph of the proposed modified rhombus slot antenna.

4. Conclusions

The compact modified rhombus slot antenna with the offset microstrip feed line and the corner-truncated protruded ground plane has been demonstrated. Experimental results show that the impedance bandwidth of a printed slot antenna can be significantly improved by the use of an offset microstrip feed line and the slot size can be reduced (about 52 %) by the use of corner-truncated protruded ground plane. The measured impedance bandwidth determined for 10 dB return loss can reach an operating bandwidth of 5210 MHz (108.2%) with respect to the center frequency at 4815 MHz. Within this wide impedance bandwidth, the same polarization planes and similar broadside radiation patterns can be obtained. The gain variations in the range of 2.3-3.8 and 5.2-5.8 GHz are less than 0.8 and 0.5 dB, respectively, for the 2.4/5.2/5.8 GHz WLAN bands and 2.5/3.5/5.5 GHz WiMAX bands. Therefore, the proposed antenna is suitable for WLAN/WiMAX applications.

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