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Frequency Reconfigurable Triple Band-Notched Ultra-Wideband Antenna with Compact Size

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Abstract—A compact planar reconfigurable triple band-notched UWB Microstrip antenna is proposed in this paper for UWB applications. A band rejection at ITU 8-GHz is generated by inserting an inverted U-shaped metallic strip at the slotted ground plane. Moreover, by cutting two slots on radiating patch, the second rejection at 3.6 GHz for WiMAX and the third rejection at 5.5 GHz for WLAN application are generated. Then, by embedding two (PIN) diodes along the patch slots, switchable dual or single band-notched behavior is added to the antenna performance. The simulated and measured results show that the antenna can operate in a wider bandwidth from 3.1 GHz to 11 GHz, and it has a good omnidirectional radiation pattern with stable gain. Furthermore, the designed antenna has a simple structure and compact size of $20 \times 20\,\mathrm{mm}^2$. The proposed antenna can use the full potential of UWB frequency range with reconfigurable band-notched behavior at 3.6, 5.5, 8.1 GHz to avoid interference with WiMAX, WLAN, ITU systems respectively.

1. INTRODUCTION

Microstrip antennas have been found in many applications of wireless communication systems because of their attractive characteristics such as low profile, light weight, low cost and easy fabrication [1–4]. Nevertheless, the major problem faced by microstrip antenna is its narrow bandwidth [5]. So, there is increased interest to improve the bandwidth by using different techniques in microstrip antenna such as creating slots [6], using gap coupled [7, 8], using partial ground [9] and inserting spirals rings [10]. The bandwidth of these microstrip antennas may reach more than 30%. To deal with the current and future applications, a UWB antenna is required with good characteristics such as VSWR, radiation pattern and gain [11, 12]. However, some applications, such as WLAN for IEEE 802.11a operating in (5.15–5.35) and (5.725–5.825) GHz bands, WIMAX operating in (3.3–3.6) GHz and (5.25–5.85) GHz bands, C-band in (3.7–4.2) GHz and ITU in (8.025–8.4) GHz, face interference problem because of the allocation of FCC for UWB communications between (3.1–10.6) GHz [13–15]. To avoid this interference, an antenna with multiband rejections is required [16]. To utilize the full potential of UWB, switching between the rejections can be the best solution [17, 18].

Hence, this paper presents a novel design of a triple band-notched UWB microstrip antenna with switchable characteristics for the band notches. The patch geometry has two inverted U-shaped slots with different dimensions which offer satisfactory notches at 3.6 GHz for WIMAX and 5.5 GHz for WLAN. Moreover, a notch appears at 8 GHz by implementing inverted U-shape beside the partial ground. Finally, two switches (PIN diodes), which are chosen with specific properties, are embedded along the patch slots, and they can switch between the existence and non-existence of the dual band notches operating at 3.6 and 5.5 GHz. The numerical simulations are done by using commercial software. Good VSWR and radiation characteristics are obtained, and these characteristics are very desirable for the current applications.

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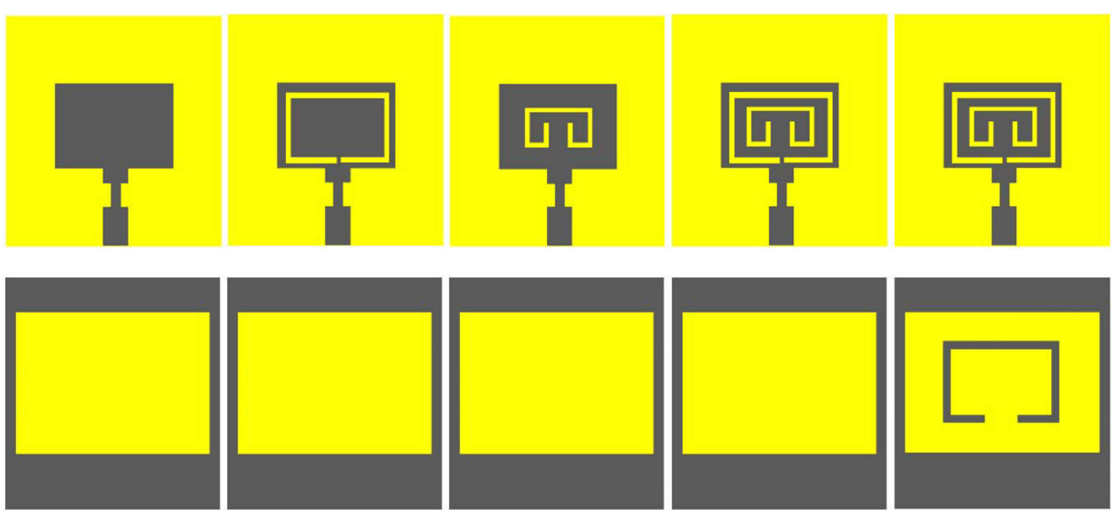
The paper is organized as follows. Section 2 presents the design procedures of the proposed triple band-notched UWB antenna. In Section 3, the numerical and experimental results of the optimized triple band-notches with/without the reconfigurable characteristics are introduced. Finally, the conclusion, which summarizes the main contributions of this work, is presented in Section 4.

2. DESIGN PROCEDURES OF THE PROPOSED TRIPLE BAND-NOTCHED ANTENNA

The proposed rectangular UWB antenna is mounted on an FR4-epoxy substrate with $\varepsilon_r = 4.4$, thickness 0.8 mm and loss tangent 0.018. This microstrip antenna is directly fed by feed line of 50 Ω. The structure of the antenna is very simple as it is made of rectangular slotted ground in order to enhance the impedance bandwidth. The configuration of the presented antenna model is based on improving bandwidth performance of the microstrip antenna, because its major disadvantage is having very narrow bandwidth. Hence, in order to improve the impedance bandwidth performance of the antenna, some modifications should occur at the design such as creating slots in the radiation patch or notches with suitable dimensions on the metallic parts.

Two small slots have been etched in the feed line and a larger slot in the ground plane as shown in Fig. 1(a) to cover the range of UWB communications. The first case of the proposed antenna covers a range of frequencies from 3.1 to 11 GHz as shown in Fig. 2. Then, according to the FCC's allocations of UWB frequency range from 3.1 to 10.6 GHz, it will cause interference with the existing wireless communication systems. So, to avoid this problem at certain frequency bands, some techniques are used here. In the second case, a large inverted U-shaped slot is etched in the radiation patch as shown in Fig. 1(b). This slot is directly responsible for notching a certain frequency which is for WIMAX application at 3.6 GHz as shown in Fig. 2. Another smaller inverted U-shaped slot is etched in the radiating patch as shown in Fig. 1(c). It can be noticed form Fig. 2 that the second slot is directly responsible for presenting a notch at 5.5 GHz for WLAN application. These two etched slots act as band-stop filters, and they have suitable dimensions. The two slots are presented in the fourth case to achieve simultaneous band-notched characteristics at the two operating bands of WLAN and WiMAX as shown in Fig. 1(d), and it results in two band rejections at 3.6 and 5.5 GHz as depicted in Fig. 2. The last stage of implementing a metallic inverted U-shape in the slotted ground plane is shown in Fig. 1(e). Also, this metallic part acts as a band-stop filter which is directly responsible for introducing notchat 8.1 GHz for ITU band. After embedding the third resonator in the ground plane of the proposed UWB antenna, it can be observed from Fig. 2 that triple notches have been obtained in the three desired bands



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

Figure 1. The proposed UWB antenna design procedures. (a) Case I, (b) Case II, (c) Case III, (d) Case IV, (e) Case V.

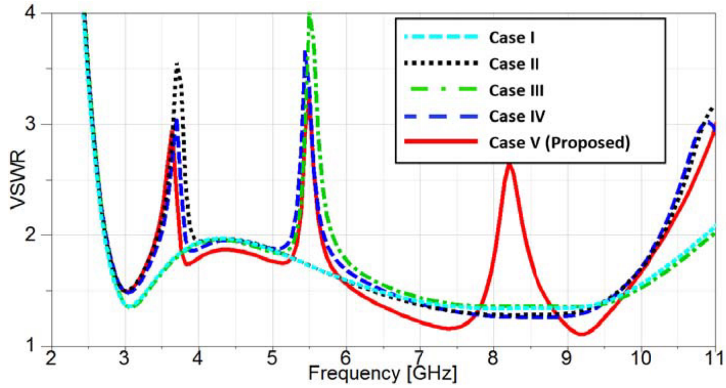


Figure 2. Simulated VSWR for different cases.

in order to mitigate the interference problem with WLAN and WiMAX and ITU systems simultaneously.

The concept of etching slots in the radiation patch to act as a band-stop filters is because the surface current, which will take longer path, and its direction will be changed, flows along the radiation stub, and it will act as $\frac{\lambda}{2}$ resonator at the notched frequencies, which disturbs the resonance response [19]. The dimensions of these band-notched filters are determined by using the rule based on the desired notch frequency (f_{notch}) as follows [20]:

$$\frac{\lambda_g}{2} = \frac{c}{2f_{\text{notch}}\sqrt{\varepsilon_{\mathit{eff}}}} \tag{1}$$

$$\varepsilon_{\mathit{eff}} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + \frac{12h}{w_f}\right)^{-0.5} \tag{2}$$

where λ_g is the guided wavelength, c the speed of light, ε_r the relative permittivity of the substrate, $\varepsilon_{\mathit{eff}}$ the effective relative permittivity, h the substrate height, and w_f the width of the feed line.

3. RESULTS AND DISCUSSION

The proposed rectangular slotted microstrip antenna is printed on a low cost FR4-epoxy substrate with compact dimensions of $2 \times 2\,\text{cm}^2$. Fig. 3 shows the top and bottom views of the proposed triple band-notched UWB antenna with detailed parameters. The optimized parameters of the proposed antenna are listed in Table 1. In this section, the simulated and measured results of voltage standing wave ratio

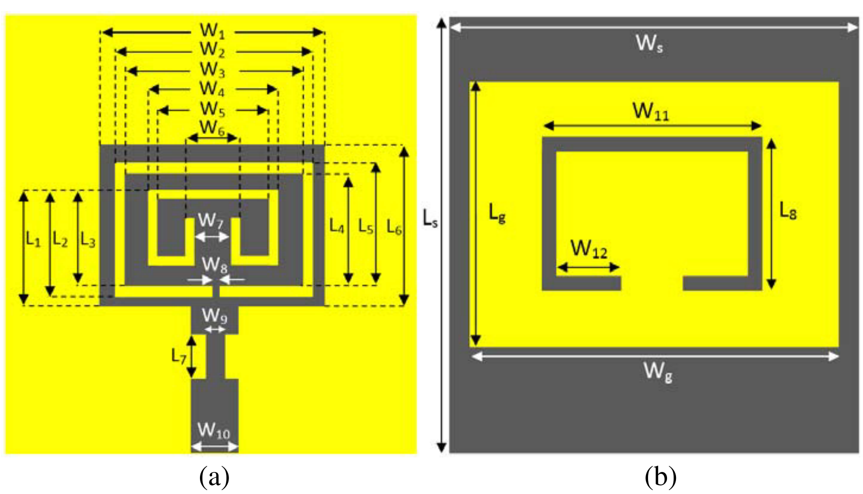
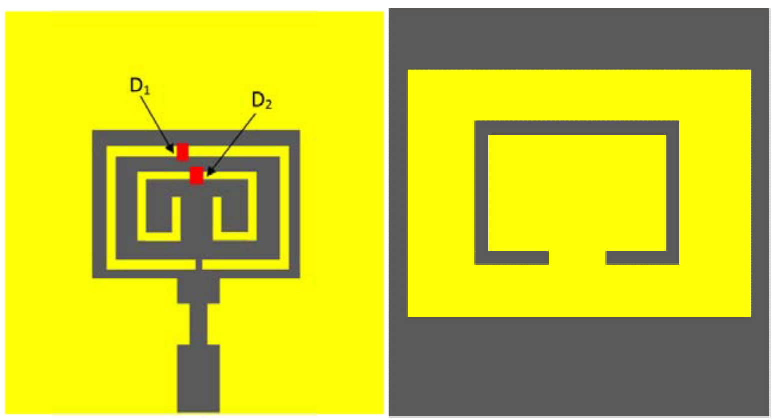


Figure 3. Detailed geometry of triple band-notched UWB antenna. (a) Top view. (b) Bottom view.

Table 1. Optimized parameters of the UWB antenna.

Parameter	Length (mm)	Parameter	Length (mm)
W_s	20	W_{11}	9
W_g	19	W_{12}	2.1
W_1	9	L_s	20
W_2	8	L_g	12
W_3	7	L_1	5.55
W_4	6	L_2	4.65
W_5	5.2	L_3	4.35
W_6	3.6	L_4	5.3
W_7	2.8	L_5	5.8
W_8	0.2	L_6	7.7
W_9	0.8	L_7	1.5
W_{10}	1.5	L_8	5.4



(a) (b)

Figure 4. Geometry of antenna with PIN diodes. (a) Top view. (b) Bottom view.

(VSWR), return loss (S_{11}), current distribution and radiation patterns are presented and discussed. The performance of proposed antenna is verified by simulating it using high frequency structure simulator (HFSS 13) software tool [21].

Finally, in order to switch between the band notches and to achieve a reconfigurable structure, two PIN diodes are embedded along the large and small slots on the radiating patch as shown in Fig. 4. Since D_1 is mounted along the large slot responsible for the WiMAX frequency at 3.6 GHz, and D_2 is mounted along the small slot responsible for the WLAN frequency at 5.5 GHz, there are four states of switching can be shown in Table 2, and the simulated VSWR curves is shown in Fig. 5. Good agreement between the desired VSWR behaviours and the data listed in Table 2 can be noticed, confirming the ability of the proposed antenna to be reconfigurable between different band notches efficiently.

The proposed triple band-notched antenna is fabricated as shown in Fig. 6 on a low cost FR4 substrate, then the measured VSWR is compared with the simulated ones. The two curves are typically similar to each other since the three notches are centered at 3.6, 5.5, 8.1 GHz for both cases as shown in Fig. 7. A comparison between simulated and measured results of the proposed triple band-notched UWB antenna is presented in Table 3. The fabricated model covers a range of frequencies from 3.1 to 11 GHz, which makes this model suitable for UWB applications. After these good results, two PIN diodes are embedded along the antenna slots to achieve the reconfigurability between band notches for the proposed model as shown in Fig. 8.

Table 2. Different states of PIN diodes.

State	D_1	D_2	Notches
1	OFF	OFF	3.6–5.5–8.1 GHz
2	ON	OFF	5.5–8.1 GHz
3	OFF	ON	3.6–8.1 GHz
4	ON	ON	8.1 GHz

Table 3. Simulation and measurement comparison of the proposed UWB antenna.

	Simulation			Measurement		
Frequency range (GHz)	2.7–10.6			3.1–10.8		
Notched frequencies (GHz)	3.6	5.5	8.1	3.6	5.5	8.15
Notched bands (GHz)	3.42–3.73	5.35–5.67	8.01–8.4	3.52–3.7	5.33–5.65	8.03–8.33

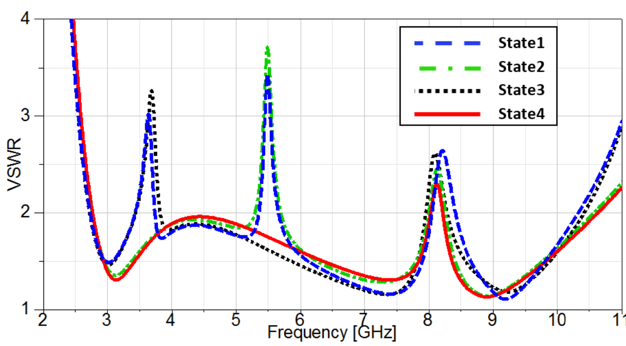
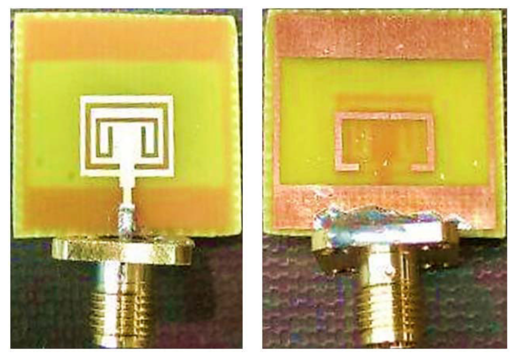


Figure 5. Simulated VSWR for different states of PIN diodes.



(a) (b)

Figure 6. Prototype of the fabricated triple band-rejected UWB antenna. (a) Front view. (b) Rear view.

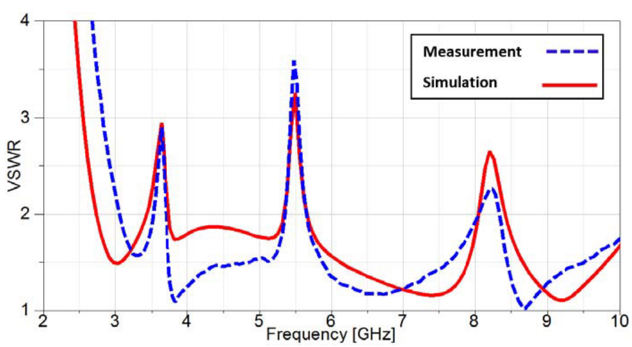
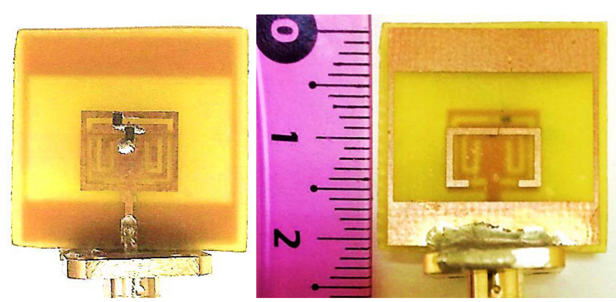


Figure 7. VSWR characteristics of the proposed band-rejected antenna.



(a) (b)

Figure 8. Prototype of the fabricated reconfigurable triple band-rejected UWB antenna. (a) Front view. (b) Rear view.

Then, by comparing the simulated VSWR and S_{11} curves with the measured ones as shown in Fig. 9 and Fig. 10, respectively, it can be noticed that simulated and measured results are almost the same when all switches are in the "ON" and "OFF" states. Moreover, the VSWR curve has three notches at 3.6, 5.5 and 8.1 GHz with values greater than 2, which means that the three stopbands are

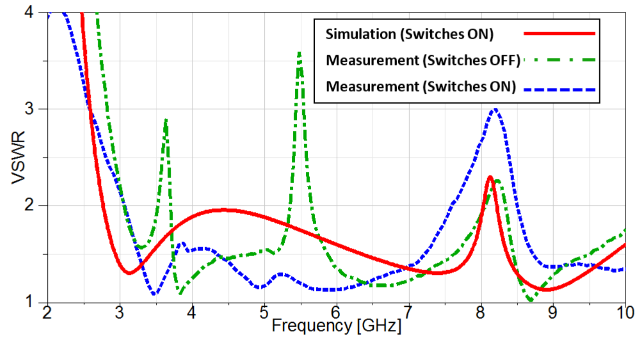


Figure 9. VSWR comparison between simulated and fabricated results.

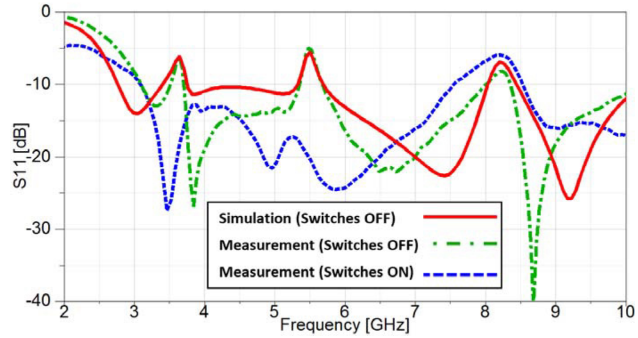


Figure 10. Return loss comparison between simulated and fabricated results.

active when all switches are "OFF". After switching "ON" the two PIN diodes, the two notches at 3.6 and 5.5 GHz become below 2, which means that the stopbands are not activated at the operating bands of WLAN and WiMAX as shown in Fig. 9. From S_{11} curves shown in Fig. 10, it can be observed that all notches have above -10 dB return loss when all switches are "OFF" for both cases of simulation and measurement, which means that the desired bands are rejected. Also, when all switches are "ON", the two notches at 3.6, and 5.5 GHz are below -10 dB, which confirms that the two band-stop filters etched on the patch are idle.

To study the effect of the two different slots etched in the radiating patch and the effect of the metallic part, which is implemented in the ground plane on the performance of proposed UWB antenna, Fig. 11 explains the surface current distributions along the band-notched resonators at their respective resonance frequencies.

Figure 11(a) shows the current distribution at 3.6 GHz, which is mainly concentrated at the large slot, while the current is shown concentrated in Fig. 11(b) at the small slot which is responsible for band-notched function at 5.5 GHz. Furthermore, the current is distributed along the metallic resonator on the ground plane when the antenna is excited with $f = 8.1$ GHz as shown in Fig. 11(c). The concentration of current along the three resonators as in Fig. 11 confirms the ability of the proposed UWB antenna to provide band-stop behaviour at the three desired frequency bands of WiMAX, WLAN, and ITU applications, and it cannot radiate at these three bands.

Figure 12 shows the simulated far-field radiation patterns of the proposed antenna in the three different planes, x-z, y-z and x-y planes. These planes reveal the radiation characteristics of the proposed antenna at two different frequencies in the passband (3 and 7.5 GHz). The lower and higher resonance frequencies have bi-directional radiation patterns at x-z and x-y planes and omnidirectional radiation pattern at y-z plane, which are preferred and highly recommended for various wireless communication applications.

The simulated realized gain of the proposed triple band-notched UWB antenna is illustrated in Fig. 13. The average simulated realized gain of the reconfigurable UWB antenna is around 2.8 dBi over the achieved frequency band, except the three notched frequency bands (3.6, 5.5, 8.1 GHz) with values equal to -4.8 dBi, -3.7 dBi and -1.1 dBi, respectively. As can be depicted from Fig. 13, the realized gain response validates the triple band-notched behaviour of the proposed UWB reconfigurable antenna, which makes it applicable to UWB applications with high immunity from electromagnetic interference attributed to wireless communication systems allocated in the UWB spectrum.

Table 4 introduces a performance comparison between the proposed work and other similar relatively recent works in terms of the size, relative permittivity and thickness of substrate, and the bandwidth of each notch with its respective resonance frequency. It is demonstrated in Table 4 that the proposed antenna has the same type of substrate but with a compact size of $2 \times 2\,\mathrm{cm}^2$, and the triple notches cover the specific bandwidths of WiMAX, WLAN and ITU centred at 3.6, 5.5, 8.1 GHz, respectively.

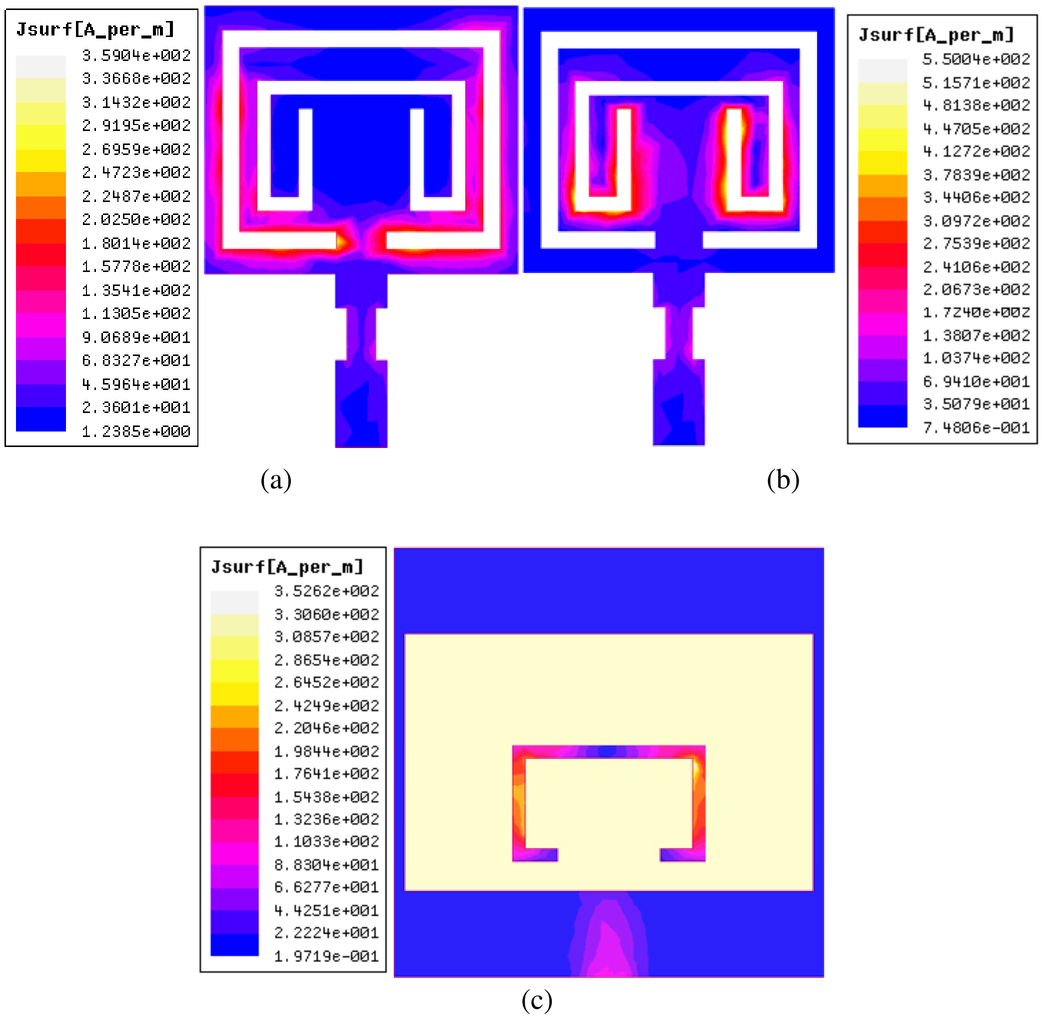


Figure 11. Current distributions at the three notch frequencies. (a) $f = 3.6$ GHz. (b) $f = 5.5$ GHz. (c) $f = 8.1$ GHz.

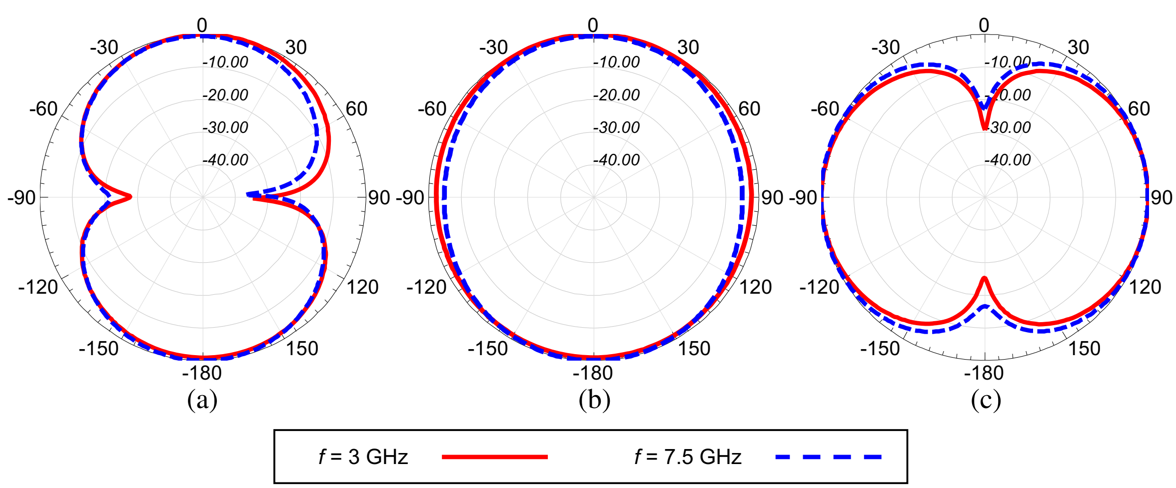


Figure 12. Normalized 2-D radiation patterns of the proposed antenna at two different frequencies. (a) x-z plane. (b) y-z plane. (c) x-y plane.

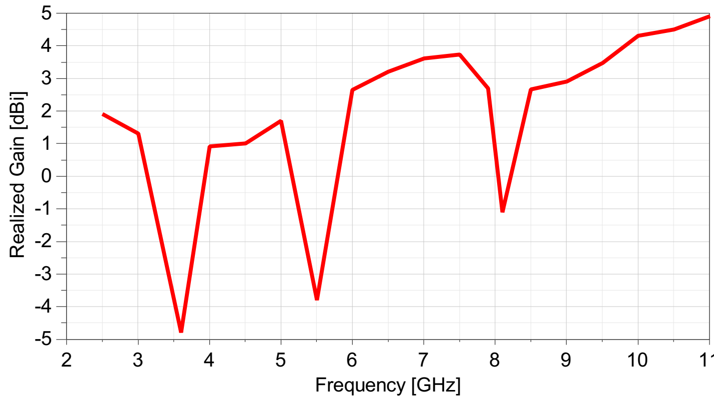


Figure 13. The simulated realized gain of the optimized structure against frequency.

Table 4. Comparison between different triple band-notched designs.

Ref	Size (cm^2)	Substrate	Notches (GHz)	1st band	2nd band	3rd band
[22]	4×4	FR4 ($\varepsilon_r = 4.4$)	2.2, 3.54, 5.68	1.6–2.66 GHz (48.18%)	3–4 GHz (28.24%)	5.13–6.03 GHz (15.8%)
[23]	2.8×3.2	FR4 ($\varepsilon_r = 4.4$)	3.6, 5.2, 7.3	3.3–3.7 GHz (11.11%)	5.15–5.35 GHz (3.84%)	7.25–7.75 GHz (6.84%)
proposed	2×2	FR4 ($\varepsilon_r = 4.4$)	3.6, 5.5, 8.1	3.4–3.7 GHz (8.3%)	5.33–5.67 GHz (6.2%)	8.01–8.35 GHz (4.2%)

4. CONCLUSION

In this paper, a compact triple band rejected microstrip antenna with reconfigurable single/dual band notches is proposed for operation in UWB applications. The proposed antenna is printed on a low cost FR4-epoxy substrate with dimensions of $2 \times 2\,\text{cm}^2$, and a larger impedance bandwidth from 3.1 to 11 GHz has been achieved except triple notches at 3.6, 5.5, 8.1 GHz for interference mitigation purpose with WiMAX, WLAN, ITU systems. The band-notched behaviour of each slot in the radiating patch is reconfigured electronically by using PIN diode integrated within the antenna to suppress the unwanted interfering signals. By changing the states of the switches, the antenna can switch between various frequency responses. Good consistency can be observed between measured and simulated impedance characteristics, which demonstrates that the proposed antenna can be utilized for various UWB applications that are immune to interferences from neighbouring RF systems. Moreover, the proposed antenna has an omnidirectional radiation pattern, and the realized gain is almost stable over the entire bandwidth with sharp notches.

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