A Compact Design and New Structure of Monopole Antenna with Dual Band Notch Characteristic for UWB Applications

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Abstract **─** In this paper, a compact design and new structure of monopole antenna with dual band notch characteristics for UWB applications has been presented. The antenna consists of a triangular patch with C-shaped slot, two L-shaped and one split ring shaped parasitic backplane elements structure. By inserting three slots in the rectangular truncated ground plane as defected ground structures (DGSs), much wider impedance bandwidth can be produced, and moreover to improve the input matching quality of the antenna at all its operating bands which are spread in a vast frequency range, a modified stepped feed-line is employed. These changes much improves the antenna's impedance bandwidth by 112% which covers the entire UWB bandwidth range. In order to generate single band notch characteristic, split ring shaped parasitic element backplane structure is utilized on the ground plane side of the substrate. In addition, by etching a C-shaped slot on the radiating patch, a dual band notch function is achieved. The measured frequency results show an impedance bandwidth of 3.15-10.78 GHz for a Voltage Standing Wave Ratio (VSWR) less than 2 with two eliminated bands placed at 3.49-3.81 GHz (320 MHz, 8.8%) and 5.24-6.22 GHz (980 MHz, 17%), which reject the WiMAX band, and Wireless Local Area Network (WLAN) band, respectively. A prototype was fabricated and measured based upon optimal parameters and experimental results show consistency with simulation results. The measured radiation patterns of proposed antenna for most frequencies are omnidirectional and this antenna as wide impedance bandwidth.

Index Terms **─** C-shape slot, dual band notch, monopole antenna, split ring shaped parasitic element, ultra wideband (UWB).

I. INTRODUCTION

In 2002, Federal Communications Commission (FCC) of US declares the frequencies from 3.1 to 10.6 GHz as an unlicensed band for wireless radio communication [1]. This technology uses short duration pulses that result in very large or wideband transmission bandwidths. With proper technical standards, UWB devices can be operated using spectrum, occupied by existing radio services without causing interference, thereby permitting scarce spectrum resources to be used more efficiently [2]. One key component, necessary to fulfill these requirements in UWB system, is a planar antenna that is capable of providing a wide impedance bandwidth. The antenna needs to work over the UWB, as it is defined by the FCC. In addition, it needs to give omnidirectional radiation coverage over the entire UWB frequency range [3]. 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 [4-13].

UWB systems have met a hostile radio environment which may cause potential interferences to the UWB band. For instance, IEEE 802.16 WIMAX system operates at 3.3–3.7 GHz and IEEE 802.11a WLAN system operates at 5.15–5.825 GHz [6-10]. However, the use of filters increases the complexity and cost of the UWB system. The frequency band notch characteristics can be essentially achieved using one of the two common methods [13]. Two common methods to creation the band notch are using C-shaped, T-shaped, H-shaped, U-shaped, L-shaped slots [4-8], on the radiation patch or on the ground plane and the parasitic elements with various geometric shapes on the back-plane of antenna or in the

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vicinity of the patch [12].

In this paper, a dual band notch compact monopole antenna has been presented. In the proposed structure to improve the bandwidth, three slots in the rectangular truncated ground plane and a modified stepped feed-line is used which creates an extra resonance, and hence, much wider impedance bandwidth can be produced. This change much improves the antenna's impedance bandwidth up to 112%. Adding a split ring-shape as a parasitic element on the back-plane of the antenna structure leads to a single band notch function which occurs at frequencies near 5.5 GHz, and then cutting a C-shaped slot on the antenna radiating patch creates an added band notch function at frequencies next to 3.7 GHz. The designed antenna has a small size of $20\times18\times1.6$ mm^3. Good VSWR and radiation pattern characteristics are obtained in the frequency band of interest. Also, the antenna is provided for parametric analysis. The finally design of the proposed antenna has been fabricated and tested and the results are acceptable.

II. ANTENNA DESIGN

The dual band notch compact monopole antenna with C-shaped slot and split ring 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 1.6 mm, permittivity of 4.4, and loss tangent of 0.018. The basic antenna structure consists of a radiating triangular patch, a 50 Ω microstrip modified stepped feed-line, and three slots in the rectangular truncated ground plane. The radiating stub is connected to the feed-line of width W_F (2.8 mm), as shown in Fig. 1 (b). Proposed antenna is connected to a 50 Ω SMA connector for signal transmission. A single band notch function is provided by inserting a split ring shaped parasitic element backplane and a dual band notch characteristic is obtained by using a C-shaped slot in the triangular 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. Simulated results are obtained using Ansoft simulation software High-Frequency Structure Simulator (HFSS) [14]. Final design parameters values of the presented antenna are specified in Table 1.

Figure 2 shows the structure of various antennas which were used for simulation studies of UWB antenna without notch bands. VSWR characteristics for ordinary triangular patch antenna (Fig. 2 (a)), triangular patch antenna with three slots in the rectangular truncated ground plane (Fig. 2 (b)), proposed UWB antenna without split ring-shape parasitic element and C-shape slot (Fig. 2 (c)) are compared in Fig. 3. As shown in Fig. 3, three slots in the rectangular truncated ground plane directly influence both the upper and lower band edge frequencies. 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 [7-9]. It is found that by etching steps on the feed-line additional resonance (at 9 GHz) is excited, and hence, much wider impedance bandwidth can be produced, because of multi-resonance characteristics.

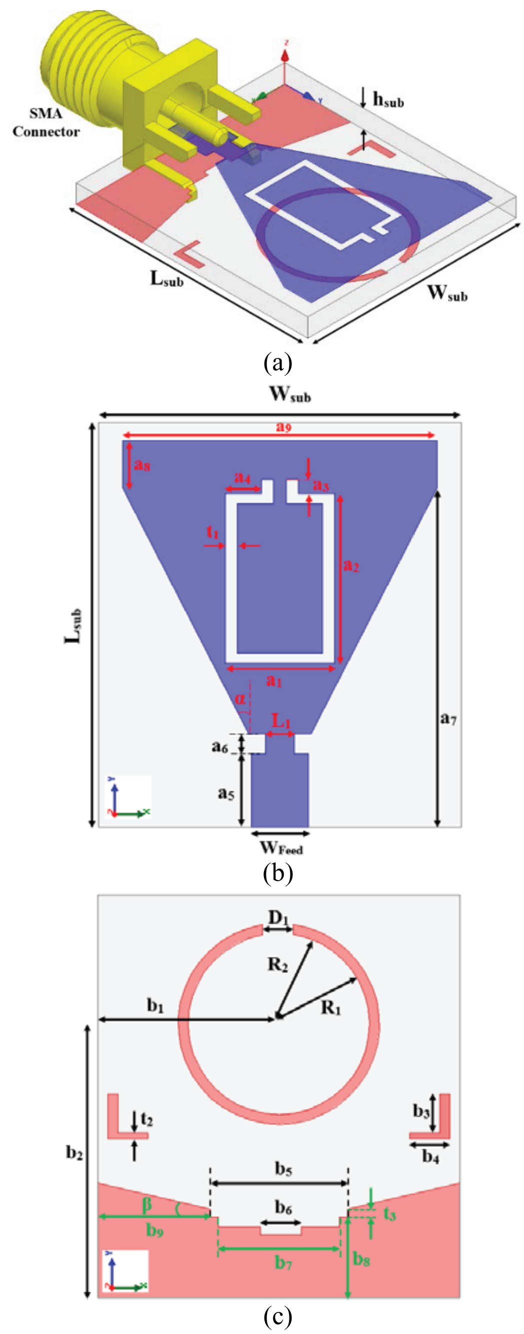


Fig. 1. Geometry of the proposed monopole antenna: (a) side view, (b) top view, and (c) bottom view.

Table 1: The final dimensions of the designed monopole antenna

Param.	mm	Param.	mm	Param.	mm
a_1	5	b_1	9	W_{sub}	18
a_2	8.1	b_2	13.7	L_{sub}	20
a_3	0.6	b_3	1.8	R_1	4.5
a_4	1.5	b_4	2	R_2	5
a_5	3.5	b_5	6.8	D_1	1.5
a_6	1	b_6	2	L_1	1.5
a_7	16.7	b_7	6	t_1	0.5
a_8	2.3	b_8	4.3	t_2	0.3
a_9	15.5	b_9	5.6	t_3	0.9

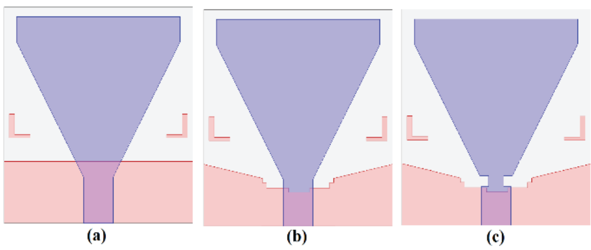


Fig. 2. (a) Ordinary triangular patch antenna, (b) triangular patch antenna with three slots in the rectangular truncated ground plane, and (c) proposed UWB antenna without the split ring-shape parasitic element and C-shape slot.

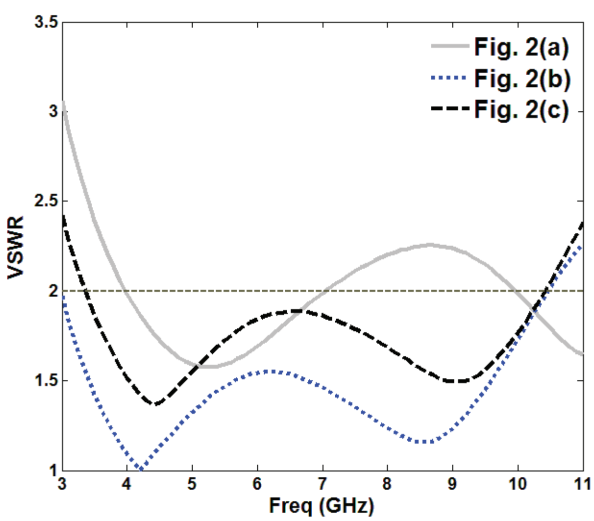


Fig. 3. Simulated VSWR characteristics for antennas shown in Fig. 2.

To understand the phenomenon behind this new exited resonance performance by modified stepped feed-line, the simulated current distributions on the triangular patch at 9 GHz for the antennas with and without etching steps on the feed line are compared in Fig. 4. As it can be observed in Fig. 4, at 9 GHz the current is more dominate along the edges of the modified stepped feed-line, and therefore, the antenna impedance changes at this frequency due to the resonant properties of these etching [10-12].

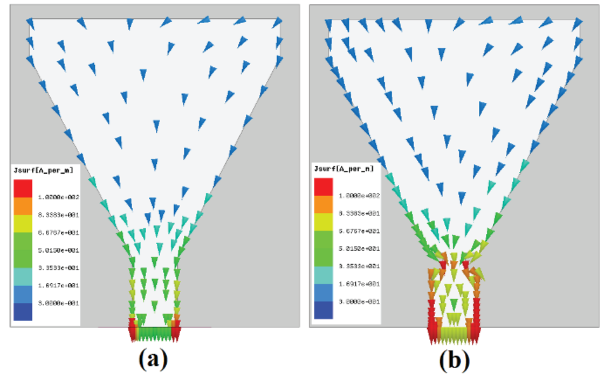


Fig. 4. Simulated surface current distribution on the triangular patch antenna with: (a) the simple feed-line at 9 GHz, and (b) the modified stepped feed-line at 9 GHz.

Figure 5 shows the structure of various antennas used for band notch function simulation studies. The VSWR characteristics for the triangular patch antenna without split ring-shape parasitic element and C-shape slot (Fig. 5 (a)), antenna with C-shaped slot on the radiating patch (Fig. 5 (b)), and the proposed antenna (Fig. 5(c)) are compared in Fig. 6. As it is observed in Fig. 6, adding C-shaped slot on the radiating patch of the antenna structure generates single band notch characteristics. In order to eliminate interferences from WiMAX system line break operating at 3.5-3.7 GHz, a C-shaped slot with a width of 0.5 mm is etched on the radiation patch to generate band notch function. The total length of the C-shaped slot on the radiation patch is $L_{Notch}=a_1+2[a_2+a_3+a_4]$ [10-11]. Besides WiMAX system, WLAN operating from 5.3 to 6 GHz may cause interferences to the UWB system too. By printing a split ring-shape as a parasitic element, on the backplane of proposed antenna, 5.7 GHz band-notched function is realized [7].

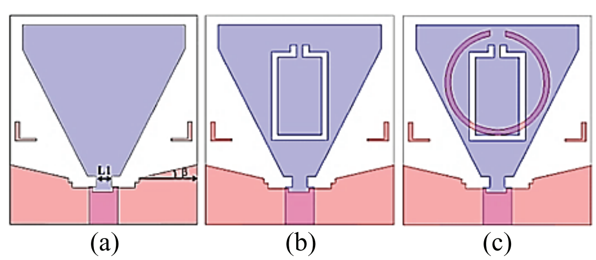


Fig. 5. (a) Primary antenna without split ring-shape parasitic element and C-shape slot, (b) antenna with C-shape slot, and (c) proposed antenna.

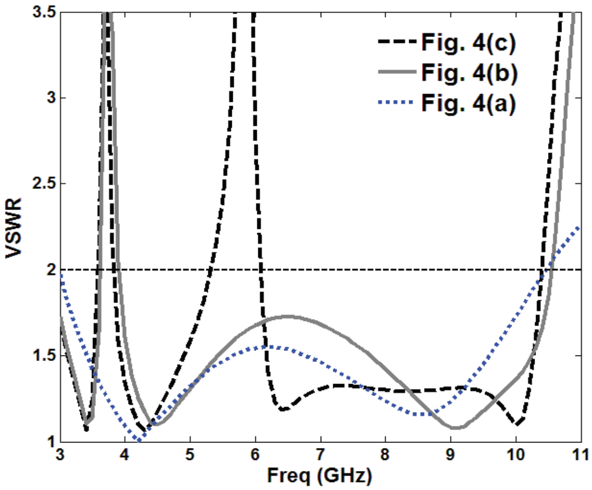
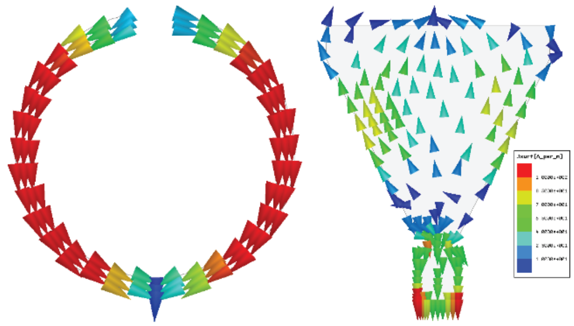


Fig. 6. Simulated VSWR characteristics for antennas shown in Fig. 5.

To understand the phenomenon behind this dual band notch performance, the simulated current distribution for the proposed antenna at the notched center frequencies of 3.6 GHz and 5.7 GHz is presented in Fig. 7 (a) and Fig. 7 (b), respectively. The large current distribution with red vector and small current distribution with blue vector is shown in Fig. 7. As it can be observed from Fig. 7 (a), at the lower notched center frequency (3.6 GHz), the current flows are more dominant around the C-shaped slot and they are oppositely directed between the slot edges [8]. Therefore, the antenna impedance changes at this frequency due to the band notch properties of the proposed structure, and as a result the desired high attenuation is achieved. According Fig. 7 (b), at the upper notched center frequency (5.7 GHz), the current flows are more dominant around the parasitic element, the surface currents are oppositely directed between this parasitic element and the radiating patch [9]. Therefore, the resultant radiation fields cancel, and high attenuation near the notched frequencies is produced, and as a result, the antenna does not radiate efficiently at the notched frequencies [13].

(a)



(b)

Fig. 7. Simulated surface current distributions for the proposed antenna at its notched band center frequencies: (a) at 3.6 GHz and (b) at 5.7 GHz.

III. RESULTS AND DISCUSSIONS

In this section, the monopole antenna with a new dual band-notched structure with various design parameters was constructed, and the experimental results are presented and discussed. The parameters of this proposed antenna are studied by changing one parameter at a time and fixing the others. Figure 8 shows the VSWR to change in the L_1, without the parasitic element and C-shape slot of proposed antenna (Fig. 2(c)). According to Fig. 8, choose the size L_1=1.5 mm to increase the upper bandwidth of the antenna. Figure 9 shows the VSWR to change in the parameter β, without the parasitic element and C-shape slot of proposed antenna (Fig. 1 (b)). By choose the β = 12.9° selecting the primary antenna bandwidth is between 3.2-10.6 GHz. Three slots (air gaps) on the rectangular truncated ground plane, increases the bandwidth and relatively good matching with UWB.

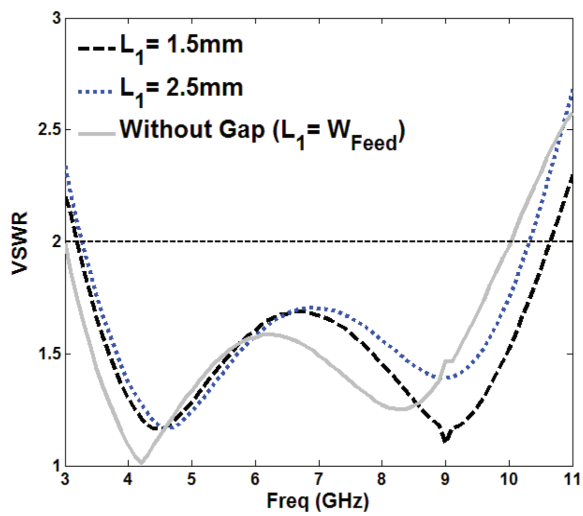


Fig. 8. Simulated VSWR characteristic for various size of L_1.

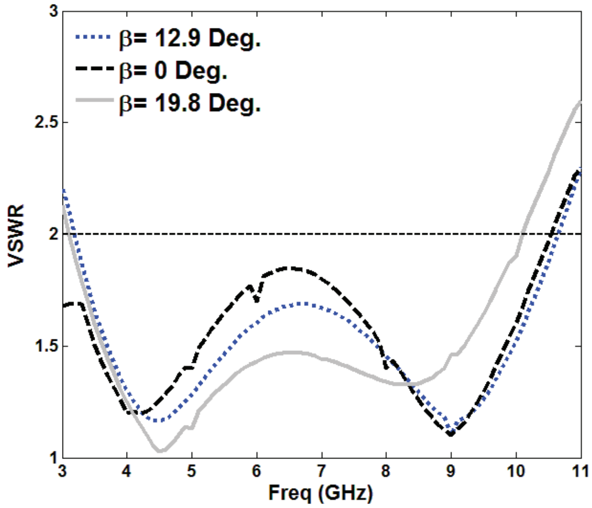
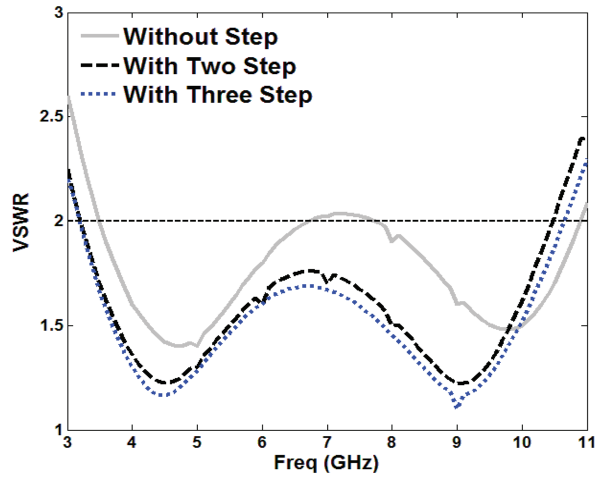


Fig. 9. Simulated VSWR characteristic for various of β angle.

As can be seen in Fig. 10, choice three slots (air gaps) on the rectangular truncated ground plane, improving the bandwidth of the primary antenna. 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 [5-7].

In the proposed antenna length of the C-shape slot on the radiation patch, and width of the split ring-shape parasitic element on the backplane, as control parameters for choose band notch. Following the analysis each of the parameter will be discussed. By changing the length of the C-shape slot, the notched frequency will change. According to Fig. 11, with the choice of L_{Notch} = 26.4 mm, between 3.5-3.7 GHz amount VSWR is bigger than 2. Therefore, the WiMAX frequency band can be notched. The place, length and width of the C-shaped slot have great effects on the band notch performance and should be tuned carefully. In the next phase of the proposed antenna design, changes in the width of the parasitic element alter the band notched. Parasitic element is formed of the inner radius (R_1) and the outer radius (R_2). The width of the split ring-shaped conductor changes with constant outer radius and inner radius shift. Figure 12 shows simulated VSWR for different values of R_1 with other parameters fixed and also shows the effect of R_1 parameter in the VSWR parameter on the frequency bandwidth, impedance matching, higher and lower operating frequency. It is observed that the VSWR at the R_1 = 4.5 mm for 5.3-6 GHz is bigger 2, actually the WLAN band notched. In other words, the band-notch for WLAN can be controlled by the radius of the split ring-shaped. Actually, changes in the width of the split ring-shape due to the frequency-notched change.

(a)



(b)

Fig. 10. (a) Various slot number (air gaps) on the rectangular truncated ground, and (b) simulated SWR characteristic.

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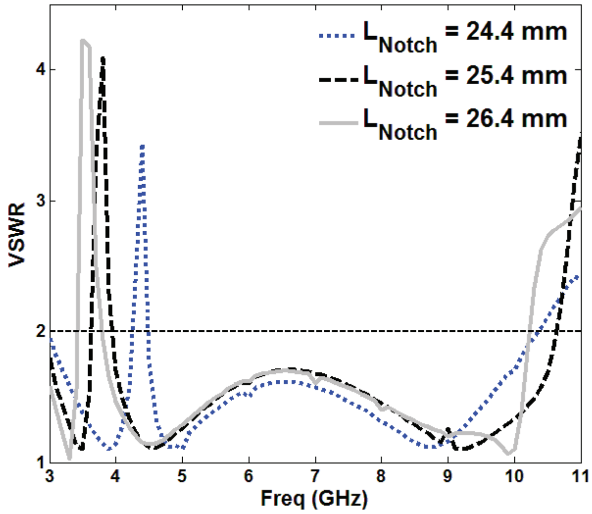


Fig. 11. Simulated VSWR characteristic for various length C-shaped slot.

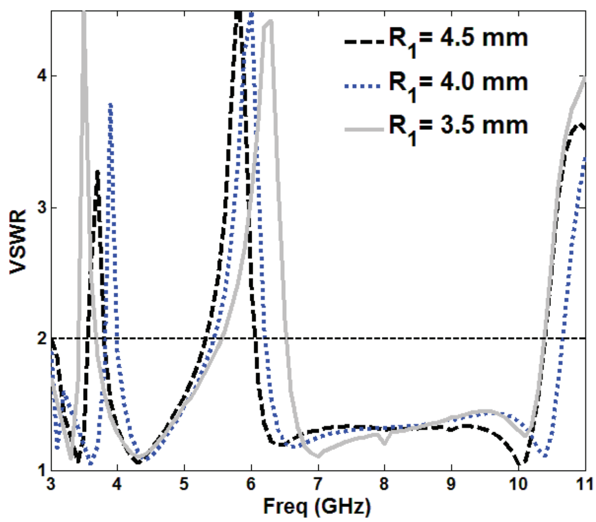
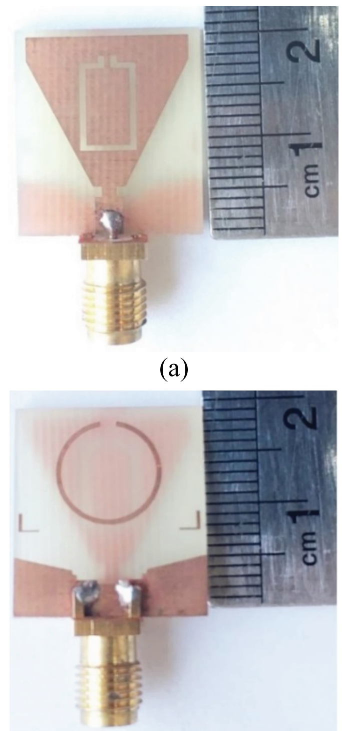


Fig. 12. Simulated VSWR characteristic for various R_1.

A prototype of the proposed dual band-notched antenna was fabricated and its radiation characteristics have been measured and investigated. The photograph of the fabricated antenna is shown in Fig. 13 and its measured and simulated VSWR characteristics are compared in Fig. 14. The fabricated antenna provides a wide usable fractional bandwidth of more than 112% (3.15 to 10.78 GHz) also band notched 8.8% (3.49 to 3.81) and 17% (5.24 to 6.22 GHz). In simulated of proposed antenna with dual band-notched fractional bandwidth of more than 111% (3 to 10.6 GHz) also band notched 5.5% (3.4 – 3.7) and 12% (5.3 – 6 GHz). As shown in Fig. 14, there exists a discrepancy between measured data and the simulated results. This discrepancy between measured and simulated results 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, in other words FR4 substrate quality on which the antenna is fabricated, the wide range of simulation frequencies and also the effect of SMA soldering [15-16].



(a)

(b)

Fig. 13. Fabricated antenna: (a) top view and (b) bottom view.

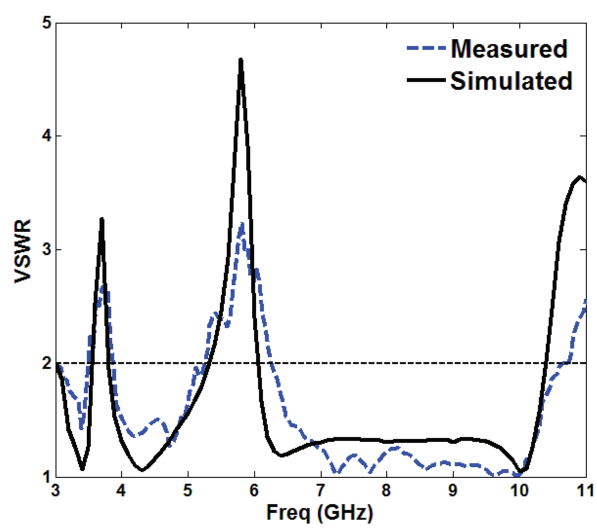


Fig. 14. Measured and simulated VSWR characteristics of the proposed antenna.

Figure 15 shows the measured radiation patterns including the co- and cross-polarization in the H- and E-planes. The main purpose of the radiation patterns is to demonstrate that the antenna actually radiates over a wide range of frequencies. From an overall view of these radiation patterns, the antenna behaves similarly to the typical printed monopoles. It can be seen that the radiation patterns in the H-plane are nearly omnidirectional for the three frequencies. The omnidirectional patterns can enhance and increase the channel capacity [10]. As shown in Fig. 15 (c), the 10 GHz, H-plane pattern has a larger cross polarization compared to similar UWB antennas. This discrepancy between measured and expected results is mostly due to the small ground plane effects and the change of excited surface current distributions on the system ground plane at high frequencies [12].

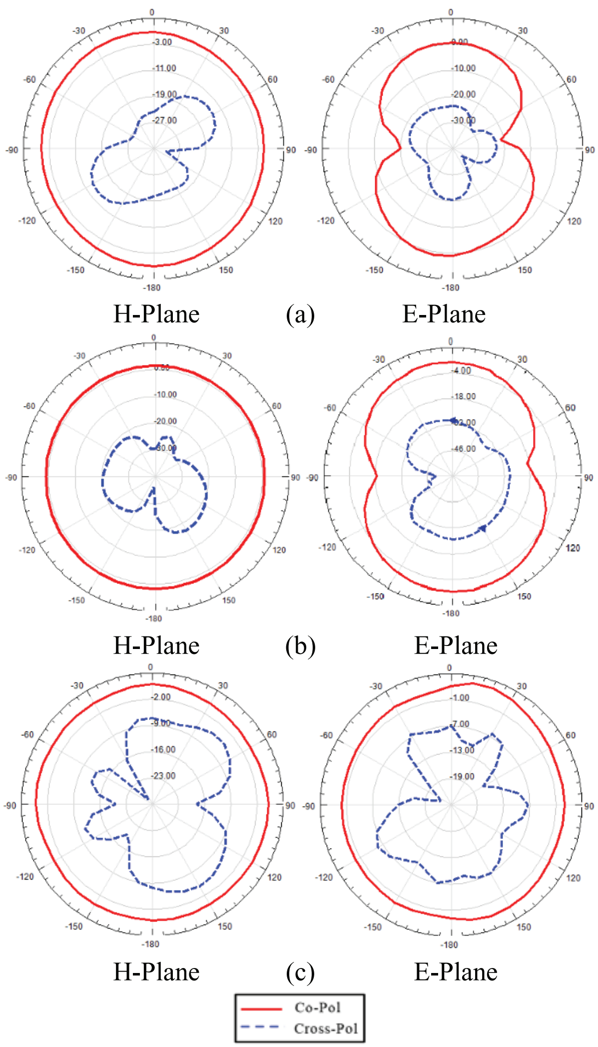


Fig. 15. Measured E- and H-planes radiation pattern for the proposed antenna at: (a) 4.7 GHz, (b) 7 GHz, and (c) 10 GHz.

Figure 16 presents the measured peak gains of the proposed antenna with dual band notch within its working frequency band. The proposed antenna has a gain variation between 2.3 dBi and 3.2dBi in the UWB. A sharp decrease of maximum gain in the notched frequency band at 3.6 and 5.7 GHz is shown. For other frequencies outside the notched frequency band, the antenna gain with the filter is similar to those without it.

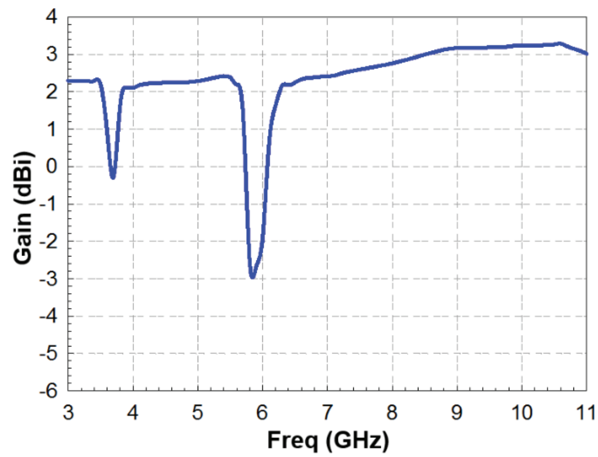


Fig. 16. The measured peak gain of the proposed antenna with dual band notch.

IV. CONCLUSION

In this paper, a compact design and new structure of monopole antenna with dual band notch characteristics for UWB applications is presented. In this design, the proposed antenna can work from 3 GHz to 10.6 GHz with VSWR < 2. Moreover, by inserting a C-shaped slot on the radiating patch and a split ring-shaped parasitic element on the other side of the substrate, a dual band notch characteristic is generated. In other word, WiMAX and WLAN band is notched in this antenna. The proposed antenna has advantages of low cost, compact size, and ease of fabrication. 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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