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A COMPACT UWB MONOPOLE ANTENNA WITH WIMAX AND WLAN BAND REJECTIONS

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Abstract—A compact ultrawideband (UWB) monopole antenna with two U-shaped slots for WLAN and WiMAX dual band-notched functions is proposed and experimentally studied. The proposed antenna with the size of $28\,\mathrm{mm} \times 24\,\mathrm{mm} \times 1.6\,\mathrm{mm}$ is excited by a $50\,\Omega$ microstrip feed line. The band-notch functions are realized by loading two approximate half-wavelength U-shaped slots which change the current distribution on the Y-shaped patch. The obtained results show that the designed antenna has an impedance bandwidth of 2.95 GHz–12 GHz for $S_{11} \leq -10\,\mathrm{dB}$, except two frequency stop-bands of 332 GHz–3.98 GHz for WiMAX and 4.81 GHz–6.68 GHz for WLAN. The antenna has successfully fabricated and measured. The return loss, band-notched characteristic, radiation patterns and peak gains are presented

1. INTRODUCTION

In antenna terminology, an antenna with a bandwidth equal to 6 : 1 or more is defined as a UWB antenna. The Federal Communications Commission allocated the frequency band 3.1–10.6 GHz for the UWB services in 2002 [1, 2]. However, over the designated UWB frequency band, there are existing WiMAX and WLAN operating bands such as the 3.5 GHz (3400–3690 MHz), the 5.2 GHz (5150–5350 MHz) and 5.8 GHz (5725–5825 MHz) bands that UWB devices may cause interference to [3, 4]. A possible way to solve this problem is to design UWB antennas with band-notched characteristics Various techniques have already been proposed, such as using the embedded resonant cells [5, 6], parasitic elements [7] and embedding U-shaped, L-shaped,

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V-shaped slots, or simple slits in planar antennas to introduce a frequency notch [8]. Comparison of these techniques above, the microstrip slot antenna may be a good choice as it is compact, low profile and easy to integrate with monolithic microwave integrated circuits (MMICs) [9].

In this article, a compact monopole antenna consisting of a Y-shaped patch with two U-shaped slots for dual band-notched UWB applications and a $50\,\Omega$ microstrip feed line is presented in detail. The two U-shaped slots incise and change the path of the surface current on the rectangle patch. Furthermore, the long U-shaped slot deals with the low notched band from 3.32 GHz to 3.98 GHz while the short one deals with the high notched band from 4.81 GHz to 6.68 GHz. At the frequency stop-bands, only are the corresponding slots active while the others are inactive. The simulated and measured results on the return loss, peak gains and radiation patterns indicate the good agreement with each other. The designed and experimental results of the proposed antenna are explained fully in the following sections.

2. ANTENNA DESCRIPTION

The final design of the dual band-notched UWB antenna with a size of $28\,\text{mm} \times 24\,\text{mm}$ is illustrated in Figure 1. The proposed antenna is printed on the FR4 substrate with relative dielectric constant of $\varepsilon_r = 4.4$ and thickness of 1.6 mm. Figure 2 shows the geometry and dimensions of the proposed antenna. On the top of the substrate, a monopole microstrip antenna consisting of a Y-shaped patch is printed to create a relatively wide frequency band, while the two U-shaped

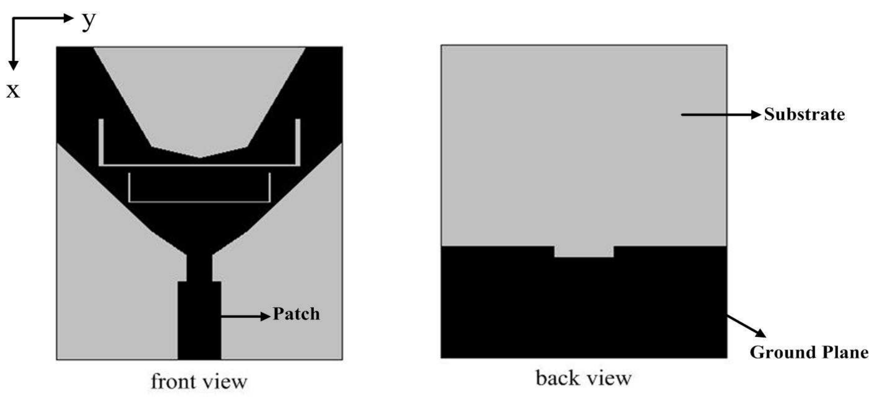


Figure 1. Geometry of the proposed antenna.

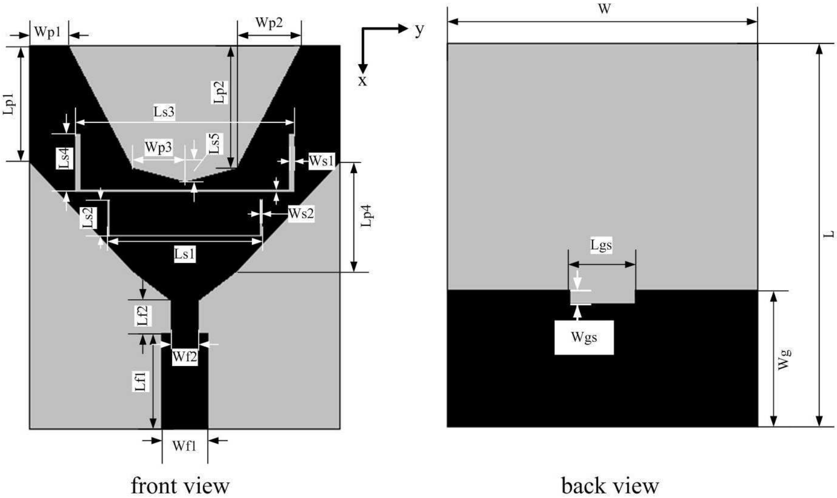


Figure 2. Geometry and dimensions of the proposed antenna.

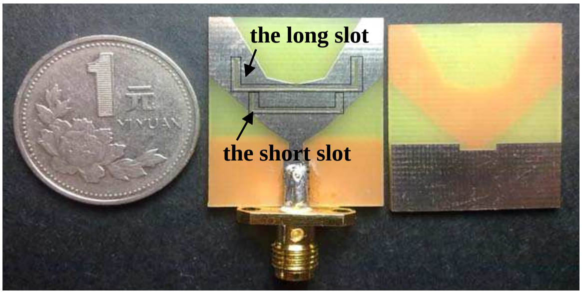


Figure 3. Photograph of the manufactured dual band-notched.

slots on the Y-shaped patch have the effect on the notched bands. This structure is fed by a single microstrip line of 50 Ω. On the opposite side of the substrate, a conducting partial ground plane of width Wg is placed which plays an important role to obtain the good impedance matching from 3 GHz to 11 GHz. To improve the matching at higher frequency, a staircase notch is embedded in the truncated ground plane. This is because the truncation creates a capacitive load that neutralizes the inductive nature of the upper patch [3]. Finally, a wider impedance matching is obtained when the magnitude of some important parameters vary. The photograph of the manufactured dual band-notched antenna with the SMA connector is shown in Figure 3. The following Table 1 is the optimal parameters of the proposed antenna for us to reach into the performance of the proposed antenna:

Table 1. The optimal parameters of the proposed antenna (unit: mm).

W	**Wp1**	**Wp2**	**Wp3**	**Ws1**	**Ws2**	**Wf1**	**Wg**	**Wgs**	**Lgs**	**Wf2**
24	3	5	4	0.5	0.2	3.5	10	1	5	2
L	**Lp1**	**Lp2**	**Lp4**	**Ls1**	**Ls2**	**Ls3**	**Ls4**	**Lf1**	**Lf2**	**Ls5**
28	8.5	9	8	12	2.8	17	4.3	7	2.4	1

3. ANTENNA PERFORMANCES

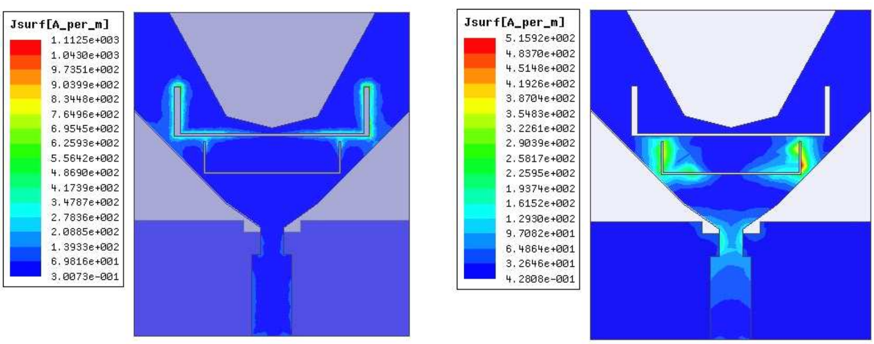
An important feature of the proposed antenna is the capability of impedance matching of 2.95–12 GHz, except two frequency stop-bands by using the two slots which are presented above, the simulated current distribution on the antenna at the frequencies of 3.5 GHz and 5.5 GHz is presented in Figure 4. For comparison, the simulated current distributions on the antenna with the long slot at 3.5 GHz and with the short slot at 5.5 GHz respectively are shown in Figure 5 and the simulated current distributions on the antenna without the slots at the same frequencies is also presented in Figure 6. It can be seen that stronger current distribute in the U-shaped slots than any other area at 3.5 GHz and 5.5 GHz of the notched-bands, so the slots play an important role in the band-notched filters. By means of the equivalent circuit analysis, it can be able to obtain that the slot introduces a LC circuit, and the size of the slot, especially the length, has a great effect on the resonant frequency. When the size has an appropriate dimension, the LC circuit will cause a current resonance and a stop-band will be brought. In addition, at the desired frequency, only are the corresponding slots active while the others are inactive, confirming the independence of the frequency bands. The natural interpretation is that the slots are not the major contributor of antenna performance except for the notch frequency.

For better understanding of the proposed antenna behavior, the simulated return loss of the designed antenna with the long slot and with the short slot is presented in Figure 7, and the result of the reference antenna without notched characteristics is also shown for comparison. It can be seen that the long slot which are etched on the patch primarily results in the frequency stop-band of 3.5 GHz and the short one result in the stop-band at 5.5 GHz in Figure 7. The dimensions of the slots have a great effect on the matching performance of the proposed antenna. When the lengths of the slots are approximately equal to halfwavelength in the medium, the optimal notched characteristics are achieved. Furthermore, the mathematical calculation of the wavelength in the medium is defined as

$$\lambda_g = \frac{c}{f\sqrt{\varepsilon_r}} \tag{1}$$

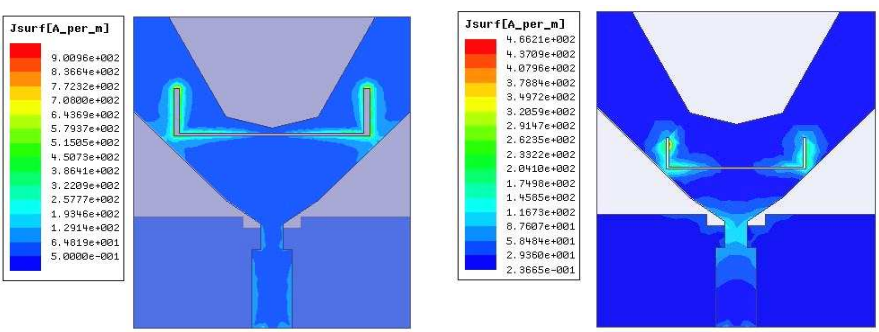
where λ_g is the wavelength in the medium, f is frequency, ε_r is the relative permittivity. Therefore, half-wavelengths in the medium of 3.5 GHz and 5.5 GHz are 20.5 mm and 13 mm respectively.

Figure 8 shows the simulated return loss of the designed antenna without the inner V-shaped structure in the inner side of the Y-shaped patch and the slot in the top middle edge of the ground plane, and the result of the proposed antenna is shown for comparison. It can be seen that the designed antenna without the inner V-shaped structure in the inner side of the Y-shaped patch has no effect on the impedance bandwidth, but the slot in the top middle edge of the ground plane improves the matching at higher frequency (9.17 GHz–11 GHz).



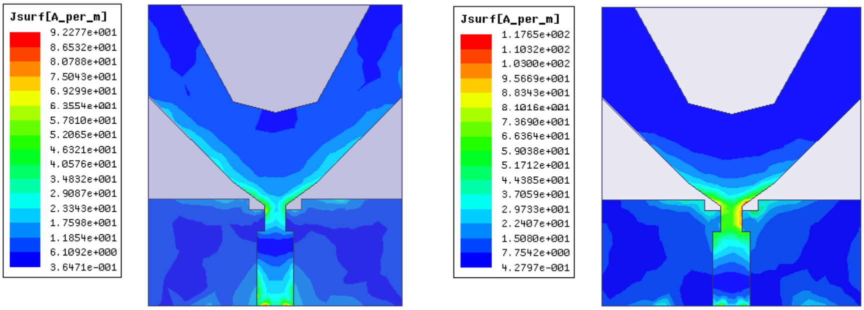
(a) (b)

Figure 4. Surface current distributions on the antenna with the two slots. (a) 3.5 GHz. (b) 5.5 GHz.



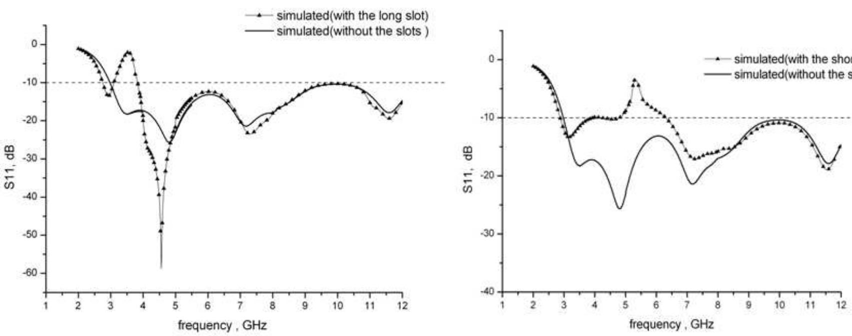
(a) (b)

Figure 5. Surface current distributions on the antenna (a) with the long slot at 3.5 GHz, (b) with the short slot at 5.5 GHz.



(a) (b)

Figure 6. Surface current distributions on the antenna without the two slots. (a) 3.5 GHz. (b) 5.5 GHz.



(a) (b)

Figure 7. Simulated return loss of the designed antenna (a) with the long slot, (b) with the short slot.

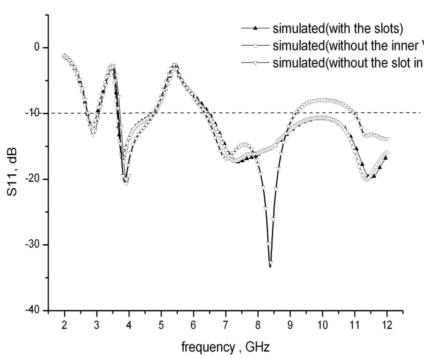


Figure 8. Simulated return loss of the designed antenna.

The proposed dual band-notched antenna is measured by a network analyzer Agilent N5230A (10 MHz–50 GHz). Results of the reference antenna without notched characteristics are also shown for comparison. In Figure 9, it is can be seen that the proposed antenna has an impedance bandwidth of 2.95 GHz–12 GHz for $S_{11} \leq -10$ dB, except two frequency stop-bands of 3.32 GHz–3.98 GHz for WiMAX and 4.81 GHz–6.68 GHz for WLAN. The measured return loss reasonably agrees with the simulated results with an acceptable frequency discrepancy, which may be referred to the difference between the simulated and the measured environments. In Figure 7 we can note that the effect of mutual coupling between notch bands is slight.

The far-field radiation characteristics of the proposed dual band-notched antenna are also investigated. Figures 10–12 show the radiation patterns including the vertical (E_θ) and the horizontal (E_Φ) polarization patterns in the x-y plane, x-z plane and y-z plane of the proposed antenna at 3 GHz, 4 GHz, 7 GHz and 10.6 GHz, respectively. Nearly dipole-like radiation patterns in the x-y plane and x-z plane and omnidirectional radiation patterns in the y-z plane are obtained

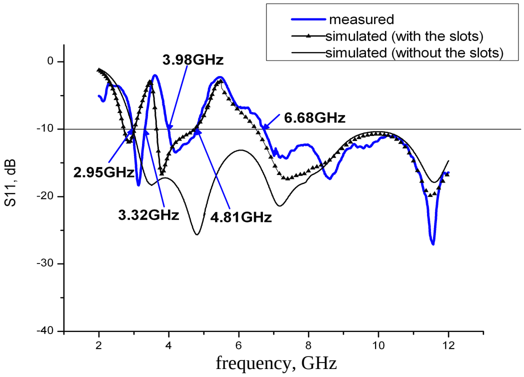


Figure 9. Simulated and measured return loss of the double band-notched antenna.

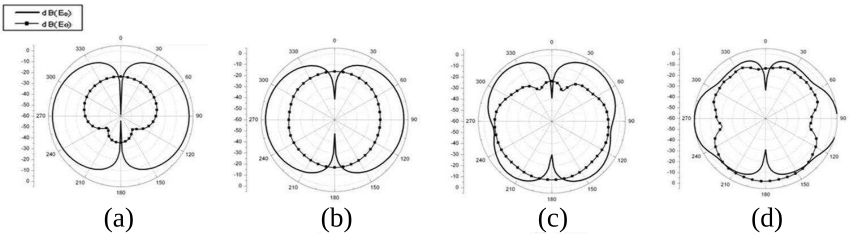
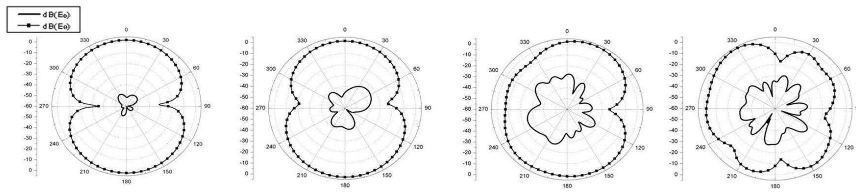
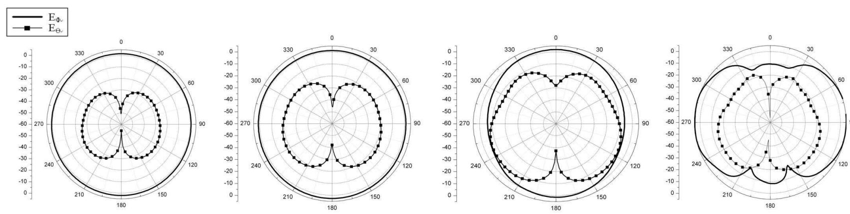


Figure 10. Radiation patterns in the x-y plane for the proposed antennas. (a) 3 GHz. (b) 4 GHz. (c) 7 GHz. (d) 10.6 GHz.



(a) (b) (c) (d)

Figure 11. Radiation patterns in the x-z plane for the proposed antennas. (a) 3 GHz. (b) 4 GHz. (c) 7 GHz. (d) 10.6 GHz.



(a) (b) (c) (d)

Figure 12. Radiation patterns in the y-z plane for the proposed antennas. (a) 3 GHz. (b) 4 GHz. (c) 7 GHz. (d) 10.6 GHz.

at these frequencies. The results show that there is an increase in the cross-polarized pattern in all planes for higher frequency of operation. The results also reveal the fact that the radiation patterns of the antenna are stable in these planes.

Figure 13 shows the result of a group delay in time domain. Considering the values in an available range from 2.95 to 12 GHz, the group delay variation is approximately 1 ns. Maximum result of group delay is about 3.1 ns and 6.4 ns at 3.48 GHz and 5.67 GHz, respectively, in the vicinity of the notched-bands. The reason is the fact that the input and output signal power is very low in these bands and it is difficult to detect this signal in a measuring system.

Figure 14 represents the peak gain verses frequency. The gain increases with the frequency and the peak gains within the operation frequency bands range from 2.0 dB to 5.3 dB. It is clear that there are two sharp dips in the gain at around 3.5 GHz and 5.5 GHz, which confirms the effective operation of the UWB dual band-notch antenna in the two-narrow band systems. As observed in the figure the gain in rejection bands is expected to be sharply reduced as low as −4.7 dB. For other frequencies outside the rejected bands, the gains remain good and stable in performance. All of these show that the proposed antenna has good band-notched characteristics and effectively minimize the potential interferences between UWB system and the wireless communication systems.

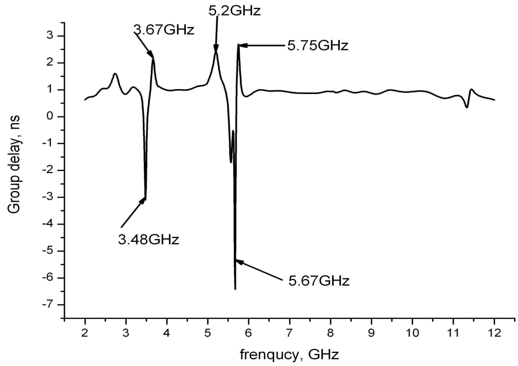


Figure 13. Group delay in time domain of the proposed antenna.

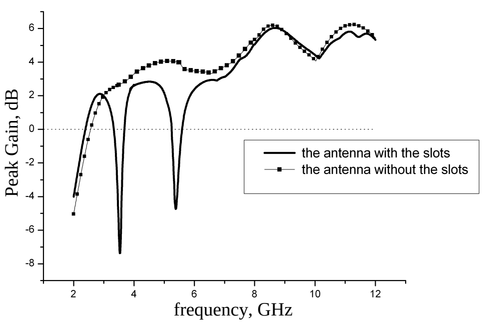


Figure 14. Peak gain of the proposed antenna.

4. CONCLUSION

The characteristics of a compact ultrawideband (UWB) monopole antenna with two U-shaped slots for WLAN and WiMAX dual band-notched functions have been proposed and verified with simulation and measurement. The proposed antenna has a small size (28 mm × 24 mm × 1.6 mm) and simple geometry which is easy to be designed. By employing the two U-shaped slots which are different in size, the proposed antenna creates two stop bands, 3.5-GHz for WiMAX and 5.5 GHz for WLAN. The effects of the slots on the feature of the proposed antenna have also been discussed. Good antenna performances of the operating frequencies across the three operating bands have been obtained and the measurements on the fabricated printed monopole antenna had a good agreement with the simulated results. The electrical performance and superior frequency characteristics make the proposed antenna desirable for ultrawideband applications.

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