Planar Ultra-Wideband (UWB) Antenna with C-Band Rejection Using Self-Complementary Structures

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Abstract **─** In this paper, we describe an application of the Self-Complementary Structures (SCS) to design a low-profile UWB monopole antenna with band-notched function. The proposed antenna consists of a square radiating patch with a rotated Z-shaped slot, a ground plane with a rectangular slot and rotated Z-shaped parasitic structure inside slot; which provides a wide usable fractional bandwidth of more than 125% (2.81-12.63 GHz), with band-notched function around 3.7-4.2 GHz, to avoid interference from C-band communications. In the presented antenna, by using a rotated Z-shaped parasitic structure inside the rectangular slot in the ground plane, additional resonances are excited and hence much wider impedance bandwidth can be produced; especially at the higher band. To generate a band-stop characteristic, we use the self-complementary structure of the configuration that was inserted in the ground plane, which is a rotated Z-shaped slot at square radiating patch; with this design we can give a C-band rejection performance. The designed antenna has a small dimension of $12\times18\times0.8$ mm^3.

Index Terms **─** Microstrip-fed antenna, rotated Z-shaped structure, Self-Complementary Structure (SCS), ultra-wideband system.

I. INTRODUCTION

In UWB communication systems, one of key issues is the design of a compact antenna while providing wideband characteristic over the whole operating band. Consequently, a number of microstrip antennas with different geometries have been experimentally characterized [1-2]. Moreover, other strategies to improve the impedance bandwidth have been investigated [3-4]. The frequency range for UWB systems between 3.1-10.6 GHz will cause interference to the existing wireless communication systems. For example, the Wireless Local Area Network (WLAN) for IEEE 802.11a operating in 5.2/5.8 GHz or 3.7-4.2 GHz for C-band; therefore, the UWB antenna with a band-notched function is required.

In this paper, a different method for designing a novel and compact microstrip-fed monopole antenna with band-notched characteristic for UWB applications has been presented. In this structure, by using a rotated Z-shaped parasitic structure inside rectangular slot in the ground plane, an additional resonance in higher frequencies was excited. By obtaining this resonance, the usable upper frequency of the antenna is extended from 10.3 GHz to 12.63 GHz. To generate a frequency notch band function, we use a rotated Z-shaped slot with variable dimensions. The designed antenna has a small size and the impedance bandwidth of the designed monopole antenna is higher than the UWB antennas reported recently [5-8].

II. ANTENNA DESIGN

The proposed antenna fed by a 50-Ohm microstrip line is shown in Fig. 1, which is printed on a FR4 substrate with thickness of 0.8 mm and permittivity of 4.4. The width of the microstrip

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feed line is fixed at 1.5 mm. The basic antenna structure consists of a square radiating patch, a feed line and a ground plane. The square radiating patch with rotated Z-shaped slot is connected to a feed line, as shown in Fig. 1. On the other side of the substrate, a conducting ground plane has a self-complementary structure of the radiating stub configuration that is a rotated Z-shaped parasitic structure inside a rectangular slot. The proposed antenna is connected to a 50Ω SMA connector for signal transmission.

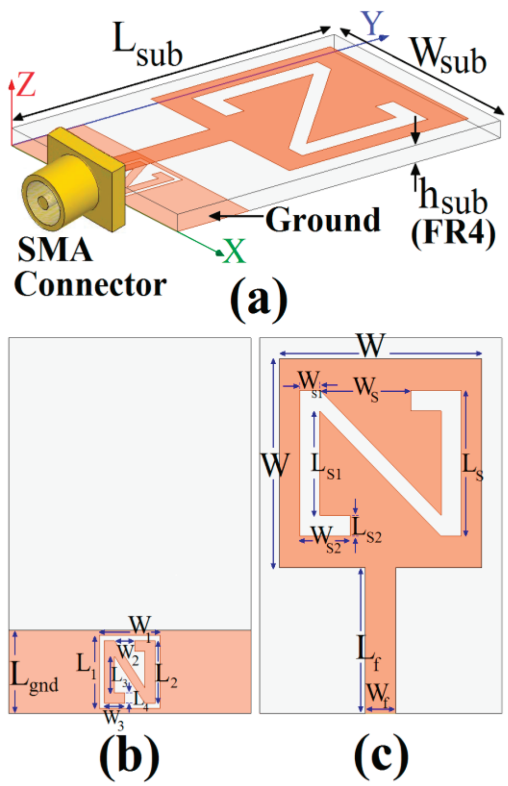


Fig. 1. Geometry of the proposed microstrip-fed monopole antenna: (a) side view, (b) bottom layer and (c) top layer.

In this proposed antenna, the rotated Z-shaped parasitic structure inside rectangular slot is playing an important role in the broadband characteristics of this antenna, because the creating slot in the ground plane provides an additional current path and improves its impedance bandwidth without any cost of size or expense [6]. In addition, using the square radiating patch with rotated Z-shaped slot with variable size generates the frequency band-notch function [7]. At the notch frequency, the current concentrated on the edges of the interior and exterior of the rotated Z-shaped slot. As a result, the desired high attenuation near the notch frequency can be produced. The variable band-notch characteristics can be achieved by carefully choosing the parameters of W_{S2} for the rotated Z-shaped slot.

The optimal dimensions of the designed antenna are specified in Table 1.

Table 1: The dimensions of the designed antenna

Param.	mm	Param.	mm	Param.	mm
W_{Sub}	12	L_{Sub}	18	h_{Sub}	0.8
W_S	4.5	L_S	7	W	10
W_f	1.5	L_f	7	L_{gnd}	4
W_{S1}	1	L_{S1}	5	W_{S2}	2.5
L_3	1	W_1	3	L_1	3.5
W_2	1	L_3	3	W_3	1
L_3	1.7				

III. RESULTS AND DISCUSSIONS

The proposed microstrip-fed monopole antenna with various design parameters were constructed and the numerical and experimental results of the input impedance and radiation characteristics are presented and discussed. The Ansoft simulation software High-Frequency Structure Simulator (HFSS) [9] is used to optimize the design.

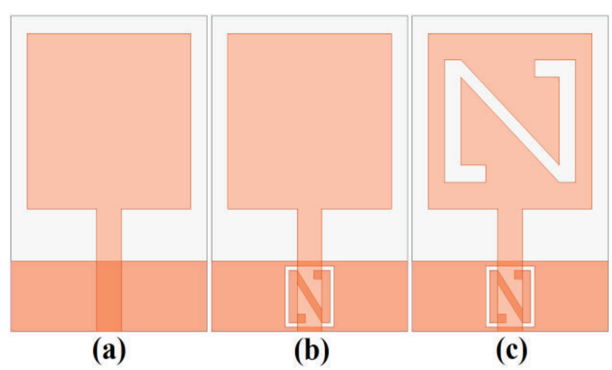


Fig. 2. (a) Ordinary square antenna, (b) square antenna with a rotated Z-shaped parasitic structure inside rectangular slot in the ground plane and (c) the proposed monopole antenna.

The configuration of the presented monopole antenna was shown in Fig. 1. Geometry for the ordinary square monopole antenna (Fig. 2 (a)), with a rectangular slot with rotated Z-shaped parasitic structure inside slot in the ground plane (Fig. 2 (b)) and the proposed monopole antenna (Fig. 2 (c)), structures are shown in Fig. 2. VSWR characteristics for the structures that were shown in Fig. 2 are compared in Fig. 3. As shown in Fig. 3, it is observed that the upper frequency bandwidth is affected by using the rotated Z-shaped parasitic structure inside slot in the ground plane and the notch frequency bandwidth is sensitive to the rotated Z-shaped slot at square radiating patch. The input impedance of the proposed monopole antenna on a Smith chart is shown in Fig. 4.

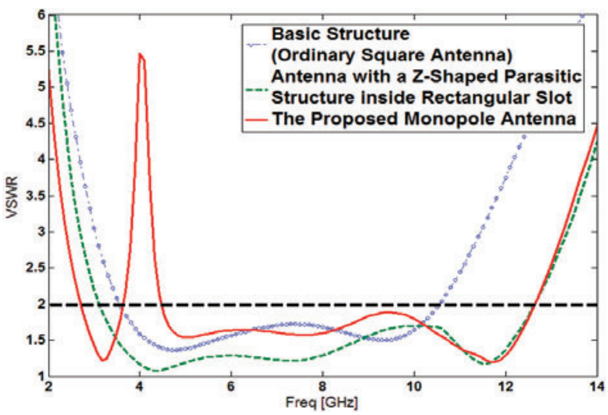


Fig. 3. Simulated VSWR characteristics for the various monopole antennas shown in Fig. 2.

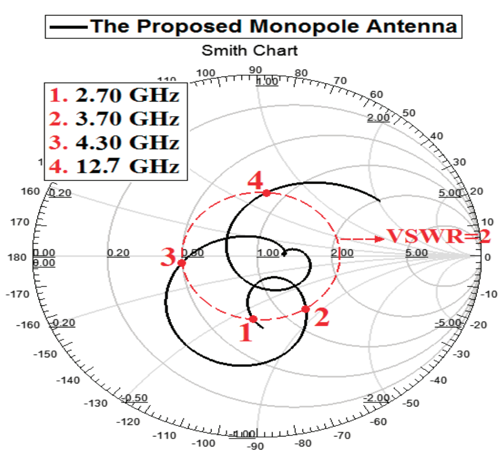
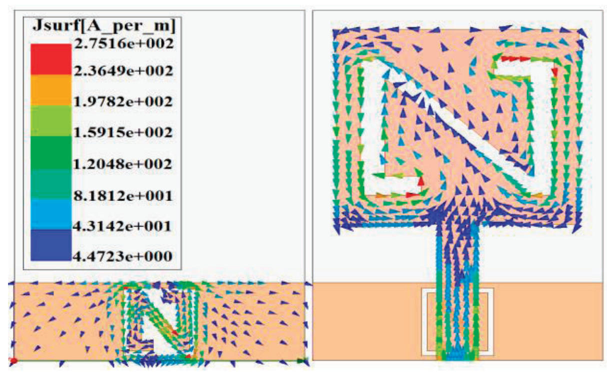
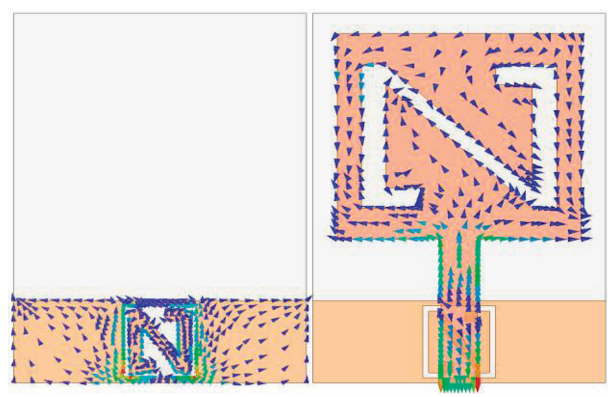


Fig. 4. Smith chart demonstration of the simulated input impedance for the proposed antenna.

To understand the phenomenon behind this additional resonance performance, the simulated current distributions at 11.5 GHz on the ground plane and radiating patch for the proposed antenna are presented in Figs. 5 (a) and 5 (b). It is found that by using the rotated Z-shaped parasitic structure inside rectangular slot, third resonance can be achieved. This behavior is mainly due to the change of surface current path by the dimensions of Z-shaped strip, as shown in Fig. 5 (a). Another important design parameter of this structure is the rotated Z-shaped slot at square radiating patch. Figures 5 (c) and 5 (d) present the simulated current distributions on the ground plane and radiating patch at the notched frequency (4.2 GHz). As shown in Fig. 5 (d), at the notched frequency the current flows are more dominant around of the rotated Z-shaped slot.



(a) (b)



(c) (d)

Fig. 5. Simulated surface current distributions for the proposed antenna: (a) in the ground plane at 11.5 GHz, (b) on the radiating stub at 5.5 GHz, (c) in the ground plane at 5.5 GHz and (d) at the radiating patch at 11.5 GHz.

Figure 6 shows the simulated VSWR curves with different values of W_{S2}. As shown in Fig. 6, when the width of the rotated Z-shaped slot increases from 1.5 mm to 5.5 mm, the center of notched frequency is decreased from 4.2 GHz to 3.4 GHz; also, filter bandwidth is varied from 1.3 GHz to 0.7 GHz. From these results, we can conclude that the notch frequency is controllable by changing the width of the rotated Z-shaped slot.

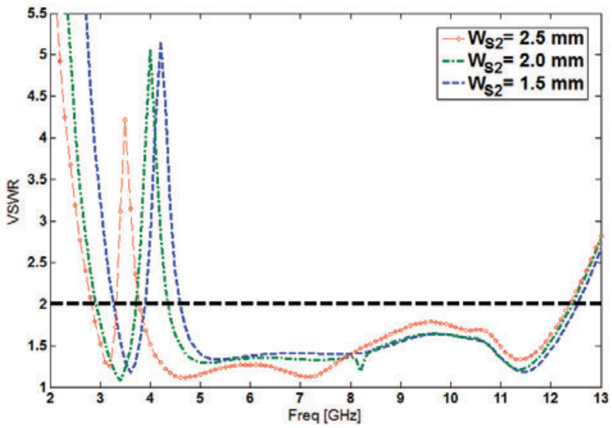


Fig. 6. Simulated VSWR characteristics for the proposed antenna with different values of W_{S2}.

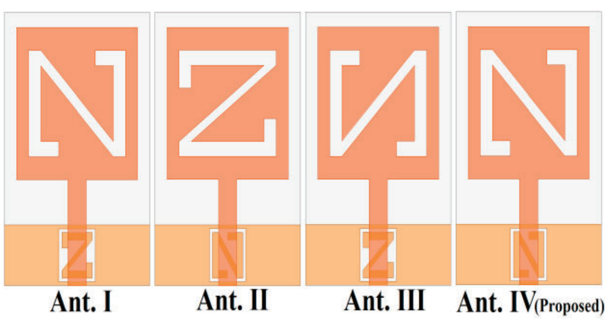


Fig. 7. Various configurations of the proposed design.

Configurations of the proposed design with different rotation of Z-shaped structures are presented in Fig. 7. VSWR characteristics for the various structures that were shown in Fig. 7 are compared in Fig. 8. As seen, it is observed that the upper frequency bandwidth is affected by using the correct direction of Z-shaped parasitic structure inside slot in the ground plane and the notch frequency bandwidth is sensitive to the rotated Z-shaped slot at square radiating patch. The proposed design (Ant. IV) has a good impedance matching with desired band-stop function, in comparison to the other structure shown in Fig. 7.

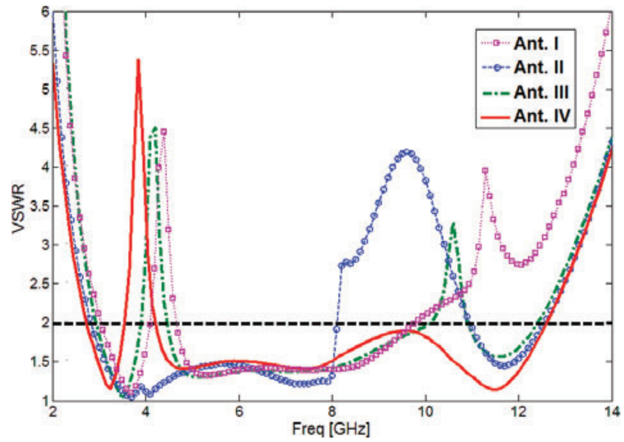


Fig. 8. Simulated VSWR characteristics for the various antennas shown in Fig. 7.

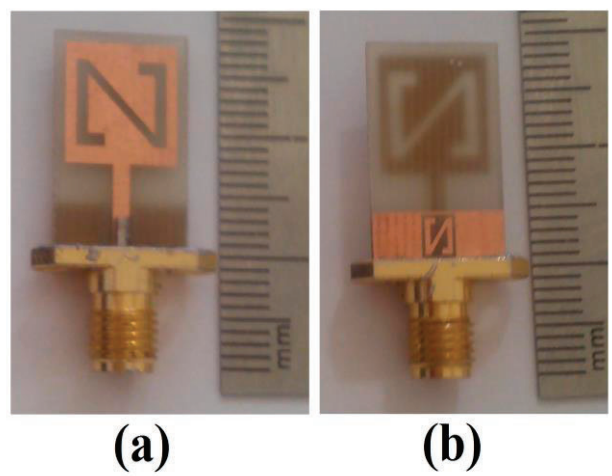


Fig. 9. Realized antenna: (a) top view and (b) bottom view.

The proposed antenna with final design as shown in Fig. 9, was built and tested. The VSWR characteristic of the antenna 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, the 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).

Measurement set-up of the proposed antenna for the VSWR and antenna gain and radiation pattern characteristics are shown in Fig. 10.

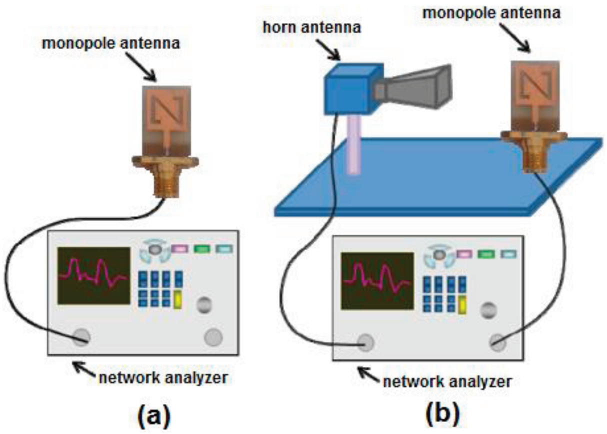


Fig. 10. Measurement set-up of the proposed antenna: (a) VSWR and (b) antenna gain and radiation patterns.

The measured and simulated VSWR characteristic of the proposed antenna was shown in Fig. 11. The fabricated antenna has the frequency band of 2.81-12.63 GHz, with band-notched function around 3.7-4.2 GHz, to avoid interference between UWB and C-band communications.

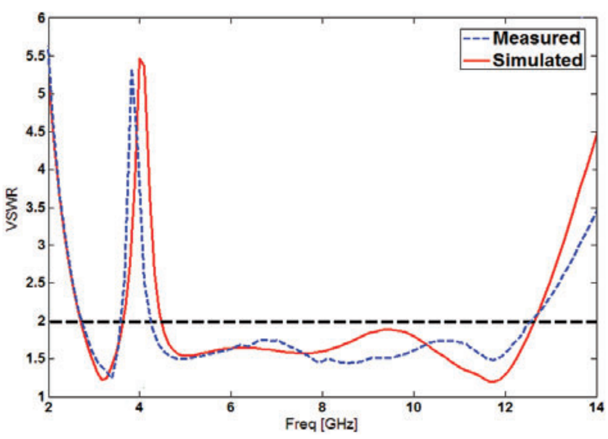


Fig. 11. Measured and simulated VSWR characteristics for the proposed antenna.

Figure 12 shows the measured radiation patterns, including the co-polarization in the H-plane (x-z plane) and E-plane (y-z plane). The radiation patterns on the y-z plane display 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. 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 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 [17-20].

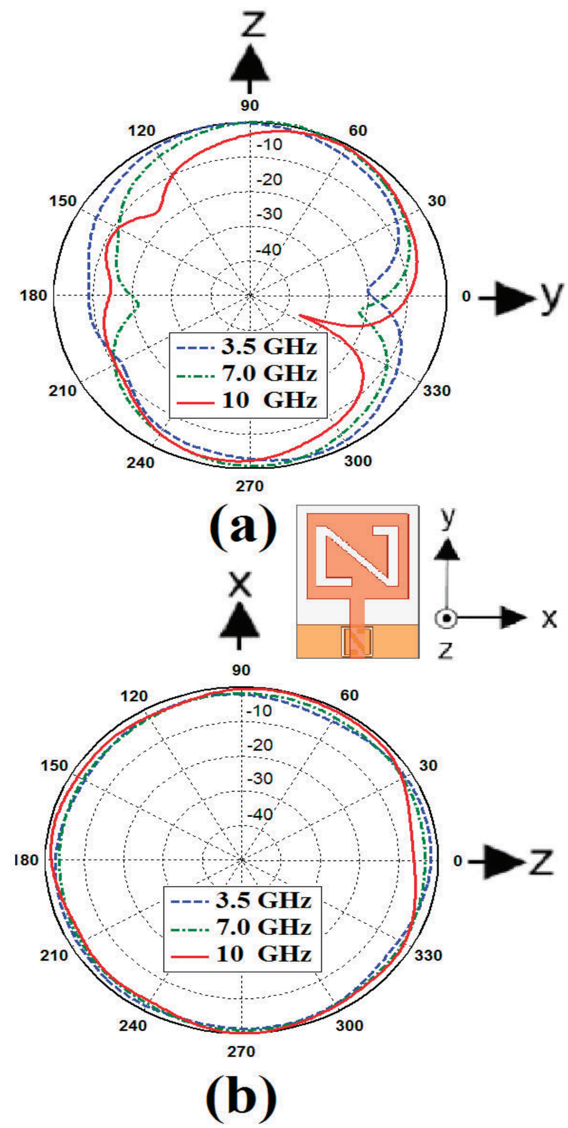


Fig. 12. Measured radiation patterns of the proposed antenna: (a) E-plane and (b) H-plane.

The simulated 3D radiation patterns of the proposed antenna at 3.5, 7 and 10 GHz are shown in Fig. 13. As illustrated, the radiation pattern looks like a doughnut, similar to that of a dipole pattern at 3.5 GHz. At 7 GHz and 10 GHz, the radiation pattern is somewhat like a pinched doughnut (i.e. omnidirectional). As the frequency moves toward the upper end of the bandwidth, the radiation pattern is somewhat slightly distorted as it reaches higher frequencies (i.e. 10 GHz and above).

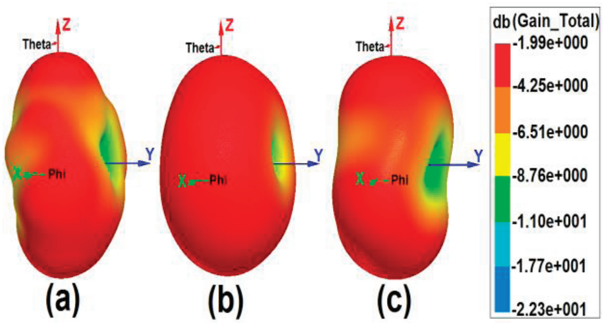


Fig. 13. Simulated 3-D radiation patterns of the proposed antenna: (a) 3.5 GHz, (b) 7 GHz and (c) 10 GHz.

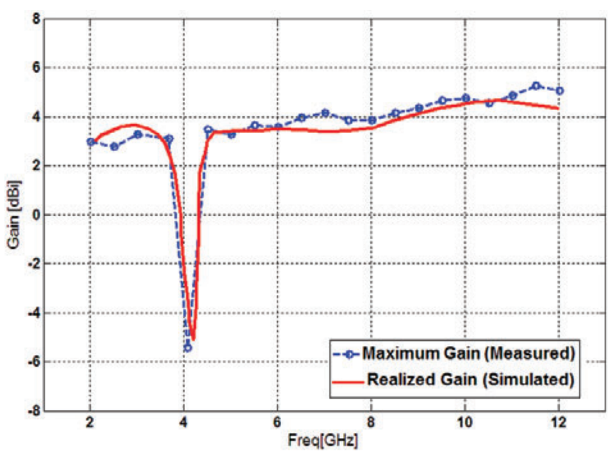


Fig. 14. Measured maximum gain for the proposed antenna.

Figure 14 illustrates the measured and simulated maximum and realized gains of the proposed antenna. The antenna gain has a flat property, which increases by the frequency. As illustrated, a sharp decrease of maximum gain in the notched frequency band was shown in Fig. 9. Also, the proposed microstrip-fed monopole antenna has sufficient and acceptable antenna gain levels in the operation bands.

Table 2 summarizes the previous designs and the proposed antenna. As seen, the proposed antenna has a very compact size with very wide bandwidth, compared to the pervious works. In addition, compared with previous band-notched antennas, the proposed antenna displays a good omnidirectional radiation pattern even at lower and higher frequencies. Also, the proposed microstrip-fed monopole antenna has sufficient and acceptable antenna gain levels in the operation bands.

Table 2: Comparison of previous designs with the proposed antenna

Ref.	Size (mm)	FBW (%)	Gain (dBi)
[15]	30×30×1.6	130% (2-12.4)	2.8~5.3
[16]	20×20×0.8	47% (3.7-6.1)	3-3.7
[17]	20×20×0.8	110% (3-10.8)	2~4.5
[18]	20×20×0.8	112% (3-11.2)	3.2-5
[19]	12×18×1.6	28% (3.3-4.4)	1.8~2.8
[20]	12×18×1.6	117% (3-11.5)	2.5-3.5
This Work	12×18×0.8	125% (2.8-12.6)	3~.5.1

The radiating mechanism of the proposed antenna is more novel than was explained in previous works. Main novelty of the proposed design is the application of self-complementary structures, to create an extra frequency resonance and enhance the bandwidth. The proposed structure is the combination of the monopole antenna with the dipole and slot antenna. In this study, the modified ground-plane structure is the combination of the monopole antenna and the slot antenna. The embedding parasitic structure on the other side of the substrate of the monopole antenna acts as a dipole. As seen, the proposed antenna has a compact size with very wide bandwidth, compared to the pervious works for UWB applications. Additionally, the antenna has a good antenna gain level in the operation bands [21-23].

IV. CONCLUSION

In this paper, a novel design of ultra-wideband monopole antenna with variable band-notched function is proposed. The presented antenna can operate from 2.81 GHz to over 12.63 GHz, with VSWR < 2 and with a rejection band around 3.7 GHz to 4.2 GHz. By using a rotated Z-shaped parasitic structure inside rectangular slot in the ground plane, additional resonance at higher frequency range is excited and much wider impedance bandwidth can be produced. In order to generate a frequency band-stop performance, we use the self-complementary structure of the inserted structure in the ground plane; which is the rotated Z-shaped slot at radiating patch. The designed antenna has a small size. The measured results show good agreement with the simulated and measured results. Experimental results show that the presented antenna could be a good candidate for UWB applications.

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