Low Profile Dual Band-Notched Slot Antenna with Modified Ground Plane for UWB Systems

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Abstract **─** In this paper, a new compact microstrip-fed slot antenna with dual band-notched performance for Ultra-Wideband (UWB) communications is presented. In the proposed structure, by using an inverted U-shaped conductor-backed plane, a new resonance at 12.5 GHz is excited and hence much wider impedance bandwidth can be produced. In order to generate a single band-notched function, we use an inverted T-shaped strip protruded inside the rectangular slot, with this structure first rejection band around of 3.3-4.2 GHz can be achieved. By inserting a pair of C-shaped slots in the ground plane, dual band-notched function can be produced. The measured results reveal that the presented dual band-notched slot antenna offers a wide bandwidth from 2.62 GHz to 13.81 GHz, with two notched bands covering all the 5.2/5.8 GHz WLAN, 3.5/5.5 GHz WiMAX and 4-GHz C bands. The proposed antenna has a small size. Simulated and experimental results obtained for this antenna show that it exhibits good radiation behavior within the UWB frequency range.

Index Terms **─** C-shaped slot, dual band-notched performance, inverted U-shaped conductor-backed plane, protruded T-shaped strip and UWB slot antenna.

I. INTRODUCTION

Ultra-Wideband (UWB) systems and applications developed rapidly in recent years. It has plenty of advantages, such as simple structure, small size and low cost due to having received increased attention; especially microstrip antenna, it's extremely attractive to be used in emerging UWB applications and growing research activity is being focused on them. Consequently, a number of planar microstrip antennas with different geometries have been experimentally characterized [1-4]. The frequency range for UWB systems between 3.1 GHz to 10.6 GHz will cause interference to the existing wireless communication systems, such as, the Wireless Local Area Network (WLAN) for IEEE 802.11a operating in 5.15–5.35 GHz and 5.725–5.825 GHz bands and WiMAX (3.3-3.6 GHz and C-band 3.7-4.2 GHz); therefore, the UWB antennas with single and dual band-stop performance are required [5-9].

In the proposed structure, based on Electromagnetic Coupling Theory (ECT), by adding an inverted U-shaped conductor-backed in the substrate backside, additional coupling between the bottom edge of the radiating stub and the ground plane is introduced and the antenna impedance bandwidth is improved; which achieves a multi resonance performance. Also, single and dual band-strop properties are generated by using a T-shaped strip and a pair of C-shaped slots in the ground plane. Good VSWR and radiation pattern characteristics are obtained in the frequency band of interest.

II. MICROSTRIP ANTENNA DESIGN

The presented small slot antenna fed by a 50-Ω microstrip line is shown in Fig. 1, which is printed on an FR4 substrate of thickness of 0.8

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mm, permittivity of 4.4, and loss tangent of 0.018. The basic slot antenna structure consists of a square radiating stub, a feed line and a ground plane. The proposed antenna is connected to a 50-Ω SMA connector for signal transmission. The radiating stub is connected to a feed line with the width of W_f and the length of L_f, as shown in Fig. 1. On the other side of the substrate, a conducting ground plane of width W_{sub} and length L_{gnd} is placed. The width W_f of the microstrip feed-line is fixed at 1.5 mm. The proposed antenna is connected to a 50-ohm SMA connector for signal transmission. The simulated results are obtained using the Ansoft simulation software High-Frequency Structure Simulator (HFSS) [10].

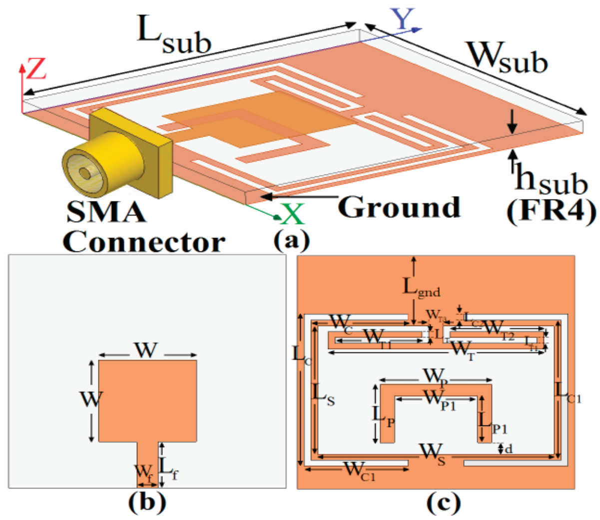

Fig. 1. Geometry of the proposed slot antenna; (a) side view, (b) top layer and (c) bottom layer.

Table 1: The final dimensions of the antenna

Param.	mm	Param.	mm	Param.	mm
W_{Sub}	20	L_{Sub}	20	W_f	1.5
L_f	4	W	7	L_{gnd}	6
W_P	8	L_P	5	W_{P1}	6
L_{P1}	4	W_T	15.5	L_T	0.5
W_{T1}	6.25	L_{T1}	0.5	W_{T2}	6.75
W_{T3}	1	L_S	11	W_S	17
L_C	13	W_C	6.5	L_{C1}	12
W_{C1}	7.5	L_{C2}	0.5	d	1

In this work, we start by choosing the aperture length L_S. We have a lot of flexibility in choosing this parameter. The length of the aperture mostly affects the antenna bandwidth. As L_S decreases, so does the antenna BW and vice versa. In the next step, we have to determine the aperture width W_S. The aperture width is approximate, whereas the slot wavelength depends on a number of parameters, such as the slot width as well as the thickness and dielectric constant of the substrate on which the slot is fabricated. Then to choose the width of the radiating patch W. This parameter is approximate, whereas the guided wavelength is the microstrip line [3]. The last and final step in the design is to choose the length of the resonator and the band-stop filter elements. In this design, the optimized length $L_{resonance}$ is set to resonate at $0.25\lambda_{resonance}$, where $L_{resonance} = 0.5\ (W_{p1}+L_{p1})$. Also the optimized length L_{notch} is set to band-stop resonate at $0.5\lambda_{notch}$, where $L_{notch1}=0.5\ (W_{T1}+W_{T2}) + L_T+L_{T1}$, and $L_{notch2}=L_{C2}+0.5\ W_{C1}+0.25\ L_C$. λ_{notch1} and λ_{notch2} corresponds to first band-notched frequency (3.9 GHz) and second band-notched frequency (5.5 GHz), respectively.

In this study, to design a novel antenna, the modified inverted U-shaped strip is placed inside rectangular slot in the ground plane. Regarding ECT, by adding a modified conductor-backed plane in the substrate backside, additional coupling is introduced between the bottom edge of the radiating stub and the ground plane and the antenna impedance bandwidth is improved without any cost of size or expense. Moreover, these structures change the inductance and capacitance of the input impedance, which in turn leads to change the bandwidth [4-6]. Therefore, by adding an inverted U-shaped parasitic structure in the ground plane, much enhanced impedance bandwidth may be achieved.

In addition, to create a desired dual frequency band-stop characteristic, a T-shaped strip with a pair of C-shaped slots are used in the ground plane. At the notched frequencies, the current flows are more dominant around the T-shaped and C-shaped structures and they are oppositely directed between the embedded structures and the radiating stub. As a result, the desired high attenuation near the notched frequency can be produced [10-12]. Final values of the presented antenna design parameters are specified in Table. 1.

III. RESULTS AND DISCUSSIONS

The presented microstrip-fed slot antenna were constructed and studied to demonstrate the effect of the proposed dual band-notched function and bandwidth enhancement technique. The simulated and experimental results of the input impedance and radiation characteristics are presented and discussed.

Figure 2 shows the structure of the various antennas used for simulation studies. VSWR characteristics for ordinary slot antenna (Fig. 2 (a)), with an inverted U-shaped conductor-backed plane in the ground plane (Fig. 2(b)), with inverted U-shaped conductor-backed plane and T-shaped strip (Fig. 2(c)) and the proposed antenna structure (Fig. 2 (d)), are compared in Fig. 3.

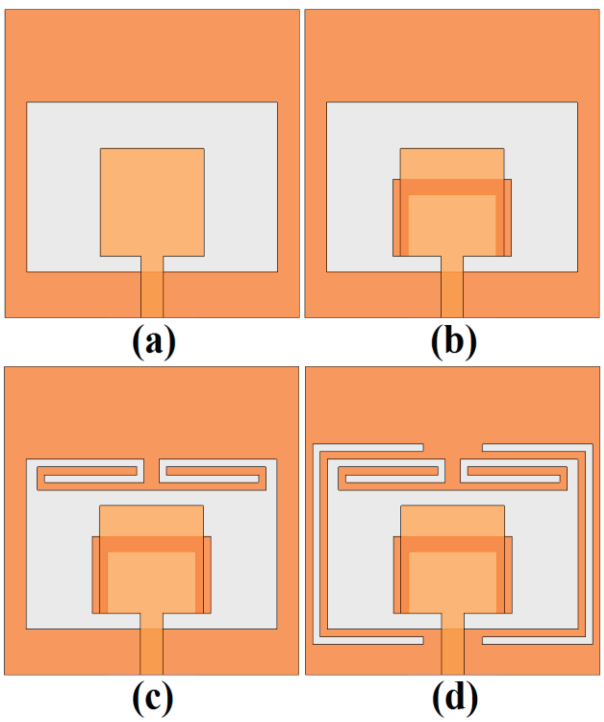

Fig. 2. (a) basic structure (ordinary slot antenna), (b) antenna with an inverted U-shaped conductor-backed plane, (c) antenna with inverted U-shaped conductor-backed plane and protruded T-shaped strip and (d) the proposed antenna.

As shown in Fig. 3, in the proposed antenna configuration, the ordinary slot antenna can provide the fundamental and next higher resonant radiation band at 4 GHz and 8 GHz, respectively. As illustrated in Fig. 3, the inverted U-shaped conductor-backed plane is playing an important role in the broadband characteristics and in determining the sensitivity of impedance matching of this antenna [4].

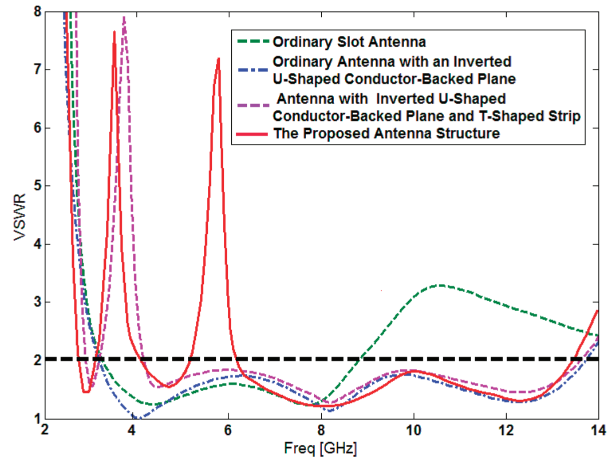

Fig. 3. Simulated VSWR characteristics for the various structures shown in Fig. 2.

It is found that by inserting the inverted U-shaped conductor-backed plane at the ground plane, additional resonance (third resonance at 12.5 GHz) is excited and hence much wider impedance bandwidth with multi resonance characteristics can be produced; especially at the higher band [11-12]. As shown in Fig. 3, in order to generate single band-notched characteristics (3.9 GHz), we use an inverted T-shaped strip protruded inside rectangular slot. By inserting a pair of C-shaped slots in the ground plane, dual band–notched function is achieved covering all the 5.2/5.8 GHz WLAN, 3.5/5.5 GHz WiMAX and 4-GHz C bands.

In order to understand the phenomenon behind this additional resonance performance, the simulated current distributions on the ground plane for the presented antenna are presented in Fig. 4. As shown in Fig. 4 (a), at the third resonance frequency, the current flows are more dominant around of the inverted U-shaped conductor-backed plane at third resonance frequency (12.5 GHz). Figure 4 (b) presents the simulated current distributions on the ground plane at the first notched frequency (3.9 GHz). As shown in Fig. 4 (b), at the first notched frequency the current flows are more dominant around of the inverted T-shaped strip. Another important design parameter of this structure is use of the pair of C-shaped slots.

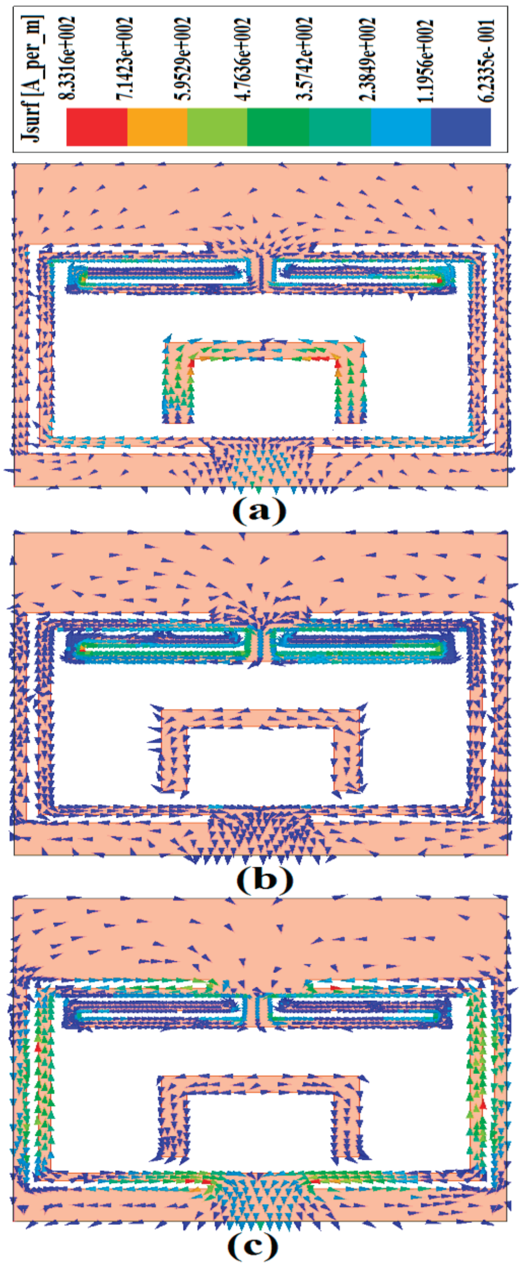

Fig. 4. Simulated current distributions for the proposed antenna on the ground plane; (a) at the new resonance frequency (12.5 GHz), (b) at first notched frequency (3.8 GHz) and (c) at second notched frequency (5.5 GHz).

Figure 4 (c) presents the simulated current distributions on the ground plane for the proposed antenna at the second notched frequency (5.5 GHz). It can be observed in Fig. 4 (c), that the current concentrated on the edges of the interior and exterior of the C-shaped slots. Therefore, the antenna impedance changes at this frequency due to the notch band properties of this slot [13].

The proposed microstrip monopole antenna with final design as shown in Fig. 5, was built and tested and the VSWR characteristic was measured using a network analyzer in an anechoic chamber. The radiation patterns have been measured inside an anechoic chamber using a double-ridged horn antenna as a reference antenna placed at a distance of 2 m. Also, a two-antenna technique using a spectrum analyzer and a double-ridged horn antenna as a reference antenna placed at a distance of 2 m, is used to measure the radiation gain in the z axis direction (x-z plane).

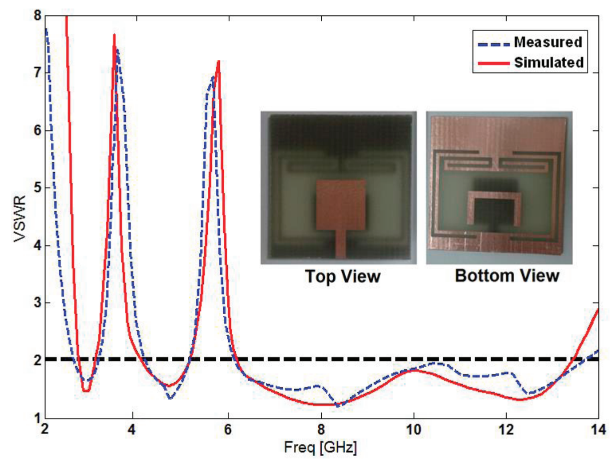

Fig. 5. Measured and simulated VSWR for the proposed antenna.

Figure 5 shows the measured and simulated VSWR characteristics of the proposed antenna. The fabricated antenna has the frequency band from 2.62 GHz to 13.81 GHz, with two rejection bands around 3.32-4.28 GHz and 5.13-6.08 GHz.

Figure 6 depicts the measured and simulated radiation patterns of the proposed antenna, including the co-polarization and cross-polarization in the H-plane (x-z plane) and E-plane (y-z plane). It can be seen that the quasi-omnidirectional radiation pattern can be observed on x-z plane over the whole UWB frequency range; especially at the low frequencies. The radiation pattern on the y-z plane displays a typical figure-of-eight, similar to that of a conventional dipole antenna. It should be noticed that the radiation patterns in E-plane become imbalanced as frequency increases, due to the increasing effects of the cross polarization. The patterns indicate at higher frequencies and more ripples can be observed in both E and H-planes, owing to the generation of higher-order modes. [14-16].

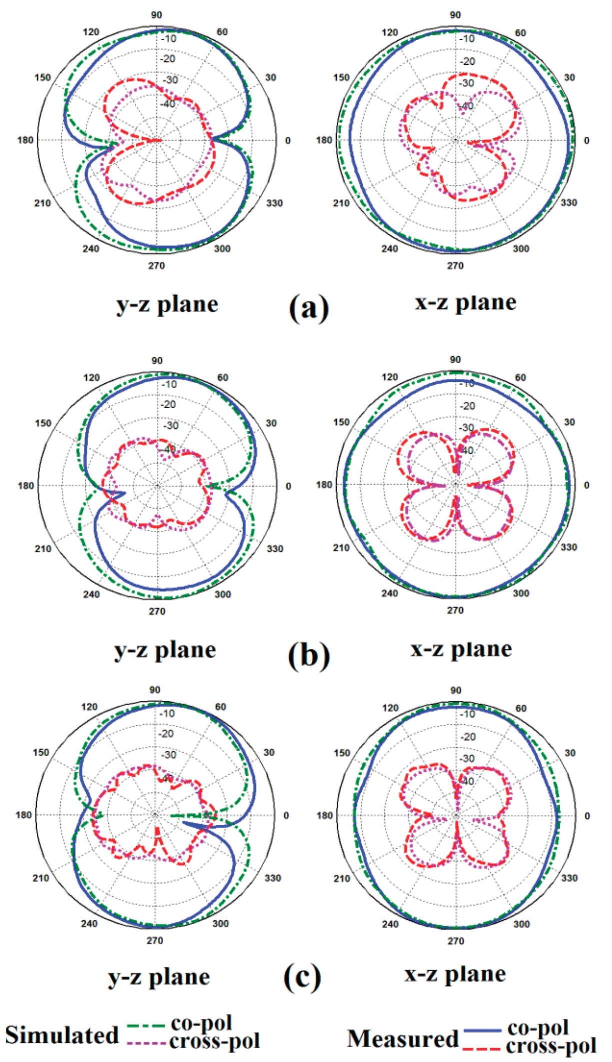

Fig. 6. Measured and simulated radiation patterns of the proposed antenna; (a) 4.5 GHz, (b) 7.5 GHz and (c) 10 GHz.

The simulated and measured input impedance characteristics of the proposed antenna are shown in Fig. 7. As seen, in the notched frequencies, the imaginary component curve shows parallel resonances and the real component presents high resistance characteristics. As a result of impedance curve of proposed antenna, it is suggested that the input impedance of the notched antenna is equivalent to the input impedance R_a of the un-notched reference ordinary antenna, connected with two parallel LC-resonant circuits in series.

Also, the conceptual circuit model of the antenna is shown in Fig. 8. When the proposed antenna is operating at the two desired notched frequencies, the two corresponding LC resonant circuits mentioned above will be syntonic, which leads to the input impedance to be opened. Therefore, proposed band-notched UWB antenna presents high impedance characteristics at notched frequencies.

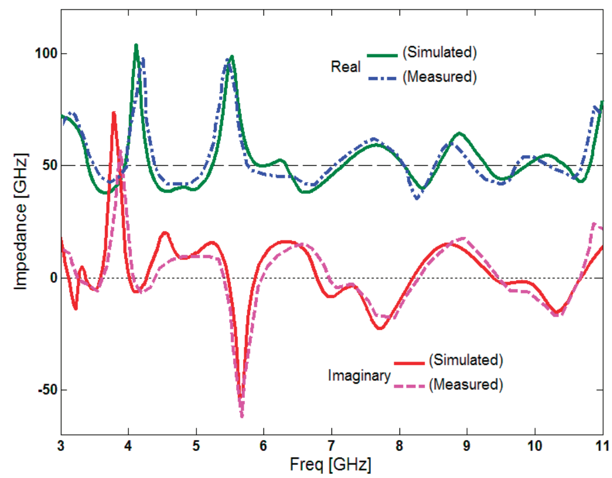

Fig. 7. Measured and simulated input impedance characteristics of the proposed antenna.

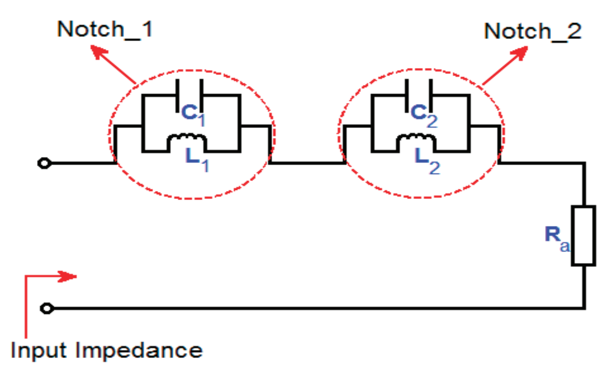

Fig. 8. Conceptual circuit model for proposed antenna.

In addition, measured and simulated input impedance characteristics of the proposed antenna on a Smith chart are shown in Fig. 9.

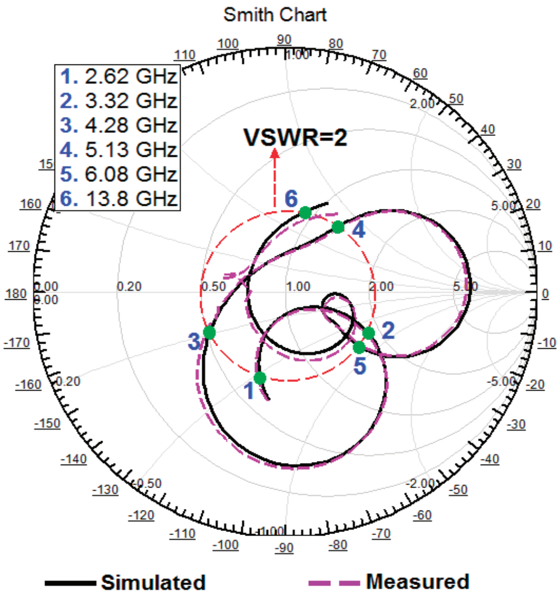

Fig. 9. Measured and simulated input impedance on a Smith chart of the proposed antenna.

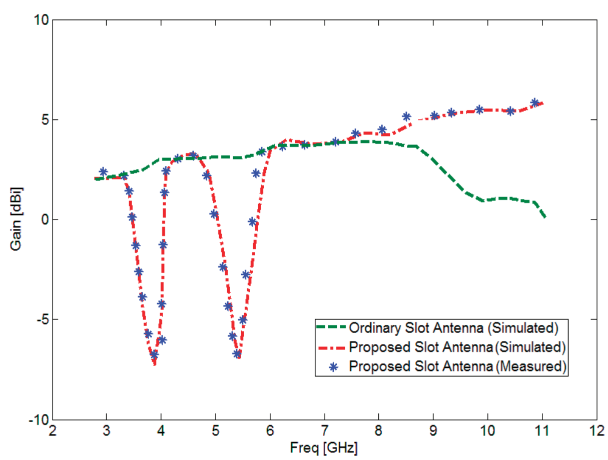

Fig. 10. Measured and simulated maximum gain for the proposed antenna in comparison with ordinary structure.

Measured maximum gain of the proposed antenna was shown in Fig. 10. As illustrated, two sharp decreases of maximum gain in the notched frequency bands at 3.9 GHz and 5.5 GHz is shown in Fig. 10. For other frequencies outside the notched frequency band, the antenna gain with the filters is improved in comparison with ordinary structure. As seen, the proposed antenna has sufficient and acceptable gain levels in the operation bands [17].

IV. CONCLUSION

In this paper, a novel planar slot antenna (PMA) with single and dual band-notched characteristics for various UWB applications has been proposed. The proposed antenna consists of a square radiating stub and a modified ground plane with an inverted U-shaped conductor-backed plane, two C-shaped sots and an inverted T-shaped strip. Fabricated antenna can operate from 2.62 GHz to 13.81 GHz with two rejection bands around 3.32-4.28 GHz and 5.12-6.07 GHz. The proposed antenna has a simple configuration and is easy to fabricate. Experimental results show that the proposed antenna could be a good candidate for UWB applications.

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