Progress In Electromagnetics Research M, Vol. 54, 153–162, 2017

A Printed Compact Band-Notched Antenna Using Octagonal Radiating Patch and Meander Slot Technique for UWB Applications

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Abstract—An octagonal shape monopole antenna with dual band-notched features used for ultra-wide band applications is presented. The monopole antenna has good impedance matching from 3.4 GHz to 12 GHz. The dual notched bands are achieved by using a U-shaped parasitic strip and meandered slot etched in the radiating patch. The first band notched is achieved using meandered slot to reduce the interference with WIMAX from 3.3 to 3.9 GHz. The second band notched is achieved using a U-shaped parasitic strip placed above the ground plane to eliminate the interference with WLAN from 5.2 GHz to 5.9 GHz. The proposed antenna is designed, simulated and measured. The measured result shows that the antenna structure achieves (VSWR < 2) from 3.2 to 10.8 GHz. Also, the simulated radiation pattern and current distribution at different frequencies are presented. The measured and simulated results confirm that the proposed antenna is suitable for UWB applications.

1. INTRODUCTION

The Federal Communications Commission (FCC) approved rules for the commercial operation of ultra-wide band (UWB) within the range of 3.1 GHz to 10.6 GHz [1], and as a result, the design and implementation of UWB systems have attracted much attention for communication systems. The UWB communication systems have several advantages such as enabling high data rates, increased communication security, low power consumption and simple hardware configuration in practical applications [2]. UWB antennas have to meet many requirements such as small size, omnidirectional radiation patterns, high and stable gain across the whole band, and they can be made compatible to RF components [3–8]. The Wireless LAN applications (5 GHz–6 GHz) and WiMAX applications (3.3 GHz–3.9 GHz) technologies occupy small portions of the UWB band, which introduce interference between them. In order to eliminate this interference, the antenna is designed to have band-notched features. Researchers have proposed several techniques to design band-notched antennas [9–17].

In this paper, a UWB antenna with dual band-notched characteristics is presented. First, a UWB antenna is designed, which exhibits radiating characteristics in the frequency band 3.4 GHz–12 GHz. Second, a U-shaped parasitic strip and meandered slot are used to achieve the band-notched characteristics. The first notch is achieved at frequency band (3.3 GHz–4.1 GHz). The second notch is achieved at frequency band (5.1 GHz–6 GHz). The detailed design of the antenna is introduced. The commercial software CST microwave studio was employed in the full wave simulations.

2. UWB ANTENNA CONFIGURATION

The configuration of the UWB octagonal monopole antenna is illustrated in Fig. 1. The radiating element is designed in the form of octagonal shape, and the antenna is fed using 50 Ω microstrip line.

Received 28 December 2016, Accepted 3 February 2017, Scheduled 17 February 2017

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The octagonal monopole antenna is chosen due to its broad bandwidth and good radiation patterns. The octagonal monopole antenna is printed on a substrate FR4 with relative permittivity $\varepsilon_r = 4.4$ and thickness $(h) = 1.6$ mm. From Fig. 1(b), the partial ground plane is used to enhance the matched impedance of the UWB antenna from 3.4 GHz to 12 GHz. Fabrication photos of the UWB antenna are shown in Fig. 1(c) and Fig. 1(d). The simulated and measured results of return loss and VSWR of the UWB antenna are shown in Fig. 2(a) and Fig. 2(b). Fig. 2 shows that the simulated results have good input impedance matching with VSWR < 2 in the band of 3.4–12 GHz. The measured results show that the antenna operates at frequency band from 4 GHz to 12 GHz. It is clear that the simulated and measured results are in a good agreement. However, a frequency shift between the simulated and measured results can be observed. This can be a result of the imperfect full wave simulation and fabrication process such as substrate loss, soldering and connectors which cannot be totally avoided.

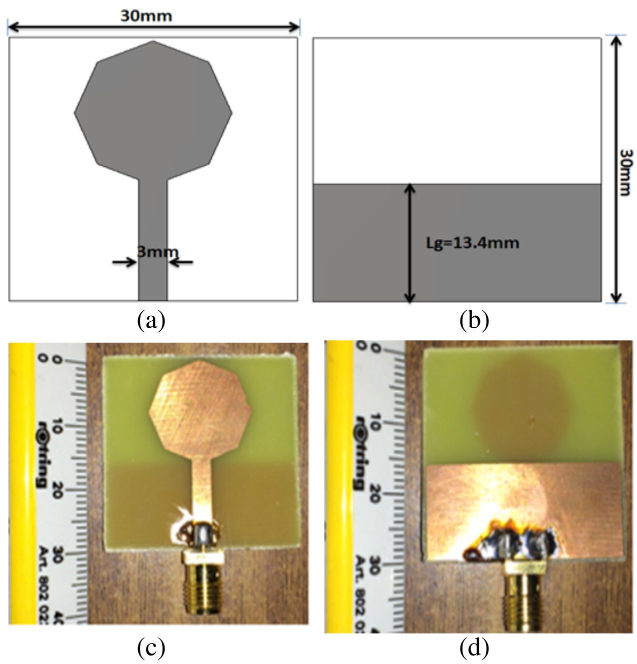


Figure 1. The octagonal monopole antenna. (a) Top view, (b) back view, (c) fabricated photo top view, (d) fabricated photo back view.

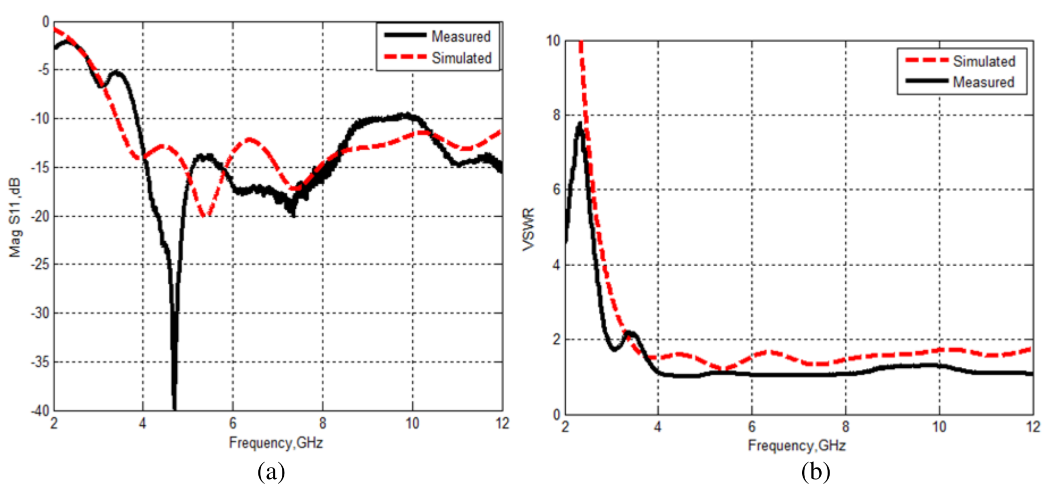


Figure 2. Simulated and measured results of UWB antenna response. (a) Return Loss, (b) VSWR.

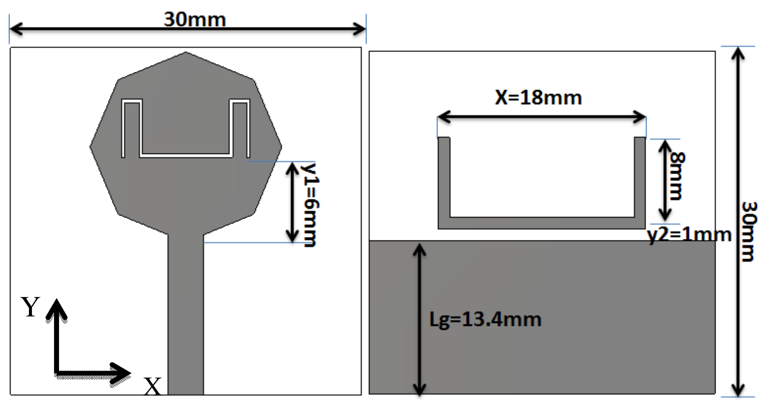
3. PROPOSED ANTENNA WITH DUAL BAND-NOTCHED FEATURES

The 2-D layout of the proposed UWB antenna is illustrated in Fig. 3. To achieve the desired frequency band notch from 3.3 GHz–3.9 GHz (WIMAX applications), a meandered slot which equals quarter wavelength of the notched frequency is etched in radiating patch as illustrated in Fig. 3(a). Also in order to reject frequency band of WLAN from 5.2 GHz–5.9 GHz), a U-shape parasitic strip which equals half wavelength of the notched frequency is employed above the ground plane as demonstrated in Fig. 3(b). This frequency notched band is designed to reduce the interference between the WIMAX, WLAN applications and UWB operations. The simulated results of return loss and VSWR are shown in Fig. 4(a) and Fig. 4(b), respectively. It is obvious that there are two notches at the desired frequency bands. From the simulated results, the return loss and VSWR of the proposed antenna are lower than 2 from 3 GHz to 10.8 GHz except the band notched region from 3.3 GHz to 4.1 GHz and from 5.1 GHz to 6 GHz. The U-shape length (L_{total}) is designed to achieve the desired central frequency of the band notched by using the following equation:

$$L_{total} \approx \frac{\lambda_g}{2} = \frac{c}{2 f_{notch} \sqrt{\varepsilon_{eff}}},$$

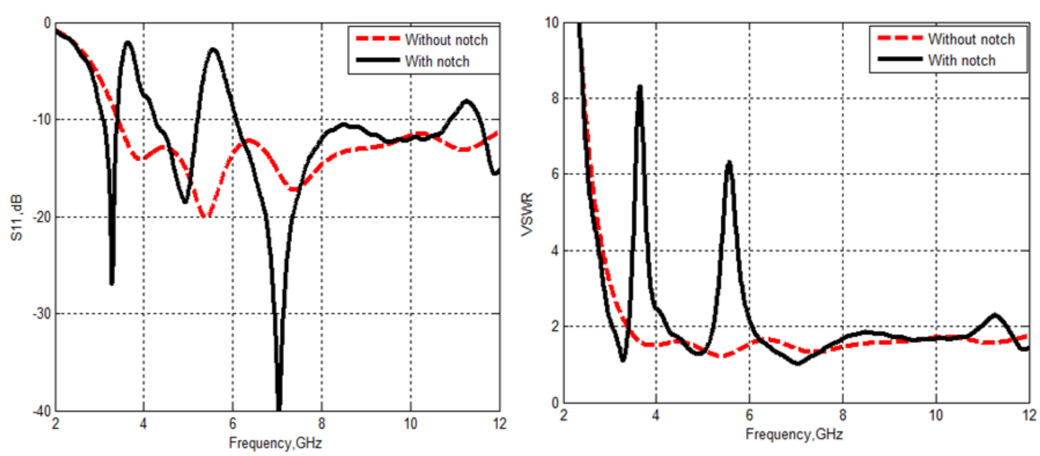
and the meandered slot length (L_{total}) is designed by using the following equation:

$$L_{total} \approx \frac{\lambda_g}{4} = \frac{c}{4 f_{notch} \sqrt{\varepsilon_{eff}}}, \quad \text{where } \varepsilon_{eff} \approx \frac{\varepsilon_r + 1}{2}$$



(a) (b)

Figure 3. Geometry of proposed antenna: (a) Top view, (b) back view.



(a) (b)

Figure 4. Simulated results of proposed UWB antenna response. (a) Return Loss, (b) VSWR.

The real (resistive) and imaginary (reactive) components of the antenna's input impedance are illustrated in Fig. 5(a) and Fig. 5(b), respectively. From Fig. 5(a) and Fig. 5(b) it is seen that in the dashed red curve (without notch) the resistive component fluctuates around 50 ohms, and the reactive component fluctuates around 0 Ω. Also from Fig. 5(a) and Fig. 5(b) it is clear that in the solid black curve (with notch) the resistive component jumps to 300 Ω, and the reactive component becomes 150 Ω from 3.3 GHz to 4.1 GHz at the first notch. Also the resistance jumps again to 80 Ω and the reactance to −50 Ω from 5 GHz to 6 GHz at the second notch. In this case, the matching is destroyed, and a high value of return loss will appear.

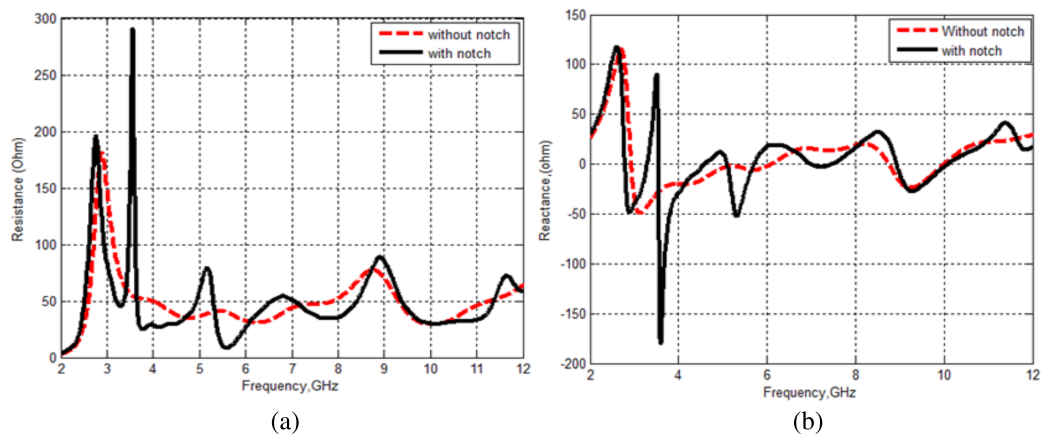


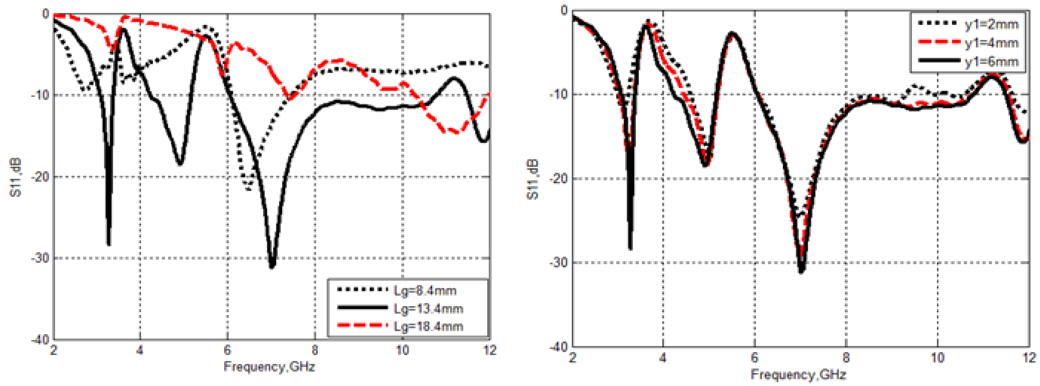
Figure 5. The simulated input impedance of the UWB antenna. (a) Resistance, (b) reactance.

4. PARAMETRIC ANALYSIS

The important criteria in the design of the desired UWB antenna are adjusting the impedance bandwidth and the desired center frequency of the notched band. In the previous section, dual notched bands are designed by using a meandered slot and U-shaped parasitic strip to provide notched band at center frequency of 3.5 GHz for WIMAX applications and 5.5 GHz for WLAN applications. Several parameters affect the behavior of the proposed antenna, and some of them have strong effect than others. Therefore, in this parametric study, the parameters with significant effect on the antenna performance, such as the position of the slot distance higher than feed line with distance ($y1$), distance of U-shaped strip above ground plane with distance ($y2$), length of the ground length (Lg) and length of the U-shape parasitic strip (x), are investigated. First, the effect of the ground plane length (Lg) on the proposed antenna performance when $y1 = 6$ mm, $y2 = 1$ mm and $x = 18$ mm is illustrated in Fig. 6(a). It is obvious that the length of Lg has strong effect on the antenna bandwidth. Also the notched band is affected by the length of the Lg. The optimized length $Lg = 13.4$ mm. Second, the effect of the meandered slot position ($y1$) is shown in Fig. 6(b). It is clear that the bandwidth of the notch is decreased with increase in the position ($y1$), and the optimized position is chosen to be 6 mm when $y2 = 1$ mm, $Lg = 13.4$ mm and $x = 18$ mm.

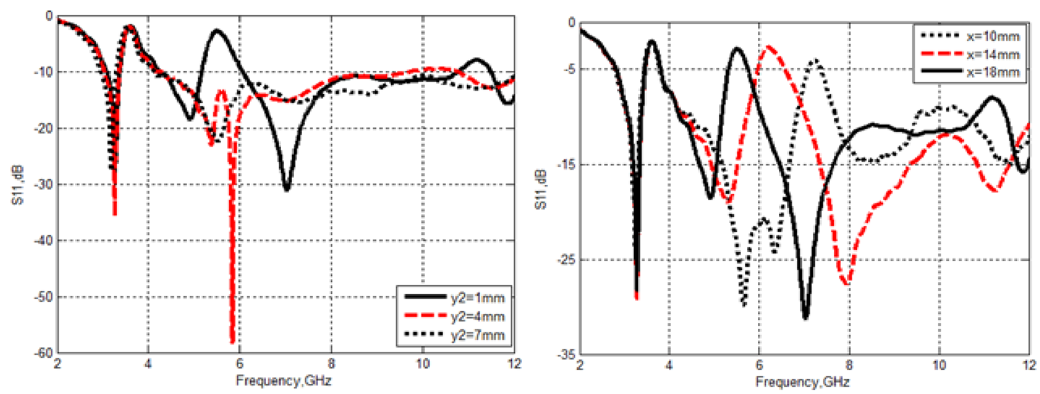
Third, the effect of position of the U-shaped parasitic strip ($y2$) above the ground plane on the antenna return loss is studied as shown in Fig. 7(a). From Fig. 7(a) it is obvious that when the distance ($y1$) is increased above the ground plane, the effect of the U-shaped strip on the return loss does not appear.

Therefore, the optimized place for the U-shaped strip is 1 mm above the ground plan to achieve the required notched frequency band. Finally, the effect of length of the U-shape parasitic strip (x) is demonstrated in Fig. 7(b). The length of the U-shape parasitic strip acts as the inductance. Therefore, when the length of the resonator increases, the resonance frequency of the notch decreases. The resonance frequency is decreased from 6.7 GHz to 5.5 GHz when the length of the U-shaped strip is increased from 10 mm to 18 mm.



(a) (b)

Figure 6. Simulated return loss of UWB antenna, (a) for different length of partial ground plane (Lg), (b) at different position of etched meander in radiating patch ($y1$).



(a) (b)

Figure 7. Simulated return loss of UWB antenna, (a) at different U position ($y2$), (b) at different U-shape length (x).

5. CURRENT DISTRIBUTION AND RADIATION PATTERN

In order to understand the behavior of the band-notched characteristics, the simulated current distributions of the proposed antenna at 3.5 GHz and 5.5 GHz are shown in Fig. 8. First, from Fig. 8(a) the concentration of the surface current is increased around the slot at 3.5 GHz which is considered the center of the notched band of the WIMAX applications. Also from Fig. 8(b) it is obvious that the concentration of the surface current is increased around the U-shaped parasitic strip at 5.5 GHz which is the center of the WLAN frequency band. From the two figures it is concluded that the antenna does not radiate at these frequency bands.

The simulated radiation patterns for the x-z, y-z and x-y planes of the proposed antenna at 4.5 GHz, 7 GHz and 9.5 GHz are shown in Fig. 9, Fig. 10 and Fig. 11, respectively. It is clear that the antenna has nearly omnidirectional patterns in x-y and y-z planes and a bi-directional one in the x-z plane. A comparisons between the simulated peak gain and efficiency of the proposed antenna with and without notch are illustrated in Fig. 12(a), and Fig. 12(b), respectively. As shown in the figure, it is clear that in the case of absence of the notch, the average gain equals approximately 3 dB, and the averaged efficiency equals 85%. On the other hand, the average peak gain and efficiency equal 3 dB and 80% except the two notched frequency bands. The peak gain and efficiency equal −3 dB, −2 dB and −12%, −10%, respectively in the case of the presence of the notch.

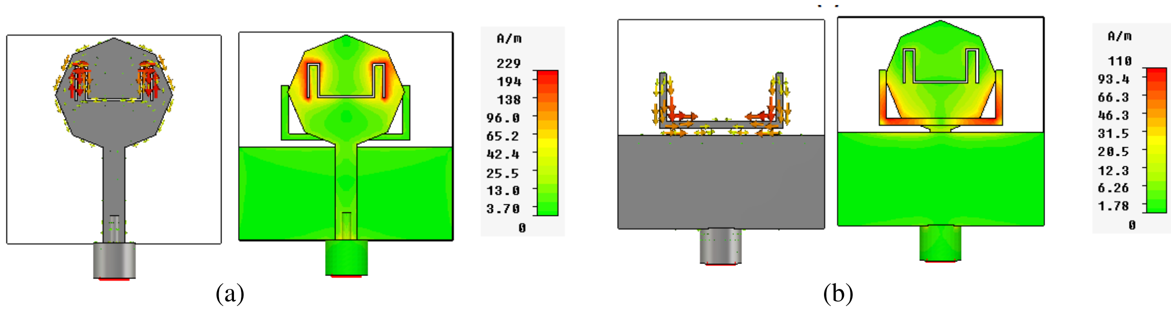


Figure 8. Simulated surface current distributions of proposed UWB. (a) At $f = 3.5\,\text{GHz}$, (b) at $f = 5.5\,\text{GHz}$.

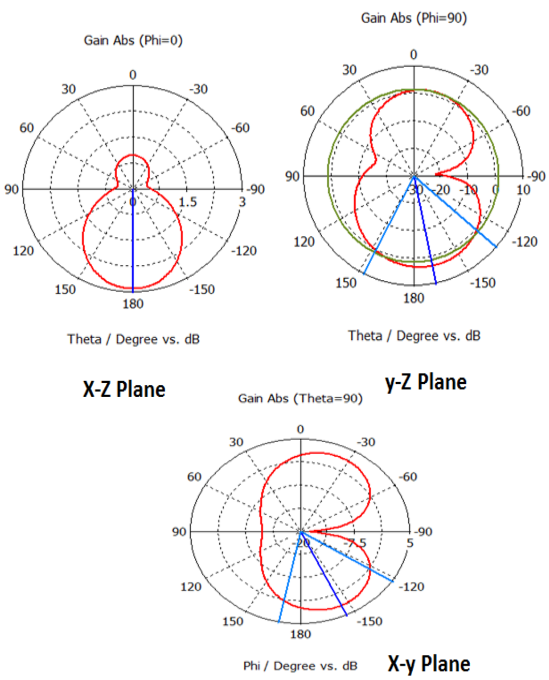


Figure 9. The simulated gain of the proposed antenna at 4.5 GHz.

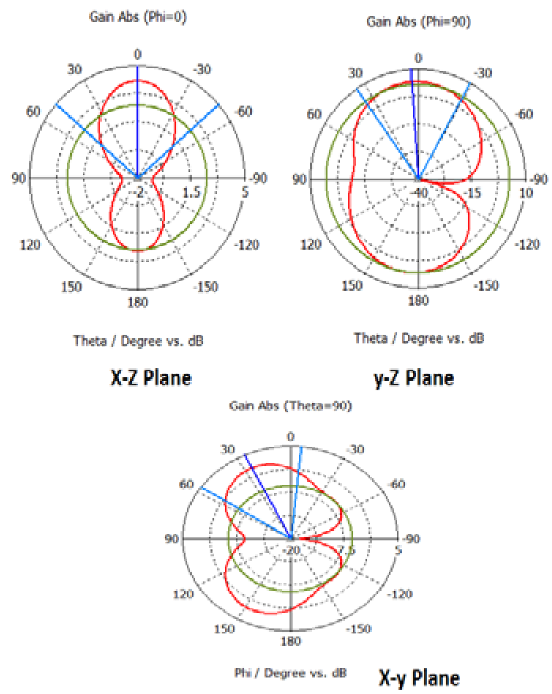


Figure 10. The simulated gain of the proposed antenna at 7 GHz.

6. FABRICATION AND EXPERIMENTAL RESULTS

The proposed UWB antenna has been fabricated on an FR4 substrate with a relative dielectric constant of 4.4, thickness of 1.6 mm and dielectric loss tangent $\delta = 0.025$. The fabricated prototype is shown in Fig. 13. As a final check for the designed proposed UWB antenna, the return loss parameter of the antenna was measured and compared to the simulated ones as illustrated in Fig. 14. As shown in the figure, the experimental results illustrate that the fabricated antenna operates from 3.2 GHz to 12 GHz with return loss lower than 10 dB except the frequency band from 8.5 GHz to 10.5 GHz. The return loss equals -6 dB approximately. There are dual frequency bands notched from 3.3 GHz to 4.1 GHz and from 5.1 GHz to 6 GHz. Compared to simulated results, we can claim that simulated and experimental results agree at the good levels for antenna return loss. However, a frequency shift between the simulated and measured results can be observed. This can result from fabrication process. A comparison between our proposed antenna and other published works is demonstrated in Table 1. It is clear that our antenna has compact size and is suitable for UWB antenna applications.

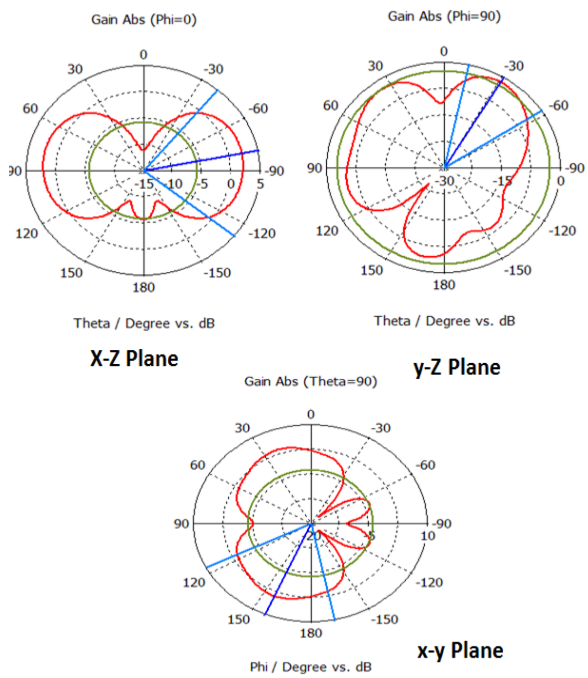
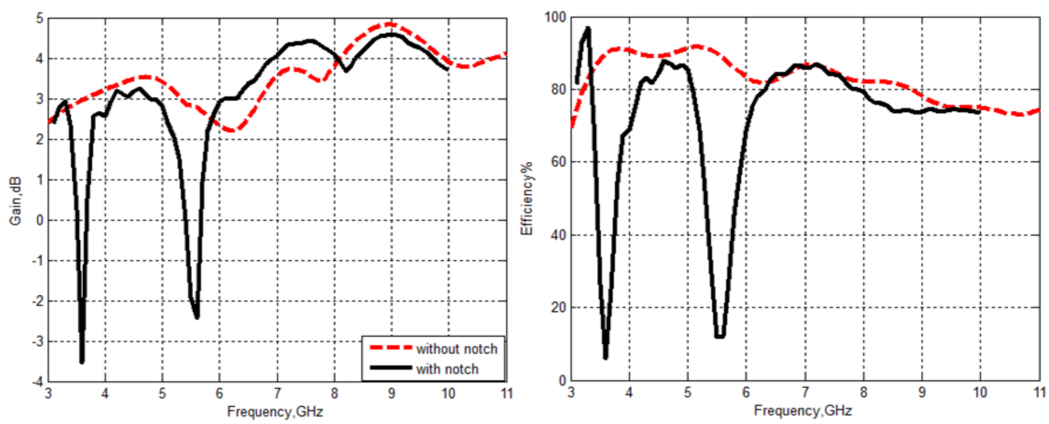
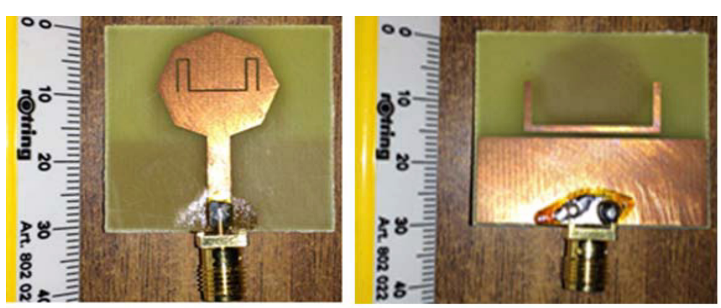


Figure 11. The simulated gain of the proposed antenna at 9.5 GHz.



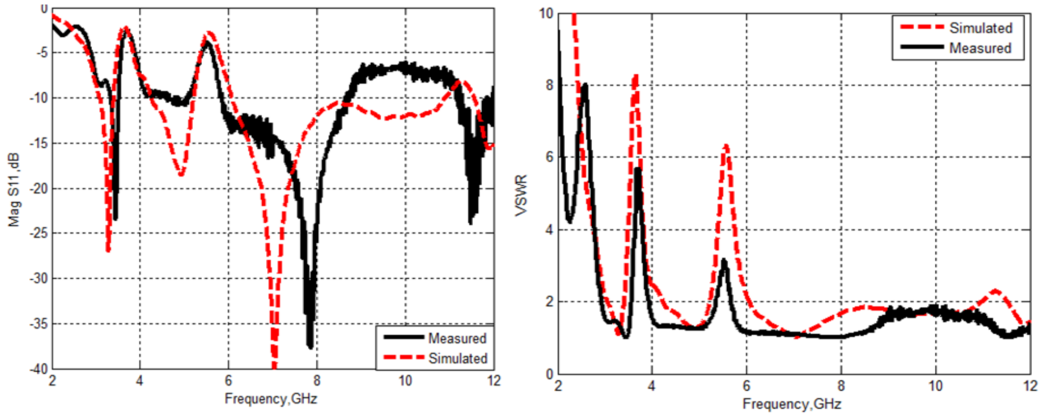
(a) (b)

Figure 12. (a) Simulated peak gain of the UWB antenna, (b) simulated efficiency of the UWB antenna.



(a) (b)

Figure 13. The Fabricated photos of the proposed UWB antenna. (a) Top view, (b) back view.



(a) (b)

Figure 14. Simulated and measured results of the proposed UWB antenna response. (a) Return Loss, (b) VSWR.

Table 1. A comparison between the proposed antenna and other published work.

	Size (mm^2)	**Frequency range (GHz)**	**Notch frequencies (GHz)**	**Realized gain (dBi)**
[18]	25×32	3–11	5.5	−5.2
			8.7	−3.6
[19]	58×65.5	3.1–11	-	-
[20]	24×32	2.9–12.5	5.5	−4.9
			7	−3.9
[21]	45×55	2-10.5	2.4	-
			3.5	-
			5.2	-
[22]	12.3×28	3-12.8	3.5	−3.3
			8.2	−2.5
This work	30×30	3.1–12	3.5	−4
			5.5	−2.5

7. CONCLUSION

A monopole antenna with octagonal shape radiator is introduced. The proposed antenna is used for ultra-wide band applications with dual band-notched characteristics. The dual notched bands are achieved by employing a U-shaped parasitic strip and meandered slot etched in the octagonal radiating patch. The interference with WIMAX applications from 3.3 GHz to 3.9 GHz and WLAN applications from 5.2 GHz to 5.9 GHz is reduced by using the meandered slot and U-shaped parasitic strip, respectively. The simulated results confirm that the proposed antenna is suitable for UWB applications.

ACKNOWLEDGMENT

The authors thank the German Research Foundation (DFG) for financial support and also thank Boutjdir Brahim, Ouali Fatima, M.Sc. Eng. Sonja Boutejdar, Mehdi Boutejdar, Karim Boutjdir, Mohamed Boutejdar for their assistant and help and Mr. Harald Dempewolf, the lab manager of the Institute for Electronics, Signal Processing and Communication (IIKT) at the University of Magdeburg, Germany, for his support.

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