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DESIGN OF TRI-BAND PRINTED MONOPOLE ANTENNA FOR WLAN AND WIMAX APPLICATIONS

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Abstract—A novel printed monopole antenna with a pair of parasitic patches for wideband operation is proposed and studied. With the use of parasitic patches along the microstrip feed line, a good performance of bandwidth enhancement is obtained. The measured impedance bandwidth, defined by voltage standing wave ratio (VSWR) $\leq$ 2, can operate from 2.3 to 6.2 GHz. A tri-band printed monopole antenna is created by introducing two notched bands in the wideband antenna. Etching an n-shaped slot on the radiating element and embedding a U-shaped parasitic strip on the bottom, two notched bands from 2.78 to 3.34 GHz and from 3.78 to 5.1 GHz are achieved. The measured impedance bandwidths of the tri-band antenna are 410 MHz (2.37–2.78 GHz), 440 MHz (3.34–3.78 GHz) and 1000 MHz (5.1–6.1 GHz), which can meet the bandwidth requirements of 2.4/5.2/5.8 GHz wireless local area network (WLAN) and 2.5/3.5/5.5 GHz worldwide interoperability for microwave access (WiMAX) standards. In addition, the proposed antennas have good omnidirectional radiation characteristics and stable gains over the whole operating bands.

1. INTRODUCTION

Recently, with the rapid development of the modern wireless communication systems, many novel wireless products have been introduced to the consumers. The design trend of these wireless products is to integrate many functions into a single product. Therefore, the antenna used in the wireless communication systems must have wideband or multiband. The printed monopole antennas have aroused much interest because they usually have

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a wide impedance bandwidth and can be applied to various wireless communication systems such as 2.4/5.2/5.8 GHz WLAN and 2.5/3.5/5.5 GHz WiMAX. Furthermore, they also have the advantages of low profile, simple structure, easy fabrication, and good monopole-like radiation pattern. Many dual-wideband and wideband printed monopole antennas have been proposed in [1–7] for WLAN and WiMAX applications. However, when these antennas are used in WLAN and WiMAX systems, additional band pass filters are required to avoid collision and minimize frequency interference because their wide operating bands cover many existing narrowband services. Many tri-band antennas have been proposed for WLAN and WiMAX applications in literatures [8–15], which have the better rejections in the undesired bands in comparison with wideband antennas. A paw-shaped antenna in [8], a wide-slot antenna with two pairs of inverted L-strips in [9] and a T-shaped antenna with two parasitic elements in [10], they create three operating bands by applying three different resonant lengths. In addition, another method to create three operating bands by introducing two notched bands in a wideband antenna is applied in [11–15]. Many methods have been introduced to reject the dispensable bands, such as inserting the strip in the slot [11] or on the radiating patch [13, 15], etching the slot on the radiating patch [12, 14] or on the ground plane [11–13], and embedding the parasitic strip [14].

In this paper, a printed monopole antenna with a pair of parasitic patches for bandwidth enhancement is proposed firstly. The enhanced bandwidth is about 3900 MHz (2.3–6.2 GHz), covering both WLAN in 2.4/5.2/5.8 GHz bands and WiMAX in 2.5/3.5/5.5 GHz bands. And then, an extended tri-band antenna is proposed by introducing two notched bands in the wideband antenna. Etching an n-shaped slot on the radiating element and embedding a U-shaped parasitic strip on the bottom, two notched bands can be obtained. Three proper operating bands can be achieved for 2.4/5.2/5.8 GHz WLAN and 2.5/3.5/5.5 GHz WiMAX applications by adjusting the dimensions of the n-slot and U-strip. Details of the antenna design and the parameter study are presented and discussed as follows.

2. ANTENNA DESIGN

In order to show the design evolution process of the proposed tri-band antenna, three antennas are plotted in Figure 1. They are all designed and fabricated on a substrate with relative permittivity of 4.4 and thickness of 1.6 mm. Ant. 1 in Figure 1(a) is a traditional printed monopole antenna fed by a 50-Ω microstrip line, which has

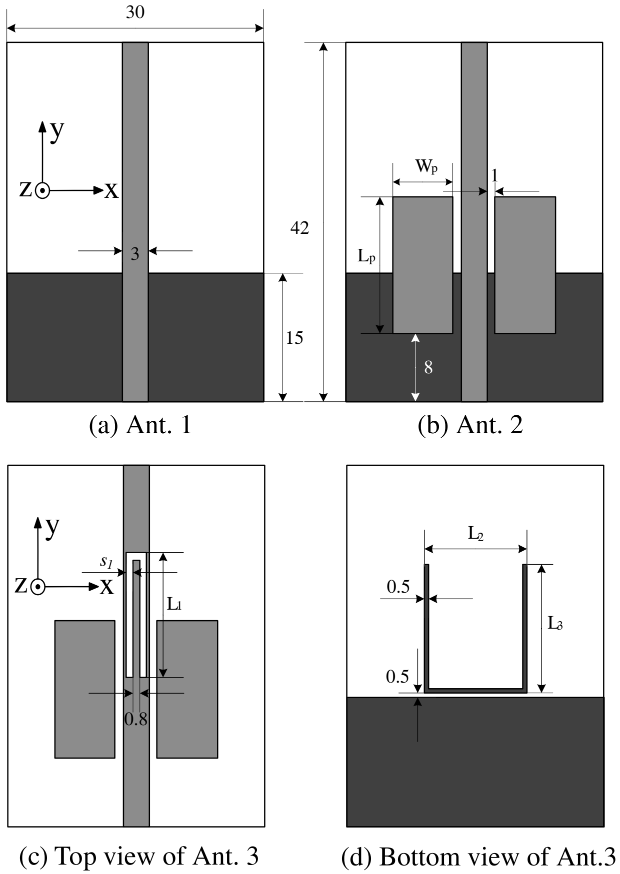


Figure 1. Geometry of the proposed antennas (unit: mm).

a length of 15 mm. In order to excite the operating frequencies at around 2.4 GHz, the printed radiating element has a length of 27 mm. For design simplicity, the width of the element is chosen to be 3 mm, which is the same as that of the 50-Ω microstrip line. According to the design of Ant. 1, a pair of parasitic rectangular patches with size of $L_p \times W_p$ is applied to the design of Ant. 2, as shown in Figure 1(b). The parasitic patches are located on both sides of the microstrip feed line with a gap of 1 mm. In order to obtain a sufficient space for the parasitic patches, the width of the proposed antenna is chosen to be 30 mm. In Figure 1(b), we can see that the patches and the ground plane overlap, and the overlap increases the coupling between the radiating element and the ground and enhances the impedance matching. Based on the Ant. 2, by etching an n-shaped slot on the radiating element and embedding a U-shaped parasitic strip on the bottom, a novel tri-band antenna is proposed, as shown in Figures 1(c) and (d). The width of the slot is s_1 and the length of the vertical slot is L_1. The U-shaped parasitic strip comprises a horizontal strip and two vertical strips with the lengths of L_2 and L_3, respectively. The width of the strips is fixed at 0.5 mm, which is the same as the gap between the horizontal strip and the ground plane. The required analysis of geometrical parameters are studied with the aid of Ansys's High Frequency Structure Simulator (HFSS) software, and the final optimum design parameters are following: $L_p = 16$, $W_p = 7$, $L_1 = 14.5$, $s_1 = 0.8$, $L_2 = 12$ and $L_3 = 15$.

3. PARAMETER STUDY

3.1. Parameter Study on Ant. 2

In order to excite more resonant modes and enhance impedance bandwidth, a pair of parasitic rectangular patches with the size of $L_p \times W_p$ is employed in Ant. 2. Figure 2 shows the measured VSWR curves of Ant. 2 for different values of L_p and W_p. It is obvious that L_p and W_p have strong effects on the impedance bandwidth. The result seems to be ideal when $L_p = 16$ mm and $W_p = 7$ mm. Furthermore, from the detailed simulated results in Table 1, we can see that when L_p varied from 16 to 18 mm ($W_p = 7$ mm) and W_p varied from 6 to 8 mm ($L_p = 16$ mm), the impedance bandwidths are moderate. They can cover the 2.4/5.2/5.8 GHz WLAN and 2.5/3.5/5.5 GHz WiMAX

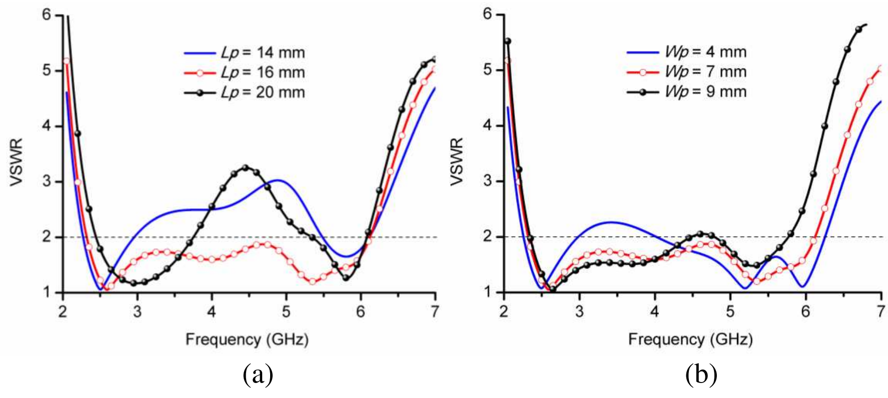


Figure 2. Simulated VSWR of Ant. 2 for various (a) L_p and (b) W_p.

Table 1. Simulated frequency band (VSWR ≤ 2) of Ant. 2 for various L_p and W_p.

Fixing $W_p = 7$ mm	frequency band (GHz)	Fixing $L_p = 16$ mm	frequency band (GHz)
$L_p = 14$ mm	2.28–2.95, 5.49–6.12	$W_p = 4$ mm	2.25–3, 4–6.25
$L_p = 15$ mm	2.3–3.19, 5.15–6.12	$W_p = 5$ mm	2.27–3.17, 3.62–6.22
$L_p = 16$ mm	2.32–6.13	$W_p = 6$ mm	2.30–6.18
$L_p = 17$ mm	2.35–6.10	$W_p = 7$ mm	2.32–6.13
$L_p = 18$ mm	2.38–6.10	$W_p = 8$ mm	2.33–6.01
$L_p = 19$ mm	2.41–4.1, 4.9–6.08	$W_p = 9$ mm	2.34–5.76
$L_p = 20$ mm	2.38–3.75, 5.35–6.08	$W_p = 10$ mm	2.37–5.5

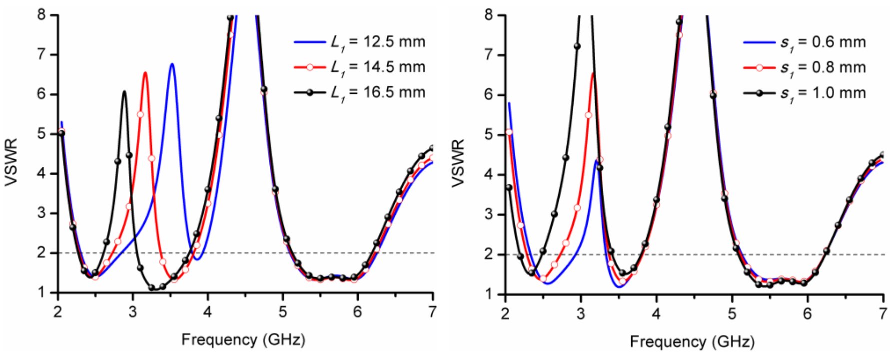


Figure 3. Simulated VSWR of Ant. 3 for various L_1 and s_1.

operating bands. It means Ant. 2 has a good advantage of tolerance in fabrication.

3.2. Parameter Study on Ant. 3

Based on the analysis of Ant. 2, Ant. 3 with two notched bands is designed by etching an n-shaped slot on the radiating element and embedding a U-shaped parasitic strip on the bottom. The etched slot with the vertical length L_1 and width s_1 is designed to produce the first notched band at the lower frequency. The center frequency is determined by L_1 and the peak VSWR in the notched band is affected by s_1. Figure 3 shows the variation of simulated VSWR with various L_1 and s_1. From the simulated results we can see that the first notched band shifts towards the lower frequency with the increase of L_1 and the peak VSWR in the notched band increases when s_1 increases. The embedded U-shaped parasitic strip with the horizontal length L_2 and vertical length L_3 is used for the second notched band at the higher frequency. Figure 4 shows the variation of simulated VSWR with different values of L_2 and L_3. The lengths L_2 and L_3 control the second notched band. The longer the L_2 and L_3 are, the lower the center frequency is. The two notched bands can be adjusted independently. Considering the requirements of the operating bandwidth and the characteristic of the notched bands, the final optimum parameters are chosen as (unit: mm) $L_1 = 14.5$, $s_1 = 0.8$, $L_2 = 12$, and $L_3 = 15$.

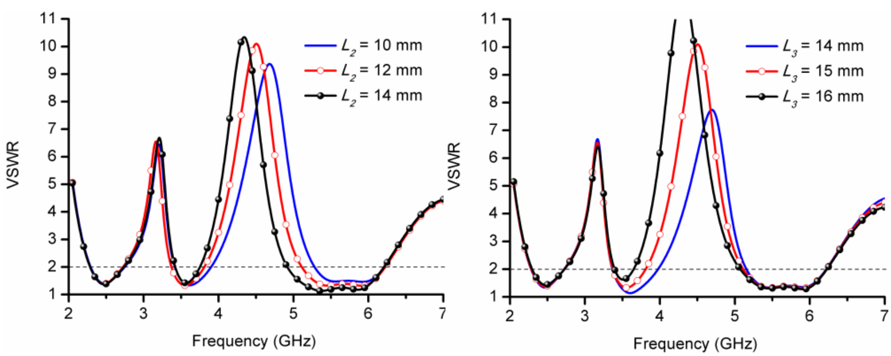
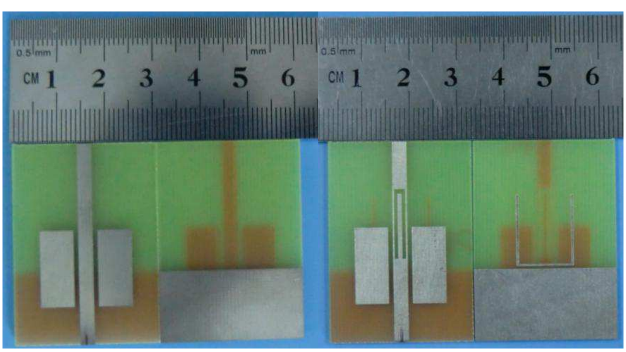


Figure 4. Simulated VSWR of Ant. 3 for various L_2 and L_3.



(a) Prototype of Ant. 2 (b) Prototype of Ant. 3

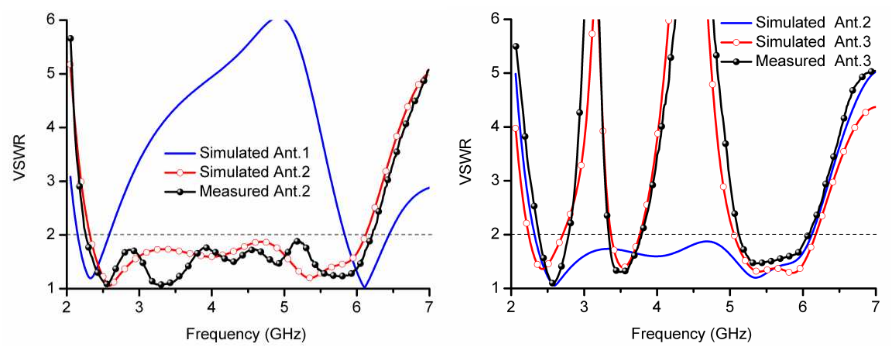
Figure 5. Prototypes of the proposed antennas.

4. RESULTS AND DISCUSSION

According to the aforementioned design results, the prototypes of Ant. 2 and Ant. 3 are fabricated, as shown in Figure 5. With the help of the Ansys's HFSS software and WILTRON37269A vector network analyzer, the simulated and measured VSWR curves are plotted in Figure 6. A good agreement is observed between simulation and measurement. In Figure 6(a), we can see that a good performance of bandwidth enhancement is obtained by introducing a pair of parasitic patches and properly choosing their dimensions. The enhanced bandwidth is 3900 MHz, from 2.3 to 6.2 GHz. Etching an n-shaped slot on the radiating element and embedding a U-shaped parasitic strip on the bottom, two notched bands from 2.78 to 3.34 GHz and from 3.78 to 5.1 GHz are achieved. The measured impedance bandwidths of Ant. 3 are 410 MHz (2.37–2.78 GHZ), 440 MHz (3.34–3.78 GHz) and 1000 MHz (5.1–6.1 GHz), as shown in Figure 6(b). The measured results indicate that the proposed antennas can meet the bandwidth requirements of 2.4/5.2/5.8 GHz WLAN and 2.5/3.5/5.5 GHz WiMAX standards.

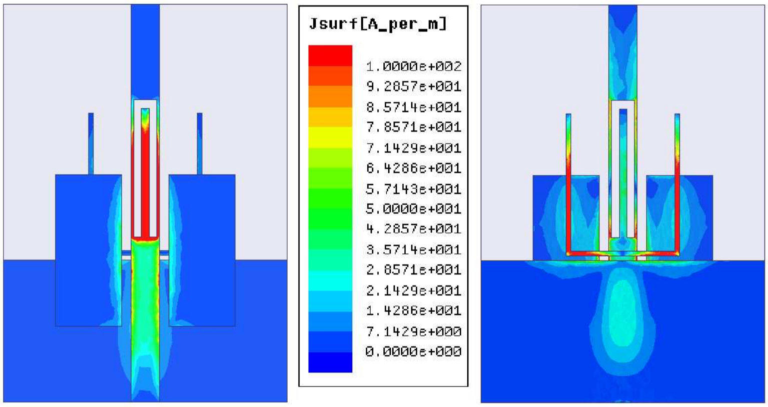
The surface current distributions at the rejected frequencies 3.1 and 4.5 GHz are presented in Figure 7. The surface current distributions at 3.1 GHz are concentrated on the n-slot as shown in Figure 7(a), while that at 4.5 GHz are concentrated on the U-strip as shown in Figure 7(b).

The measured E-plane (x-y plane) and H-plane (x-z plane) radiation patterns at 2.5, 3.5 and 5.5 GHz for Ant. 2 and Ant. 3 are shown in Figures 8 and 9, respectively. From the measured results



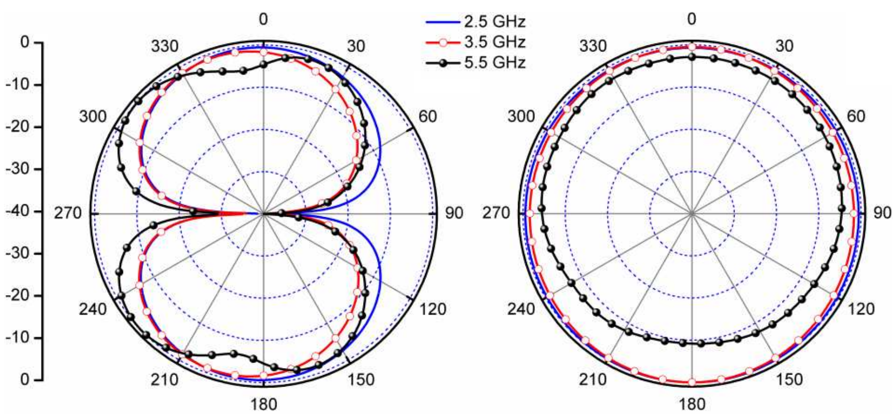
(a) (b)

Figure 6. Comparison of the simulated and measured VSWR for the proposed antennas.



(a) Top view at 3.1GHz (b) Bottom view at 4.5GHz

Figure 7. Simulated current distributions of Ant. 3 at (a) 3.1 GHz and (b) 4.5 GHz.



(a) E-plane (x-y plane) (b) H-plane (x-z plane)

Figure 8. Measured radiation patterns of Ant. 2 in (a) E-plane and (b) H-plane.

we can see that the radiation characteristic of Ant. 2 is similar to that of Ant. 3 and both the antennas have bi-directional radiation patterns in the E-plane. The radiation patterns in H-plane are nearly omnidirectional at 2.5 and 3.5 GHz, but slightly distorted at 5.5 GHz. The measured peak gain is shown in Figure 10. The Ant. 2 gain

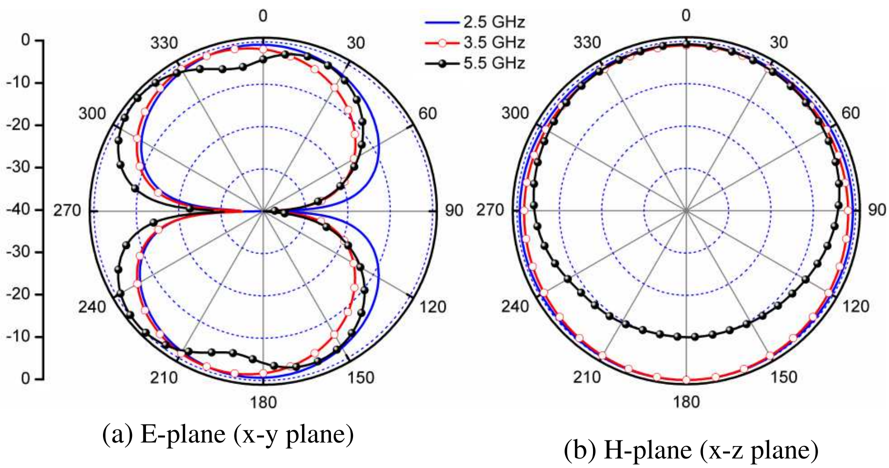


Figure 9. Measured radiation patterns of Ant. 3 in (a) E-plane and (b) H-plane.

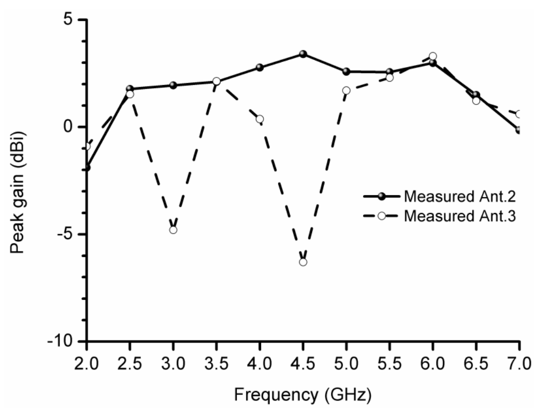


Figure 10. Measured peak gains of Ant. 2 and Ant. 3.

variation is observed to be less than 2 dB with a maximum gain of 3.5 dB at 4.5 GHz. It is noted that the gains of Ant. 3 are almost the same as that of Ant. 2 in the operating bands but have two significantly drops in the notched bands.

5. CONCLUSION

The design of tri-band printed monopole antenna for WLAN and WiMAX applications has been successfully implemented. First, a good performance of bandwidth enhancement is obtained by employing a pair of parasitic rectangular patches in a traditional printed monopole antenna. Then, in order to remove unwanted bands, two band-notched characteristics are achieved by etching an n-shaped slot on the radiating element and embedding a U-shaped parasitic strip on the bottom. In the experimental results, the proposed antennas have enough bandwidth for the 2.4/5.2/5.8 GHz WLAN and 2.5/3.5/5.5 GHz WiMAX applications. In addition, the proposed antennas have good omnidirectional radiation characteristics and stable gains over the whole operating bands.

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