Bandwidth Enhancement of Small Square Monopole Antenna with Dual Band Notch Characteristics Using U-Shaped Slot and Butterfly Shape Parasitic Element on Backplane for UWB Applications

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Abstract **─** In this study, a dual band notch microstrip antenna for UWB applications has been presented. The antenna consists of a stepped patch with U-shaped slot, two rectangular shaped slots in the ground plane and a butterfly shaped parasitic backplane element structure. By inserting two rectangular shaped slots in the ground plane, much wider impedance bandwidth can be produced. This modification significantly improves the antenna's impedance bandwidth by 155% which covers the entire UWB bandwidth range and even more. In order to generate single band notch characteristic, a butterfly shaped conductor backplane structure is utilized on the ground plane side of the substrate. In addition, by cutting a U-shaped slot on the radiating patch, a dual band notch function is achieved. The measured frequency results show an impedance bandwidth of 2.35-13 GHz for a Voltage Standing Wave Ratio (VSWR) less than 2 with two eliminated bands placed at 3.25-3.85 GHz and 4.9-6.2 GHz, which reject the Wireless Local Area Network (WLAN) band, WiMAX band, and a major part of the C-band. The measured E-plane and H-plane radiation patterns show a very good correlation with the requirements of UWB applications.

Index Terms **─** Dual band notch, monopole antenna, parasitic element, Ultra-Wideband (UWB), U-shaped slot.

I. INTRODUCTION

Nowadays, wireless communication systems are becoming increasingly popular. However, the technologies for wireless communication still need to be improved further to satisfy the demands for higher resolutions and high data rate requirements. That is why UWB communication systems covering from 3.1 to 10.6 GHz released by the FCC in 2002 are currently under development. Recently, printed monopole antennas featured with many attractive merits such as low profile, easy fabrication, wide impedance bandwidth and omnidirectional radiation patterns have drawn great attention. These features have provided a very challenging opportunity for antenna

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designers. A lot of effort has been put into designing new antennas which can satisfy the requirements of modern communication systems. As a result of accelerating growth of UWB technology, there has been a vast body of literature introducing novel antennas for UWB applications and systems [1-17]. Some of the bandwidth enhancement techniques that are used to design planar antennas have been stated as below: a staircase-shaped feed technique [1-3], two L-shaped conductor backed-plane [5], different shaped slots in the ground plane to improve the antenna's impedance bandwidth [7-12], and double feed [13]. Moreover, other strategies to improve the impedance bandwidth which do not involve a modification of the geometry of the planar antenna have been investigated [14-17].

Despite all its advantages, the UWB system suffers from interference with other existing communication systems, such as WLAN (5.15-5.825 GHz), WiMAX (3.3-3.6 GHz) and C-band (3.7-4.2 GHz). Consequently, various printed microstrip antennas with single [7-9] or dual [10-17] band notch function have been recently proposed. To solve this problem, the existing techniques in extensive use can be classified into the following two categories: one method focuses on embedding various slots, such as U-shaped slot [1,10], meander-shaped slot [2], square-shaped slot [7], H-shaped slot [8] and modified co-directional Complementary Split Ring Resonator (CSRRs) slots [14]. The other effective method is loading diverse parasitic elements on the antennas [9,11-12], such as Stepped Impedance Resonators (SIRs) near the feed line [15], and angle-shaped parasitic slit [16-18]. In [13], dual band notch function is achieved by inserting a W-shaped conductor backed-plane and a modified T-shaped slot in the radiating patch.

In this paper, a dual band notch small monopole antenna has been presented. In the proposed structure in order to improve the bandwidth, two rectangular shaped slots are etched on the ground plane which creates an additional resonance, and hence, much wider impedance bandwidth can be produced. This modification significantly improves the antenna's impedance bandwidth up to 155%. Adding a butterfly shaped conductor backplane to the antenna structure leads to a single band notch function which occurs at frequencies near 5.5 GHz, and then cutting a U-shaped slot on the antenna radiating patch creates an additional band notch function at frequencies adjacent to 3.5 GHz. Good VSWR and radiation characteristics are obtained in the frequency band of interest. In the next sections, the antenna design is explained in details and simulated and measured results are presented to validate the usefulness of the proposed antenna structure for UWB applications.

II. ANTENNA DESIGN

The dual band notch small monopole antenna with U-shaped slot and butterfly shaped parasitic element fed by a 50-Ω microstrip line is shown in Fig. 1, which is printed on a FR4 substrate with thickness of 1 mm, permittivity of 4.4, and loss tangent of 0.018. The basic antenna structure consists of a triangular stub, a 50-Ω microstrip feed-line, and a rectangular truncated ground plane. The radiating stub is connected to the feed-line of width W_F and length L_F, as shown in Fig. 1. The proposed antenna is connected to a 50-Ω SMA connector for signal transmission. A single band notch function is provided by inserting a butterfly shaped conductor backplane and a dual band notch characteristic is obtained by using a U-shaped slot in the radiating patch. The planar monopole antenna with its final design parameters was constructed, and the numerical and experimental results of the input impedance and radiation characteristics are presented and discussed. The parameters of this proposed antenna are studied by changing one parameter at a time while others were kept fixed. The simulated results are obtained using Ansoft simulation software High-Frequency Structure Simulator (HFSS) [19].The final design parameters values of the presented antenna are specified in Table 1.

Table 1: The final dimensions of the designed monopole antenna

Param.	mm	Param.	mm	Param.	mm
R_1	3.3	R_2	5	R_3	2.8
W_1	18	W_2	3.85	W_3	0.5
L_G	6	L_S	2	L_u	9
W_4	2	W_S	7.5	W_u	7
W_F	1.85	L_F	8	L_1	4
W_{sub}	22	L_{sub}	22	h_{sub}	1

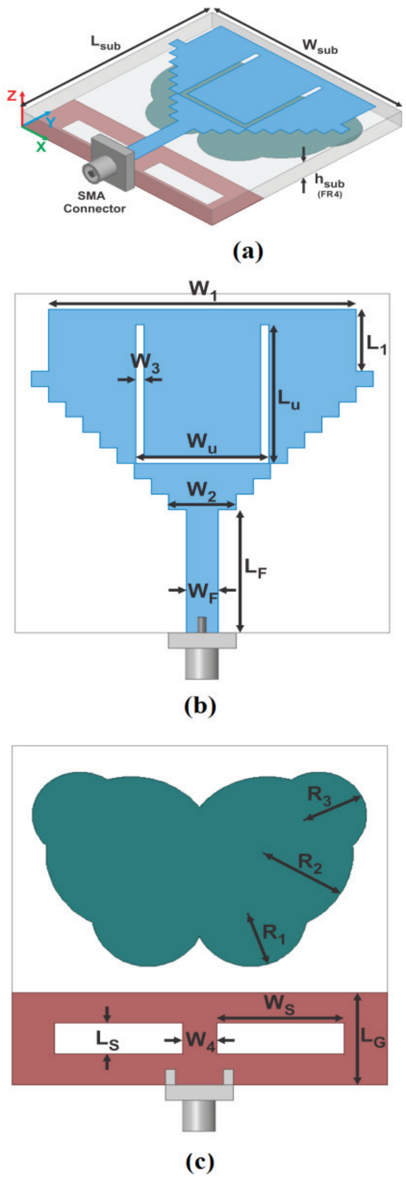

Fig. 1. Geometry of proposed microstrip-fed monopole antenna: (a) side view, (b) top view, and (c) bottom view.

Figure 2 shows the structure of various antennas which were used for simulation studies. VSWR characteristics for ordinary triangular patch antenna (Fig. 2 (a)), triangular patch antenna with stepped radiating patch (Fig. 2 (b)), and triangular staircase patch antenna with rectangular slots in the ground plane (Fig. 2 (c)) are compared in Fig. 3. As shown in Fig. 3, repeatedly embedded notches on the patch directly influence both the upper and lower band edge frequencies. The triangular patch antenna with stepped radiating patch (Fig. 2 (b)) has smooth VSWR at the frequency higher than 9 GHz, and it also shows the effect of these steps on the impedance matching. As illustrated in Fig. 3, the rectangular slots on the ground plane conductor play an important role in the broadband characteristic of the proposed antenna and also in determining the impedance matching sensitivity of this antenna [5-7]. It is found that by inserting the rectangular slots in the ground plane additional resonance (at 12.2 GHz) is excited, and hence, much wider impedance bandwidth can be produced; especially at the higher band, because of multi-resonance characteristics. The bandwidth of the antenna without the slots on the ground plane is 150%, while the antenna with the rectangular slots on the ground plane has a bandwidth of 155%. Another important parameter to be considered is the distance of W_4 between the slots as illustrated in Fig. 1. This distance should be large enough to reduce the coupling between two slots; whereas, by increasing W_4, the required exciting degree for the slots by the microstrip line is weakened. Also note, that by varying this parameter, the surface current density in the central portion of the ground plane exactly below the microstrip-fed line is adjusted. On the other side of the substrate, a conducting ground plane of width W_{Sub} and length L_G is placed. The truncated ground plane plays an important role in the broadband characteristics of this antenna, because it helps to match the patch with the feed line in a wide range of frequencies. This is because the truncation creates a capacitive load that neutralizes the inductive nature of the patch to produce nearly pure resistive input impedance [3-5].

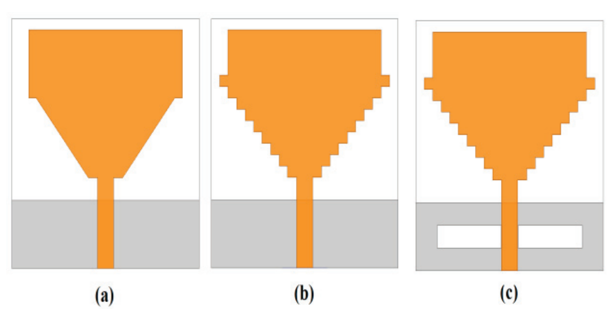

Fig. 2. (a) Ordinary triangular patch antenna, (b) triangular patch antenna with stepped radiating patch, and (c) triangular staircase patch antenna with rectangular slots in the ground plane.

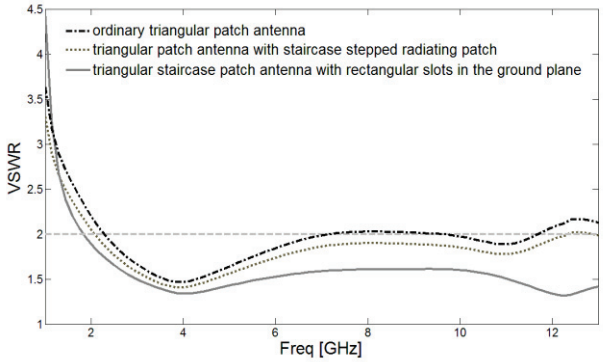

Fig. 3. Simulated VSWR characteristics for antennas shown in Fig. 2.

To understand the phenomenon behind this new exited resonance performance, the simulated current distributions on the ground plane 12 GHz for the antennas with and without slots on the ground plane are compared in Fig. 4. As it can be observed in Fig. 4, at 12 GHz the current is concentrated along the interior and exterior edges of the slots, and therefore, the antenna impedance changes at this frequency due to the resonant properties of these slots [4-6].

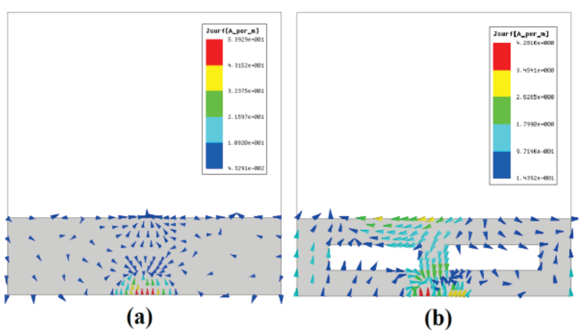

Fig. 4. Simulated surface current distribution on the ground plane for the triangular staircase patch antenna: (a) the ordinary ground plane at 12 GHz, and (b) the ground plane with rectangular slots at 12 GHz.

Figure 5 shows the structure of various antennas used for band notch function simulation studies. The VSWR characteristics for the triangular staircase patch antenna with rectangular slots in the ground plane (Fig. 5 (a)), antenna with two rectangular slots and a butterfly shaped conductor backplane on the ground plane (Fig. 5 (b)), and the proposed antenna (Fig. 5(c)) are compared in Fig. 6. As it is observed in Fig. 6, adding the conductor backplane to the antenna structure generates single band notch characteristics. Moreover, according to Fig. 5 (c) and its corresponding frequency response in Fig. 6, cutting a U-shaped slot in the radiating patch adds an additional band notch function to the performance of the antenna and consequently a dual band notch function is achieved. The implementation of the conductor backplane on the other side of the substrate of the monopole antenna acts as a dipole that can provide an additional coupling path. Moreover, this structure changes the inductance and capacitance of the input impedance, which in turn leads to change of the bandwidth. Based on electromagnetic coupling theory, the conductor backplane perturbs the resonant response and also acts as a parasitic half-wavelength resonant structure which is electrically coupled with the rectangular monopole [11-13].

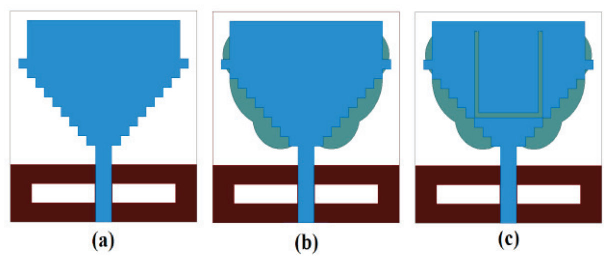

Fig. 5. (a) Triangular staircase patch antenna with rectangular slots in the ground plane, (b) antenna with two rectangular slots and a butterfly shaped conductor backed-plane in the ground plane, and (c) the proposed antenna.

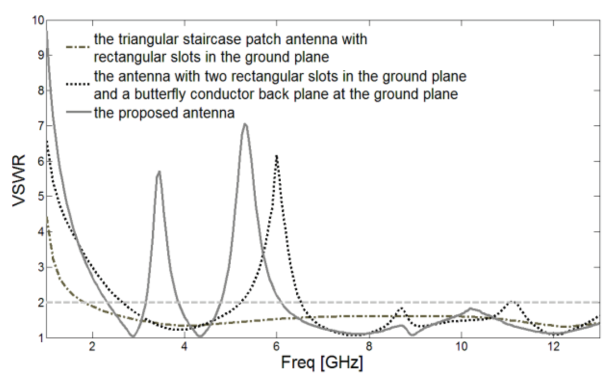

Fig. 6. Simulated VSWR characteristics for antennas shown in Fig. 5.

To understand the phenomenon behind this dual band notch performance, the simulated current distribution for the proposed antenna at the notched center frequencies of 3.5 GHz and 5.4 GHz is presented in Figs. 7 (a) and (b), respectively. As it can be observed from Fig. 7 (a), at the lower notched center frequency (3.5 GHz), the current flows are more dominant around the U-shaped slot and they are oppositely directed between the slot edges [10]. Therefore, the antenna impedance changes at these frequencies due to the band notch properties of the proposed structure, and as a result the desired high attenuation is achieved. According to Fig. 7 (b), at the upper notched center frequency (5.4 GHz), the current flows on the parasitic element are more dominant and the surface currents are oppositely directed between this parasitic element and the radiating patch. Therefore, the resultant radiation fields cancel out, and high attenuation near the notched frequencies is produced, and as a result, the antenna does not radiate efficiently at the notched frequencies [4].

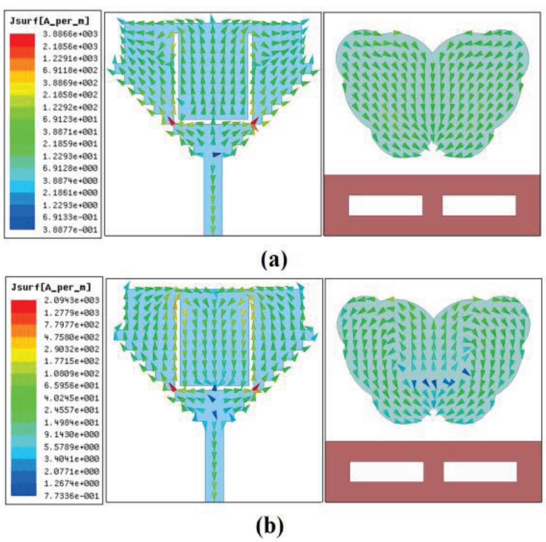

Fig. 7. Simulated surface current distributions for the proposed antenna at its notched band center frequencies: (a) at 3.5 GHz, and (b) at 5.4 GHz.

III. RESULTS AND DISCUSSIONS

The proposed antenna with final design parameters, as shown in Fig. 8, was fabricated and tested at the Northwest Antenna and Microwave Research Lboratory (NAMRL), Urmia University, Iran. Figure 9 shows the measured and simulated VSWR characteristics of the proposed antenna. The fabricated antenna covers the frequency band of 2.35-13GHz with two rejection bands at 3.25-3.85 GHz and 4.9-6.2 GHz, which reject the Wireless Local Area Network (WLAN) band, WiMAX band, and a major part of the C-band. As shown in Fig. 9, there exists a discrepancy between the measured data and the simulated results. The discrepancy is mostly due to a number of parameters, such as the fabricated antenna dimensions as well as the thickness and dielectric constant of the substrate on which the antenna is fabricated, and also the wide range of simulation frequencies. In order to confirm the accurate return loss characteristics for the designed antenna, it is recommended that the manufacturing and measurement process need to be performed carefully. Besides, SMA soldering accuracy and FR4 substrate quality need to be taken into consideration [2-5].

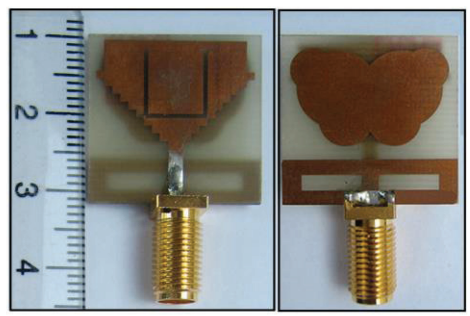

Fig. 8. Photograph of the fabricated antenna prototype with parasitic element.

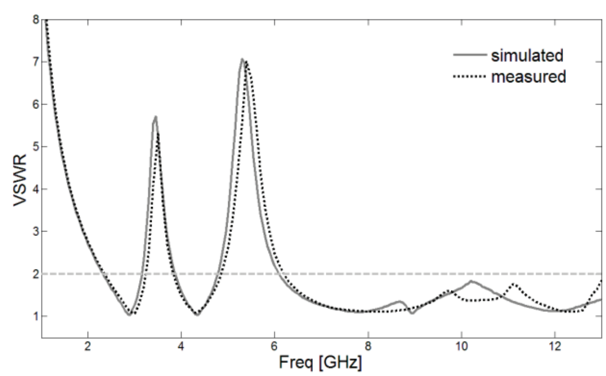

Fig. 9. Measured and simulated VSWR for the proposed antenna.

Figure 10 shows the measured radiation patterns including co-polarization and cross-polarization in the H-plane (x-z plane) and E-plane (y-z plane). The main purpose of the radiation patterns is to demonstrate that the antenna actually radiates over a wide range of frequencies. It can be seen that the radiation patterns in x-z plane are nearly omnidirectional for the three frequencies. Moreover, the measured maximum gain for the fabricated antenna is presented in Fig. 11. As it is observed in this figure, for dual band notch performance of the antenna, the gain drops dramatically at the notched frequency bands.

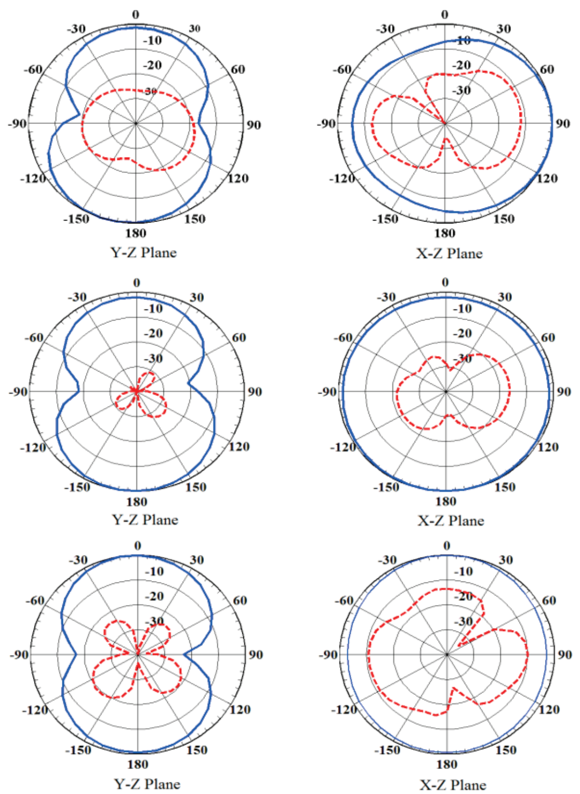

Fig. 10. Measured radiation patterns of the proposed antenna. (a) 4.4 GHz, (b) 8 GHz, and (c) 11 GHz.

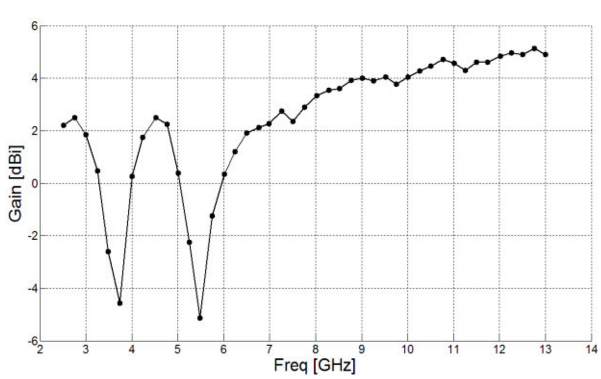

Fig. 10. Measured maximum gain.

IV. CONCLUSION

In this paper, a compact wideband planar monopole antenna with dual band notch characteristics has been proposed for various UWB applications. The fabricated antenna covers the frequency band from 2.35 to 13 GHz with two rejection bands 3.25-3.85 GHz and 4.9-6.2 GHz. In the presented structure, triangular staircase shaped radiating patch is used to improve the impedance bandwidth and also an additional resonance is excited by cutting two rectangular shaped slots on the ground plane. Moreover, by inserting a U-shaped slot on the radiating patch and a Butterfly shaped conductor backplane on the other side of the substrate, a dual band notch characteristic is generated. The designed antenna has a simple configuration and easy fabrication process. The experimental results show that the realized antenna with a very compact size, simple structure, and wide bandwidth can be a good candidate for UWB application.

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