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A Tri-Band-Notched UWB Planar Monopole Antenna Using DGS and Semi Arc-Shaped Slot for WIMAX/WLAN/X-Band Rejection

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Abstract—In this paper, a novel monopole printed fork-shaped antenna for ultra-wideband (UWB) applications with triple band-notched characteristics is presented. The proposed antenna, with compact size of $42 \times 24 \times 1.6\,\text{mm}^3$, yields an impedance bandwidth of 3.1–11 GHz for $S_{11} < -10\,\text{dB}$, except on the notched bands which are obtained by introducing three different types of slots. A U-shaped and two extended U-shaped defected ground structure (DGS) slots give respectively two notched bands, 3.3 to 3.7 GHz for WiMAX and 7.1 to 7.76 GHz for downlink X-band satellite communication systems. Therefore, a semi arc-shaped slot is etched on the radiating patch to notch the band from 5.15 to 5.825 GHz for WLAN applications. The proposed antenna is fabricated and measured.

1. INTRODUCTION

Ultra-wideband (UWB) communication technology has been attractive since the Federal Communication Commission (FCC) allocated the frequency range of 3.1–10.6 GHz to be free band in 2002. However, there are several other technologies that can interfere the UWB band systems, such as the Worldwide Interoperability for Microwave Access (WiMAX) in the 3.3–3.7-GHz band, Wireless Local Area Network (WLAN) in the 5.15–5.825-GHz band, and 7.25–7.75 GHz band for downlink of X-band satellite communication systems. Several technics, e.g., slots and C-shape strips, are used to filter the frequency bands in the UWB frequency spectrum [1], to design single or dual band-notched characteristics [12, 13, 18, 20], and triple or multiple notched bands are proposed in [8, 19].

Various UWB antenna structures with band rejected characteristics have been developed, e.g., a planar UWB monopole antenna with triple band-notched characteristics based on a hook-shaped defected ground structure (DGS) and semi-octagon-shaped resonant ring of the antenna [4], π-shaped slot [14], elliptical slot UWB antenna with a half circular ring radiator element [15], a tri-notched band antenna by etching two semicircular round shape slots in radiating patch, and a pair of rotated V-shape slots are etched on the ground plane [16], parasitic strips [17], and arc-shaped parasitic strips or slots and slits for single or dual band-notched characteristics [12, 13, 18, 20]. Other resonator forms, such as elliptic single complementary split-ring resonators and rectangular split-ring resonators etched in microstrip-fed UWB antenna [9, 10], open-looped resonator structure etched in a UWB antenna [5], folded strips, T-shaped stubs, capacitive-load strips [6, 11], and dual band-notch UWB antenna with single tri-arm resonator [22], have been applied for band-notching purposes.

In this paper, a printed fork-shaped monopole antenna for UWB applications [3] is modified with tri-band notched characteristics. The tri-band notched characteristic is obtained by defected ground structure (DGS) U-shaped and two extended U-shaped slots [2] for WIMAX and X-band satellite communication systems, respectively. However, in order to realize the notched band in the WLAN band, a semi arc-shaped slot is etched in the radiating element. The rejected bands can be controlled by adjusting the length of slots and the radius of semi arc-shaped slot. The performances of the proposed antenna are studied, and the simulated and measured results are presented.

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2. ANTENNA DESIGN

To obtain the desired notched bands, defining dimensions and position of introduced slots is one of the crucial elements on band-notched antenna design [7].

The notch frequency is given by:

$$f_{notch} = \frac{c}{2 \times L \times \sqrt{\varepsilon_{eff}}} \tag{1}$$

$$\varepsilon_{eff} \approx \frac{\varepsilon_r + 1}{2} \tag{2}$$

when L is the total length of DGS and slots at the notch frequency, C the velocity of the light in free space, and ε_{eff} the effective dielectric constant. Therefore, the notched band can be shifted to the desired frequency range by adjusting the dimensions of the U-slot and two extended U-shaped and semi-arc slots.

Figure 1 shows the geometry of the proposed antenna with tri-notch band characteristics. The proposed UWB antenna is printed on a $42 \times 24\,\text{mm}^2$ FR4 substrate with a thickness of $h = 1.6\,\text{mm}$ and relative permittivity of 4.3. To achieve 50-ohm characteristic impedance, the width value of the microstrip feedline is fixed at 2.4 mm. To achieve triple notched bands, a semi arc-shaped slot is etched on the radiating patch to reject the 5.5 GHz band. However, a U-shaped slot and a pair of extended U-shaped DGS slots are introduced to generate notched bands on the 3.5 GHz and 7.5 GHz bands, respectively.

The dimensions of the proposed antenna are: $Ws = 24\,\text{mm}$, $Ls = 42\,\text{mm}$, $wf = 2.4$, $lf = 13.2\,\text{mm}$, $wg = 20.4\,mm$, $Lg = 12.7\,mm$, $R1 = 4\,mm$, $R2 = 4.75\,\text{mm}$, $R3 = 6\,\text{mm}$, $R4 = 10.2\,\text{mm}$, $L1 = 1.4\,\text{mm}$, $L2 = 20.6\,\text{mm}$, $L3 = 1\,\text{mm}$, $L4 = 11.5\,\text{mm}$, $L5 = 4.5\,\text{mm}$, $L6 = w1 = 6.2\,\text{mm}$, $w2 = 2\,\text{mm}$, $w3 = 3.2\,\text{mm}$, $w4 = 1.6\,\text{mm}$, $w5 = 2.4\,\text{mm}$, $G1 = 0.4\,\text{mm}$, $G2 = 0.4\,\text{mm}$, $G3 = 1.25\,\text{mm}$, $d1 = 2\,\text{mm}$, $d2 = 3\,\text{mm}$.

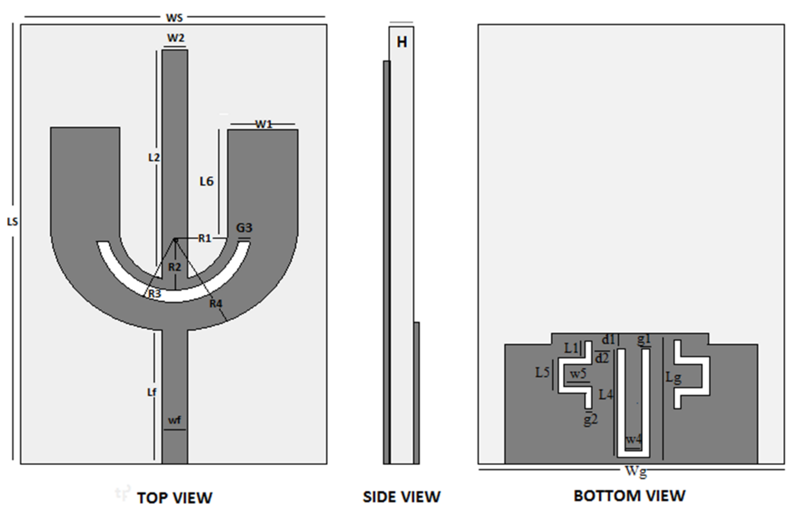
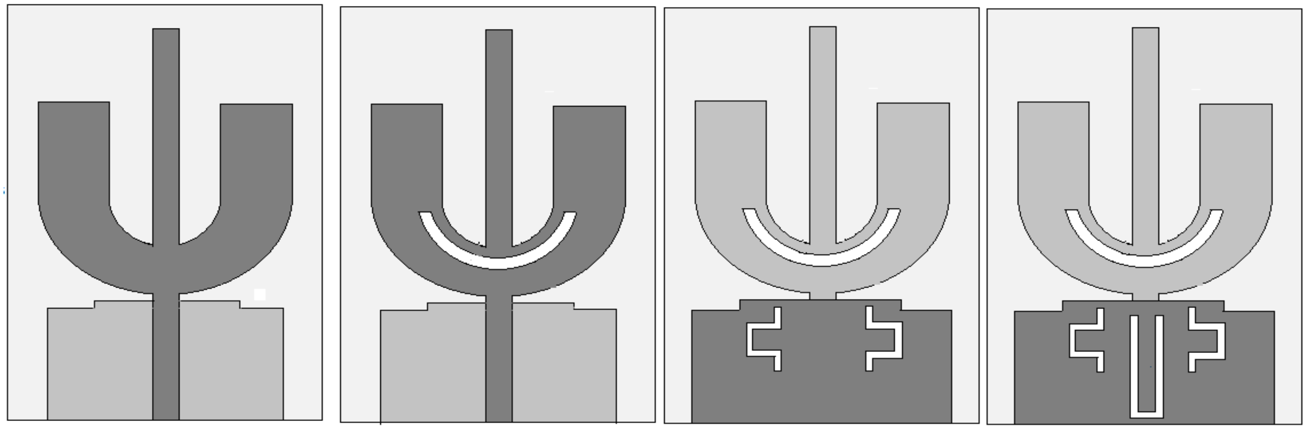


Figure 1. Geometry of the proposed antenna.

Figure 2 illustrates the steps followed in designing the proposed antenna with tri-notched band characteristic. The return loss parameters for different antenna structures are given in Fig. 3 including those of the reference antenna [3]. As shown in Fig. 3, a semi arc-shaped slot etched on the radiating fork antenna leads to a single notched band covering the WLAN band, when symmetrically cutting two V-shaped defected ground structure (DGS) elements near the center of the partial ground plane generates a band notch at 7.5 GHz covering the X-band satellite communication band (7.1–7.76 GHz). Adding U-shaped DGS elements of suitable dimensions in center of the partial ground plane gives an additional band notch at 3.6 GHz covering the WIMAX band (3.3–3.7 GHz).



(a) Ant I (b) Ant II (c) Ant III (d) Ant VI

Figure 2. (a) Ant I: reference antenna, (b) Ant II: antenna with semi arc shaped slot only, (c) Ant III: antenna with arc-shaped and two extended U-shaped DGS slots, and (d) Ant IV: antenna with arc shaped, DGS U-slot and two extend U-shaped slot.

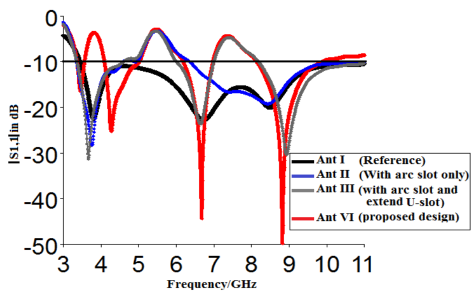
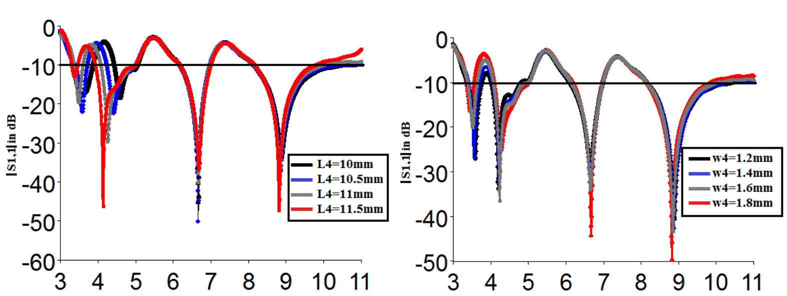


Figure 3. The simulated return loss for Ant I, Ant II, Ant III and Ant IV.

3. PARAMETRIC STUDIES FOR THE REJECTED BANDS

3.1. The WIMAX Rejected Band

Figure 4 shows effects of the U-shaped slot dimensions. As observed, the notched frequency is shifted from 4.3 to 3.5 GHz when the length $L4$ of U-slot increases from 10 to 11.5 mm. Moreover, the reflexion coefficient increases from -7 dBi to -3 dBi when the width of U-slot varies from 1.2 to 1.8 mm. The optimum dimensions to achieve the WIMAX rejection band are $L4 = 11.5$ mm and $W4 = 1.8$ mm. This proposed antenna can be applied also to notch the (3.7–4.2 GHz) frequency band suitable to C-band



(a) (b)

Figure 4. S_{11} parameters for U-slot dimensions. (a) The Length effect, (b) the Width effect.

satellite communication systems application by adjusting the length and width of U-slot to be 9.5 mm and 1.6 mm, respectively.

3.2. The WLAN Rejected Band

Figure 5 shows the return-loss parameters for different values of the semi arc-shaped slot radius R_2. It can be seen that the reflexion coefficient S_{11} at the notched bands is significantly dependent on R_2 values. The notched bands shift toward the lower frequency band when R_2 increases. The radius values of 4.75 mm can exhibit a good impedance bandwidth to cover the desired notched band centred at 5.5 GHz/WLAN band.

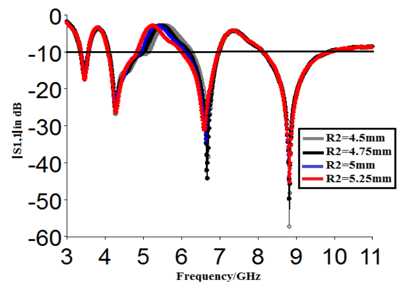


Figure 5. S_{11} parameters for different semi-arc shaped radius R_2.

3.3. The X-Band Rejected Frequency

Figure 6 shows the effect of the width and length of the extended U-shaped slot ($W5$, $L5$, $L1$ and $G2$, respectively). As shown in Fig. 6(a), the central notched frequency is shifted to the higher frequency from 7.3 to 8.3 GHz when width $W5$ of the extended U-shaped slot increases from 2.5 to 2.8 mm. On the other hand, increasing $L1$ and $L5$ parameters leads to shifting the central 7.5 GHz notched band from higher to lower frequency as shown in Fig. 6(b) and Fig. 6(c).

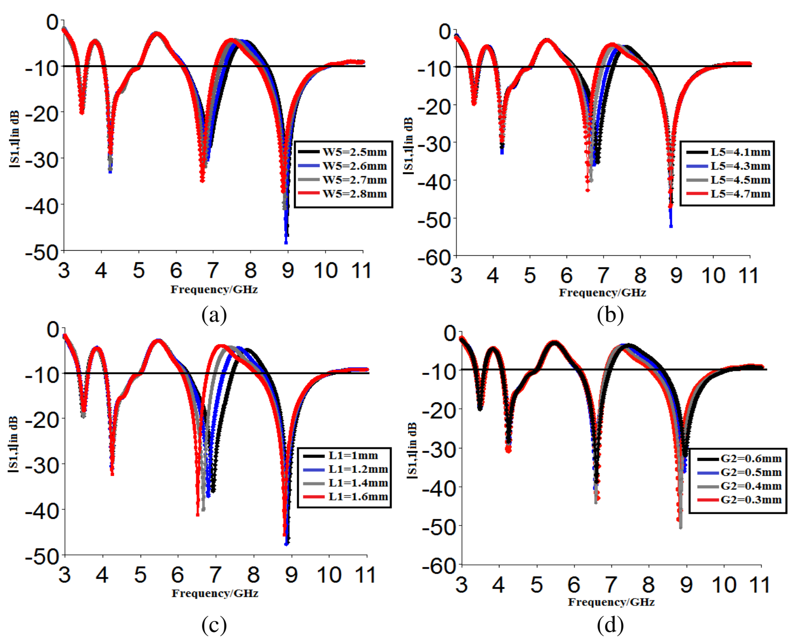


Figure 6. S_{11} parameters for different extended U-slot dimensions; (a): Width effect; (b)–(c): Length $L1$ and $L5$ effects; (d) gap $G2$ effect.

Figure 6(d) shows the simulated results of different gap extended U-shaped slots $G2$. With fixed values of other parameters, the central frequency is obviously changed while $G2$ is decreased, and the central frequency of notch band is around 7.5 GHz. The optimum values for good band rejection are $W5 = 2.6$ mm, $L5 = 4.5$ mm, $L1 = 1.4$ mm and $G2 = 0.3$ mm.

3.4. Simulated Current Distribution

To understand the creation of notch bands [21], the current distributions on the surface of the proposed antenna at 3.5, 5.5, 7.5 and 9 GHz are shown in Fig. 7. to understand the creation of notch bands [21]. Fig. 7(a) shows that most of the surface current is concentrated in the U-shaped slot while the rest of the antenna has a very low current distribution. Fig. 7(b) depicts the surface currents at 5.5 GHz, and as seen in this figure, the current is strongly distributed around the semi arc-shaped slot comparing to the other part of the antenna.

Figure 7(c) gives the current distribution in the antenna at 7.5 GHz. This current flows around two extended U-shaped slots to reject 7.5 GHz band. Therefore, the antenna impedance changes at these frequencies due to the insertion of parasitic slots, which introduces additional paths to the surface currents at notch frequencies. Hence, the direction of current is opposite to that of the radiating patch [22]. Other than WiMAX X-BAND and WLAN bands (as displayed in Fig. 7 (d)), the surface current is distributed uniformly over the antenna. As a result, the filter elements are considered as a part of the radiating element and radiate effectively.

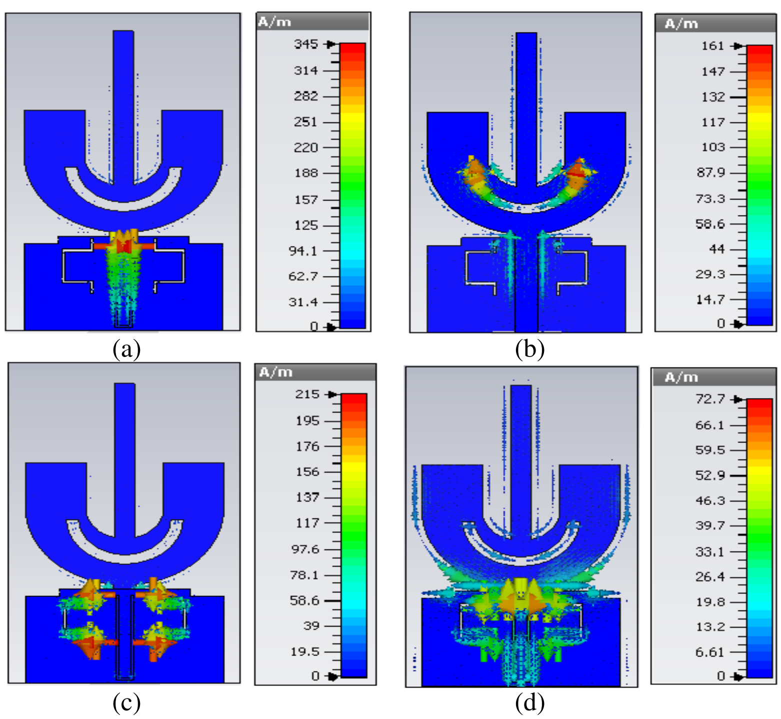
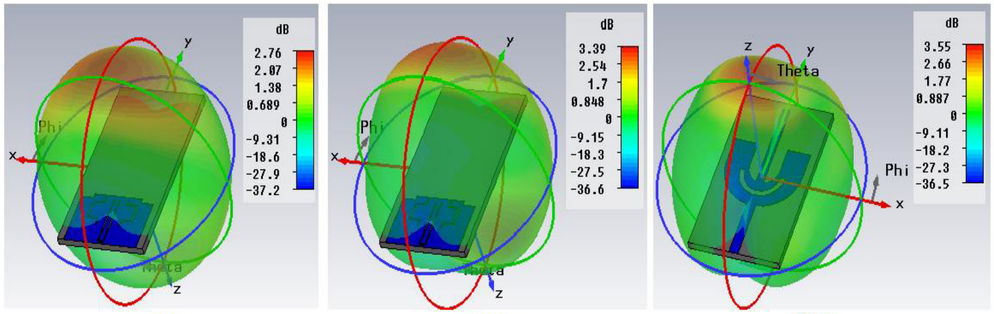


Figure 7. Current distributions at (a) 3.5 GHz, (b) 5.5 GHz, (c) 7.5 GHz, and (d) 9 GHz.

3.5. Gain and Radiation Pattern

Figure 8 shows 3D plots of the radiation patterns and gain values of the proposed antenna at three frequencies 4.5, 6.5 and 9 GHz. The E (x-y plane) and H (y-z plane) fields in the figures imply that at lower frequencies, they have reasonable omnidirectional radiation patterns. Therefore, the antenna has good gain at the notched frequencies.

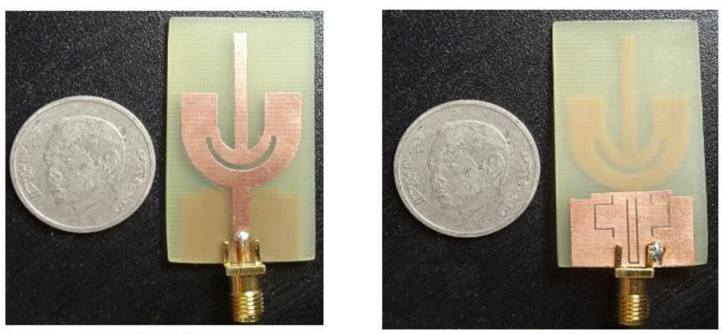


4.5GHz 6.5GHz 9GHz

Figure 8. 3D radiation patterns at 4.5, 6.5 and 9 GHz.

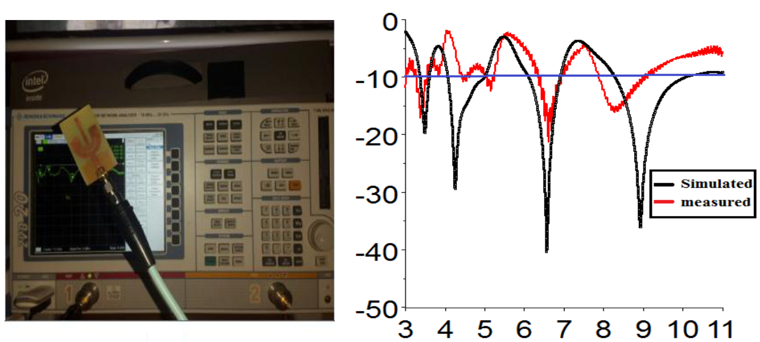
4. MEASUREMENT RESULTS AND DISCUSSION

The proposed antenna is fabricated, and the return loss parameters are measured by using the ZVB 20 — Vector Network Analyzer 20 MHz–20 GHz. The prototype of the proposed antenna is presented in Fig. 9. Simulated and measured S_{11} parameters are presented in Fig. 10. A little shift is seen between the simulated and measured results due to the fabrication inaccuracy and measurement conditions.



(a) Top view (b) Bottom view

Figure 9. Photographs of the fabricated antenna.



(a) (b)

Figure 10. (a) The proposed antenna under test. (b) Simulated and measured S_{11} parameters.

The simulated peak gains of the reference UWB antenna [3] and the proposed antenna over the UWB frequency range (3.1–11 GHz) are shown in Fig. 11. The simulated results show that substantial reductions in peak gain can be achieved at the notch frequencies.

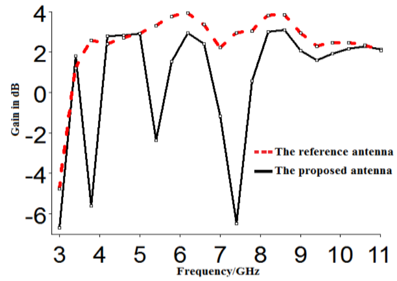


Figure 11. The simulated gain values of the reference and modified UWB antennas.

5. COMPARISON BETWEEN RECENTLY DEVELOPED ANTENNAS AND THE PROPOSED ANTENNA

Table 1 presents a comparison between the performance of some references developed band-notched antennas and the prototype antenna. The proposed antenna shows good notched band, compact size, and good gain characteristics at the notched frequency.

Table 1. Comparison between recently proposed antennas and this antenna.

Antennas	Dimensions (mm^3)	Operating Bands	Gain (dB) (Except notch Band)
Our work	$24 \times 42 \times 1.6$	UWB with triple band-notched	2.7–3.6
[5]	$26 \times 30 \times 1.6$	UWB with dual band-notched	2.5–3.7
[6]	$25 \times 26 \times 1$	UWB with single band-notched	3–4
[9]	$35 \times 35 \times 1.6$	UWB with triple band-notched	2–3.5
[11]	$22 \times 22 \times 1$	UWB with single band-notched	2.5–4
[12]	$32 \times 35 \times 1$	UWB with dual band-notched	2.5–6
[13]	$40 \times 40 \times 1.6$	UWB with dual band-notched	Not defined
[15]	$19 \times 38 \times 1.5$	UWB with single band-notched	3–5
[20]	$22 \times 24 \times 1.6$	UWB with dual band-notched	2–3.5

6. CONCLUSION

In this work, a printed fork monopole UWB antenna with tri-band-notched characteristics has been proposed. Defected ground structure with a U-shaped slot and two extended U-shaped slots are introduced to have band notched at 3.5 and 7.5 GHz central frequency to avoid interference with WIMAX and X-band satellite communication bands, respectively. Furthermore, a semi arc-shaped slot is cut into the fork radiating element to reject the 5.5 GHz central frequency suitable for WLAN band. The bandwidths of these filters can be adjusted by dimensions of the slots. The prototype antenna is measured to validate the simulated results.

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